REPORT NOS. DOT-TSC-NHTSA-79-45 HS-803 293

NOISE ABATEMENT TECHNIQUES FOR CONSTRUCTION EQUIPMENT

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AUGUST 1979
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
Office of Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No. HS-803 293	2. Government Accession No.	3. Recipient's Catalog No. PB300948
4. Title and Subtitle NOISE ABATEMENT TECHNIQUES FOR CONSTRUCTION EQUIPMENT		5. Report Date August 1979
		6. Performing Organization Code
7. Author(s) William J. Toth		8. Performing Organization Report No. DOT-TSC-NHTSA-79-45
9. Performing Organization Name and Address Society of Automotive Engineers, Inc.* 400 Commonwealth Drive Warrendale PA 15096		10. Work Unit No. (TRAIS) HS931/R9402
		11. Contract or Grant No. DOT-TSC-915
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration Office of Research and Development Washington DC 20590		13. Type of Report and Period Covered Final Report Jan. 1976-Feb. 1977
		14. Sponsoring Agency Code

15. Supplementary Notes

*Under contract to: U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

16. Abstract The primary objective of this work was to transfer technology developed in the area of truck noise reduction to that of construction equipment. Included is information gathered from previous contracts, surveys of manufacturers, a noise impact ranking by equipment type, engine and equipment test results, specific information to enable equipment owners to reduce noise from their equipment, and recommendations dealing with reasonable noise level goals for used equipment. Work accomplished under this contract involved the compilation of comprehensive specifications for diesel engines greater than 50 horesepower used in the construction industry, the development of a comparative muffler selection procedure, and the collection of costs for mufflers and complete exhaust systems. A noise impact ranking was developed to characterize equipment types with respect to degree of noise pollution. This ranking was based on: the average machine noise level, the typical percentage of time the machine was at full load, the average production rate per year based on production figures of the last ten years, and proximity of machine use to human population. Using the noise impact rating system, front-end loaders, tractors, and backhoes (excavators) were identified as the three machines of the greatest impact. Detailed tests conducted on two classes of tractors, a front-end loader and a backhoe, identified the contributions of the various major component noise sources to overall machine noise levels. Results indicate that construction equipment produced since the late 1960's have utilized reasonable muffling such that exhaust noise is not generally the dominant noise source.

17. Key Words Noise, Construction equipment noise, Ground transportation noise, Diesel engine noise, Engine exhaust noise, Engine mufflers	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		A09-A01

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

PREFACE

This report summarizes the subcontractual effort on the Society of Engineer (SAE) Contract R-22, The Application of Truck Noise Abatement Techniques to Off-Highway and Stationary Equipment. The U.S. Department of Transportation awarded the prime contract to the SAE who subcontracted to Donaldson Company. Technical efforts were basically performed during the months of January through September 1976, with the final report completed February 1977. The main objectives of this contract were: (1) to compile comprehensive specifications of all diesel engines greater than 50 horsepower used in the construction industry, (2) to develop a comparative muffler selection procedure, and (3) to provide costs for mufflers and complete exhaust systems. These objectives were requested because engine exhaust noise was assumed to be the dominant noise source in construction equipment. This report was written by Stephen Schmeichel and David Winnes.

Donaldson Company, Inc. relied on the assistance of many engine, equipment, air cleaner and muffler manufacturers for their contributions. In addition, numerous iron mines, gravel quarries, construction sites, coal mines, etc., contributed greatly to the contractual effort by allowing their equipment to be tested on site. We wish to extend thanks to the above companies and people for their contributions and especially to extend thanks to Paul Schomer, Charles Sanders, and Walter Page, members of the SAE monitoring panel, who contributed immeasurably to the contract effort.

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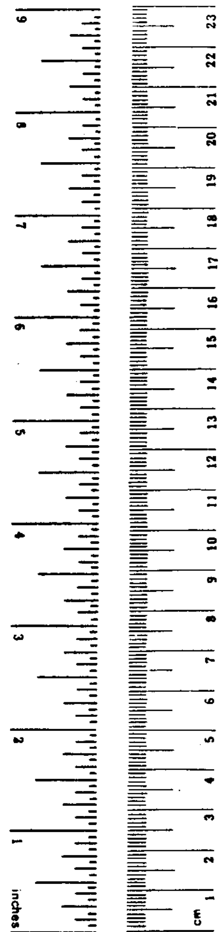
METRIC CONVERSION FACTORS

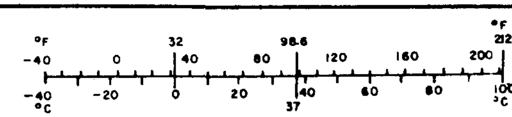
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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



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1. INTRODUCTION

In late 1975 the Department of Transportation (DOT) awarded a research contract entitled "Application of Truck Noise Abatement Techniques to Off-Highway and Stationary Equipment" to the Society of Automotive Engineers (SAE). The primary objective of this contract was to transfer technology developed in the area of truck noise reduction to that of construction equipment. This final report summarizes the work accomplished by Donaldson Company with respect to this program. Included in this report is information gathered from previous contracts and surveys of manufacturers, a noise impact ranking by equipment type, the results of engine and equipment tests, specific information for the equipment operator to use in equipment noise reduction, recommendations dealing with reasonable noise level goals for used equipment, and techniques which can be utilized to reduce other sources of noise on construction equipment.

1.1 Background

The construction process, both urban and rural, has been identified by the EPA* as a major noise problem. The amount of construction equipment in use is increasing; likewise, the size of this equipment and, consequently, the engine power plant size is also increasing. This growth reflects the industry's aim toward efficiency in moving maximum amounts of earth and materials with minimum labor output; however, an undesirable side effect of this growth is increased noise emissions. These excessive noise emissions have been recognized as not only a nuisance to the community, but also a hazard to the equipment operator himself.

Many states and communities, as well as the Federal Government, have proposed and/or enacted regulations limiting noise levels for various vehicles. The major effect in this area has been related to the heavy duty trucks, identified as a primary contributor of noise to the community (Federal Register, Vol. 39, 38208, October 29, 1974).

To help define the magnitude of the truck noise problem, the Department of Transportation has entered into a number of contracts (most of which have been cost sharing) with

*6-21-74 (39 F.R., p. 22297)
5-28-75 (40 F.R., p. 23069)

industry. Through these efforts, substantial information and data has been accumulated to help both the end-user and manufacturer reduce truck noise levels in a cost effective manner. Part of the contract work has consisted of cataloging intake and exhaust emission data on current diesel engines used in truck application. The purpose of this work has been to provide cost and performance data on available exhaust and intake components when installed in various configurations on these engines. This information has then been utilized for further contract activity in the area of retrofit, as well as utilized by the end-user.

In a study conducted by Bolt, Beranek and Newman for the Environmental Protection Agency, entitled Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances, it was assessed that "The greatest near-term abatement potential for all current equipment powered by internal combustion engines lies in the use of better exhaust mufflers, intake silencers and engine enclosures . . ." This fact was recognized by the Department of Transportation in its subsequent contract work involving the quieting of heavy duty highway trucks. Since many of the engines involved in these heavy duty truck contracts are very similar to those used in construction equipment, the application of the noise abatement techniques developed can be applied to construction equipment. To accomplish this transfer of technology, DOT awarded contract to the SAE who subcontracted to the Donaldson Company.

1.2 Scope of the Contract

The primary objective of this contract was to transfer the technology in the truck noise reduction area to the construction equipment noise area. This contract concentrates on determining typical noise levels for construction equipment produced the last 15 years. The engine had to be 50 hp or greater and the specific equipment had to be produced in quantities of 1000 or more. The primary assumption was that the exhaust noise is the dominant noise source for these particular types of equipment. Where data has shown otherwise, the dominant noise source is indicated and generalized noise reduction techniques are suggested.

Originally, DOT requested that the contract effort deal with 14 specific pieces of equipment. The list, revised slightly, is:

Earth Moving

Compactors (Rollers)
Front End Loaders (Integral Wheel Type)
Excavators (Integral Backhoe)
Tractors
(a) Track Type
(b) Wheel Type
Scrapers
Graders
Off-Highway Trucks
Pavers

Materials Handling

Concrete Pumps
Cranes (Moveable)
Cranes (Derrick)

Stationary

Pumps
Generators
Compressors

Initial contract efforts indicated that only limited information existed in the truck noise reduction area which could be transferred to the construction industry. As a result, it was decided to increase emphasis with respect to the manufacturer survey efforts and to add an actual field survey to the program. In this field survey, experienced acoustical personnel went to various construction sites in the Southwest, Midwest, Northeast and Southeast sections of the United States to get as broad a cross section of data for various machine types as possible. The results of this detailed field survey, along with the other surveys and literature search, serve as the information base of the contract.

2. SUMMARY

Work accomplished under this contract involved the compilation of comprehensive specifications for diesel engines greater than 50 horsepower used in the construction industry, the development of a comparative muffler selection procedure and the collection of costs for mufflers and complete exhaust systems.

2.1 Overview of Work Accomplished

There were four phases of the SAE contract to be completed within ten months. The first phase involved the development of a manufacturer-equipment-engine matrix. The purpose of this matrix was to identify which manufacturers produced engines and equipment per the SAE definition being used in the construction industry. Seven of the different equipment types over a 15-year period were researched and as a result, data was gathered for over 1100 pieces of equipment produced by 100 different manufacturers.

The second phase consisted of selecting and contacting 31 construction equipment manufacturers, 18 engine manufacturers, 8 muffler manufacturers, and 6 intake system manufacturers. The manufacturers contacted were selected on the basis of the information gathered in the first phase. The purpose of these surveys was to gather specific information to complete the engine specification sheet as well as to obtain typical noise levels of equipment from the various manufacturers. This information was supplemented by extensive field surveys in various parts of the United States, which provided work cycles, sound levels and exhaust system configurations typical of construction equipment.

The third phase involved data reduction. During this phase, information gathered from Phase II was sorted and organized into the requested engine specifications file, muffler horsepower guides, muffler recommendation sheets, system costs and configurations, muffler costs and installation procedures.

The fourth phase involved verification of data and the proposed muffler application technique. A noise impact ranking was developed to characterize equipment types with respect to degree of noise pollution. This noise impact ranking was based on four factors: The average machine type noise level, the typical percent of time the machine was at full load, the average production rate per year based on production figures of the last ten years, and the proximity to human population. The intent of the noise impact ranking (NIR) was to serve as a guide so that machines tested as part of the data verification phase would indeed represent machines that affect the greatest proportion of the population most significantly. The final NIR found front-end loaders, tractors, and backhoes (excavators) to be the three machines of the greatest impact. Tests were conducted on four pieces of equipment (two classes of tractors) to identify the contributions of the various sources to the overall machine noise level. Concurrently, one engine of each type was tested on a dynamometer to validate the proposed Muffler-Horsepower Guide and to evaluate silencing capabilities of various styles of air cleaners.

2.2 Conclusions and Recommendations

It was concluded from the data gathered and tests conducted under the contract that construction equipment produced since the late 1960's or early 1970's have utilized adequate muffling such that exhaust noise is not generally the dominant noise source. In addition, if reasonable mufflers are used, the exhaust noise level will not vary significantly with the size of the machine. Improved muffling will generally lower the overall level by 1 to 3 dB (A). In cases, however, where a particular piece of equipment either does not have or has a very poor muffler, exhaust noise is dominant and application of a good muffler will reduce the overall noise by 6 to 12 dB (A).

The dominant noise sources on machines with adequate mufflers are engine-mechanical, hydraulic systems and fans. A correlation exists between machine size and these noise sources such that the larger the engine, the higher the specific noise level contribution of engine mechanical, hydraulic and fan noise. Some of the various noise sources are highly directional; e.g., fan noise is a dominant noise source only on the equipment side it is facing or near to; mechanical engine and hydraulic noises show the same tendency. With typical vertical exhaust outlet and intake inlets, exhaust noise and, to a lesser degree, intake noise generally radiate evenly in all directions. If the orientation were horizontal, there would be a higher degree of directionality. In all the tests run, equipment with attachments at the front of the machine and the engine towards the rear tended to transmit very little noise toward observers in front of the machine. At the present time, the most reasonable noise reduction technique is the utilization of improved mufflers. A significant noise reduction requires the use of barrier techniques to prevent transmission of engine mechanical and hydraulic noise. Although some engine manufacturers do provide add-on noise reduction devices for specific engine components (such as valve cover noise enclosures), there are, at present, no known commercially-available engine compartment noise panels which will both lower the noise level and still allow adequate cooling.

With respect to the various test procedures, idle-max rpm-idle (IMI) tests measured using fast response give the best correlation to overall operating machine noise levels. See Appendix for a description of the IMI test per SAE J88a and a rationale for using fast response for the IMI test.
Max rpm tests give a good value for fan noise; however, in this test mode, mechanical, hydraulic and exhaust may be measured 6 to 10 dB(A lower than they actually are at peak load.

Based on the test data gathered and surveys conducted under this contract 88 dB(A) (per SAE J88a modified to use fast response for the IMI test) is a reasonable noise level to expect for used equipment with engine horsepower of 400 or less. Before establishing specific noise level goals for various construction equipment, studies are needed to determine the relationship of fan, hydraulic, and mechanical noise with engine size. After which, noise level goals can be established for construction equipment based on engine size.

3. SUPPORT INFORMATION

3.1 Theoretical Considerations

Internal combustion engines inherently have noise as an undesirable by-product. Noise is propagated out both the intake and the exhaust. The noise is not only radiated from the open ends of the exhaust and intake pipes, but is also transmitted through the pipes and muffler walls. The designs of intake and exhaust systems are extremely complex. The acoustical performance of any element is greatly affected by elements either upstream or downstream of the particular element. For this reason, the control of exhaust noise is much more involved than just putting on a better muffler. In this section, the basic techniques for silencing intake and exhaust noise are discussed as well as the effects of excessive intake restriction and exhaust back pressure.

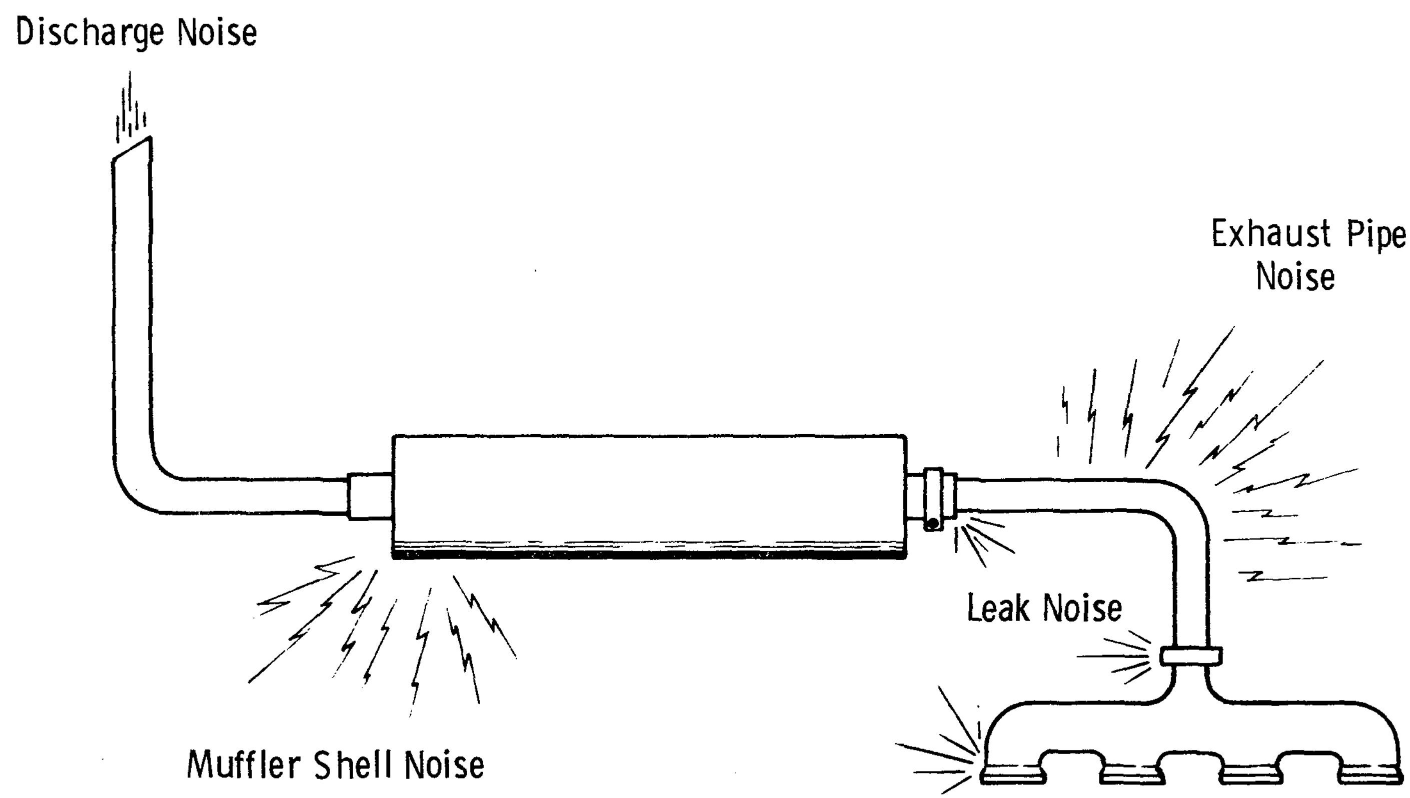
3.1.1 Intake and Exhaust System Operation

Large quantities of air are required for the efficient operation of an internal combustion engine. The primary function of the intake system is to provide the engine with clean filtered air. Following either injection or carburetion of fuel into this clean air, combustion caused by high temperatures associated with the diesel compression cycle or by spark ignition in the otto cycle, takes place. Following this process, the high temperature products of combustion are exhausted. The function of the exhaust system is to duct exhaust gas to a location where it does not affect either the machine or the equipment operator. The basic cause of intake and exhaust noise is the high velocity gas moving through the valve port of the engine, the flow being caused by the pressure differential across the port or valve. The high velocity is quickly dissipated; however, some of the energy is transformed into pressure waves which propagate as sound along the intake and exhaust system. These pressure waves are periodic and the frequencies are a function of the engine speed, the number of cylinders, and the engine cycle.

The intake system must be designed not only to provide clean and unrestricted air, but also to suppress noise. The exhaust system must also be utilized not only to duct the exhaust gas away, but to silence the exhaust noise. Even though mufflers and air cleaners provide some degree of silencing, a certain amount of noise will still propagate from the open ends of the pipe. The noise transmitted from the intake system will be referred to as intake noise and that which is transferred from the exhaust system will be referred to as exhaust noise (Ref. Figure 1). Another mechanism for emitting noise from an engine is transmission of sound through the walls of the intake or exhaust system. Basic laws of physics indicate that a certain amount of acoustical energy is radiated from a wall in two ways: 1) by transmission through the wall, in which the amount transmitted is based on mass of the wall, and 2) from resonance of the wall, in which frequencies and amount transmitted is dependent on mass, stiffness, and inherent damping of the wall. Another significant contributor to overall equipment noise is that noise which escapes from leaks in the system. Providing a completely leak-free system is very difficult, particularly in the flexible joints found in many types of equipment. The final source of intake and exhaust noise is the mounting of the particular systems. If mounts are too rigid, wall vibrations can be transmitted to the supporting structure and radiated as noise. Often this noise increases the cab noise or operator noise but typically does not affect the observer noise levels. An incorrect mounting, however, can affect more than the noise - it can also adversely affect the service life of the exhaust and intake system.

3.1.2 Types of Muffler Devices

Basically, there are three types of muffling devices which can be used to reduce intake and exhaust noise. These types are referred to as absorptive, reactive and dispersive mufflers. A fourth type would be a combination of these. Each type of muffler has a different principle of operation and produces a different result. Absorptive mufflers are mufflers which operate on a principle of absorbing the sound energy in a porous material. A typical application of an absorptive muffler, shown in Figure 2, is on a "straight through" automotive car muffler where the tubing is perforated and is backed by a porous material of either glass fibers or steel wool. The noise reduction capability of this type of muffler is dependent on the diameter of the pipe and the length of the muffler. Basically, these mufflers are used where high frequency noises are predominant, as absorption performance of mufflers is very minimal at low frequencies. The negative aspect of absorptive silencing techniques is the difficulty of finding packing materials which have an adequate life in the exhaust environment, i.e., a material which can remain intact withstanding pulsations at high temperatures.



Leak + Pipe + Muffler + Discharge Noises = Exhaust Noise

Example: 79 + 83 + 82 + 85 = 89 dB(A)

Figure 1. Sources of Exhaust Noise

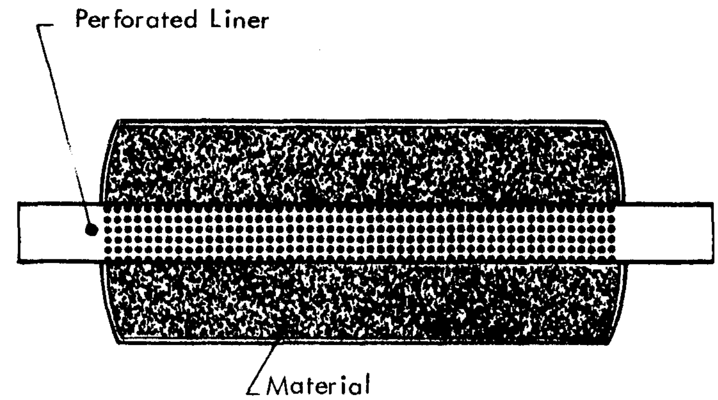


Figure 2. Typical Absorptive Style Muffler

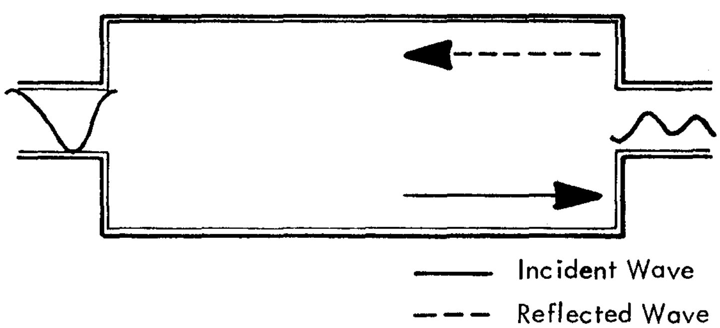


Figure 3. Expansion Can Showing Schematically the Acoustic Wave Reflection

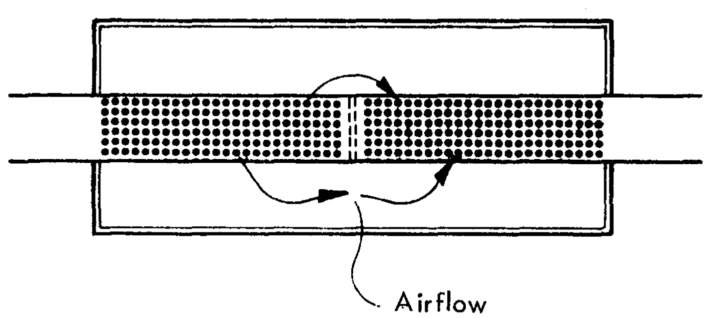


Figure 4. Typical Dispersive Type Acoustical Element

Reactive mufflers act on the reflection or interference principle in which the sound wave is reflected back towards the source. Elements utilizing this principle are the expansion chamber and the side branch resonator (Ref. Figure 3). These devices have pass band characteristics, i.e., they reflect certain frequencies and allow others to pass through. In general, the noise reduction from these devices depends on the dimension of the chambers, as well as the dimension of the exhaust or intake pipe; thus, a combination of these elements must be considered very carefully to develop a broad band, well-tuned muffler design.

The third type of acoustical filter is a dispersive muffler. This device consists of a perforated tube in a chamber where all the flow must pass through the perforations (Ref. Figure 4). The noise reduction capability of this element is largely dependent on the size of the perforations and the average exhaust velocity through the perforations. It is basically a broad band attenuator, but one must consider that flow through perforations generates a great deal of backpressure; thus, great care must be taken in application of this muffler element. To achieve the compact, high attenuating needs of construction equipment, all three devices are often combined to form a practical muffler.

With respect to the intake system, the filter itself acts as a dispersive element while the actual can which the filter is in acts as an expansion chamber. Thus, the intake system and the design of the air cleaner itself can greatly affect the attenuation of the intake noise.

3.2 Background Data

As a basis for setting forth a comprehensive listing of engine specifications and recommendations for intake and exhaust silencing, background data was obtained through a literature search and several different manufacturer surveys. The literature search included a review of the extensive work done on quieting truck noise and the gathering of statistical data on engines and construction equipment types from several sources. Survey forms went to engine manufacturers, equipment manufacturers, exhaust system manufacturers and intake system manufacturers. Before the surveys were completed, a manufacturer-equipment-engine matrix was constructed to aid in the surveys.

3.2.1 Manufacturer-Equipment-Engine Matrix

A matrix was constructed listing major construction equipment manufacturers, their products and the associated diesel engines used during the years 1961 through 1975. To obtain data for the matrix, Donaldson Company used specification issues of Construction Equipment and Construction Methods and Equipment, and supplementary data from Construction Equipment Cost Guide, published by the Department of the Army, Construction Engineering Research Laboratory. The matrix was then used as a guide to indicate, in general, which engines were used and which types of equipment were built by each manufacturer. From this, Donaldson Company proceeded to survey specific engine manufacturers, and equipment manufacturers. The matrix was not intended to be comprehensive, but rather to be used as a guide. Seven of the original fifteen equipment types are listed: rollers, loaders, tractors, scrapers, graders, trucks, and portable air compressors. Listings for the other equipment types could not be found. Approximately 1100 pieces of equipment from 100 different manufacturers were catalogued.

The original list of equipment types to be studied was as follows:

Earth Moving

- Compactors (rollers)
- Front Loaders
- Backhoes
- Tractors
- Scrapers, Graders
- Pavers
- Trucks

Materials Handling

Concrete Mixers
Concrete Pumps
Cranes (moveable)
Cranes (derrick)

Stationary

Pumps
Generators
Compressors

As the matrix developed, several clarifications were made to this list. The clarifications are as follows: "Front loaders" were more specifically defined as integral wheel-type front-end loaders, excluding skid steer loaders, as these were typically less than 50 hp. "Backhoes" excluded tractors with backhoe attachments and shovels. It included only integral type excavators. "Tractors" included two major types: (1) Track-type tractors with integral dozer, loader, or other attachments, and (2) wheel-type tractors (industrial and utility) with add-on loader, dozer, or backhoe attachments. "Trucks" included only off-highway types. The category "concrete mixers" was dropped for two reasons: (1) Auxiliary engines, where used, are most often gasoline and under 50 hp in size, and (2) in nearly all other cases, the mixer is driven by the carrier chassis engine. The carriers are over-the-road trucks on which extensive work has already been done towards defining noise sources and silencing them. The revised list is shown as follows:

Types of Off-Highway and Stationary Equipment - Revised

Compactors, Rollers
Front End Loaders (Intergral Wheel Type)
Excavators (Integral Backhoe)
Tractors
a) Track Type
b) Wheel Type

Scrapers
Graders
Pavers
Off-Highway Trucks
Concrete Pumps
Cranes (Moveable)
Cranes (Derrick)
Pumps
Generators
Compressors (Portable)

Using this revised listing, surveys were sent to various engine, equipment, intake system, and exhaust system manufacturers for specific data.

3.2.2 Engine Manufacturer Survey

From the manufacturer-equipment-engine matrix and the sources used to compile the matrix, there were twenty-five manufacturers of diesel engines found world-wide whose engines were used to power construction equipment utilized in the United States. These twenty-five manufacturers made all of the engines encountered during the course of this contract. Comprehensive listings were compiled for sixteen of these twenty-five companies. Eight companies were not listed as their engines were rarely encountered or they were lacking in available data. These eight were British Motor Corporation, David Brown, Dorman, Komatsu, Leyland, Murphy, Oliver, and White. One Company requested not to be included. Twelve out of the sixteen companies listed were selected to be surveyed as being representative of the vast majority of engines used. The data gathered was used in the engine specification sheets, Section 4.2, supplemented by other literature.

The contract called for the following specifications on each engine:

Model
Manufacturer
Number of cylinders and form
Two-cycle or four cycle
Aspiration

Bore and stroke
Fuel injection method
Rated speed and horsepower
Relevant design and operational details
Current production level
Overall market status
Intake and exhaust noise emissions

In surveying the engine manufacturers, the form was somewhat detailed. To aid manufacturers, critical pieces of desired data were highlighted by being boxed. The survey form is shown in Figure 5. Table 1 indicates the companies surveyed and their responses. In total, only six manufacturers replied with data. In all cases, the data was partial. Population data was considered proprietary and no company supplied intake and exhaust noise data.

3.2.3 Equipment Manufacturer Survey

The purpose of this survey was to gather data on engines and exhaust systems to determine general population figures, usage and engine load factors, and equipment noise levels. The survey forms are shown in Figure 6. Data was requested from each source on its three most popular models of a given equipment type. Of over 3000 companies which manufacture construction equipment, surveys were sent out to divisions of 31 major companies. Forty-eight surveys were sent out in all. For each equipment type, an effort was made to survey at least three manufacturers. For more common types of equipment, five to eight companies were surveyed. Table 2 shows the breakdown and results of the survey. There were 21 responses, 19 with data. Data provided was largely on newer equipment; consequently, the noise data provided was largely on equipment having muffled exhaust systems. This data shows that most equipment, except for off-highway trucks, have utilized mufflers since 1971. Typically off-highway trucks duct the engine exhaust through the box frame (heated box). This data was utilized in the development of a noise impact ranking, Section 3.3.

SAE Construction Equipment Noise Study

DIESEL ENGINE MANUFACTURER SURVEY

Engine Manufacturer ____________ Configuration: ☐ Vee ☐ Inline
Engine Model No. ____________ Number of Cylinders ____________
Maximum brake horsepower ____________ @ ____________ rpm.
Maximum rated torque ____________ @ ____________ rpm.

☐ 2 cycle
☐ 4 cycle
Cubic inch displacement ____________
Bore ________ Stroke ________
Fuel injection: ☐ Direct
☐ Precomb. chamber

Aspiration: ☐ Naturally aspirated
☐ Turbocharged
☐ Blown (mechanically)
☐ Aftercooled

Open pipe exhaust noise @ rated load and speed: dB(A) @ 50 ft. ____________
other noise data (describe) ____________

Open pipe intake noise @ rated load and speed: dB(A) @ 50 ft. ____________
other noise data (describe) ____________

Other noise data: Octave band, 1/3 octave band, narrow band, etc. -- attach data

Intake air flow @ rated load and speed ____________ CFM
Exhaust temperature @ rated load and speed ____________ °F
Exhaust system backpressure limit ____________ " Hg
Recommended exhaust system diameter ____________ " single ____________ " dual

Intake air flow @ high idle ____________ CFM
Exhaust temperature @ high idle ____________ °F
Intake system restriction limit ____________ "H_2O

Quantity of this engine produced from 1961 to 1975 for construction equipment used in the United States:

1975	______	72	______	69	______	66	______	63	______
74	______	71	______	68	______	65	______	62	______
73	______	70	______	67	______	64	______	61	______

In your estimation, how many engines of this model are operating in the field in construction equipment of any type? ____________

Figure 5. Survey Form for Engine Manufacturers

Table 1. Survey of Diesel Engine Manufacturers
(See Sec. 4.2 for data obtained from survey)

Company	Surveyed	Survey Response*
Allis Chalmers	yes	No Response
JI Case	yes'	Responded
Caterpillar	yes	Declined
Chrysler-Nissan	no	--------
Continental	no	--------
Cummins	yes'	Responded
Deere and Company	yes	Declined
Detroit Diesel	yes'	Responded
Deutz	yes'	Responded
Ford	yes	No Response
Hercules	yes	Responded
International Harvester	yes'	No Response
Mack	no	--------
Mercedes-Benz	no'	--------
Minneapolis Moline	no	--------
Murphy	yes	Declined**
Perkins	yes	Responded
Waukesha	yes'	Declined

* "Responded indicates that the manufacturer replied with data, either partial or complete. "Declined" indicates those manufacturers who expressed the desire not to provide data and/or not to have data included.

** Murphy's response was that it had no engines sold in quantities of 1000 or more during the period 1961 through 1975.

' These companies validated data on their engines as it would be listed in the final report.

DIESEL POWERED CONSTRUCTION EQUIPMENT -- GENERAL SURVEY

Equipment Type	Estimated percent of normal operating cycle machine is at full load	Estimated total population of all manufacturers for this equipment type 1961 - 1975

Figure 6. SAE Construction Equipment Noise Study (Sheet 1 of 2)

DIESEL POWERED CONSTRUCTION EQUIPMENT - EQUIPMENT MODEL SURVEY

1961 - 1975

Manufacturer ______________________

Equipment Type ______________________

Model Number ______________________

Engine: Manufacturer ________ ________ ________

Model ________ ________ ________

Rating (hp @ rpm) ________ ________ ________

Which years (from 1961 thru 1975) ________ ________ ________

Exhaust System

	Unmuffled	Silenced by Turbocharger	Silenced by muffler or silencer*	
			Muffler I Single Dual	Muffler II Single Dual
Which years (from 1961 thru 1975)				
Overall vehicle noise level (if available) dB(A) @ 50 ft.				

* If different mufflers were used at different times, list in order of years used.

If possible, complete the following information on muffler(s):

	I	II
Manufacturer		
Model		
Size		
Muffler orientation (horizontal or vertical)		
Tailpipe orientation (horizontal or vertical)		

Figure 6. SAE Construction Equipment Noise Study (Sheet 2 of 2)

Table 2. Summary of Construction Equipment Survey

Manufacturer	Compactors	Front-End Loaders	Excavators	Tractors	Scrapers	Graders	Pavers	Off-Highway Trucks	Concrete Pumps	Cranes (moveable)	Cranes (derrick)	Pumps	Generators	Compressors	Response*
1. Am Hoist & Derrick	X		X								X				N
2. Barber-Greene							X								N
3. Blaw-Knox							X								N
4. Bucyrus-Erie			X							X	X				Y
5. JI Case		X	X	X						X					P
6. Caterpillar		X	X	X	X	X									D
7. Challenge-Cook									X						N
8. Clark		X	X		X	X				X	X				P
9. Cummins													X		N
10. Deere & Company		X	X	X	X										D
11. Eaton Corp.		X													Y
12. Euclid								X							N
13. FMC										X	X				N
14. Fiat-Allis		X	X	X	X	X									P
15. Galion	X					X				X					Y
16. Gardner-Denver												X		X	N
17. Grove										X					N
18. Harnischfeger										X	X				N
19. Huber	X					X									N
20. Ingersoll-Rand												X		X	N
21. International Harvester		X		X	X			X							Y
22. Jaeger									X			X		X	Y
23. Joy														X	D
24. Kohler													X		N
25. Northwest Engineering											X				Y
26. Onan													X		N
27. Rexnord	X						X								Y
28. Sullair														X	N
29. Tampo	X														Y
30. Terex		X		X	X			X							Y
31. WABCO					X	X		X							P
32. Warner-Swasey			X							X					Y
Totals	5	8	8	6	7	6	3	4	2	8	6	3	3	5	

*Response
Y: All divisions surveyed responded with data.
P: Partial response, not all divisions responded with data.
D: Declined to provide data.
N: No response.

3.2.4 Field Survey

A field survey was conducted to supplement the equipment manufacturer survey. Data was taken on more than 90 pieces of construction equipment under typical working conditions by Donaldson Company personnel. Machines were observed under actual operating conditions at road construction sites, residential developments, mines and quarries. The data gave information on: (a) Typical sound levels under working conditions, (b) extent of muffler usage, (c) work cycle data, and (d) exhaust system configurations. The survey form is shown in Figure 7. Table 3 gives a summary of the results of the field survey, listed by equipment type. The loudest machine tested was unmuffled (99 dB(A) at 50 ft). Sound levels ranged from 77 to 99 dB(A). Of the 90 pieces of equipment tested, 34 were unmuffled.

3.2.5 Exhaust System Survey

Exhaust system manufacturers were surveyed for available-for-order mufflers to include in a selection guide. Information was asked on attenuation characteristics, dimensional data, flow characteristics, and prices. Table 4 lists the companies surveyed.

Those who responded were able to provide sufficient information to incorporate into a listing of exhaust systems developed during the contract.

3.2.6 Intake System Survey

Manufacturers of intake systems were surveyed for noise attenuation data on intake systems to be used as supplementary data. As opposed to the exhaust system survey, only general questions were asked concerning attenuation values for various typical air cleaner configurations. Table 5 shows companies surveyed.

3.2.7 Literature Search

Originally intended to be a major thrust in the contract work, the literature search was directed towards extracting usable information from the extensive amount of work already accomplished on noise suppression, particularly in over-the-highway trucks.

FIELD SURVEY

Equipment: Mfr: ____________ Type: ____________ Model: ____________ Year: ______

Engine: Mfr: ____________ Model: ____________ Rating: ______ hp @ ______ rpm

What is the work cycle of this machine? ____________ hrs/day: ____________ hrs/week

Total Vehicle noise level @ 50': ______ dB(A) Is the exhaust noise dominant? O Yes O No

What additional noise sources contribute to this level? ____________

EXHAUST SYSTEM

Exhaust Silencing Device:

- O Attenuation provided by muffler
- O Attenuation provided by turbo
- O Unmuffled

MUFFLER DATA

Mfr: ____________

Model: ____________

Size: ____________

Inlet Dia: ____________

Outlet Dia: ____________

3. INTAKE SYSTEM

A/C MFR: ____________

Model: ____________

Type: Dry O Oil Bath O

Size: ____________

Inlet Size: ____________

O Tubular O Perforated O Open Face

Outlet Dia: ____________

Is intake noise satisfactorily silenced with present system?

O Yes O No ____________

____

Exhaust System

- O Single
- O Dual

Muffler Orientation

- O Horizontal
- O Vertical

Tailpipe Orientation

- O Horizontal
- O Vertical

Please sketch exhaust system:

Observations:

dB(A) Levels at 50'

Stationary Run Up

_____ Passby Loaded

_____ % Time Full Load

_____ Work Cycle

Figure 7. Field Survey Form

Table 3. Summary of Field Survey Data

EQUIPMENT TYPE	Number Tested		Noise Level (dB(A))		
	Muffled	Unmuffled	Loudest	Quietest	Average
Compactors	3	--	83	80	81.7
Front End Loaders	16	3	99	78	86.5
Backhoes, Excavators	4	1	95.5	77	83.5
Tractors	3	5	96	81	87.9
Scrapers	5	2	93	81	88.7
Graders	6	1	88	78	83.0
Pavers	--	1	--	--	80.0
Trucks	5	2 unmuffled 11 heated box	96	79	88.7
Concrete Pumps (Located on only 1 site, not in operation)	--	--	--	--	--
Cranes (moveable and derrick)	4	--	90	85	86.0
Pumps	1	--	--	--	80.0
Generators	2	1	99	81	84.0
Compressors	7	1	99	78	90.25

Table 4. Exhaust System Survey

Company	Response
AP	No product in this market
Burgess-Manning	No response
Cowl	Responded
Donaldson	Responded
Maremont	Responded
Maxim	No response
Nelson	Responded
Riker	No response
Stemco	Responded
Walker	Responded

Table 5. Intake System Survey

Company	Response
Air Maze	Responded
Donaldson	Responded
Farr	No response
Fram	No available data
United Filtration	No response
Mann and Hummel	Responded

However, as work on the contract progressed, it became evident that the real objectives of the contract couldn't be achieved by utilizing the previous truck noise work. Previous work on truck and bus engines involved roughly 40 engines, whereas the work in this contract involved over 400 engines. With the work of this contract concentrating on assembling exhaust system information for the 414 engines listed, previous work was not applicable to the effort.

Twenty-eight reports, including DOT contract work, EPA reports and reports from the Army's Construction Engineering Research Laboratory were reviewed. In addition, nine SAE papers were studied. Most of these sources were not used directly for data, although reference was made to them in some cases.

In the collection of specification data on diesel engines and construction equipment, as mentioned earlier, statistical issues of Automotive Industries and Construction Methods and Equipment covering the past fifteen years were used extensively. Also consulted were various issues of Diesel and Gas Turbine Worldwide Catalog.

3.3 Noise Impact Ranking

The noise impact ranking (NIR) was developed to objectively rate the particular equipment types in order of noise severity. This rating served as a guide for selecting machines for source identification work as well as muffler application verification. Four factors to be included in the rating of the various equipment types were established with the assistance of the SAE contract monitoring panel. These factors were as follows: 1) Sound level, 2) machine usage, 3) machine population, and 4) nearness to human population. Machine capacity was not included because of the difficulty of breaking down these four factors based on machine capacity. Since only a limited trend existed between horsepower and sound level, it was felt there was justification in not including machine size.

Thirteen basic types of equipment were considered in this rating: Off-highway trucks, scrapers, compressors, front end loaders, concrete pumps, tractors, cranes, generators, pumps, backhoes and excavators, compactors, graders and pavers. Initially, the machines were rated, in descending order, according to average sound level measured at 50 feet as shown on Table 6. These sound levels were the statistical averages and were based on cumulative results of the field and equipment surveys.

Table 6. Original Noise Impact Ranking,
Ranked by Sound Level

Equipment Type	Sound Level (dB(A))	Rating Factor*
1. Truck	89	3
2. Scrapers	88.1	3
3. Compressors	86.7	3
4. Front End Loaders	86.5	2
5. Concrete Pumps	86	2
6. Tractors	86	2
7. Cranes	85	2
8. Generators	84	2
9. Pumps	84	2
10. Backhoes	83.7	2
11. Compactors	82.5	1
12. Graders	82	1
13. Pavers	80	1

*Rating Factor #1 80 - 83.5 dB(A)
#2 83.6 - 86.5 dB(A)
#3 86.6 - 89 dB(A)

Trucks category refers to off-highway trucks only.

Tractors category includes tracked vehicles and industrial tractors.

Note: When gathering noise data from the equipment manufacturer survey and the field survey, we investigated previously-gathered noise data on construction equipment. Of interest was a bar chart published in EPA report NTID300.1, entitled "Noise From Construction Equipment and Operations, Building Equipment, and Home Appliances," (December, 1971). This chart, based on limited data, listed construction equipment noise level ranges. Sources were various reports and field measurements in the vicinity of Boston. In several cases, the data gathered under the present contract gave different noise level ranges, significantly higher in some cases, than shown in the above mentioned report. Fig. 8 is a bar chart showing, for each equipment type listed, noise level ranges from the report, our field survey data, and equipment manufacturer survey data. Also listed are the mean sound levels for the latter two sources. Of interest is the front-end loader category, where data from both surveys indicate a noise level range of 8 to 12 dB(A) higher than the previous data. Other types of equipment also show differences, but to a lesser degree.

Noise levels were based on machines with a variety of engines and muffling systems and in some cases, no muffler at all. Further, the field survey involved machines built over a fifteen year span while the equipment surveys provided noise levels, for the most part, of only the newer model machines produced when, in general, manufacturers began devoting more attention to noise reduction. The averaged sound levels for the 13 different types vary from 80 to 89 dB(A). These sound levels were grouped into three ranges. Machines with sound levels of 80 to 83.5 dB(A) were assigned a value of 1, those with sound levels from 83.6 to 86.5, a value of 2 and those with sound levels from 86.6 to 89, a value of 3.

The second factor considered for the NIR was the work cycle of the machine which denoted the percent of time during typical operation that the machine was operating at full load. The noise levels were based on full load (worst case) noise levels. The percentages used are based on data gathered from the construction equipment field survey and the equipment manufacturer's survey. These work cycle factors are adjusted in some instances to take into account the rest of the work cycle. These work cycle percentages were categorized into three ranges and assigned a value of 1, 2, or 3, consistent with the sound level ranking procedure. Table 7 shows the work cycle, the rating factor, and the combined ranking which was determined by multiplying the noise ranking by the work cycle ranking.

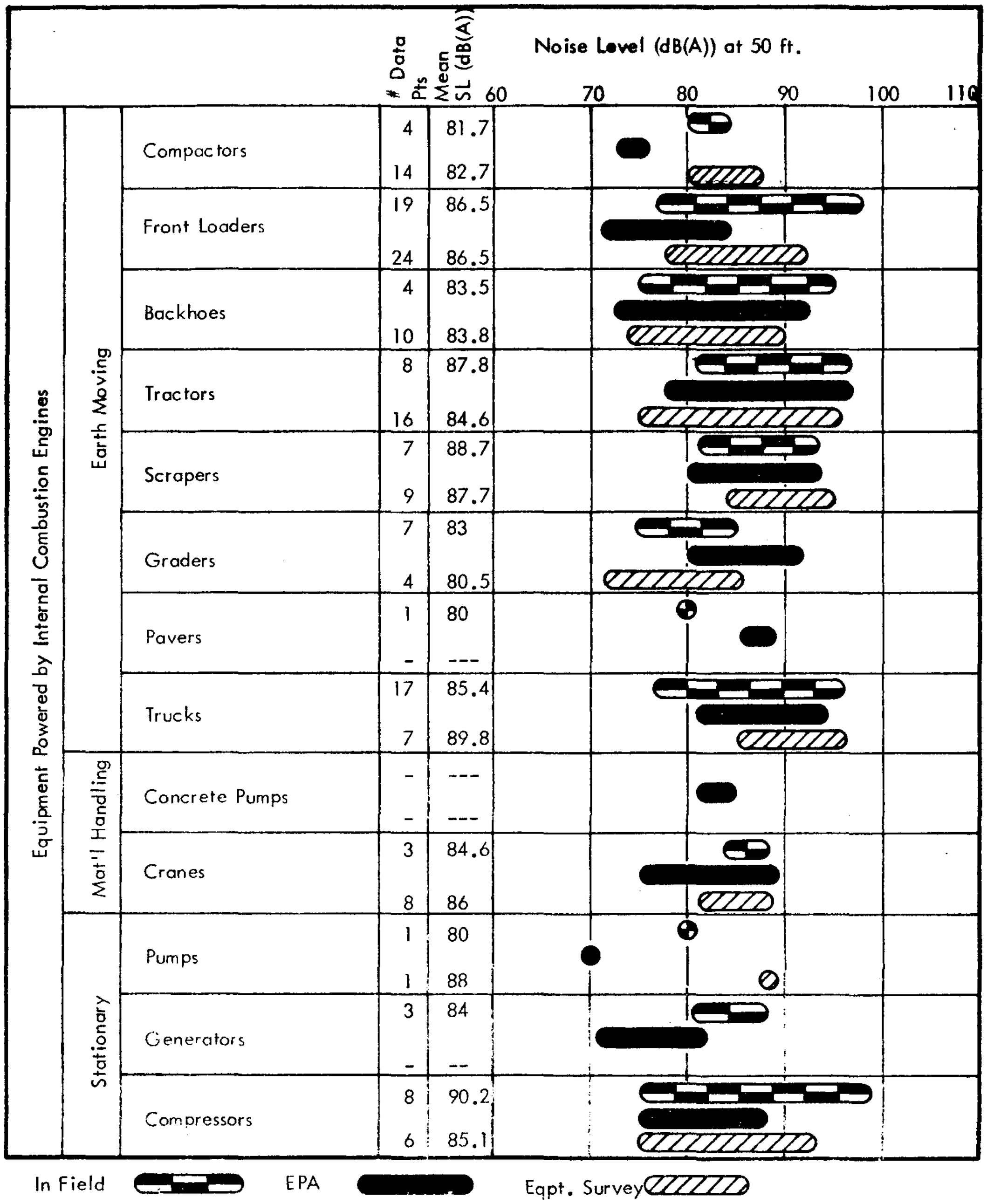


Figure 8. Comparison of Data from EPA Report, Field Survey and Equipment Manufacturer Survey

Table 7. Noise Impact Ranking Showing Combined Factors of Work Cycle and Sound Level

Equipment	Work Cycle (%)	Rating Factor*	Combined Rating
1. Trucks	0.60	3	9
2. Scrapers	0.65	3	9
3. Tractors	0.60	3	6
4. Backhoes	0.55	3	6
5. Front End Loaders	0.45	2	4
6. Compressors	0.30	1	3
7. Concrete Pumps	0.30	1	2
8. Cranes	0.35	1	2
9. Generators	0.30	1	2
10. Pumps	0.30	1	2
11. Compactors	0.45	2	2
12. Graders	0.40	2	2
13. Pavers	0.30	1	1

*Rating Factor #3 0.65 - 0.55%
#2 0.50 - 0.40%
#1 0.35 - 0.30%

The monitoring panel recommended that a third and fourth factor be incorporated into the NIR: a nearness to human population density factor and a population by machine type factor.

The nearness to population factor was deemed more important than the sound level factor for two reasons: 1) The limited variation in average sound levels, and 2) the contract emphasis on observer noise levels. A ranking was developed based on typical machine proximity to human population -- very low (1), low (2), average (3), high (4), and very high (5). For instance, crawler tractors were placed in the average range (a value of 3); whereas, off-highway trucks and scrapers were placed in the very low range (a value of 1). Typically, off-highway trucks and scrapers are found in construction sites with very few people being exposed to these noises. Conversely, crawlers, being very versatile, are used for many operations in a variety of locations, frequently in highly populated areas. These figures were discussed with the monitoring panel and the final values were approved. The ranking, as well as the combined values, are shown in Table 8.

The monitoring panel felt that the machine population was as important as the nearness to population, thus a range of 5 was also used here. Because the information was either unavailable or of proprietary nature, attempts to determine the total machine population proved unsuccessful, so the average production rate per year was used. These figures, obtained from the Bureau of the Census and supplemented by Construction Industry Manufacturers Association (CIMA), were average yearly production levels over the past ten years. It was possible to obtain figures for only ten pieces of equipment and of these ten, only nine directly from the Bureau of Census. The population figures for compressors were supplied by a major manufacturer of compressors. These figures were based on estimates of the population of compressors rated at 125 cfm or over which the manufacturer felt were closely correlated to machines of 50 hp or larger. The production figures, rating breakdown, and combined ratings are shown on Table 9.

Based on this evaluation technique, the three equipment types with the most noise impact are: 1) Tractors, 2) Front-End Loaders, and 3) Backhoes-Excavators. One of each of these types were to be tested for noise source identification; however, the number of machines actually tested was four, so that both a crawler-tractor and an industrial tractor could be evaluated.

Table 8. Noise Impact Ranking Showing Combined Factors of Work Cycle, Sound Level and Human Population Density Factor

Equipment	Population Density * V. High (5)	High (4)	Med. (3)	Low (2)	V. Low (1)	Combined Rating
1. Backhoe	X					30
2. Tractors		X				24
3. Front End Loaders		X				16
4. Compressors		X				12
5. Truck					X	9
6. Scraper					X	9
7. Concrete Pumps		X				8
8. Cranes			X			6
9. Generators			X			6
10. Compactors			X			6
11. Graders			X			6
12. Pumps				X		4
13. Pavers			X			3

*Population Density is a relative indication of the percentage of time a machine type is used in a highly populated area.

Table 9. Final Noise Impact Ranking

Equipment	Machines Produced/Year	Rating Factor*	Combined Rating
1. Tractors	25000	5	120
2. Front End Loaders	15000	4	64
3. Backhoes	3940	1	30
4. Compressors**	5500	2	24
5. Trucks	7970	2	18
6. Compactors	7225	2	12
7. Cranes	6420	2	12
8. Graders	6000	2	12
9. Scrapers	4600	1	9
10. Pavers	950	1	3

*Rating Factor #1 0 - 4,999
#2 5,000 - 9,999
#3 10,000 - 14,999
#4 15,000 - 19,999
#5 20,000 - 25,000

**Population source for the compressor category was not the Bureau of Census. This figure was based on manufacturer estimates based on size range of 125 cfm or higher.

3.4 Muffler Application Evaluation

Engine tests were conducted to verify the proposed muffler application techniques. These engines were selected, with discussions and approval by the panel, based on three objectives:

1. Each of the engines selected should be of a different horsepower range.
2. One turbocharged and one naturally-aspirated engine and one 2-cycle and one 4-cycle engine should be tested.
3. Engines tested for verification of the Muffler Horsepower Guide should be the ones used in the equipment tests.

The engines selected and the equipment match-ups are shown in Table 10.

Table 10. Engine-Equipment Test Selection

Engine	Type	Horsepower (bhp)	Equipment
1. Detroit Diesel 4-53	2 cycle NA	115	Excavator
2. Cummins NTC 380	4 cycle Turbo	380	Front End Loader
3. Ford D201	4 cycle NA	59	Industrial Tractor
4. Detroit Diesel 8V-71	2 cycle NA	318	Crawler Tractor

3.4.1 Test Procedure

Engine exhaust and intake noise were evaluated at the Donaldson Company Test and Evaluation Facility. Here, exhaust or intake noise can be completely isolated from other noise sources. This is accomplished by completely enclosing the engine and dynamometer test lab and routing the intake or exhaust outside to the test pad area. The test pad is an open area and has a concrete base extending sufficiently so that 50 foot distance measurements can be made. This test pad is acoustically calibrated outside the test site to conform with SAE J88a requirements. The anechoic wall (lined with an absorptive material) is essentially non-reflective for all engine frequencies. See Figures 9 through 11.

Once the exhaust is routed outside the dynamometer room, further source identification can be carried out on the three elements of exhaust noise. These are first, discharge noise (noise coming directly out the tailpipe), second, shell and pipe noise (noise radiated from the muffler shell and off pipe surfaces) and third, leak noise (noise radiated from leaks at connections or holes in the system). Reference Figure 1.

Inside the dynamometer room, the engine can be put through the various test modes by varying throttle and load, while at the same time measuring engine functions such as, rpm horsepower, airflow, fuel consumption and exhaust temperature, as well as exhaust system back pressure and sound levels. Sound levels are measured using the fast response of a sound level meter. Usually three test modes are used. First, the engine is run constantly at the rated load and rpm, giving the full load sound level. After the system has reached equilibrium temperatures octave band levels, overall levels and back pressure are recorded. (Figure 12 is a copy of a typical data sheet.) Next, the engine is rapidly loaded starting from high idle rpm down to about two-thirds full load rpm. Finally, the engine is run up from idle to maximum governed rpm and back to idle, duplicating the idle-max-idle test. This test is run at least three times to evaluate the exhaust and discharge noise as the muffler cools. (The shell noise is greatly dependent on muffler skin temperature, and the IMI test causes the temperature to drop.) Results of the last two procedures are graphed, so that unusual peaks or other characteristics can be seen. (Reference Figure 13.)

Back pressure is measured near the manifold or turbocharger to ensure that the entire system backpressure is measured. Precautions are taken to avoid measuring near elbows and also to use the correct diameter tube. The measuring apparatus is set up to avoid heat transfer and to minimize effects of standing waves. Reference Appendix C.

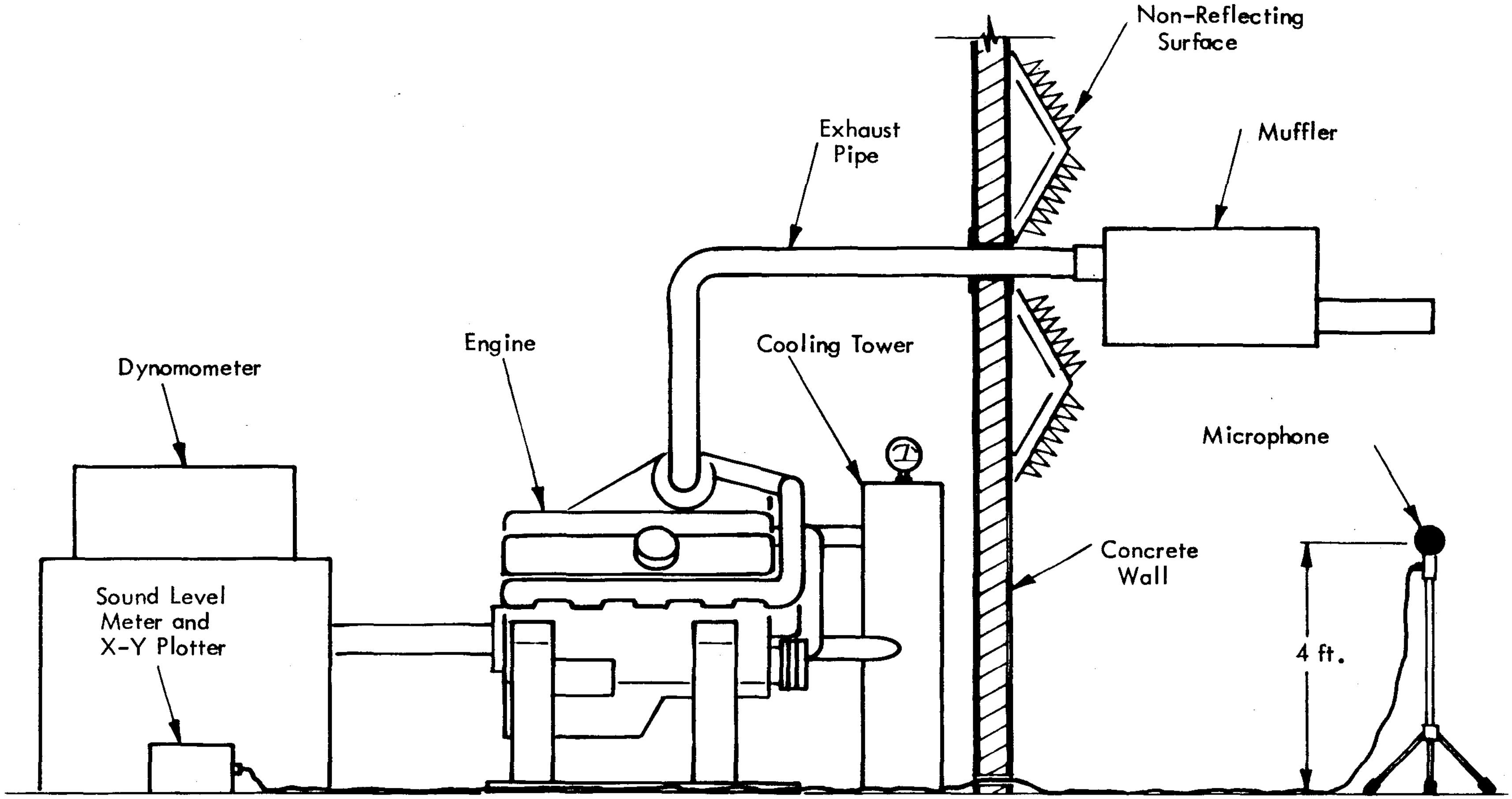


Figure 9. Exhaust Noise Test Area

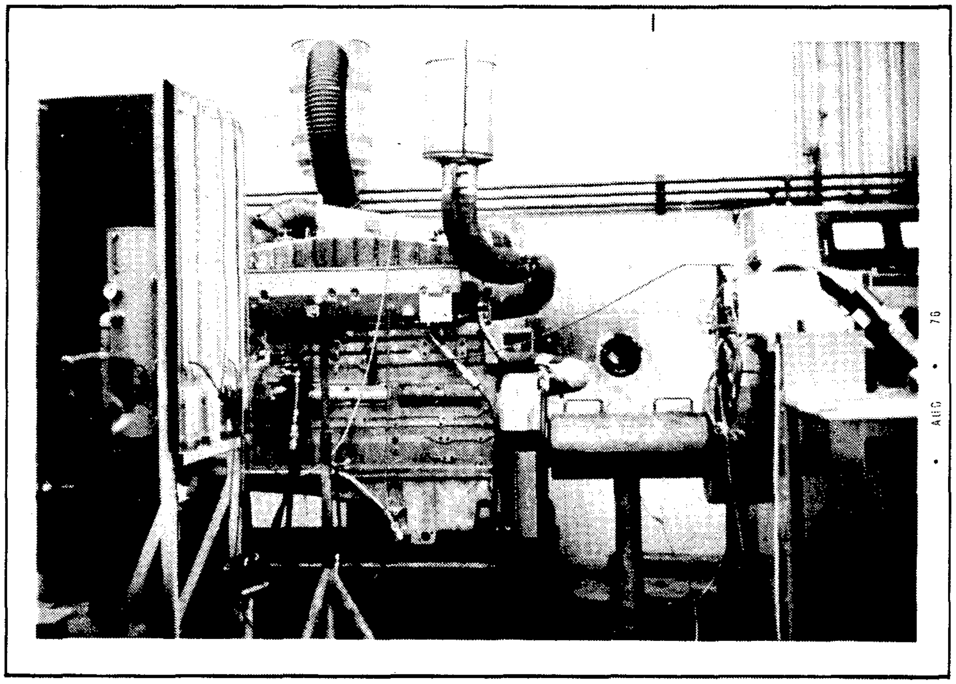


Figure 10. Engine, Dynamometer and Sound Meter in Control Room

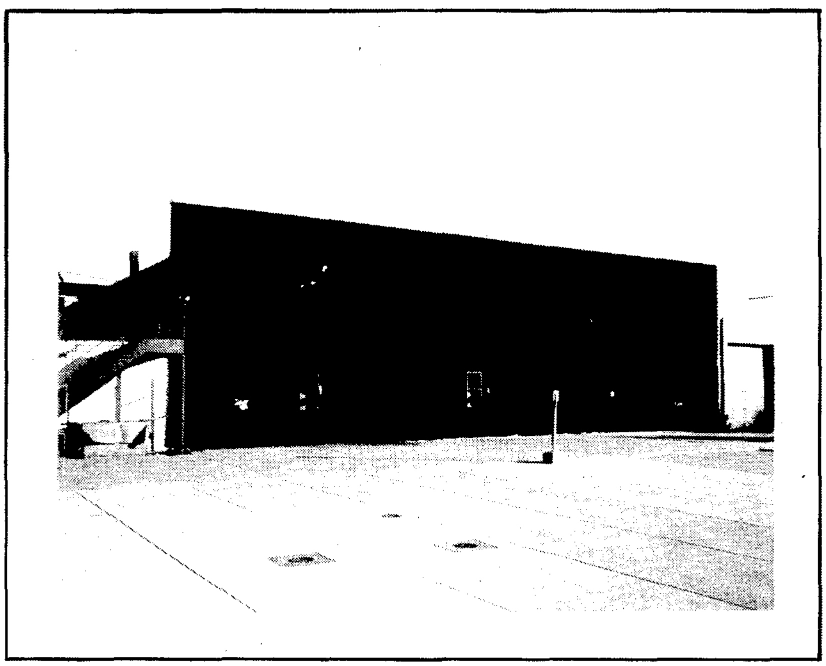


Figure 11. Test Pad Area Showing Non Reflective Walls and Hard Surface

Sheet No. 1 of 1

Reel No.

Engine D.D. 8V-92NA Test of Dual Vertical - Vertical

MUFFLER TEST SUMMARY SHEET

EWR

Project No.

Date 3-16-76

Tester JRH

Location TAYLOR DYNO

Device	5040 D 36 WRAPPED											
Hp @ RPM	364 @ 2100		@		@		@		@		@	
Bp "H2O/"Hg (circled "Hg)	3.75											
SPL db A	72.5 - 72.5											
Linear	82 - 82											
Octave Band / dbA Level	50' N.W. (48" crossed out)	50'	42"	50'	42"	50'	42"	50'	42"	50'	42"	50'
63 cps	72	72										
125 cps	80	80										
250 cps	73.5	73.5										
500 cps	68	69										
1,000 cps	66	66										
2,000 cps	66	66										
4,000 cps	58	58										
8,000 cps	52	52										
Set-up (Sketch)												
Rev / Lug	76.5 / 75.5											

Backpressure Taps at MANIFOLD OUTLET

Remarks

System	
Right Bank	
Dia.	4"
Length	8.5'
Left Bank	
Dia.	
Length	
Wye	
Common	
Dia.	
Length	
Tailpipe	
Dia.	4"
Length	3'
Exh. Man.	
Type	

Figure 12. Typical Data Sheet for Engine Test

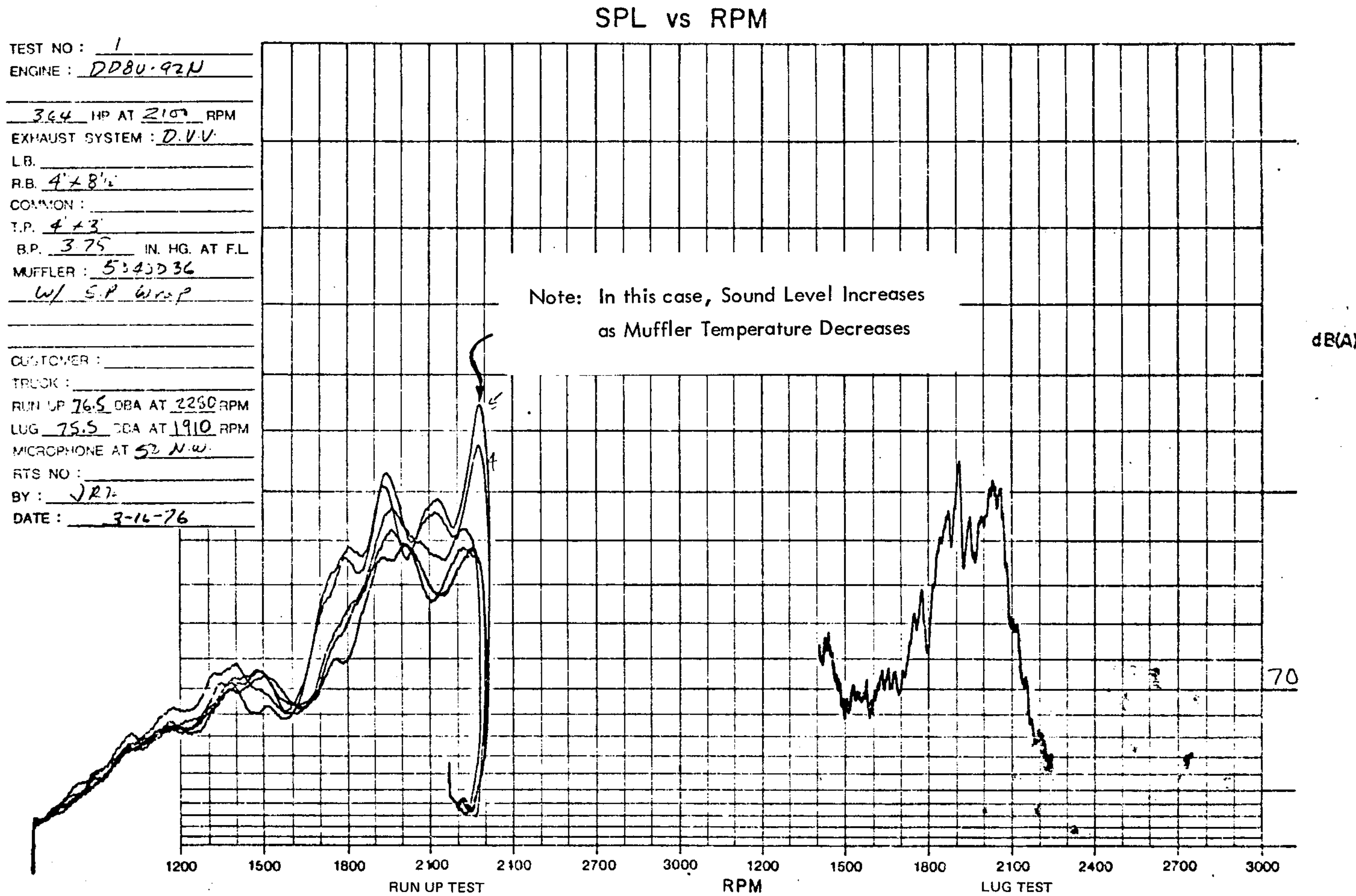


Figure 13. Typical Results of Run up and Lug Tests

3.4.2 Engine Tests

Engine tests were included in the contract effort as a means of evaluating the muffler application techniques developed as a part of the contract objective. Tests were also conducted on various styles of air cleaners to show the range of attenuation values relative to air cleaner style.

Muffler Tests

The Muffler Horsepower Guide was evaluated by testing roughly 50 mufflers on the four engines at Donaldson Company's Test and Evaluation facility. Shown in Table 11 are the predicted and actual results of representative mufflers.

The test results agree quite well with predicted values. Note the corrected back pressure values for single systems on the 8V-71. On Vee engines such as this, where a conventional wye is used before a single muffler, it was necessary to adjust the horsepower to compensate for the increase in back pressure because of the wye. The conventional wye correction curve was developed using both flow test results on typical connector systems and theoretical predictions. Each pipe diameter curve covers the typical horsepower range of the mufflers having those inlet diameters. The correction curve is shown in Figure H-1 Refer to Appendix H for an explanation of application.

Air Cleaner Tests

Air cleaner tests were also conducted on the four engines. The tests were run to show typical intake noise levels and generalized attenuation performances for the different styles of air cleaners (Figure 14). As can be seen in the discussion of equipment tests in Section 3.5, intake noise is usually not a major contributor to overall vehicle noise. On three of the four vehicles tested, intake noise was more than 10 dB(A) below the overall vehicle noise.

Generalized attenuation ranges for each of the air cleaners of Figure 14 are shown in Table 12. Attenuations are presented for two cycle and four cycle naturally-aspirated engines and turbocharged engines. These attenuation values are based on data received from the intake system survey and data gathered as a result of the engine tests. Note that:

> Integral separator air cleaners are approximately 2 dB(A) more effective than primary dry air cleaners.

Table 11. Muffler-Horsepower Guide Verification Results

Engine Muffler	Predicted		Actual	
	bp ("Hg)	Sound Level dBA @ 50 ft.	bp ("Hg)	Sound Level dBA @ 50 ft.
4-53 MFM07-0028	2.5	92	2.5	94
WSM09-0211	3.0	73	3.6	70
MOM09-0301	2.0	76	3.3	76
D201 WTM08-5106	2.0	73.5	2.2	71.5
MAM06-0158	2.5	79.5	2.2	74
NTC-350 MOM12-0186	2.8	73.5	3	74
MOM14-0002	2.4	72.5	2.6	74
WFM09-0275	2.1	73.5	2.3	73.5
8V-71 MOM12-0100	3.9 4.5*	85	4.6	84.5
MUM14-0002	2.0 2.5	86	3.1	84.5
MFM10-0165	3.0 3.0	76	2.7	78
"Duals"				
8V-71 MZM08-5008	3.0	82	3.0	81
MOM09-0301	3.0	76	3.4	79

*These back pressure values corrected for use of a conventional wye.

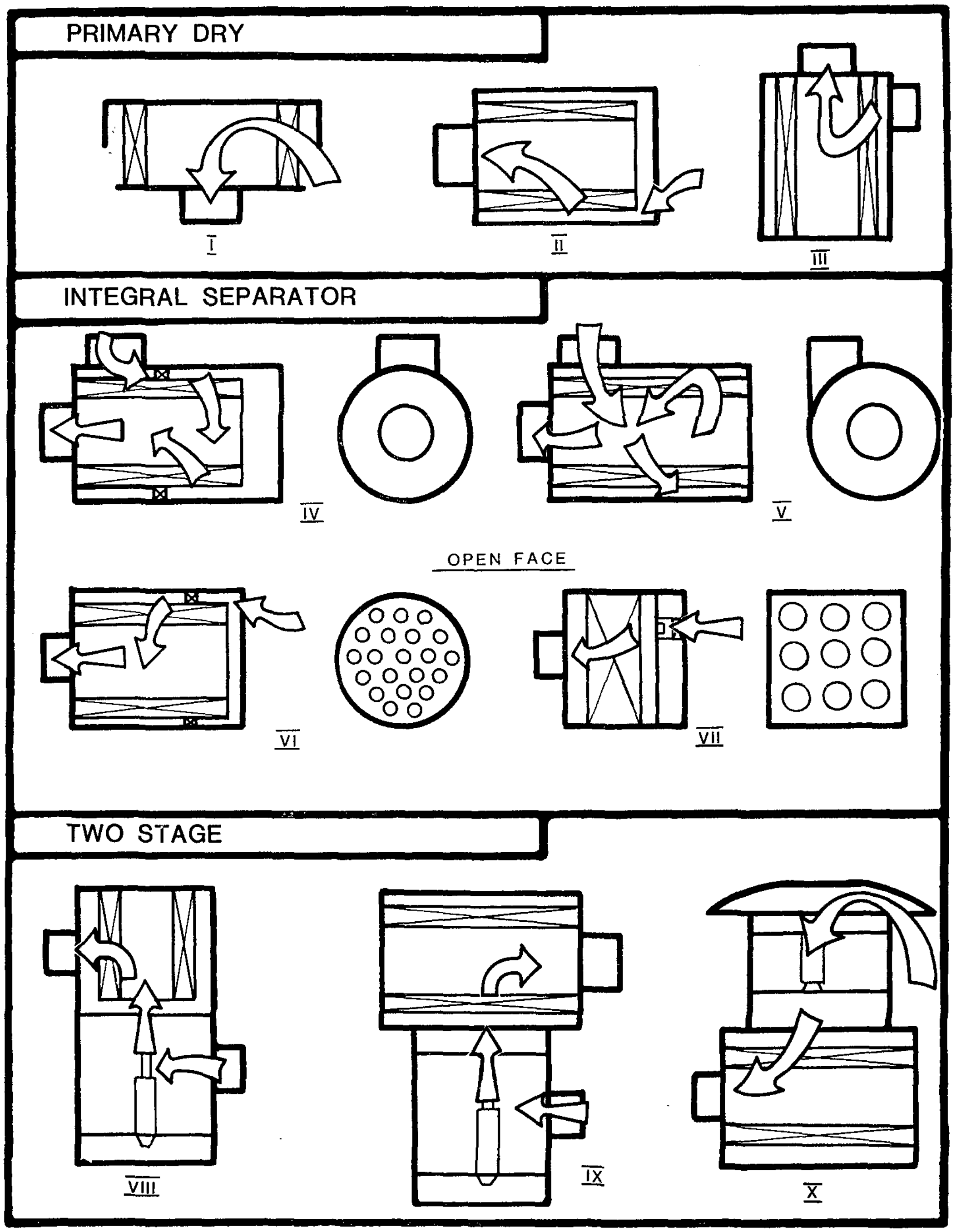


Figure 14. Styles of Air Cleaners

Table 12. Attenuations for the Various Air Cleaner Styles on Different Type Engines

	Engine Type		
	Naturally Aspirated		Turbocharged
	2 cy (dB(A))	4 cy (dB(A))	(dB(A))
Open Intake (No Air Cleaner)	85-95	73-85	83-93

Air Cleaner Style	Attenuation Range for 3 Engine Types		
	Naturally Aspirated		Turbocharged
	2 cy (dB(A))	4 cy (dB(A))	(dB(A))
Primary Dry			
I & II*	4-9	5-10	8-15
III	10-18	8-15	18-25
Integral Separator			
IV & V	12-22	10-20	20-30
VI & VII	6-11	7-12	12-22
Two Stage Air Cleaners			
VIII, IX & X	25-35	20-30	20-30

* Figure 14 shows a schematic for each type.

Attenuation values vary widely within each grouping because of the different dust capacity requirement for different applications, i.e., amount of paper and volume of can. The greater the volume and amount of paper, the greater the attenuation.

Open face air cleaners are undesirable for naturally-aspirated engines (both 2 and 4 cycle) because of the lack of low frequency attenuation.

3.5 Equipment Tests

Noise source evaluation tests were conducted on four pieces of construction equipment to determine the typical levels of contributing noise sources, to verify noise control methods and to determine the effect of exhaust system modifications. A cross section of equipment types and sizes were chosen for the tests. The machines evaluated were: (1) Warner and Swasey excavator with a Detroit Diesel 4-53 engine, (2) Michigan front-end loader with a Cummins NTC 380 engine, (3) Terex crawler-dozer with a Detroit Diesel 8V-71 engine, and (4) Ford tractor with a Ford 201DF engine.

Sound levels were measured for each of the following vehicle configurations: (a) original equipment, (b) with exhaust silenced, (c) with intake and exhaust silenced, (d) with exhaust, intake, and fan silenced, and (e) with sound insulating panels around the engine compartment. Through utilization of these test levels, the individual contributions of exhaust, intake, fan, and engine and hydraulic noise were determined. Open pipe and various muffler exhaust noise levels were also measured.

Fan noise is defined as noise generated by air flow through the fan and air flow past obstructions in the general flow field. The main contribution of fan noise is that generated by flow separation at the blade tip. There was no differentiation made between "push" and "pull" fans.

Mechanical - Hydraulic noises were combined as they could not be adequately isolated. Mechanical noise is that caused by combustion and mechanical motion (e.g., piston slap). Hydraulic noise is that caused by the hydraulic pumps, valves, etc. Exhaust and intake noise have been previously defined.

All equipment tests were conducted following J88a measurement procedures, but using fast response on the sound level meter (Ref. Appendix E). However, the SAE recommended practice requires that the test site be smooth concrete or sealed asphalt with 50 feet of the test vehicle, and the outlying areas by hard packed earth. The test on the Ford tractor was conducted on sealed asphalt, the excavator on sand and the front-end loader on hard-packed earth, and the dozer on soft, wet ground. Figures 15 through 18 show the test sites used. All test sites were relatively flat. The SAE practice also requires that no observers be in the test area or near the microphone, and that the ambient noise level be at least 10 dB(A) below measured levels.

The SAE recommended practice sets for th three stationary tests to be conducted with the microphone 50 feet from each side of the vehicle. The idle-max-rpm-idle test is conducted at no load with all component systems in neutral by operating through the "low-idle-maximum governed speed-low idle" as rapidly as possible, but holding at maximum speed for 10 seconds. The high idle test is conducted at no load with all drive systems in neutral position and held at governed speed in a stabilized condition. The loaded maximum rpm test is conducted running the engine at maximum governed speed and activating appropriate hydraulic equipment from the most retracted to the fully extended position as fast as possible. Peak sound level values were recorded using fast response on a sound level meter. Sound levels were measured 50 feet from each side, with microphone locations as follows: (1) left side; (2) rear; (3) right side; and (4) front. Figure 19 shows these microphone positions.

3.5.1 Machine Test Results

Front End Loaders

A Michigan front-end loader with a Cummins NTC 380 engine (380 hp @ 2100 rpm) was tested on a hard gravel surface as shown in Figure 15. The ambient noise level was between 50 and 55 dB(A). Per IMI test, originally the highest noise level was 89 dB(A). By using an improved muffler, this sound level dropped to 88 dB(A), a reduction of 1 dB(A). The major noise source, mechanical-hydraulic noise, was found to be 87 dB(A). The original exhaust noise level was 84.5 dB(A). Intake and fan noise were substantially lower. With exhaust and intake muffled, the fan disengaged, and three sound panels around the engine, the loader was quieted to 80 dB(A). These sound panels were constructed from plywood and

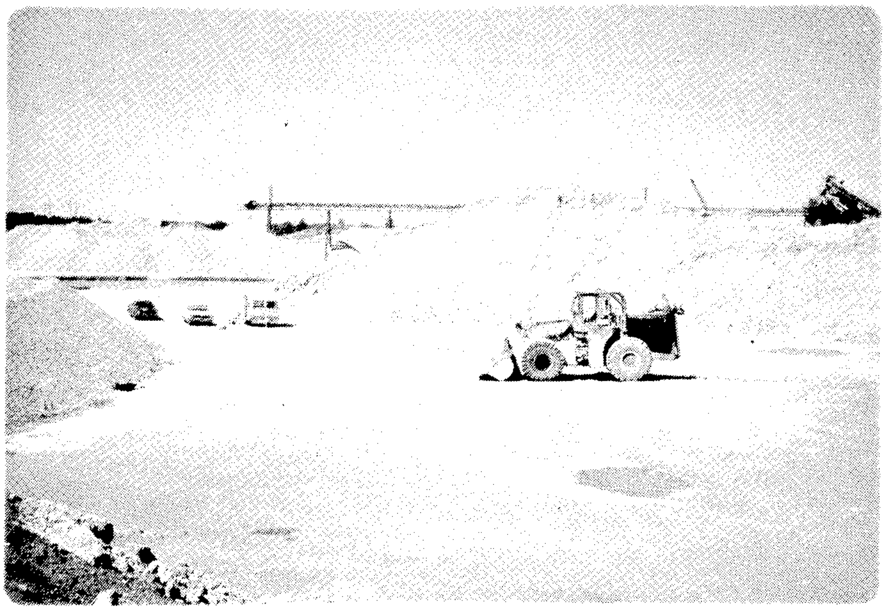


Figure 15. Front-End Loader Test Site

Figure 16. Excavator Test Site

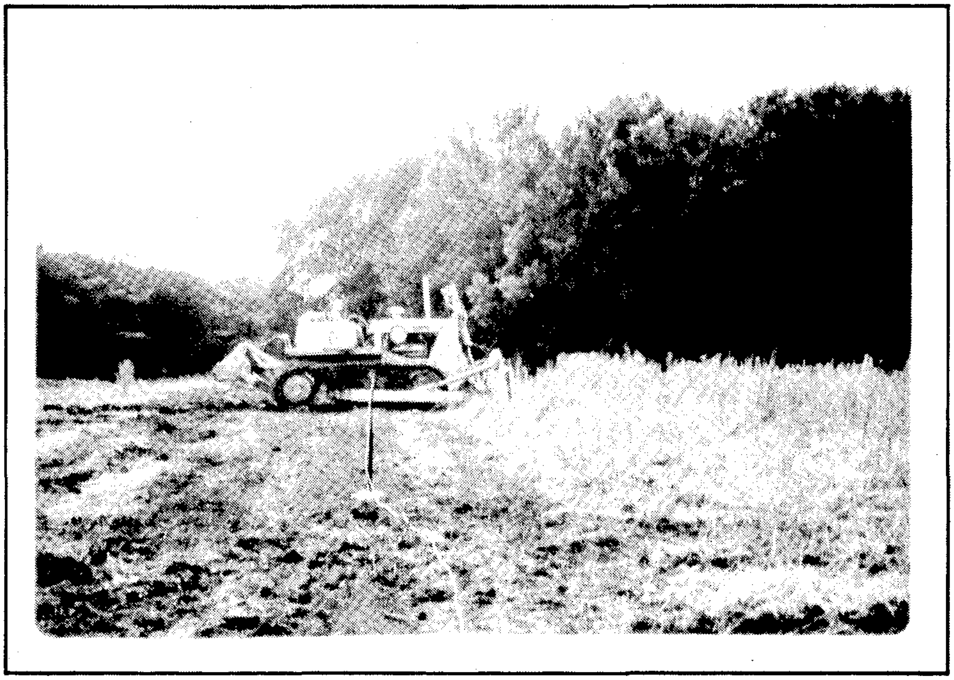


Figure 17. Crawler Tractor Test Site

Figure 18. Industrial Tractor Test Site

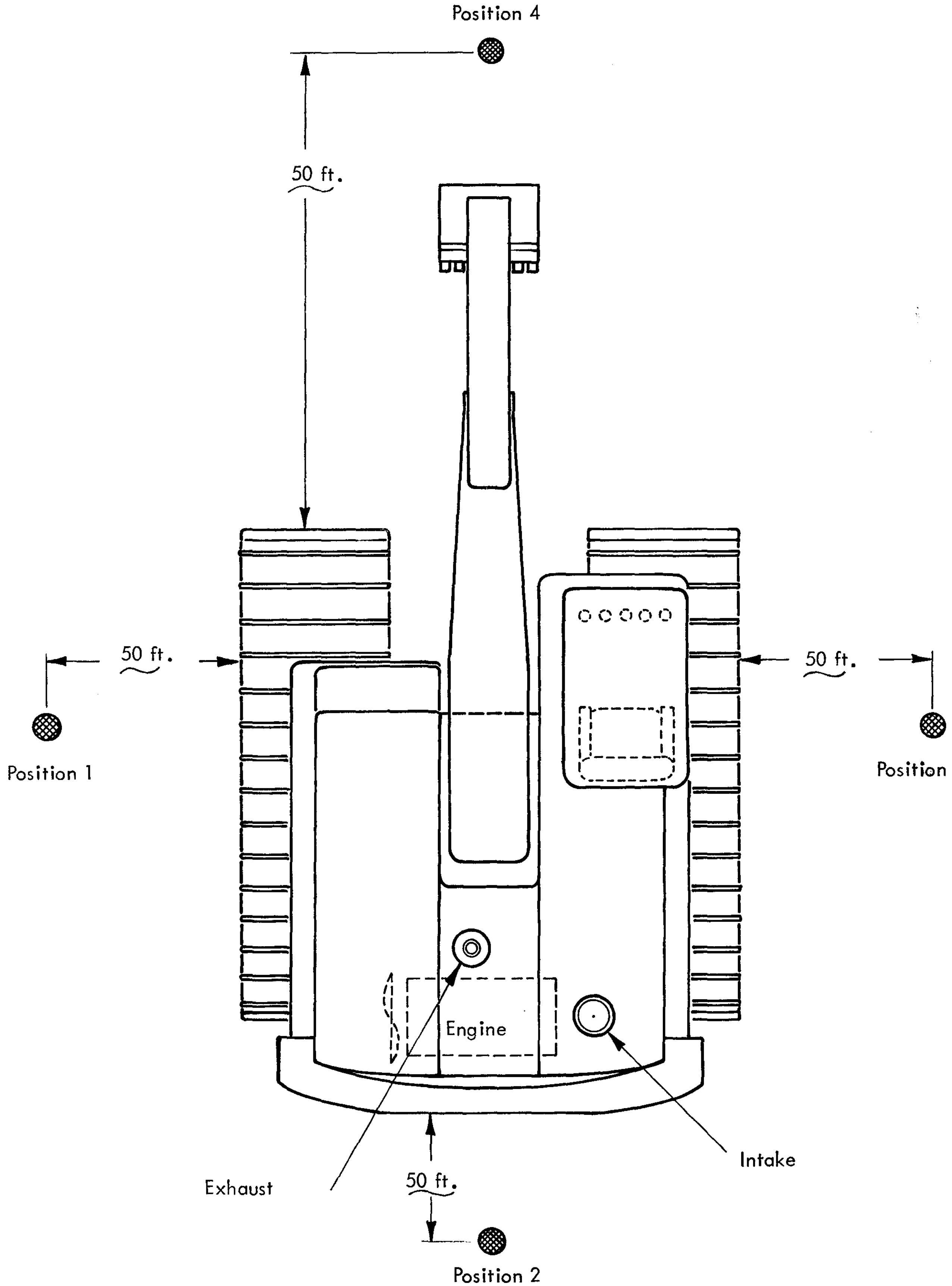


Figure 19. Microphone Positions for Stationary Tests

Table 13. Front-End Loader Noise Source Levels

	Location	Idle-Max rpm-Idle (dB(A))	Unloaded Max rpm (dB(A))	Hydraulically Loaded Max rpm (dB(A))
Original Equipment	Right	89	86.5	86
Fan	Rear	75	83	81
Intake	Rear	75	75	75
Mechanical & Hydraulic	Right	87	83	83
Original Exhaust	Right	84	81	75
Open Exhaust	Right	94	92	91.5

fiberglass in 4 ft x 8 ft panels. See Figures 20 and 21. Highest noise levels and respective locations for the particular noise sources are shown in Table 13. Complete results are in Appendix G.

Excavator

A Warner and Swasey excavator, equipped with a Detroit Diesel 4-53 engine (115 hp @ 2400 rpm) was tested on hard-packed gravel as shown in Figure 16. The ambient noise level was 55 - 60 dB(A). The excavator was originally equipped with a Donaldson MZM08-5023 muffler, and an overall vehicle noise level of 80.5 dB(A) was recorded in the idle-max rpm-idle test. The major noise source was mechanical-hydraulic at 78.5 dB(A), with exhaust 74 dB(A), intake 74.5 dB(A), and fan 71 dB(A). With improved exhaust muffling the vehicle noise level was attenuated 1.5 dB(A) to an overall level of 79 dB(A). In the quietest configuration, with improved exhaust and intake muffling, the fan disengaged, and three sound panels around the engine, the overall level was attenuated to 71.5 dB(A). Highest noise levels and respective locations for the particular noise sources are shown in Table 14. Complete results are in Appendix G.

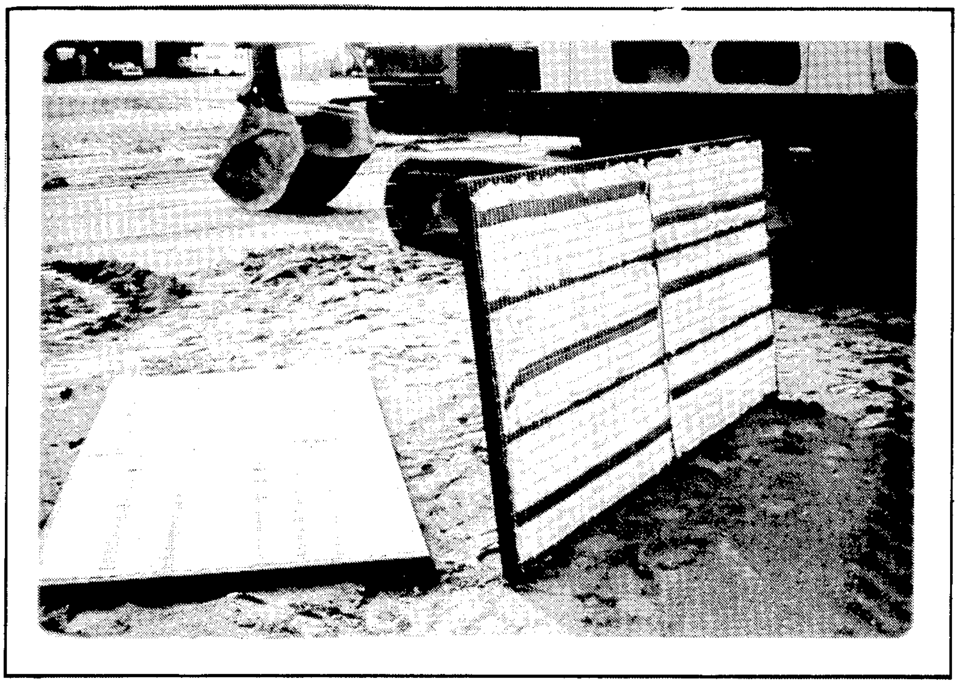


Figure 20. Sound Panels

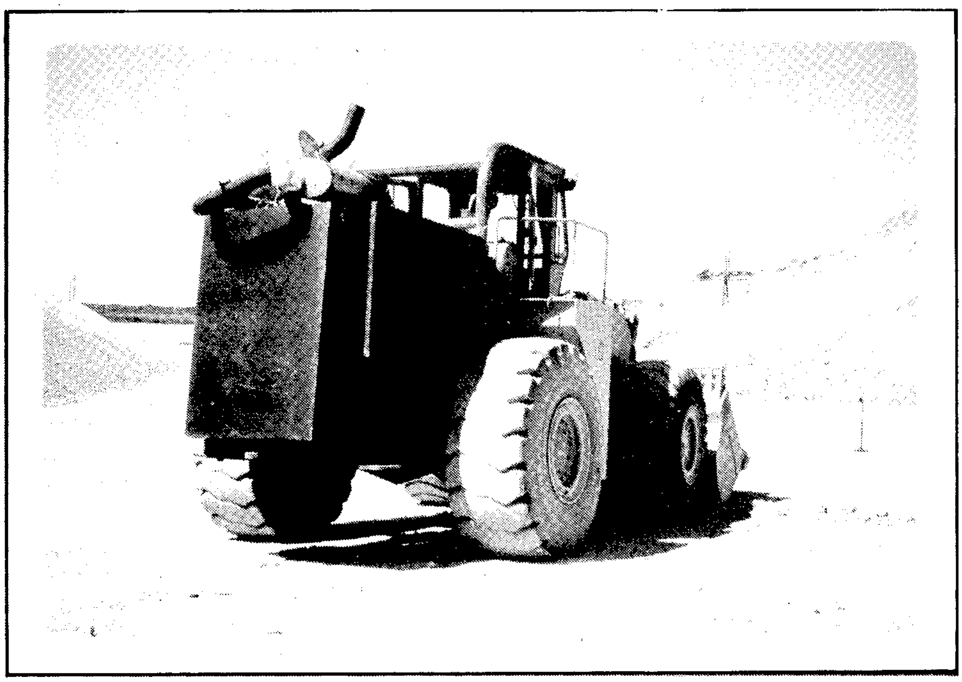


Figure 21. Sound Panels Used for Isolation of Mechanical and Hydraulic Noise

Table 14. Excavator Noise Source Levels

	Location	Idle-Max rpm-Idle (dB(A))	Unloaded Max rpm (dB(A))	Hydraulically Loaded Max rpm (dB(A))
Original Equipment	Rear	80.5	80	79
Fan	Rear	71	71	68.5
Intake	Rear	74.5	74.5	70.5
Mechanical & Hydraulic	Rear	78.5	78.5	76.5
Original Exhaust	Left	74	67	70.5
Open Exhaust	Left	96.5	87	94

Crawler Tractor

A Terex crawler-dozer with a Detroit Diesel 8V-71N engine (318 hp @ 2100 rpm) was tested at a road construction site. The site, shown in Figure 17, was not ideal for testing, since the ground was soft and wet. To obtain measurements for the four sides of the vehicle, the machine was rotated 90° per measurement with the microphone remaining in the same position throughout. Contribution of track noise could not be ascertained because of test conditions. The ambient noise level was 45 dB(A). The highest noise level originally, as measured by the idle-max rpm-idle test, was 86 dB(A). The individual contributions in the loudest case, were: (a) mechanical and hydraulic, 83.5 dB(A); (b) exhaust, 83.5 dB(A): (c) fan, 79.5 dB(A); and (d) intake, 74 dB(A). Additional muffling attenuated the overall level 2 dB(A) to 84 dB(A). By increased intake silencing, disengaging the fan, and use of three noise panels, the vehicle was further quieted to 80 dB(A). Highest noise levels and respective locations for the particular noise sources are shown in Table 15. Complete results are in Appendix G.

Table 15. Crawler-Dozer Noise Source Levels

	Location	Idle-Max rpm-Idle (dB(A))	Unloaded Max rpm (dB(A))	Hydraulically Loaded Max rpm (dB(A))
Original Equipment	Right	86	85	86.5
Fan	Rear	79.5	79	78.5
Intake	Right	74	70	78
Mechanical & Hydraulic	Right	83.5	81.5	83
Original Exhaust	Right	83.5	80.5	81
Open Exhaust	(No data obtained)			

Industrial Tractor

A Ford tractor with a Ford 201D engine (59 hp @ 2200 rpm) was tested at the Donaldson Company, Inc. The test surface, shown in Figure 18, was sealed asphalt. The ambient noise level was between 50 and 55 dB(A). The highest original noise level, 83.5 dB(A), was attenuated 1.5 dB(A) with additional exhaust silencing. The noise source contributions, each in the loudest case, were: (a) mechanical and hydraulics, 80 dB(A); (b) exhaust, 81 dB(A); (c) fan, 76.5 dB(A); and (d) intake, 71 dB(A). With additional exhaust and intake silencing, fan disengaged, and sound panels around the engine, the overall level was attenuated to 69.5 dB(A). Highest noise levels and respective locations for the particular noise sources are shown in Table 16. Complete results can be found in Appendix G.

Table 16. Industrial Tractor Noise Source Levels

	Location	Idle-Max rpm-Idle (dB(A))	Unloaded Max rpm (dB(A))	Hydraulically Loaded Max rpm (dB(A))
Original Equipment	Right	83.5	77.5	79
Fan	Right	76.5	70.5	73
Intake	Right	71	65	70
Mechanical & Hydraulic	Right	80	74.5	76
Original Exhaust	Front	81	73.5	74.5
Open Exhaust	Front	89.5	80.5	84.5

3.6 Conclusions and Recommendations

The construction equipment data accumulated as a part of this contract is extremely comprehensive. In the process of synthesizing this data, many pertinent conclusions were drawn and recommendations made as a result. The conclusions and recommendations are presented below.

Conclusions

Construction equipment produced since the late 60's or early 70's have utilized adequate muffling such that exhaust noise is not generally the dominant noise source.

Assuming reasonable mufflers are used, the exhaust noise level does not vary significantly with the size of the machine.

Dominant noise sources on today's machines are engine mechanical noise, hydraulic noise and fan noise. (Engine mechanical noise includes both noise generated by valve train, piston slap etc. and combustion originated noise.)

A correlation exists between machine size and mechanical, hydraulic and fan noise. Based on limited data, the larger the engine, the higher the specific noise level contributions of engine mechanical noise, hydraulic noise and fan noise.

With older equipment, the most reasonable noise reduction technique is the utilization of improved mufflers.

Application of improved mufflers to already muffled construction equipment will generally lower the overall level from 1 to 3 dB(A).

In cases where a particular piece of equipment either does not have or has a very poor muffler, exhaust noise is typically 10 dB(A) or more above any other source. Addition of an improved muffler will lower the overall noise level from 6 to 12 dB(A).

Some of the various noise sources are highly directional; e.g., fan noise is a dominant noise source only on the equipment side it is facing or near to. Mechanical engine and hydraulic noises also show the same tendency.

With typical vertical exhaust outlet and intake inlets, exhaust noise and, to a lesser degree, intake noise generally radiate evenly in all directions. If the orientation were horizontal, there would be a higher degree of directionality.

In all the tests conducted, equipment with attachments at the front of the machine and the engine towards the rear tended to transmit very little noise toward observers in front of the machine.

Intake noise is rarely a primary noise source on construction equipment. It is severe only when open-faced air cleaners are used on naturally-aspirated engines.

Based on test data gathered and surveys conducted, 88 dB(A) is a reasonable noise level to expect used equipment with engines of 400 hp or less to meet. However, as the engine horsepower decreases, the noise level of 88 dB(A) should similarly decrease. To lower the level further requires the use of barrier techniques to prevent transmission of mechanical engine and hydraulic noise. Although some engine manufacturers do provide add-on noise reduction devices for specific engine components (such as valve cover noise barriers), there are, at present, no known commercially-available engine compartment noise panels which will both lower the noise level and still allow adequate cooling.

Based on the presented evaluation technique results; front-end loaders, tractors, and excavators have the greatest noise impact on the observer.

With respect to the various test procedured, idle-max rpm-idle tests using fast response when measuring give the best correlation to overall machine noise levels. Max rpm tests give a good value for fan noise; however, in this test mode, mechanical, hydraulic, and exhaust may be measured 6 to 10 dB(A) lower than they actually are at peak load (Reference Figuer 22)

Recommendations

Use the IMI test with noise levels measured during fast response as a method of accurately determining a true overall machine noise level which is relevant to the observer.

Determine the relationship of engine mechanical, hydraulic and fan noise with engine size and then establish noise level standards for used equipment based on engine size.

Use a design criteria, the reduction of transmission of hydraulic, mechanical, and fan noise when designing new machines.

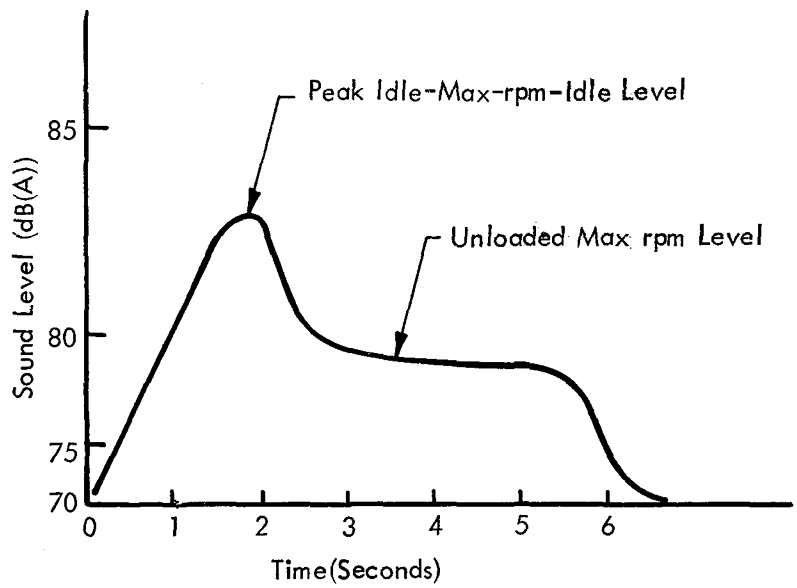


Figure 22. Overall Vehicle Idle-Max rpm-Idle Test Curve

4. EQUIPMENT NOISE REDUCTION

Section 4 is designed to be used separately as a handbook for construction equipment owners and operators. This handbook is designed to carry personnel through a systematic process from determining if exhaust noise is a problem to selecting and installing a complete exhaust system. The handbook is organized as follows:

Section	Topic
4.1	Noise Reduction Procedure
4.2	Engine Specifications File
4.3	Muffler Recommendation Sheets
4.4	Muffler-Horsepower Guide
4.5	Muffler Costs
4.6	Exhaust System Costs
4.7	Installation Procedure

4.1 Noise Reduction Procedure

Reducing a machine's exterior noise level can be unduly complicated, costly, and even frustrating. The diagnostic approach presented here as a guide for detecting and treating a particular machine has been developed and found to be the most efficient technique for controlling these noise levels. It begins with treatment of the most obvious, but usually most inexpensively-cured noise sources. Gradually, more complex and expensive noise treatment methods can be used, as needed, to solve more severe noise problems.

To reduce exterior noise, requires that one have a working understanding of the major noise sources which contribute to the total overall noise level. Principal contributors to machine noise level are the exhaust, cooling fan, the machine mechanical noise (engine, transmission, hydraulics, etc.), and intake noise . . . usually in that order of importance. These sources are described in more detail further on in this section.

For noise reduction work to be done on "in-use" machines, it will be assumed that only exhaust and intake system modifications can usually be made. Treating the other sources is only recommended as a "last resort," since required modifications could decrease machine efficiency, damage the machine, and/or be prohibitively expensive.

4.1.1 Step-By-Step Procedure

The recommended steps to be followed are:

Step 1: Determine Overall Machine Noise Level

The first step in reducing machine exterior noise is to determine the overall vehicle noise level. The test method used should be consistent with that specified by the controlling regulation and will usually involve such methods as: machine moving under full load, stationary high-idle conditions, an actual working cycle, or a stationary idle-max-idle (IMI test). Appendix E contains definition of the SAR test procedure J88a, which includes these four tests. The IMI test method consists of idling. This latter method consists of idling the machine in a stationary position and then suddenly accelerating the engine to the governed maximum rpm, allowing the rpm to stablize and then returning it suddenly to the idle condition. Since this latter test is convenient to run and provides meaningful and consistent data it will be used throughout the following steps, assuming fast response measurements (J88a calls for slow response). This type of test using fast response has a already been adopted by the EPA and DOT to evaluate in-use truck exterior noise (DOT 49 CFR, Part 325, Subpart E).

Step 2: Visual and Audible Inspection

Once the overall machine exterior noise level has been determined and is found to be above the concerned limit, a visual and audible inspection of each basic noise source should be made. Defects in the exhaust system are quite common. Loose clamps, holes in exhaust pipes, worn-out mufflers or flex tubing, and leaking joints should be repaired. Any other obvious defects such as missing engine compartment side panels, rattling sheet metal, or even engine speed beyond manufacturer's recommended rpm should be corrected.

Step 3: Retest the Repaired Machine

Retest the repaired machine following the procedure outlined in Step 1. If the machine still does not comply, proceed to Step 4.

Step 4: Exhaust Noise

Determine if exhaust noise is a major contributor to the level measured in Step 3. A relatively easy procedure for identifying the noise sources is discussed in Section 4.1.2. If exhaust noise:

> Is readily apparent to ear, it is obviously the major contributor and a significant noise reduction (6 to 12 dB(A)) in overall level could be expected by improved muffling.
>
> Can just be detected, it is roughly equivalent to the sum of the other sources and approximately a 2 - 6 dB(A) reduction in overall level can be expected by improved muffling.
>
> Cannot be detected, only a slight reduction in overall noise, perhaps 1 - 3 dB(A), can be expected by improved muffling.

Step 5: Controlling Exhaust Noise

With the findings of Step 4 in mind, select a muffler per recommendation sheets found in Section 4.3 to suit the particular installation needs of the machine. With machine level from Step 3, subjective opinions from Step 4 and predicted exhaust noise level with muffler selected, one can roughly determine the value of installing the muffler.

For example, if the overall level of Step 3 is 89 dB(A) at 50 feet, the exhaust noise can just be detected as described in Step 4 and Section 4.1.2, and the exhaust noise with selected muffler is predicted to be controlled down to 80 dB(A), the expected overall machine level with muffler would be in the 84 - 87 dB(A) range. Obviously with less effective mufflers, higher levels would be expected.

Step 6: Improved Muffling

If Step 5 so indicates, install muffler per installation instructions, Section 4.7, and retest. If the machine still does not comply, other noise sources must be considered.

Step 7: Controlling Other Sources

To control the other sources on the machine, one should first know their actual contributions to the overall noise level. Section 4.1.2 describes a method to roughly identify major noise sources. A complete detailed method for this determination can be found in Appendix F. The following general comments may prove helpful.

> Intake noise is seldom a problem but when it is, it can be readily controlled by using a plenum type air cleaner (Reference Section 3.5).
>
> Little can be done about mechanical noise other than shrouding the engine compartment by the use of side panels or contacting the engine manufacturer who may have available noise-deadening valve covers, side panels, and crank case covers. Care should always be taken not to interfere with cooling system performance.
>
> Fan noise is also difficult to control, but since fan noise is an exponential function to top speed and also of nearby obstacles, the governed rpm (hi-idle) should be checked to make sure engine speed does not exceed manufacturer's recommended setting. Also one may try to move obstacles such as accessories as far away as possible. The contribution of the fan noise may be found as described in Section 4.1.2 or as described in Appendix G. Cooling system changes should not be attempted without consulting the machine manufacturer first.

Summary

The above diagnostic approach is presented graphically in Figure 23. It has been used effectively in the control of machine noise, providing a straightforward and readily-understood procedure.

4.1.2 Determination of Dominant Noise Sources

A detailed procedure, as used in the contract (Ref. Section 3.4), for identifying the noise source contributions is presented in Appendix F. This procedure is rather involved and

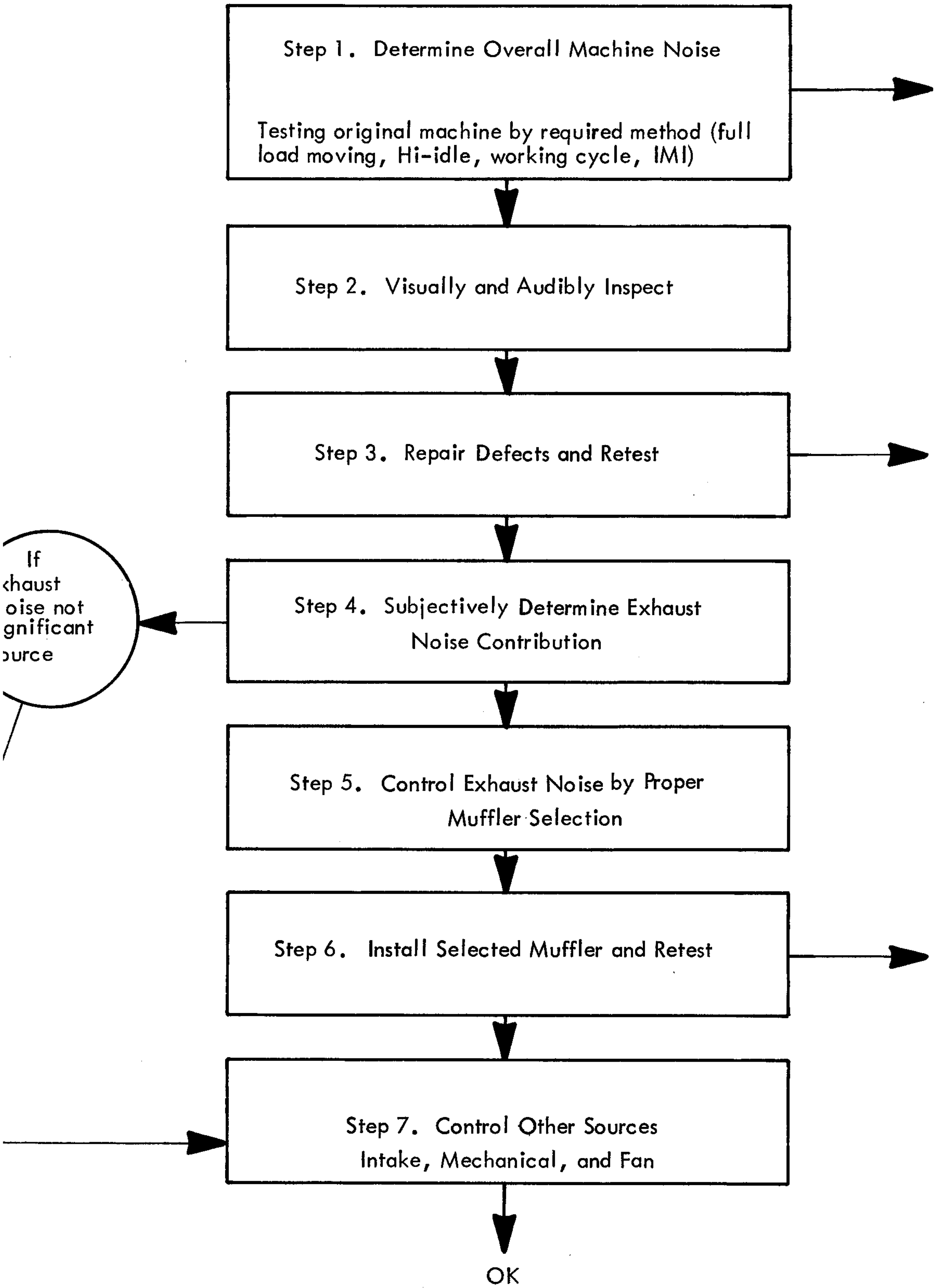


Figure 23. Machine Noise Control Procedure

the cost would be prohibitive to the average owner or operator. The following is a method whereby the contributions of the noise sources can be ascertained.

Each of the various sources has particular tonal qualities; i.e., different "sounds." Also, these sounds occur at different times in the IMI cycle. As the human ear can detect the differences in tone, and the location in the IMI test with respect to time, the dominant noise sources can be determined. Following are verbal descriptions of what the various sources sound like:

Exhaust Noise

Exhaust noise can be identified when it occurs in the IMI cycle by its noise characteristics which are described as "crack", "sharp", "high pitched", and "roar". Exhaust noise increases as the engine suddenly accelerates to hi-idle and decreases (5 - 10 dB(A)) at stablized hi-idle when the engine's inertial load is removed (Ref. Figure 24).

Fan Noise

Fan noise can be described as "whirring" or "rushing", and is maximum at stabilized hi-idle. Contribution of fan noise can be readily ascertained by eliminating it. This is done perferably by removing the fan or the fan belts. Tests can be conducted without the fan noise component (care must be taken not to overheat the engine). Since the overall level is equal to the fan noise plus the total of the other sources, the specific contribution of the fan can be quite readily calculated. This method is detailed in the Appendix G.

Engine Noise

Engine noise is "mechanical" in character and is described as having a "clanking" and "knocking" nature. It increases as engine accelerates and decreases at stablized hi-idle.

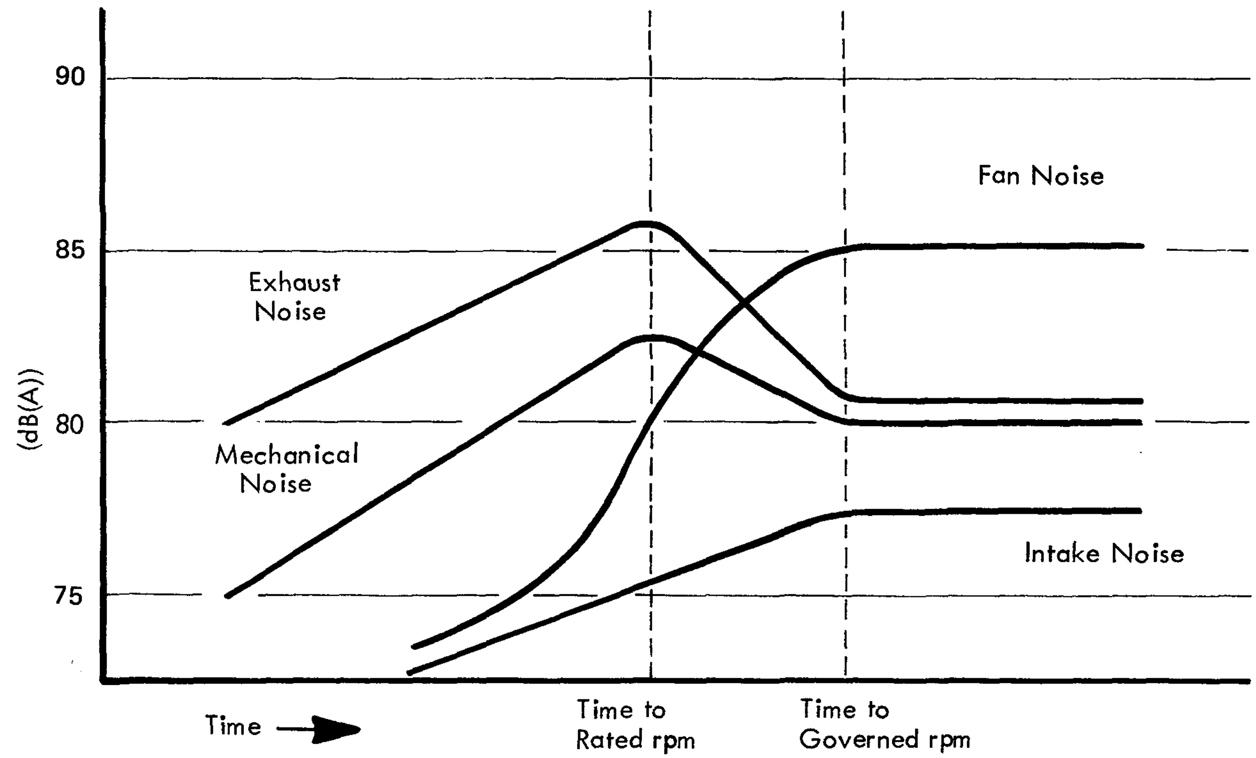


Figure 24. Typical Machine Noise Source Level Changes During IMI Test

Intake Noise

Intake noise is mostly pure tone with little high frequency pitch. It is maximum at stabilized hi-idle and is usually of little concern if the engine is turbocharged. However, if the engine is naturally aspirated or blown, intake noise could be of importance with "open faced" air cleaners. These are air cleaners which do not geometrically define a volume or plenum chamber. Those that describe a plenum chamber, that is tubular inlet, are generally adequate silencing devices. Refer to Section 3.5.

The contribution of the noise sources to the overall level under an IMI test are shown in Figure 24. When conducting these tests, two people are needed. One to operate the machine using the IMI test procedure, and one to audibly determine the dominant noise sources. The evaluator should attempt to get as close as possible to each particular source (one to two feet). To more objectively determine the dominant noise sources, point a sound level meter directly at the various sources, again with the microphone one to two feet away. One should use sound level meters per manufacturer's specifications. Avoid placing the microphone directly in the airflow stream generated by the fan unless using a wind screen. Comparison of the maximum levels obtained during the IMI tests for each source will guide the evaluator in determining the dominant source.

4.2 Diesel Engine Specifications

In this section, 384 engines from 16 manufacturers are listed; these engines are or have been used in off-highway and stationary equipment. Originally, the contract called for a listing of all diesel engines 50 hp or greater which had been manufactured in quantities of 1000 or more (total) over the period of 1961 through 1975. From the manufacturer-equipment-engine matrix and the sources used to compile it, 25 worldwide manufacturers of diesel engines whose engines were used to power construction equipment utilized in the United States were found. The engine manufacturer survey failed to produce any specific data on engine population and a subsequent check with the Bureau of the Census was not helpful. There were other possible alternatives for determining population (e.g., state vehicle registrations), but these were not pursued because of the constraints of the scope and time of the contract.

As specific engine population figures were not known, all engines for 16 of the 25 engine manufacturers are listed. Eight companies are not listed since their engines are either rarely encountered or available data is lacking. These are mentioned in Section 3.2.2. The 16 companies and the information provided for each engine included on the engine specification sheet are listed in Table 17.

Specific unsilenced exhaust noise levels are not listed for each engine, as only limited data for a few engines is available. Rather, noise level ranges are indicated. Four different ranges are listed, based on whether an engine is turbocharged or naturally aspirated, two cycle or four cycle. These exhaust noise levels are based on extensive dynamometer testing at Donaldson Company facilities.

The purpose of including the unsilenced noise levels was to allow personnel applying mufflers to determine with reasonable accuracy what the exhaust noise level would be after a muffler is applied. The noise level ranges are weighted toward the louder end of the range; i.e., some engines may have exhaust noise levels lower than their corresponding noise level range indicates. The exhaust noise tests run on our engine dynamometers have shown, in general, that when an engine straight pipe exhaust noise level is lower, it succumbs to silencing less readily than an engine with a higher noise level. Thus, a muffler may perform better on an engine having a louder exhaust, but overall it will attenuate to the same general noise level as on a quieter engine.

Engine specifications are shown in Appendix A.

Table 17. List of Manufacturers and Information Provided on the Engine Specification Sheets

Engine Manufacturers:

- Allis Chalmers
- Case
- Caterpillar
- Chrysler-Nissan
- Continental
- Cummins
- Detroit Diesel
- Deutz
- Ford
- Hercules
- International Harvester
- Mack
- Mercedes-Benz
- Minneapolis Moline
- Perkins
- Waukesha

Information for each engine:

- Manufacturer
- Model
- Number of cylinders and form
- Maximum brake horsepower rating
- Two cycle or four cycle
- Years manufactured
- Aspiration method
- Type fuel injection
- Bore and stroke
- Cubic inch displacement
- Back pressure limit
- Intake restriction limit (clean system)
- Recommended exhaust pipe size
- Exhaust noise level

4.3 Engine Muffler Recommendations

Muffler manufacturers have recommendations matching their products with many of the engines available to power construction equipment. These recommendations are usually published and provide data on specific recommended engine/muffler combinations. These recommendation sheets are available from the various exhaust system manufacturers and in many cases from local distributors. Manufacturers' recommendations should be used whenever possible in addition to the Muffler-Horsepower Guide, as data are usually available for specific engine/exhaust system configurations and improved products are continually superseding older components.

Noise levels and back pressures given by manufacturers in their recommendation sheets are usually specified at full engine load at rated engine speed. Where engine speeds are lower or fuel schedule modifications have reduced engine load capability, noise levels and back pressures will be slightly reduced. Published noise levels are usually for exhaust noise only, at a distance of 50 feet. When tail pipe direction is unspecified, a vertical tailpipe should be assumed. If the specific installation then requires a horizontal tailpipe, the exhuast noise level will increase by approximately 2 dB(A).

4.4 Muffler Horsepower Guide

4.4.1 Development of Muffler Horsepower Guide

Based on the initial premise that exhaust noise is the dominant noise source on most construction equipment, a muffler application technique was developed to properly match engines and mufflers. This guide provides the user with a method of selecting a muffler based on the engine horsepower, allowable back pressure, pipe size exhaust system configuration and desired exhaust noise level.

This method, referred to as a Muffler Horsepower Guide (MHG), was developed with the following facts serving as a baseline:

1. There are two basic kinds of internal combustion engines: 2-cycle engines and 4-cycle engines.

2. For both 2-cycle and 4-cycle engines, there are two major forms of aspiration: natural aspiration (NA) and turbocharging (T). Mechanically-blown 2-cycle engines are included in the naturally-aspirated group. Gear-driven super-charged engines were rarely encountered in the data gathering and are not considered.

3. Thus, there are four basic types of engines which are included in the MHG:
   a. 2-cycle NA
   b. 2-cycle T
   c. 4-cycle NA
   d. 4-cycle T

4. The four types of engines have different noise characteristics and noise level outputs.

5. The four types of engines each respond to silencing in a different manner.

6. Back pressure limits vary with each engine manufacturer and type of engine.

The method of engine aspiration has been shown to affect exhaust noise levels significantly. Because turbocharging dampens the exhaust pulsations significantly, straight pipe noise levels are 5 to 10 dB(A) quieter than naturally-aspirated engines. Thus, the Muffler Horsepower Guide was broken into two sections based on aspiration. In each section, muffler application data is provided for both 2- and 4-cycle engines.

To obtain muffler performance data for the four types of engines, all available engine data was gathered to determine typical airflow per horsepower, exhaust sound levels (unsilenced), and average exhaust temperature (Ref. Table 18).

Table 18. Typical Sound Levels and Flows for the Four Types of Engines

	Intake Flow and Source	Exhaust Sound Level	Exhaust Temperature
2-cycle NA	2.8 cfm/bhp	105 dB(A)	800°F
2-cycle T	3.6	98	700
4-cycle NA	2	95	1000
4-cycle T	2.7	92	800

It is necessary to emphasize that individual engines may have exhaust levels higher or lower than the indicated averages. However, typically the attenuation factor indicated on the MHG increases with higher exhaust levels and decreases with lower exhaust levels in a given engine category.

4.4.2 Description of the Muffler Horsepower Guide

A portion of the Muffler Horsepower Guide is shown in Figure 25.

Turbocharged Engines (1)												
Donaldson Company, Inc. (2)					Max. hp @ B.P. Limit							
			Attn		1.5		2		2.5		3	
Muffler	Pipe	Styl	2	4	2	4	2	4	2	4	2	4
(3)	(4)	(5)	(6)					(7)				
MTM10-0038	5.0	2	19	16	160	205	184	236	206	264	226	289

Figure 25. Example of Muffler Horsepower Guide

The following is an explanation with reference to the example of the MHG. The circled numbers on the figure correspond to the item numbers below.

Item 1. Indicates to the user which engine type.

Item 2. Indicates which manufacturer's mufflers are on a particular page. Note that the Muffler Horsepower Guide is in three segments as there were three muffler manufacturers who supplied adequate data. Each segment is subdivided into the turbocharged engine section, the naturally-aspirated engine section and a muffler physical description section.

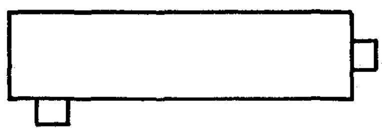
Item 3. Refers to the muffler model number.

Item 4. Refers to the inlet pipe size.

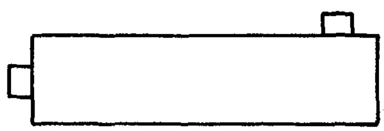
Item 5. Refers to the muffler style. The seven basic muffler styles are shown in Figure 26.

Style 1. -- On center inlet and on center outlet round or oval.

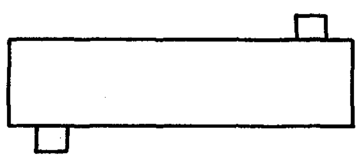
Style 2. -- Off center inlet, outlet or both, round or oval.



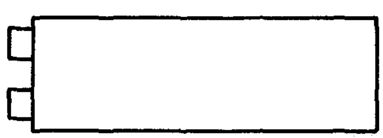
Style 3. -- Side inlet, end outlet, round or oval.



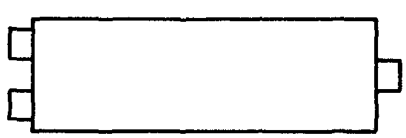
Style 4. -- End inlet, side outlet, round or oval.



Style 5. -- Side inlet, side outlet, round or oval.



Style 6. -- Inlet and outlet on same end, round or oval.



Style 7. -- Dual inlet, single outlet, round or oval.

Figure 26. Seven Basic Muffler Styles

Item 6. Refers to the mufflers attenuation factor (dB(A)). A value is indicated for both 2 cycle and 4 cycle engines.

Item 7. Indicates what the maximum horsepower engine this muffler can be applied to and still meet the back pressure limit. Back pressure limits of 1.5, 2.0, 2.5, and 3 inches mercury for T engines and limits of 2.0, 2.5, 3 and 4 in Hg are presented for NA engines. These various limits corresponded to the limits found in the data gathering phase.

4.4.3 Muffler Style-Exhaust System Configuration

The field surveys and equipment surveys provided data showing that nearly all exhaust systems could be categorized into 1 of 7 types. These types are shown in Figure 27. Indicated for each exhaust system is the preferred muffler style and also acceptable muffler styles (Reference Figure 26).

The average length for all of these systems is 6 feet of pipe 1-90° and 1-45° elbow. The back pressures indicated on the MHG are based on this system length. Cost for the mufflers included in the MHG are given in Section 4.5. The cost for system parts and total systems are given in Section 3.6. Installation procedures for the complete exhaust system are presented in Section 3.7.

4.4.4 Procedure for Use of Muffler Horsepower Guide

The following steps should be followed when using the MHG.

Step 1. Determine type of engine, horsepower, back pressure limit and exhaust pipe size. (Refer to Engine Specifications, Section 4.2.)

Step 2. Determine desired silenced exhaust noise level.

Step 3. Determine muffler style needed based on exhaust system configuration (Figure 27).

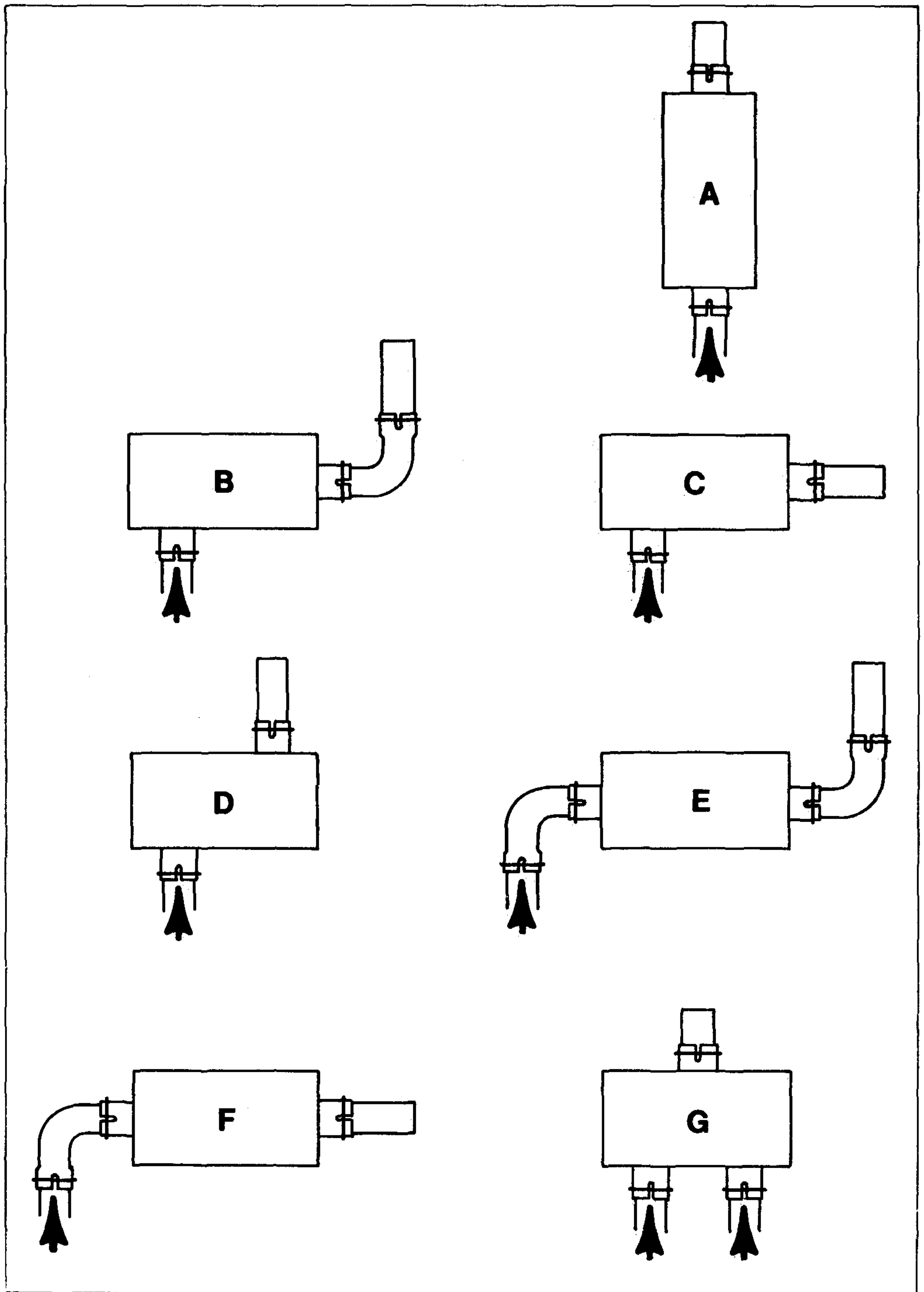


Figure 27. Basic Exhaust System Configurations

Step 4. Determine if the engine to be silenced is listed on a specific muffler recommendation sheet (Section 4.3). If the engine is listed, select a muffler, as the values provided in the muffler recommendation sheets are based on actual data.

Step 5. If a dual muffler exhaust system is desired, divide the horsepower found in Step 1 by 2.

Step 6. Determine necessary muffler attenuation by subtracting the desired exhaust noise level from the straight pipe, i.e., unsilenced, noise level (Table 18).

Step 7. Go to the appropriate section(s) and select a muffler that meets requirements.

Step 8. Refer to the physical dimensions of the muffler selected to ensure that the muffler will fit size constraints.

Figure 28 gives an example of use of the Muffler-Horsepower Guide following these steps.

4.4.5 Muffler Horsepower Guide Organization

The muffler-horsepower guide may be found in Appendix B, and is organized as follows.

A. Earth Moving or Stationary Equipment
   1. Cowl
      a. Naturally Aspirated, Turbocharged
      b. Physical Muffler Dimensions
   2. Donaldson Company, Inc.
      a. Naturally Aspirated
      b. Turbocharged
      c. Physical Muffler Dimensions

B. Stationary Equipment Silencers (Industrial)
   1. Nelson Industries
      a. Naturally Aspirated
      b. Turbocharged
      c. Physical Muffler Dimensions

Equipment: 1970 Model 745 Allis Chalmers Front-End Loader, Engine Model 11000

(The machine has been through the noise reduction procedure and it has been determined the muffler is inadequate.)

Step 1: Referring to engine specifications

4-cycle
Turbocharged
220 hp
Max. back pressure = 2 in. Hg
Pipe size data not available
Current system pipe size = 4 in. dia

Step 2: New silenced exhaust noise level goal = 78 dB(A)

Step 3: Referring to Figure 27 showing muffler styles for various exhaust system configurations:

Muffler configuration = E
Muffler style number = 2

Step 4: Muffler not listed on muffler recommendation sheets

Step 5: Dual muffler exhaust system is not desired

Step 6: Referring to Table 18, the estimated unsilenced noise level = 92 dB(A); therefore, attenuation needed = 92 - 78 = 14 dB(A).

Step 7: Turning to 4 in. inlet mufflers in turbocharged engine section, a Donaldson Company MOM12-0100 will be slightly less than 2 in. Hg. (This muffler can be used on engines up to 240 hp and still meet 2 in. Hg. Attenuation is 14 dB(A).)

Step 8: Size = 10 x 15 in. oval body length = 26 in.

Figure 28. Example of Use of Muffler Horsepower Guide

4.5 Muffler Costs

Cost data is provided for mufflers manufactured by Donaldson Company and Nelson Industries (industrial silencers), two of the three companies listed in the Muffler Horsepower Guide. Cowl did not provide this data.

Information provided on each muffler listed is the manufacturer, part number, inlet diameter, muffler style (Reference Section 4.3) and the muffler cost. Mufflers are divided by pipe size, smallest to largest, and then listed in the numerical order of the manufacturer. Cost data requested was for quantities of 1, 10, and 100. Donaldson Company supplied cost data on quantities of 10, while Nelson supplied cost data in quantities of 1. These prices can provide only relative data, as they are subject to change; accurate cost data must be determined at the time of purchase. The prices listed are effective as of May 1976. See Tables C-1 and C-2.

Muffler costs may be found in Appendix C.

4.6 Exhaust System Costs

To aid the equipment owner with replacement of complete exhaust systems, a cost schedule has been developed for exhaust systems less mufflers. To develop this cost schedule, it was necessary to define a set of typical exhaust system configurations. This was done during the field survey, in which surveys were taken on 90 different pieces of construction equipment. From these 90 field surveys, seven basic exhaust system configurations were selected as being the most common systems found in the field (Figure 27).

Having set forth seven basic configurations, it was then determined for each configuration the number of 90 degree elbows and U-clamps required (Figure 27). A U-clamp was used at every joint of muffler to pipe or pipe to pipe. It was then necessary to determine typical exhaust piping diameters and lengths. Pipe sizes found in the field survey ranged from two inches in diameter to six inches in diameter, so all standard pipe sizes within this range have been included in the cost schedule. Exhaust system piping lengths vary widely from machine to machine, so an average length of six feet (excluding muffler) was chosen. This average length was again based on field survey data. This length of six feet includes both the piping from the exhaust manifold to the muffler and the piping after the muffler.

For each pipe diameter from two inches through six inches and each of the seven configurations, costs have been prepared for each typical system. Prices per piece were derived from two major distributors assuming they were consistent with the industry. Prices listed are those as of September 1976. Table D-1 gives complete exhaust system costs. Table D-2 gives individual piece part costs.

Exhaust system costs are listed in Appendix D.

4.7 Exhaust System Installation Procedure

Partial or complete replacement of an exhaust system may at first appear to be a complex task. Maintenance personnel are faced with the responsibility of installing system components which will fulfill the requirements of not exceeding maximum allowable back pressure, providing adequate degree of silencing, and structural integrity. Failure to consider any one criterion may lead to costly problems and a great deal of annoyance. The following guidelines should be useful in making efficient and effective use of these components.

4.7.1 Back Pressure Limits

Back pressure can be thought of as the restriction to exhaust gas flow associated with the muffler, tailpipe, elbows, raincaps, and raintraps. Excessive restriction, exceeding the engine manufacturers' recommendations for maximum back pressure, translates directly into less horsepower and potential engine damage. With the Muffler Horsepower Guide found in Section 4.4 and the back pressure limits of engine manufacturers found in Chapter 4.2, it is possible to select an appropriate muffler on a rational basis. For systems with lengths much greater than 6.5 feet or containing 3 or 4 elbows, refer to Appendix H for correction figures and a description of the correct way to measure back pressure.

4.7.2 Silencing Effectiveness

Muffler style contributes more than any other single factor to successful exhaust silencing. The action of the internal silencing elements, such as volume, expansions and reductions, perforations, baffles and tubes, determine relative performance in terms of noise reduction as well as back pressure.

The muffler position with respect to total system length can also benefit the silencing effort. The silencing properties of a muffler can be enhanced by its location in the exhaust system. The best positions (maximum silencing) are in the standing wave pressure antinodes. The best location is described as the 1 and 2 position, i.e., the tailpipe is twice as long as the exhaust pipe. The next best location, called the 4 and 1 position, occurs when the exhaust pipe is four times as long as the tailpipe. The exhaust pipe lengths are as measured from the manifold or the turbocharger flange. The middle of the system is generally the worst location. (Reference Figure 29) It isn't always possible to install a muffler in the best position but when these locations are known, strive for the best location and avoid the worst. Muffler position is not nearly as significant with two cycle diesels as with four cycle engines. Typical noise reductions of from one to three dB(A) can be expected at the best location relative to the worst. In addition, keep the overall length of the system as short as possible, thus minimizing exhaust noise by minimizing the chance for resonance.

Tailpipe directionality should not be overlooked as a method for reducing objectionable noise. A vertical stack may realize a 2 dB(A) improvement over a horizontal side-directed tailpipe.

4.7.3 Structural Considerations

Expected life versus cost are of primary concern, particularly when a retrofit program on many pieces of equipment must be undertaken. A variety of materials and surface treatments are on the market, each exhibiting its own properties of corrosion resistance. Cold rolled steel is the most common base material. It is either used as is or coated with zinc (galvanized), aluminum (aluminized), and occasionally chrome. Stainless steel is sometimes found but is usually too expensive except when used in the most severe corrosive environments. The following list of materials and coatings may be used as a guide to aid in the selection process. The strength of the material is a property of only the base material.

Plain cold rolled 10-10 -- not as attractive as aluminized -- no rust inhibiting qualities.

Cold rolled with zinc (galvanized) -- use in very corrosive environments -- zinc sacrifices itself in the galvanic process and must be completely gone before steel is affected at all.

Cold rolled with aluminum (aluminized) -- perhaps the best corrosion inhibiting combination for most applications.

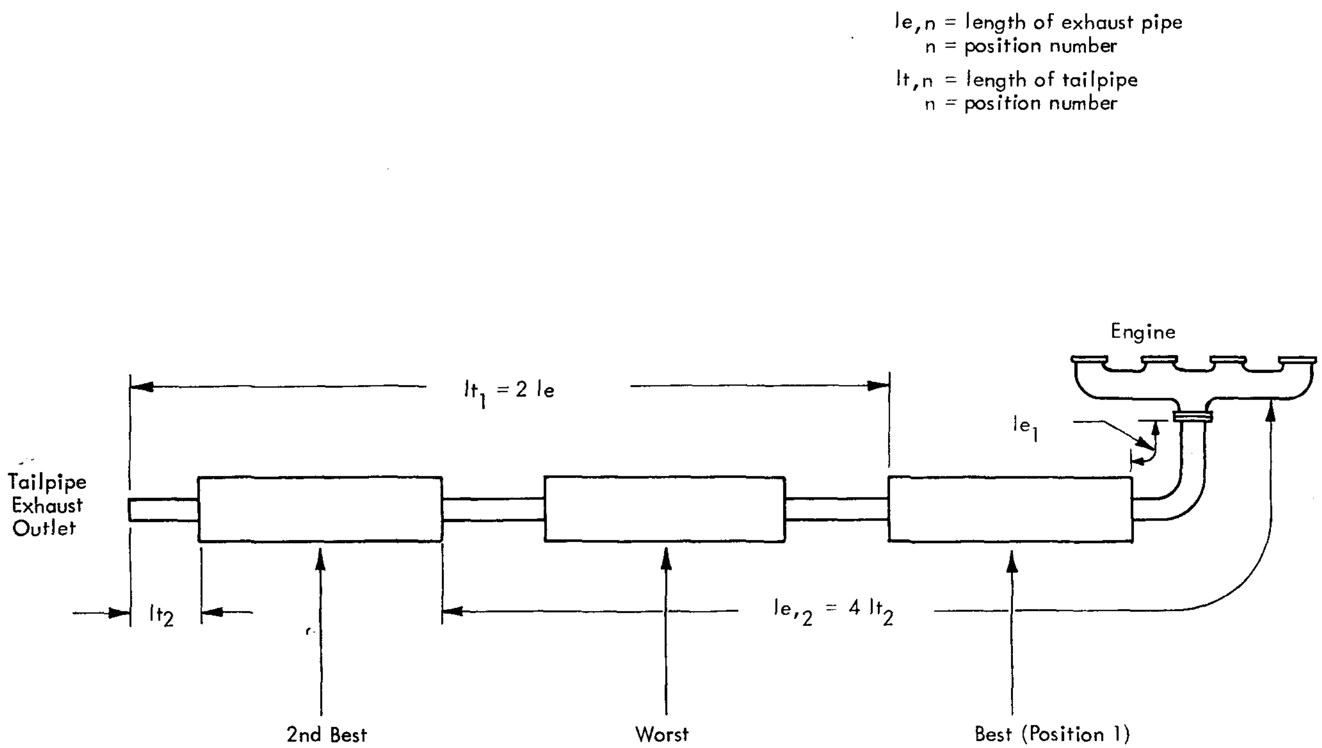


Figure 29. Preferred Muffler Location.

Cold rolled with chrome -- the hardest corrosion barrier material but once scratched, rust proceeds uninhibited.

Stainless steel -- has a tensile strength twice that of cold rolled and it has superior corrosion resistance even at high temperature.

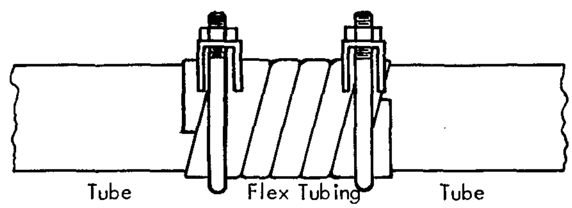
Vibration can be generated by the chassis or by the engine on an exhaust system and the effects are impossible to avoid. However, the consequent damage because of metal fatigue can be minimized by allowing the exhaust system enough built-in freedom of movement to prevent structural failure. Three distinct methods are available to allow systems to bend without breaking:

1) Flex tube (See Figure 30) is readily available to match various tube diameters but care should be taken in its use. Flex tube can be lengthened or shortened slightly by twisting the interlocking coils; if, however, the section of tube is either fully extended or fully contracted, its intended purpose has been defeated as there is no longer adequate give to the system. Likewise, flex tube should not be used for an elbow since this causes the same solid no-give condition at the apex of the bend. Stainless steel flex tube should be used rather than galvanized, as the life of galvanized flex tubing at high temperatures is short. Stainless steel flex tube should last for the life of muffler -- approximately 5000 hours.

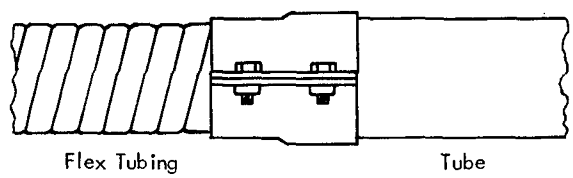
2) Slip joints (Figure 30) do allow movement but only along the axis of the tubing. They are also prone to leaking not only exhaust fumes but also noise. A device such as the Donaldson SEALCLAMP® effectively seals against leaks in flex-tube and tube-tube joints while furnishing a good mechanical connection (Figure 30).

3) Ball joints offer good vibration isolation allowing movement in three dimensions. They can be found in the smaller diameters (2 1/4 inch O.D.) but may be difficult to get in the large sizes (Figure 30).

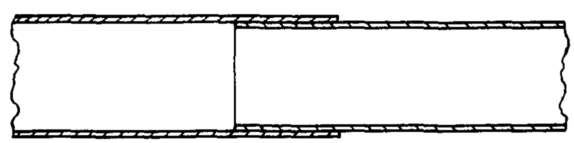
® SEALCLAMP is a registered tradename of Donaldson Company, Inc., Minneapolis, MN



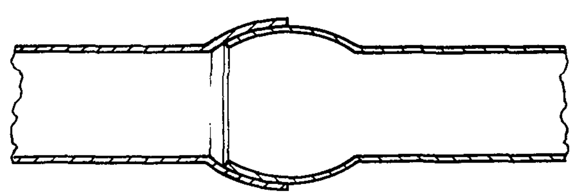
a. Flex Tube



b. SEALCLAMP



c. Slip Joint



d. Ball Joint

Figure 30. Various Exhaust Pipe Connections Which Minimize Structural Failure

Probably the most neglected structural requirement is the allowance for three dimensional thermal expansion. Allow a minimum of 1/4 inch to 3/8 inch for system expansion. Figure 31 illustrates thermal expansion effects on an exhaust system.

Some general guidelines should be followed when laying out a structurally sound exhaust system. Carefully inspect for leaks and strength of any parts of the system which are to be reused. Avoid unstable installations in either the horizontal or vertical planes as these conditions seriously strain the muffler inlets. The weight of the system should be as evenly distributed as possible and well supported using mounting bands and clamps as shown in Figure 32. Choose the muffler inlet diameter which most closely mates with the existing head pipe diameter. Avoid the use of reducers as they detract from the cleanliness of the system and increase the back pressure. Bushings are a potential trouble area as they invariably leak and may complicate a difficult noise problem.

For safety considerations certain precautions must be taken to protect flammable components from the hazard imposed by exhaust temperatures ranging from 900°F to 1200°F. Of obvious importance are fuel lines and hydraulic hoses, but attention should be focused on placing exhaust components away from walkways and hand-holds. Muffler skin temperature can be controlled somewhat by using commercially available wraps, commonly of fiberglass, sandwiched between the inner and outer steel shell. Local ordinances may require the installation of a spark arrestor to contain hot particles of carbon. To achieve maximum efficiency, the spark arrestor should be vertically mounted and cleaned as necessary (refer to manufacturer's recommendations). Spark arrestors perform optimally when they are the last element in the system. A schematic of operation is shown in Figure 33. Do not install spark arrestors after aspirating-type mufflers. (Mufflers which scavenge the air cleaner).

The exhaust outlet should never be placed so as to contaminate the air cleaner. Exhaust soot is a principal contributor to poor air cleaner life.

Rain caps are often installed on vertical stacks to prevent water from getting to the engine.

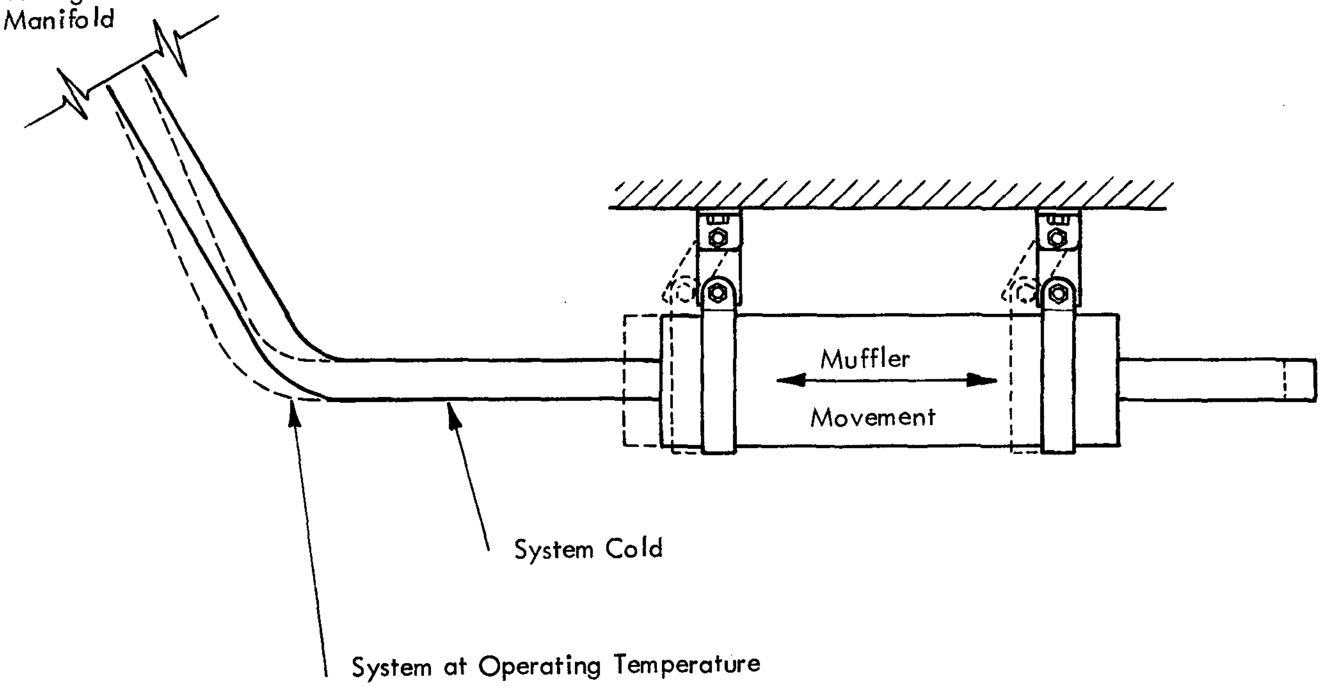


Figure 31. Illustration of Exhaust System Expansion Due to Temperature Change

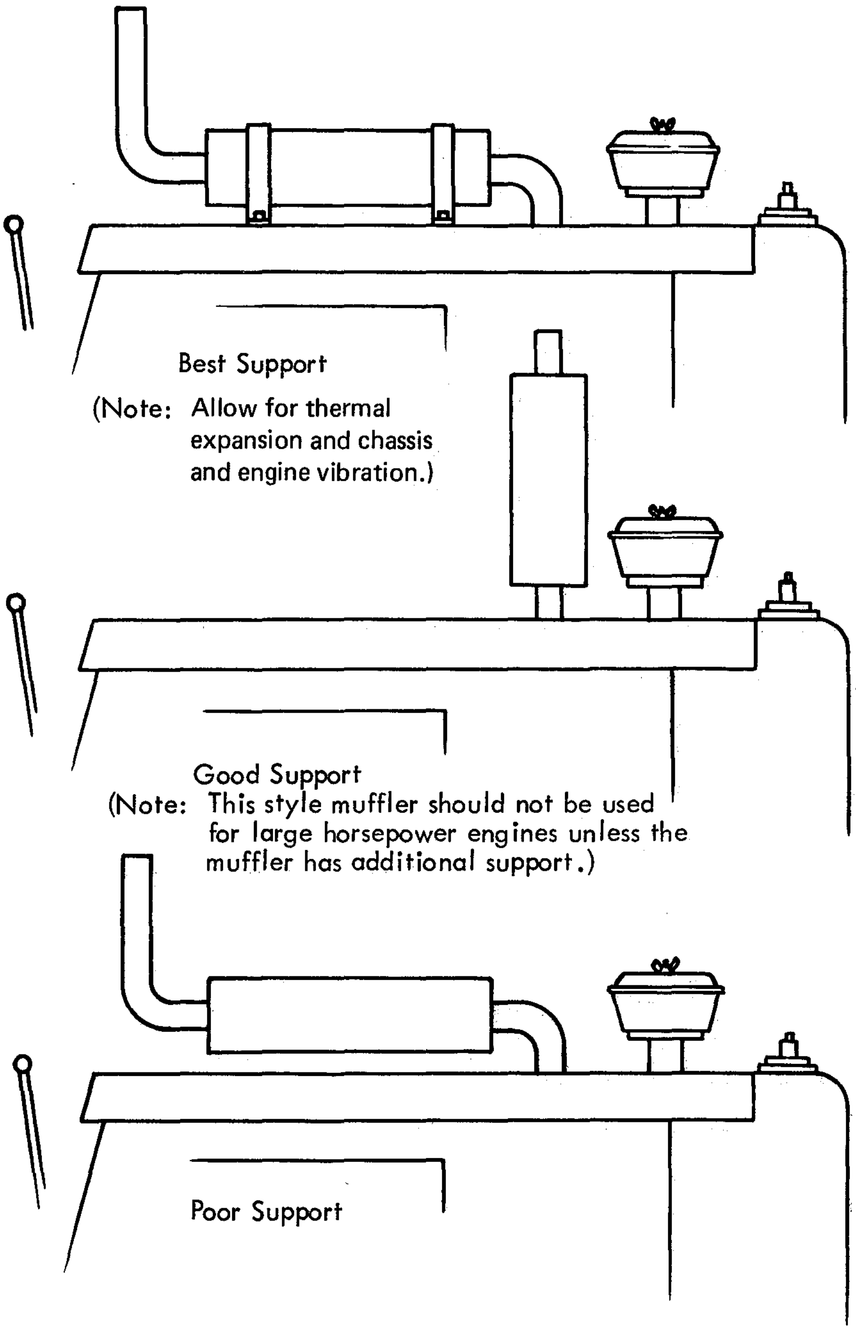


Figure 32. Schematic Showing Correct Mounting Procedure

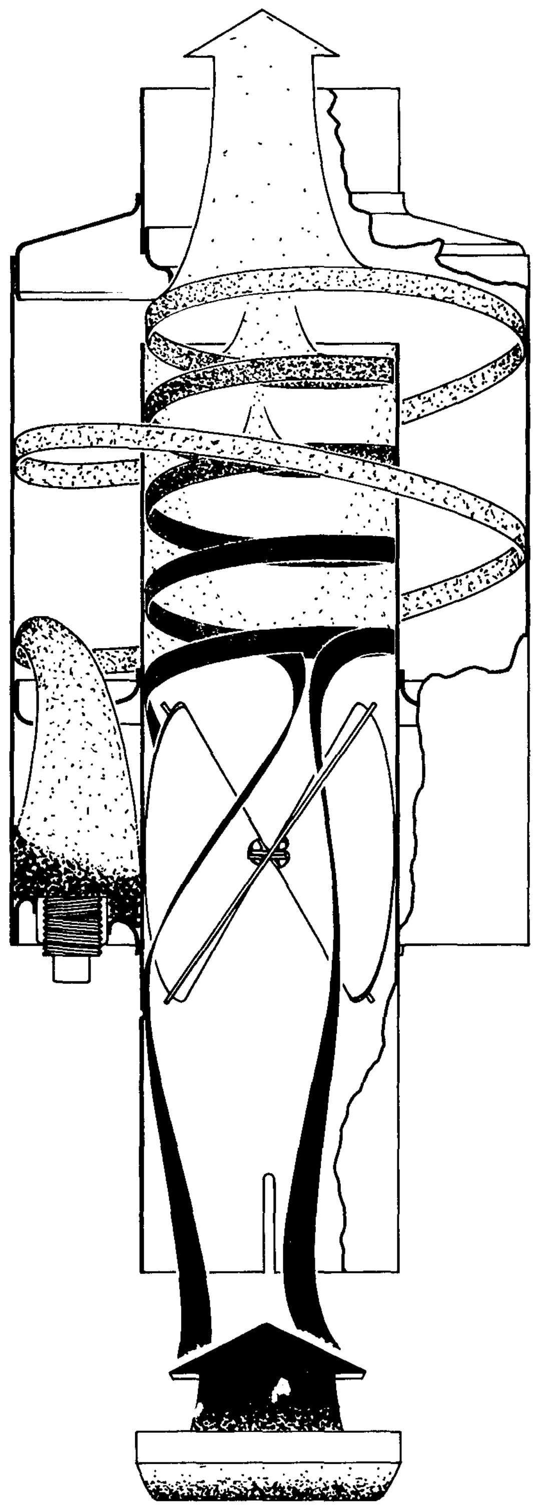


Figure 33. Operational Schematic of a Spark Arrester

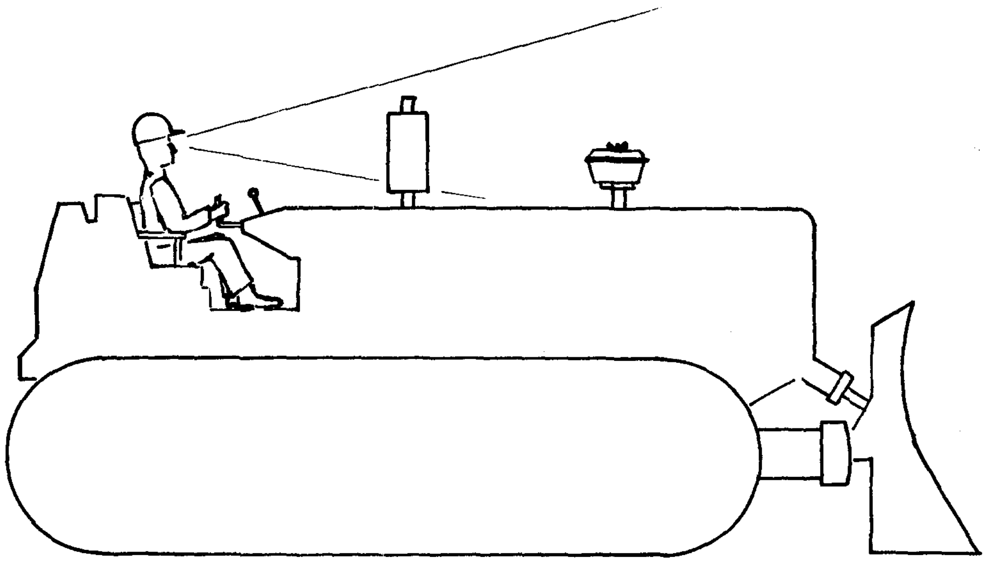
Another method for expelling rain water is the small plugged drain hole found on the lower end of some vertically-mounted mufflers*. Operator visibility may be of primary concern, depending on the type of equipment. Mufflers are commonly seen mounted vertically and directly in the operator's field of view, a very annoying situation. A six-inch diameter muffler mounted two feet from the cab area effectively eliminates 5 feet from the operator's field of view at a distance of 25 feet ahead of this position. This problem is successfully eliminated by mounting the muffler horizontally with the added benefit of extending system life because of greater stability (See Figure 34). The tailpipe should be long enough to allow exhaust gases to clear the operator's position. Horizontal tailpipes should be located so as to expel the exhaust gases away from personnel and machinery. Joints should be easily accessible to allow for periodic servicing.

Man hour estimates for installation will vary somewhat depending on difficulties encountered in different applications. Time and effort will be directly proportional to muffler size and will also dictate the type of tools and equipment needed, such as overhead lifts, pneumatic chisels and wrenches, jacks, welders, and hand tools. The following describes installation for each of the basic exhaust system configurations shown on Figure 27.

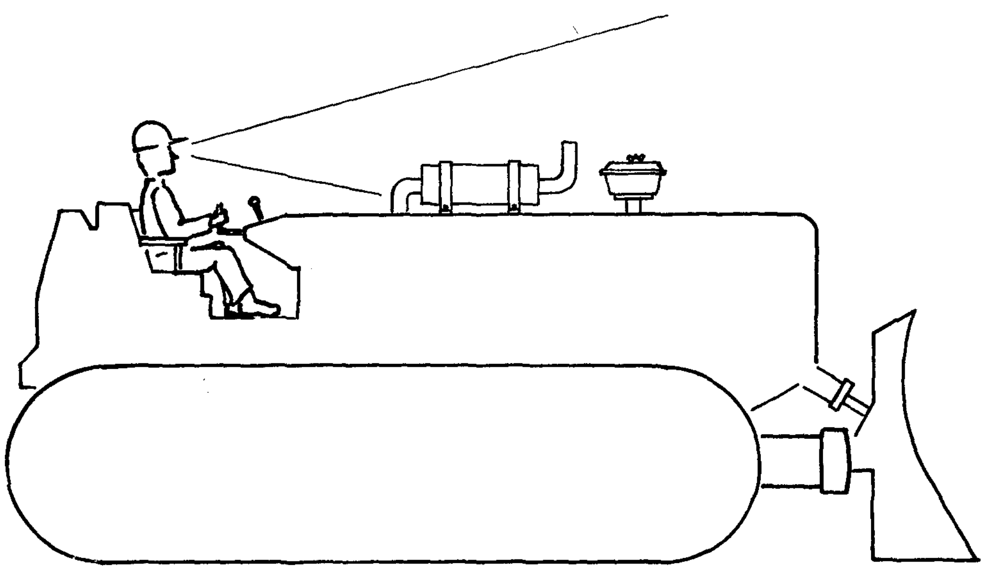
Style A: Care should be taken to limit the size of mufflers used in this application as excessive weight causes severe stress at the muffler inlet, which is often clamped directly to the manifold outlet. Large mufflers should be supported by bracketing to a stationary structural member. Use a tailpipe length that will direct the exhaust gases away from the operator. The installation time is about thirty minutes.

Ejector mufflers are normally mounted vertically as are ejector style tailpipes. It is essential that the ejector vacuum line to the pre-cleaner be airtight, direct and unobstructed to insure maximum pre-cleaner efficiency. Ejectors must be the last element in the exhaust system, except when a raincap is specified by the manufacturer.

*Pressure relief vents are also incorporated in some muffler designs to release entrapped moisture.



Poor Visibility and Too Much Stress
on Muffler Inlet Neck



Good Visibility and Muffler Well Supported

Figure 34. Muffler Orientation for Maximum Operator Visibility

Style B, C and D: Side inlet mufflers are well-suited for both under-hood and above-hood installations and should be well supported by brackets. Improper mounting will result in the inlet neck tearing away from the body of the muffler. Flex tubing is normally encountered close to the muffler inlet. Installation time will vary from 1-1/2 to 2-1/2 hours depending on the level of sophistication required for bracketing and support of the muffler body.

Style E and F: The standard end-in, end-out muffler is often mounted horizontally and almost always preceded by an elbow. Support brackets and mounting bands are a necessity, with installation times again falling in the 1-1/2 to 2-1/2 hour range.

Style G: The dual side inlet muffler is used for direct manifold mounting on V-type engines and almost always found under the hood. Variations may include insertion of flex steel tubing between inlet and manifold or an above-hood mounting position, but these mufflers are usually set up for specific engines and to use them for other than cross-engine manifold mounts is to defeat their intended purpose. When lack of availability of dual side inlet mufflers is a problem, several alternatives exist. First, the exhaust may be joined together using a common wye can device and a single muffler as shown in Figure 35. Wye connectors provide an easy, economical way to join left and right-hand exhaust pipes. Further, they provide an additional 3 to 7 dB(A) exhaust noise reduction over that of the primary muffler. Secondly, dual mufflers may be employed, but usually at higher cost. In either case, close attention should be paid to insuring that the engine back pressure limits are not exceeded. Because of the potential difficulties in alignment and bracketing, installation time could be as long as four hours.

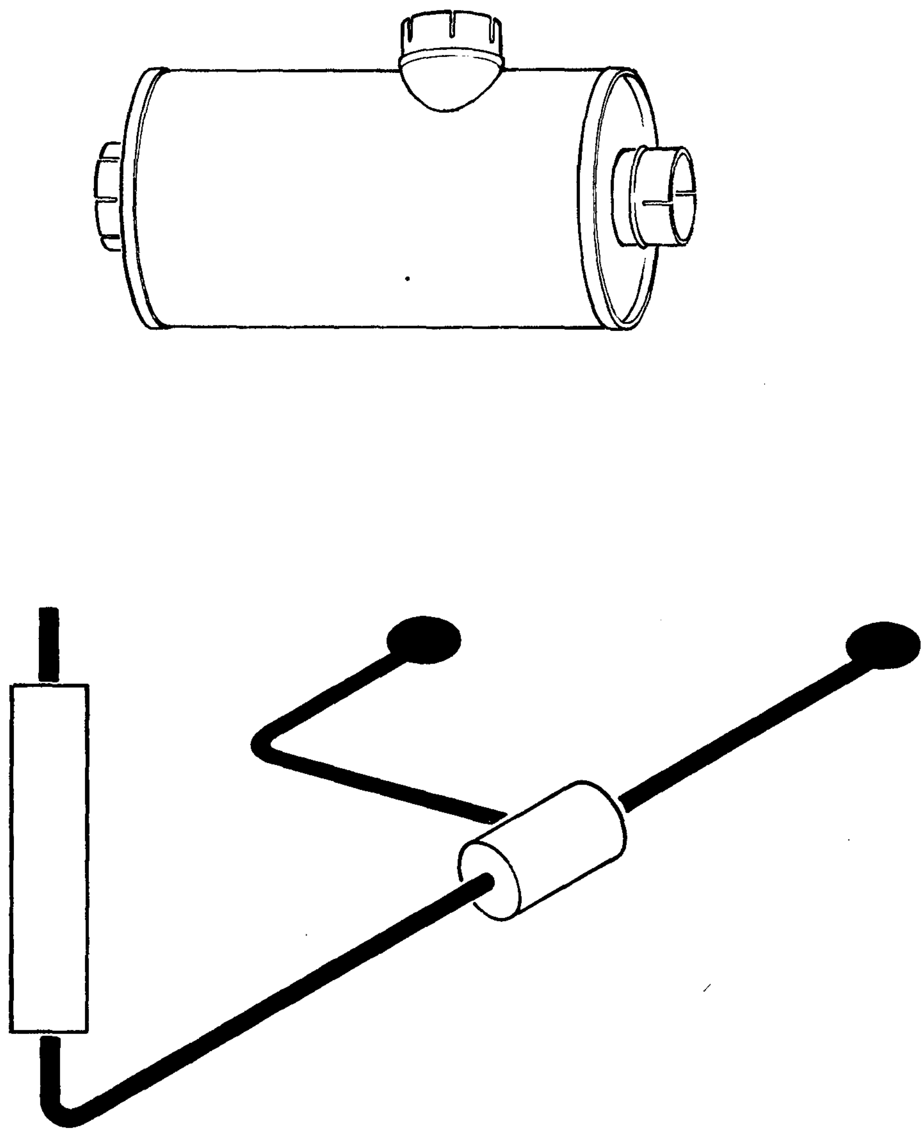


Figure 35. Wye Connector

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** NTIS No. to be assigned.

APPENDIX A

ENGINE SPECIFICATIONS

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
ALLIS CHALMERS **************													
D262	I-6	78@2200	4	61-75	N	EC	3.56 X 4.38	262	3.00	####	#####	####	87-102
D344	I-4	88@1800	4	61-62	N	EC	4.44 X 5.56	344	####	####	#####	####	87-102
2000	I-4	59@2100	4	67-73	N	DI	3.88 X 4.25	200	####	####	#####	####	87-102
2200	I-4	55@2100	4	68-74	N	DI	3.88 X 4.25	200	3.00	####	#####	####	87-102
2800	I-6	85@2600	4	66-75	N	DI	3.88 X 4.25	301	3.00	####	#####	####	87-102
2900	I-6	135@2600	4	65-75	T	DI	3.88 X 4.25	301	2.00	####	#####	####	85- 96
3400	I-6	125@2400	4	64-73	N	DI	4.25 X 5.00	426	####	####	#####	####	87-102
3500	I-6	175@2400	4	65-75	T	DI	4.25 X 5.00	426	2.00	####	#####	####	85- 96
3700	I-6	200@2400	4	##-75	TI	DI	4.25 X 5.00	426	2.00	####	#####	####	85- 96
3750	I-6	####@####	4	##-75	TI	DI	4.25 X 5.00	426	2.00	####	#####	####	85- 96
6000	I-4	104@2200	4	61-73	N	DI	4.44 X 5.56	344	####	####	#####	####	87-102
7000	I-4	160@2200	4	62-68	T	DI	4.44 X 5.56	344	####	####	#####	####	85- 96
10000	I-6	145@2200	4	61-72	N	DI	4.44 X 5.56	516	####	####	#####	####	87-102
11000	I-6	220@2200	4	61-75	T	DI	4.44 X 5.56	516	2.00	####	#####	####	85- 96
16000	I-6	250@2100	4	61-69	N	DI	5.25 X 6.50	844	####	####	#####	####	87-102
16000H	I-6	235@2100	4	70-75	N	DI	5.25 X 6.50	844	3.00	####	#####	####	87-102
17000MKII	I-6	300@2100	4	70-75	T	DI	5.25 X 6.50	844	2.00	####	#####	####	85- 96
10000	I-6	145@2200	4	61-72	N	DI	4.44 X 5.56	516	####	####	#####	####	87-102
11000	I-6	220@2200	4	61-75	T	DI	4.44 X 5.56	516	####	####	#####	####	85- 96
16000	I-6	250@2100	4	61-69	N	DI	5.25 X 6.50	844	####	####	#####	####	87-102
16000H	I-6	235@2100	4	70-75	N	DI	5.25 X 6.50	844	####	####	#####	####	87-102

NOTES:
- ### HASH MARKS: Indicate information is unavailable or does not apply.
- (1) BHP@RPM: Rating listed is maximum brake horsepower at the given RPM.
- (2) YEARS: Gathered data indcates the engine was produced during these years.
- (3) ASPIRATION: N-Naturally Aspirated; B-Mechanically Blown; T-Turbocharged; I-Intercooled.
- (4) FUEL INJECTION: PC-Pre Combustion;DI-Direct Injection; EC-Energy Cell; TC-Turbulence Chamber.
- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED ALLIS CHALMERS ************************													
17000MKII	I-6	300@2100	4	70-75	T	DI	5.25 X 6.50	844	####	####	#####	####	85- 96
19000	I-6	355@2100	4	63-66	N	DI	5.25 X 6.00	779	####	####	#####	####	87-102
21000	I-6	385@2100	4	61-69	T	DI	5.25 X 6.50	844	####	####	#####	####	85- 96
21000MKII	I-6	375@2100	4	70-75	T	DI	5.25 X 6.50	844	2.00	####	#####	####	85- 96
25000	I-6	435@2100	4	63-69	TI	DI	5.25 X 6.50	844	####	####	#####	####	85- 96
25000MKII	I-6	450@2100	4	70-75	TI	DI	5.25 X 6.50	844	2.00	####	#####	####	85- 96
61000	V12	800@2100	4	73-74	T	DI	6.00 X 6.00	2035	2.00	####	#####	####	85- 96
65000	V12	900@2100	4	73-75	TI	DI	6.00 X 6.00	2035	2.00	####	#####	####	85- 96
CASE ****													
G-188D	I-4	62@2250	4	61-75	N	DI	3.81 X 4.13	188	####	####	#####	####	87-102
A-267D	I-4	73@2000	4	61-70	N	PC	4.13 X 5.00	267	####	####	#####	####	87-102
267BD	I-4	83@2200	4	71-73	N	PC	4.13 X 5.00	267	####	####	#####	####	87-102
A-301D	I-4	82@2000	4	61-70	N	PC	4.38 X 5.00	301	####	####	#####	####	87-102
301BD	I-4	94@2200	4	71-75	N	DI	4.38 X 5.00	301	2.20	####	#####	####	87-102
336BD	I-4	104@2200	4	71-75	N	DI	4.63 X 5.00	336	2.20	####	#####	####	87-102
336BDT	I-4	126@2200	4	71-75	T	DI	4.63 X 5.00	336	1.80	####	#####	####	85- 96
A-401D	I-6	103@1800	4	61-70	N	PC	4.13 X 5.00	401	####	####	#####	####	87-102
401BD	I-6	126@2200	4	71-73	N	DI	4.13 X 5.00	401	2.20	####	#####	####	87-102
A-451D	I-6	123@2000	4	61-70	N	PC	4.38 X 5.00	451	####	####	#####	####	87-102
A-451D	I-6	145@2000	4	65-70	N	DI	4.38 X 5.00	451	####	####	#####	####	87-102

NOTES:

HASH MARKS: Indicate information is unavailable or does not apply.
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(5) B.P.: Engine Back Pressure Limit (In. HG).
(6) I.R.: Intake Restriction Limit (In. water), clean system.
(7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED CASE **************													
451BD	I-6	142@2200	4	71-75	N	DI	4.38 X 5.00	451	2.20	####	#####	####	87-102
451BDT	I-6	181@2200	4	71-75	T	DI	4.38 X 5.00	451	1.80	####	#####	####	85- 96
504BD	I-6	155@2200	4	71-75	N	DI	4.63 X 5.00	504	2.20	####	#####	####	87-102
504BDT	I-6	221@2200	4	71-75	T	DI	4.63 X 5.00	504	1.80	####	#####	####	85- 96
504BDTI	I-6	256@2200	4	75-##	TI	DI	4.63 X 5.00	504	1.80	####	#####	####	85- 96
CATERPILLAR ***********													
D311	I-4	75@2400	4	61-67	N	PC	4.00 X 5.00	252	2.50	####	#####	####	###-###
D320	I-4	105@2400	4	61-67	T	PC	4.00 X 5.00	252	2.00	####	#####	####	###-###
D320	I-4	120@2400	4	61-67	T	PC	4.00 X 5.00	252	2.00	####	#####	####	###-###
D330	I-4	135@2200	4	61-67	T	PC	4.50 X 5.50	350	2.00	####	#####	####	###-###
D330	I-4	170@2200	4	61-67	T	PC	4.50 X 5.50	350	2.00	####	#####	####	###-###
D330-TA	I-4	200@2200	4	67-67	TI	PC	4.50 X 5.50	350	2.00	####	#####	####	###-###
D330-NA	I-4	115@2200	4	68-72	N	PC	4.75 X 6.00	425	2.50	####	#####	####	###-###
D330C-T	I-4	200@2200	4	68-72	T	PC	4.75 X 6.00	425	2.00	####	#####	####	###-###
3304	I-4	115@2200	4	73-75	N	PC	4.75 X 6.00	425	2.50	####	#####	####	###-###
3304	I-4	200@2200	4	73-75	N	PC	4.75 X 6.00	425	2.00	####	#####	####	###-###
3145	V-8	175@3200	4	70-74	N	DI	4.50 X 4.11	522	2.50	####	#####	####	###-###
D333	I-6	205@2200	4	61-67	T	PC	4.50 X 5.50	525	2.00	####	#####	####	###-###
D333	I-6	225@2200	4	61-67	T	PC	4.50 X 5.50	525	2.00	####	#####	####	###-###
D333-TA	I-6	255@2200	4	67-67	TI	PC	4.50 X 5.50	525	2.00	####	#####	####	###-###

NOTES:
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- (4) FUEL INJECTION: PC-Pre Combustion;DI-Direct Injection; EC-Energy Cell; TC-Turbulence Chamber.
- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED CATERPILLAR *********************													
D333-TA	I-6	300@2200	4	67-67	TI	PC	4.50 X 5.50	525	2.00	####	#####	####	###-###
3150	V-8	185@3000	4	70-74	N	DI	4.50 X 4.50	573	2.50	####	#####	####	###-###
3160	V-8	225@2800	4	70-74	N	DI	4.50 X 5.00	636	2.50	####	#####	####	###-###
3208	V-8	220@2800	4	74-75	N	DI	4.50 X 5.00	636	2.50	####	#####	####	###-###
D333C-T	I-6	300@2200	4	68-72	T	PC	4.75 X 6.00	638	2.00	####	#####	####	###-###
3306	I-6	175@2200	4	73-75	N	PC	4.75 X 6.00	638	2.50	####	#####	####	###-###
3306	I-6	300@2200	4	73-75	N	PC	4.75 X 6.00	638	1.47	####	#####	####	###-###
D334-TA	I-6	335@2000	4	68-75	TI	PC	4.75 X 6.00	638	2.00	####	#####	####	###-###
D336	V-8	405@2200	4	66-68	TI	PC	4.50 X 5.50	700	2.00	####	#####	####	###-###
D336-TA	V-8	455@2200	4	67-71	TI	PC	4.50 X 5.50	700	2.00	####	#####	####	###-###
D343	I-6	360@2000	4	62-66	T	PC	5.41 X 6.50	893	2.00	####	#####	####	###-###
D343	I-6	420@2000	4	61-66	T	PC	5.41 X 6.50	893	2.00	####	#####	####	###-###
D343-T	I-6	395@2000	4	67-75	T	PC	5.41 X 6.50	893	2.00	####	#####	####	###-###
D343-TA	I-6	550@2000	4	67-75	TI	PC	5.41 X 6.50	893	2.00	####	#####	####	###-###
3406	I-6	395@2100	4	74-75	TI	DI	5.41 X 6.50	893	2.00	####	#####	####	###-###
3406	I-6	465@2100	4	74-75	TI	PC	5.41 X 6.50	893	2.00	####	#####	####	###-###
3408	V-8	600@2100	4	74-75	TI	PC	5.41 X 6.00	1099	2.00	####	#####	####	###-###
D346	V-8	735@2000	4	70-75	TI	PC	5.41 X 6.50	1191	2.00	####	#####	####	###-###
D342	I-6	220@1300	4	61-75	N	PC	5.75 X 8.00	1246	2.50	####	#####	####	###-###
D342	I-6	320@1300	4	61-66	N	PC	5.75 X 8.00	1246	2.00	####	#####	####	###-###
D342-T	I-6	360@1300	4	67-75	T	PC	5.75 X 8.00	1246	2.00	####	#####	####	###-###

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- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED CATERPILLAR *********************													
D353	I-6	500@1400	4	61-64	TI	PC	6.25 X 8.00	1473	2.00	####	#####	####	###-###
D353	I-6	610@1400	4	65-66	TI	PC	6.25 X 8.00	1473	2.00	####	#####	####	###-###
D353-TA	I-6	640@1300	4	67-75	TI	PC	6.25 X 8.00	1473	2.00	####	#####	####	###-###
D348	V12	1100@2000	4	69-75	TI	PC	5.41 X 6.50	1786	2.00	####	#####	####	###-###
D379	V-8	630@1300	4	62-64	TI	PC	6.25 X 8.00	1964	2.00	####	#####	####	###-###
D379	V-8	780@1300	4	65-66	TI	PC	6.25 X 8.00	1964	2.00	####	#####	####	###-###
D379-TA	V-8	850@1300	4	67-75	TI	PC	6.25 X 8.00	1964	2.00	####	#####	####	###-###
D349	V16	1460@2000	4	70-75	TI	PC	5.41 X 6.50	2382	2.00	####	#####	####	###-###
D398	V12	950@1300	4	62-64	TI	PC	6.25 X 8.00	2946	2.00	####	#####	####	###-###
D398	V12	1170@1300	4	65-66	TI	PC	6.25 X 8.00	2946	2.00	####	#####	####	###-###
D398-TA	V12	1275@1300	4	67-75	TI	PC	6.25 X 8.00	2946	2.00	####	#####	####	###-###
D399-TA	V16	1550@1300	4	67-75	TI	PC	6.25 X 8.00	3928	2.00	####	#####	####	###-###
CHRYSLER-NISSAN ***************													
IN433	I-4	61@4000	4	71-75	N	DI	3.27 X 3.94	132	####	####	#####	####	87-102
IN633	I-6	92@4000	4	71-75	N	DI	3.27 X 3.94	198	####	####	#####	####	87-102
IN375	I-3	132@2400	2	71-74	B	DI	4.33 X 5.13	226	####	####	#####	####	103-110
IN475	I-4	180@2400	2	71-74	B	DI	4.33 X 5.13	302	####	####	#####	####	103-110
IN575	I-5	224@2400	2	71-74	B	DI	4.33 X 5.13	377	####	####	#####	####	103-110
IN675	I-6	250@2200	2	71-74	B	DI	4.33 X 5.13	452	####	####	#####	####	103-110
INV875	V-8	343@2200	2	71-74	B	DI	4.33 X 5.13	603	####	####	#####	####	103-110

NOTES:
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- (4) FUEL INJECTION: PC-Pre Combustion;DI-Direct Injection; EC-Energy Cell; TC-Turbulence Chamber.
- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED CHRYSLER-NISSAN *************************													
CI655	I-6	135@3150	4	75-##	N	##	3.86 X 4.72	331	####	####	#####	####	87-102
CI8115	I-8	300@2500	4	75-##	N	##	5.31 X 5.13	908	####	####	#####	####	87-102
CONTINENTAL ***********													
D132H	I-3	52@3600	4	71-72	N	TC	3.94 X 3.94	144	####	####	#####	####	87-102
D142H	I-4	76@3600	4	71-72	N	TC	3.94 X 3.94	192	####	####	#####	####	87-102
D162H	I-6	112@3600	4	71-72	N	TC	3.94 X 3.94	288	####	####	#####	####	87-102
GD-193	I-4	59@2000	4	61-70	N	EC	3.75 X 4.38	193	####	####	#####	####	87-102
ED-201	I-4	65@2400	4	61-64	N	TC	3.62 X 4.88	201	####	####	#####	####	87-102
ED-208	I-4	68@2400	4	61-64	N	TC	3.69 X 4.88	208	####	####	#####	####	87-102
ED-223	I-4	72@2000	4	61-64	N	TC	3.81 X 4.88	223	####	####	#####	####	87-102
ED-242	I-4	70@2200	4	64-64	N	TC	3.88 X 5.12	242	####	####	#####	####	87-102
HD-243	I-4	57@1800	4	61-64	N	TC	3.75 X 5.50	243	####	####	#####	####	87-102
HD-260	I-4	62@1800	4	61-64	N	TC	3.88 X 5.50	260	####	####	#####	####	87-102
HD-227	I-4	80@2250	4	61-64	N	TC	4.00 X 5.50	277	####	####	#####	####	87-102
JD-382	I-4	93@1800	4	61-64	N	TC	4.50 X 6.00	382	####	####	#####	####	87-102
JD-403	I-4	110@2000	4	61-65	N	TC	4.62 X 6.00	403	####	####	#####	####	87-102
TD-427	I-6	140@2400	4	61-65	N	TC	4.31 X 4.88	427	####	####	#####	####	87-102
LD-478	I-6	140@2600	4	66-70	N	TC	4.56 X 4.88	478	####	####	#####	####	87-102
LDS-478	I-6	180@2600	4	66-70	N	TC	4.56 X 4.88	478	####	####	#####	####	87-102
RD-572	I-6	182@2400	4	61-65	N	TC	4.75 X 5.38	571	####	####	#####	####	87-102

NOTES:

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- (4) FUEL INJECTION: PC-Pre Combustion;DI-Direct Injection; EC-Energy Cell; TC-Turbulence Chamber.
- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED CONTINENTAL *********************													
VD-603	V-8	240@2800	4	61-64	N	TC	4.75 X 4.25	603	####	####	#####	####	87-102
SD-802	I-6	212@1800	4	62-65	N	TC	5.56 X 5.50	802	####	####	#####	####	87-102
CUMMINS *******													
C-105	I-4	105@2500	4	61-67	N	DI	4.44 X 5.00	309	3.00	15.0	#####	####	87-102
C-140	I-4	140@2500	4	61-62	N	DI	4.44 X 5.00	309	3.00	15.0	#####	####	87-102
V-352-C	I-6	140@3300	4	68-70	N	DI	4.62 X 3.50	352	3.00	15.0	#####	####	87-102
V-378-C	V-6	149@3300	4	66-75	N	DI	4.62 X 3.75	378	3.00	15.0	3.00	####	87-102
JN-130	I-6	130@2500	4	61-67	N	DI	4.12 X 5.00	401	3.00	15.0	#####	####	87-102
C-160	I-6	160@2500	4	61-67	N	DI	4.44 X 5.00	464	3.00	15.0	#####	####	87-102
C-175	I-6	175@2500	4	61-67	N	DI	4.44 X 5.00	464	3.00	15.0	#####	####	87-102
C-180	I-6	180@2500	4	61-67	N	DI	4.44 X 5.00	464	3.00	15.0	#####	####	87-102
CS-464-C	I-6	195@2600	4	68-73	N	DI	4.44 X 5.00	464	3.00	15.0	#####	####	87-102
V-470	V-8	185@3300	4	68-70	N	DI	4.62 X 3.50	470	3.00	15.0	#####	####	87-102
V-504-C	V-8	202@3300	4	66-75	N	DI	4.62 X 3.75	504	3.00	15.0	4.00	3.00	87-102
V-555-C	V-8	230@3300	4	71-75	N	DI	4.62 X 4.12	555	3.00	15.0	4.00	3.00	87-102
VT-555-C	V-8	240@3300	4	72-75	T	DI	4.62 X 4.12	555	3.00	15.0	4.00	####	85- 96
V6-200	I-6	200@2600	4	62-67	N	DI	5.50 X 4.12	588	3.00	15.0	#####	####	87-102
V-588	I-6	200@2600	4	68-69	N	DI	5.50 X 4.12	588	3.00	15.0	#####	####	87-102
H-6	I-6	160@1800	4	61-67	N	DI	4.88 X 6.00	672	3.00	15.0	#####	####	87-102
HR-6	I-6	175@1800	4	61-67	N	DI	5.12 X 6.00	743	3.00	15.0	#####	####	87-102

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- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED CUMMINS *****************													
HRF-6	I-6	190@2000	4	61-67	N	DI	5.12 X 6.00	743	3.00	15.0	#####	####	87-102
HRS-6	I-6	240@1800	4	61-67	T	DI	5.12 X 6.00	743	3.00	15.0	#####	####	85- 96
NH-220	I-6	220@2100	4	61-67	N	DI	5.12 X 6.00	743	3.00	15.0	#####	####	87-102
NRTO-6	I-6	335@2100	4	61-63	T	DI	5.12 X 6.00	743	3.00	15.0	#####	####	85- 96
NHS-6	I-6	290@2100	4	61-67	T	DI	5.12 X 6.00	743	3.00	15.0	#####	####	85- 96
NHRS-6	I-6	320@2100	4	61-67	T	DI	5.12 X 6.00	743	3.00	15.0	#####	####	85- 96
NS-743	I-6	320@2100	4	68-70	T	DI	5.12 X 6.00	743	3.00	15.0	#####	####	85- 96
N-743-C	I-6	220@2100	4	68-73	N	DI	5.12 X 6.00	743	3.00	15.0	#####	####	87-102
V8-265	V-8	265@2600	4	62-67	N	DI	5.50 X 4.12	785	3.00	15.0	#####	####	87-102
V-785-C	V-8	265@2600	4	68-74	N	DI	5.50 X 4.12	785	3.00	15.0	#####	####	87-102
NH-250	I-6	250@2100	4	61-67	N	DI	5.50 X 6.00	855	3.00	15.0	4.00	####	87-102
N-855-C	I-6	240@2100	4	66-75	N	DI	5.50 X 6.00	855	3.00	15.0	4.00	####	87-102
NT-280	I-6	280@2100	4	61-64	N	DI	5.50 X 6.00	855	3.00	15.0	5.00	####	87-102
NT-855-C	I-6	280@2100	4	66-75	T	DI	5.50 X 6.00	855	3.00	15.0	5.00	####	85- 96
NT-310	I-6	310@2100	4	63-67	T	DI	5.50 X 6.00	855	3.00	15.0	5.00	####	85- 96
NT-335	I-6	335@2100	4	61-67	T	DI	5.50 X 6.00	855	3.00	15.0	5.00	####	85- 96
NT-855-C	I-6	335@2100	4	66-75	T	DI	5.50 X 6.00	855	3.00	15.0	5.00	####	85- 96
NTA-855-C	I-6	360@2100	4	72-75	TI	DI	5.50 X 6.00	855	3.00	15.0	5.00	####	85- 96
NT-380	I-6	380@2300	4	61-67	TI	DI	5.50 X 6.00	855	3.00	15.0	5.00	####	85- 96
NTA-855-C	I-6	420@2300	4	68-75	TI	DI	5.50 X 6.00	855	3.00	15.0	5.00	####	85- 96
V-903-C320	V-8	307@2600	4	69-75	N	DI	5.50 X 4.75	903	3.00	15.0	5.00	4.00	87-102

NOTES:

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MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED CUMMINS *****************													
VT903-C350	V-8	350@ 260	4	72-75	T	DI	5.50 X 4.75	903	3.00	15.0	5.00	####	85- 96
V8-350	V-8	350@2500	4	61-67	N	DI	5.50 X 5.00	950	3.00	15.0	#####	####	87-102
VT8-430	V-8	430@2500	4	61-67	T	DI	5.50 X 5.00	950	3.00	15.0	#####	####	85- 96
KT-1150-C	I-6	450@2100	4	75-##	T	DI	6.25 X 6.25	1150	3.00	15.0	5.00	####	85- 96
KTA-1150-C	I-6	600@2100	4	75-##	TI	DI	6.25 X 6.25	1150	3.00	15.0	5.00	####	85- 96
NVH-12	V12	450@2100	4	61-62	N	DI	5.12 X 6.00	1486	3.00	15.0	#####	####	87-102
NVH-450	V12	450@2100	4	63-67	N	DI	5.12 X 6.00	1486	3.00	15.0	#####	####	87-102
VT12	V12	600@2100	4	61-64	T	DI	5.12 X 6.00	1486	3.00	15.0	#####	####	85- 96
VT12-600	V12	600@2100	4	65-67	T	DI	5.12 X 6.00	1486	3.00	15.0	#####	####	85- 96
V12-525	V12	525@2100	4	61-67	N	DI	5.50 X 6.00	1710	3.00	15.0	#####	4.00	87-102
V-1710-C	V12	525@2100	4	68-75	N	DI	5.50 X 6.00	1710	3.00	15.0	#####	4.00	87-102
VT-1710-C	V12	635@2100	4	70-75	T	DI	5.50 X 6.00	1710	3.00	15.0	#####	5.00	85- 96
VT12-700	V12	700@2100	4	62-67	T	DI	5.50 X 6.00	1710	3.00	15.0	#####	5.00	85- 96
VTA-1710-C	V12	700@2100	4	68-75	TI	DI	5.50 X 6.00	1710	3.00	15.0	#####	5.00	85- 96
VTA-1710-C	V12	800@2100	4	68-75	TI	DI	5.50 X 6.00	1710	3.00	15.0	#####	5.00	85- 96
VT12-825	V12	825@2100	4	65-67	TI	DI	5.50 X 6.00	1710	3.00	15.0	#####	5.00	85- 96
KT-2300-C	V12	900@2100	4	75-##	T	DI	6.25 X 6.25	2300	3.00	15.0	#####	5.00	85- 96
KTA-2300-C	V12	1200@2100	4	75-##	TI	DI	6.25 X 6.25	2300	3.00	15.0	#####	5.00	85- 96
DETROIT DIESEL **************													
3-53\2V	I-3	75@2200	2	##-75	B	DI	3.88 X 4.50	159	3.00	12.0	3.00	####	103-110

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MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED DETROIT DIESEL ***********************													
3-53N\2V	I-3	59@1800	2	**-75	B	DI	3.88 X 4.50	159	3.00	12.0	3.00	####	103-110
3-53\4V	I-3	94@2800	2	**-75	B	DI	3.88 X 4.50	159	4.00	16.0	3.00	####	103-110
3-53N\4V	I-3	98@2800	2	**-75	B	DI	3.88 X 4.50	159	4.00	16.0	3.00	####	103-110
4-53\2V	I-4	103@2200	2	**-75	B	DI	3.88 X 4.50	212	3.00	12.0	3.50	####	103-110
4-53N\2V	I-4	80@1800	2	**-75	B	DI	3.88 X 4.50	212	3.00	12.0	3.50	####	103-110
4-53\4V	I-4	127@2800	2	**-75	B	DI	3.88 X 4.50	212	4.00	16.0	3.50	####	103-110
4-53N\4V	I-4	136@2800	2	**-75	B	DI	3.88 X 4.50	212	4.00	16.0	3.50	####	103-110
6V-53N\4V	V-6	210@2800	2	**-75	B	DI	3.88 X 4.50	318	4.00	16.0	4.00	3.00	103-110
2-71\2V	I-2	65@2000	2	**-75	B	DI	4.25 X 5.00	142	5.00	16.0	2.50	####	103-110
3-71\2V	I-3	105@2300	2	**-75	B	DI	4.25 X 5.00	213	5.00	17.5	3.00	####	103-110
3-71N\2V	I-3	105@2300	2	**-75	B	DI	4.25 X 5.00	213	5.00	17.5	3.00	####	103-110
3-71N\4V	I-3	112@2300	2	**-75	B	DI	4.25 X 5.00	213	5.00	17.5	3.00	####	103-110
4-71\2V	I-4	150@2300	2	**-75	B	DI	4.25 X 5.00	284	5.00	17.5	3.50	####	103-110
4-71N\2V	I-4	146@2300	2	**-75	B	DI	4.25 X 5.00	284	5.00	17.5	3.50	####	103-110
4-71N\4V	I-4	159@2300	2	**-75	B	DI	4.25 X 5.00	284	4.00	17.5	3.50	####	103-110
6-71\2V	I-6	230@2300	2	**-75	B	DI	4.25 X 5.00	426	5.00	17.5	4.00	3.00	103-110
6-71N\2V	I-6	224@2300	2	**-75	B	DI	4.25 X 5.00	426	5.00	17.5	4.00	3.00	103-110
6-71N\4V	I-6	236@2300	2	**-75	B	DI	4.25 X 5.00	426	4.00	17.5	4.00	3.00	103-110
6V-71N\2V	V-6	205@2300	2	**-75	B	DI	4.25 X 5.00	426	6.00	17.5	4.00	3.00	103-110
6V-71N\4V	V-6	236@2300	2	**-75	B	DI	4.25 X 5.00	426	4.00	17.5	4.00	3.00	103-110
8V-71N\4V	V-8	314@2300	2	**-75	B	DI	4.25 X 5.00	568	4.00	17.5	5.00	3.50	103-110

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- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED DETROIT DIESEL ************************													
12V-71N\2V	V12	353@2100	2	##-75	B	DI	4.25 X 5.00	852	5.00	17.5	5.00	3.50	103-110
12V-71N\4V	V12	471@2300	2	##-75	B	DI	4.25 X 5.00	852	4.00	17.5	6.00	4.00	103-110
16V-71N\4V	V16	628@2300	2	##-75	B	DI	4.25 X 5.00	1136	4.00	17.5	8.00	5.00	103-110
4-71T	I4	178@2300	2	##-75	BT	DI	4.25 X 5.00	284	2.50	12.0	4.00	####	93- 98
6-71T	I-6	270@2300	2	##-75	BT	DI	4.25 X 5.00	426	2.50	12.0	5.00	####	93- 98
6V-71T	V-6	270@2300	2	##-75	BT	DI	4.25 X 5.00	426	2.50	12.0	5.00	####	93- 98
8V-71T	V-8	360@2300	2	##-75	BT	DI	4.25 X 5.00	568	2.50	12.0	5.00	3.50	93- 98
12V-71T	V12	525@2100	2	##-75	BT	DI	4.25 X 5.00	852	2.50	12.0	8.00	5.00	93- 98
16V-71T	V16	700@2100	2	##-75	BT	DI	4.25 X 5.00	1136	2.50	12.0	8.00	6.00	93- 98
6V-92	V-6	276@2300	2	##-75	B	DI	4.84 X 5.00	552	4.00	15.7	5.00	3.50	103-110
8V-92	V-8	368@2300	2	##-75	B	DI	4.84 X 5.00	736	4.00	15.7	6.00	4.00	103-110
16V-92	V16	720@2100	2	##-75	B	DI	4.84 X 5.00	1472	4.00	15.7	8.00	6.00	103-110
6V-92T	V-6	330@2300	2	##-75	BT	DI	4.84 X 5.00	552	2.50	12.0	5.00	3.50	103-110
8V-92T	V-8	440@2300	2	##-75	BT	DI	4.84 X 5.00	736	2.50	12.0	6.00	4.00	93- 98
16V-92T	V16	860@2100	2	##-75	BT	DI	4.84 X 5.00	1472	2.50	12.0	8.00	6.00	93- 98
6-110	I-6	309@2000	2	61-65	B	DI	5.00 X 5.60	660	4.00	####	6.00	####	103-110
12V-149	V12	800@1900	2	##-75	B	DI	5.75 X 5.75	1792	4.00	15.0	8.00	6.00	103-110
16V-149	V16	1060@1900	2	##-75	B	DI	5.75 X 5.75	2389	4.00	15.0	10.00	8.00	103-110
12V-149T	V12	1000@1900	2	##-75	BT	DI	5.75 X 5.75	1792	2.50	12.0	10.00	8.00	93- 98
16V-149T	V16	1325@1900	2	##-75	BT	DI	5.75 X 5.75	2389	2.50	12.0	12.00	8.00	93- 98
12V-149TI	V12	1200@1900	2	##-75	BTI	DI	5.75 X 5.75	1792	2.50	12.0	10.00	8.00	93- 98

NOTES:
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- (3) ASPIRATION: N-Naturally Aspirated; B-Mechanically Blown; T-Turbocharged; I-Intercooled.
- (4) FUEL INJECTION: PC-Pre Combustion;DI-Direct Injection; EC-Energy Cell; TC-Turbulence Chamber.
- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED DETROIT DIESEL ************************													
16V-149TI	V16	1600@1900	2	##-75	BTI	DI	5.75 X 5.75	2389	2.50	12.0	12.00	8.00	93- 98
DEUTZ *****													
F6L-413	V-6	170@2650	4	70-75	N	DI	4.75 X 4.88	518	2.17	19.7	#####	2.75	87-102
F8L-413	V-8	230@2650	4	70-75	N	DI	4.75 X 4.88	691	2.17	19.7	#####	2.75	87-102
F10L-413	V10	285@2650	4	70-75	N	DI	4.75 X 4.88	862	2.17	19.7	#####	3.00	87-102
F12L-413	V12	340@2650	4	70-75	N	DI	4.75 X 4.88	1035	2.17	19.7	#####	3.00	87-102
F3L-912	I-3	62@2800	4	68-75	N	DI	3.94 X 4.75	173	1.84	16.7	2.50	####	87-102
F4L-912	I-4	80@2800	4	68-75	N	DI	3.94 X 4.75	230	2.17	19.7	2.50	####	87-102
F5L-912	I-5	108@2800	4	73-75	N	DI	3.94 X 4.75	288	2.17	19.7	2.50	####	87-102
F6L-912	I-6	120@2800	4	68-75	N	DI	3.94 X 4.75	345	2.17	19.7	2.50	####	87-102
BF6L-913	I-6	160@2800	4	72-75	T	DI	4.00 X 4.88	373	1.45	19.7	2.50	####	85- 96
FORD ****													
DD	I-4	59@2400	4	61-65	N	DI	3.91 X 3.61	172	####	####	#####	####	87-102
X	I-4	60@2250	4	61-65	N	DI	3.94 X 4.52	220	####	####	#####	####	87-102
Y	I-6	96@2250	4	61-70	N	DI	3.94 X 4.52	330	####	####	#####	####	87-102
172DF	I-4	59@2400	4	62-75	N	DI	3.91 X 3.61	172	3.00	####	#####	####	87-102
175DF	I-3	52@2500	4	71-75	N	DI	4.20 X 4.20	175	3.00	####	#####	####	87-102
183D	I-3	52@2200	4	72-75	N	DI	4.20 X 4.72	183	3.00	####	#####	####	87-102
192DF	I-4	65@2400	4	72-75	N	DI	4.40 X 3.00	192	3.00	####	#####	####	87-102

NOTES:

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(4) FUEL INJECTION: PC-Pre Combustion;DI-Direct Injection; EC-Energy Cell; TC-Turbulence Chamber.
(5) B.P.: Engine Back Pressure Limit (In. HG).
(6) I.R.: Intake Restriction Limit (In. water), clean system.
(7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED FORD **************													
201DF	I-3	66@2250	4	66-75	N	DI	4.40 X 4.40	201	3.00	####	#####	####	87-102
220	I-4	69@2400	4	64-69	N	DI	3.94 X 4.52	220	####	####	#####	####	87-102
233D	I-4	68@2100	4	66-68	N	DI	4.41 X 4.41	233	####	####	#####	####	87-102
242DF	I-4	79@2500	4	62-70	N	DI	3.62 X 3.91	242	####	####	#####	####	87-102
242D	I-6	76@2230	4	62-68	N	DI	3.62 X 3.91	242	####	####	#####	####	87-102
254DF	I-4	80@2500	4	71-75	N	DI	4.22 X 4.52	254	3.00	####	#####	####	87-102
256DF	I-4	89@2500	4	69-75	N	DI	4.41 X 4.20	254	3.00	####	#####	####	87-102
330DF	I-6	111@2500	4	67-70	N	DI	3.94 X 4.52	330	####	####	#####	####	87-102
362DF	I-6	121@2500	4	67-75	N	DI	4.12 X 4.52	363	3.00	####	#####	####	87-102
363DFT	I-6	150@2400	4	71-75	T	DI	4.12 X 4.52	363	####	####	#####	####	85- 96
380DF	I-6	120@2500	4	71-75	N	DI	4.22 X 4.52	380	3.00	####	#####	####	87-102
401DF	I-6	132@2500	4	69-75	N	DI	4.41 X 4.41	401	3.00	####	#####	####	87-102
401DFT	I-6	167@2500	4	70-75	T	DI	4.41 X 4.41	401	####	####	#####	####	85- 96
HERCULES ********													
DD-198-H	I-4	72@2600	4	61-62	N	DI	3.75 X 4.50	198	####	####	#####	####	87-102
D-2000	I-4	68@2400	4	63-75	N	DI	3.75 X 4.50	198	2.50	####	2.25	####	87-102
D-2120	I-4	####@####	4	63-69	N	DI	3.88 X 4.50	212	####	####	#####	####	87-102
DD-226-H	I-4	78@2600	4	61-62	N	DI	4.00 X 4.50	226	####	####	#####	####	87-102
D-2300	I-4	72@2400	4	63-75	N	DI	4.00 X 4.50	226	2.50	####	2.25	####	87-102
D-298-H	I-6	112@2800	4	61-62	N	DI	3.75 X 4.50	298	####	####	#####	####	87-102

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- (5) B.P.: Engine Back Pressure Limit (In. HG).
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- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED HERCULES ******************													
D-3000	I-6	114@3000	4	63-75	N	DI	3.75 X 4.50	298	2.50	####	2.25	####	87-102
D-298-HT	I-6	140@2800	4	61-62	T	DI	3.75 X 4.50	298	####	####	#####	####	85- 96
D-3000T	I-6	131@2600	4	63-75	T	DI	3.75 X 4.50	298	2.50	####	2.63	####	85- 96
D-339-H	I-6	120@2800	4	61-62	N	DI	4.00 X 4.50	339	####	####	#####	####	87-102
D-3400	I-6	115@2600	4	63-75	N	DI	4.50 X 4.50	339	2.50	####	2.25	####	87-102
D-426	I-6	145@2600	4	61-63	N	TC	4.50 X 5.00	426	####	####	#####	####	87-102
D-426-T	I-6	180@2600	4	61-62	T	TC	4.50 X 5.00	426	####	####	#####	####	85- 96
D-4800	I-6	150@2400	4	69-75	N	DI	4.56 X 4.88	478	2.50	####	2.88	####	87-102
D-4800T	I-6	159@2000	4	71-75	T	DI	4.56 X 4.88	478	2.50	####	2.63	####	85- 96
INTERNATIONAL HARVESTER **********************													
D179	I-4	59@2400	4	72-74	N	##	#### X ####	179	1.80	####	#####	####	87-102
D188	I-4	62@2400	4	71-75	N	##	#### X ####	188	1.80	####	#####	####	87-102
D206	I-4	56@2500	4	70-73	N	##	#### X ####	206	####	####	#####	####	87-102
D236	I-6	65@2400	4	61-75	N	PC	3.69 X 3.69	236	1.80	####	#####	####	87-102
D239	I-4	80@2500	4	71-74	N	##	3.88 X 5.06	239	1.80	####	#####	####	87-102
DT239	I-4	78@2500	4	##-74	N	##	3.88 X 5.06	239	1.80	####	#####	####	87-102
D282	I-6	95@2400	4	61-75	N	PC	3.69 X 4.39	282	1.80	####	#####	####	87-102
D310	I-6	101@2300	4	71-74	N	##	#### X ####	310	1.80	####	#####	####	87-102
D312	I-6	117@3000	4	71-75	N	DI	3.88 X 4.41	312	1.80	####	#####	####	87-102
D360	I-6	136@3000	4	71-75	N	DI	3.88 X 5.08	360	1.80	####	#####	####	87-102

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MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED INTERNATIONAL HARVESTER ********************************													
DT360	I-6	190@3000	4	71-75	T	DI	3.88 X 5.08	360	1.80	####	#####	####	85- 96
D361	I-6	####@####	4	64-66	N	DI	4.13 X 4.50	361	####	####	#####	####	87-102
DT361	I-6	146@2600	4	64-66	T	DI	4.13 X 4.50	361	####	####	#####	####	85- 96
D370	I-4	105@2200	4	61-64	N	PC	4.62 X 5.50	370	####	####	#####	####	87-102
D407	I-6	127@2600	4	68-75	N	DI	4.33 X 4.63	407	1.80	####	#####	####	87-102
DT407	I-6	160@2500	4	68-75	T	DI	4.33 X 4.63	407	1.80	####	#####	####	85- 96
D414	I-6	157@3000	4	71-75	N	DI	4.30 X 4.75	414	1.80	####	#####	####	87-102
DT414	I-6	220@3000	4	71-75	T	DI	4.30 X 4.75	414	1.80	####	#####	####	85- 96
DT429	I-6	225@2600	4	64-69	T	DI	4.50 X 4.50	429	####	####	#####	####	85- 96
D14A	I-6	105@1800	4	61-63	N	PC	4.75 X 6.50	461	####	####	#####	####	87-102
D462	V-8	####@####	4	##-71	N	##	4.13 X 4.31	462	####	####	#####	####	87-102
D466	I-6	165@3000	4	71-75	N	DI	4.30 X 5.36	466	1.80	####	#####	####	87-102
DT466	I-6	231@2800	4	71-75	T	DI	4.30 X 5.36	466	1.80	####	#####	####	85- 96
D550B	V-8	200@3000	4	72-75	N	DI	4.50 X 4.31	549	1.80	####	#####	####	87-102
D554	I-6	150@2300	4	61-65	N	PC	4.63 X 5.50	554	####	####	#####	####	87-102
DT573	V-8	300@2600	4	64-69	T	DI	4.50 X 4.50	573	####	####	#####	####	85- 96
DT573B	V-8	260@2600	4	71-75	T	DI	4.50 X 4.50	573	1.80	####	#####	####	85- 96
D691	V-6	150@1600	4	61-65	N	PC	4.75 X 6.50	691	####	####	#####	####	87-102
DVT800	V-8	310@2600	4	##-74	T	##	#### X ####	800	####	####	#####	####	85- 96
DT817	I-6	385@2100	4	61-67	T	DI	5.38 X 6.00	817	####	####	#####	####	85- 96
DT817B	I-6	320@2100	4	68-75	T	DI	5.38 X 6.00	817	1.80	####	#####	####	85- 96

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MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED INTERNATIONAL HARVESTER ********************************													
DT817C	I-6	420@2200	4	74-75	TI	DI	5.38 X 6.00	817	####	####	#####	####	85- 96
MACK ****													
ENDT673C	6	187@2300	4	67-75	T	DI	4.88 X 6.00	672	####	####	#####	####	85- 96
ENDT673E	6	180@2100	4	68-75	N	DI	4.88 X 6.00	672	####	####	#####	####	87-102
ENDT675	6	237@1700	4	72-75	T	DI	4.88 X 6.00	672	####	####	#####	####	85- 96
END711	6	211@2100	4	64-68	N	DI	5.00 X 6.00	707	####	####	#####	####	87-102
END864	8	270@2300	4	64-68	N	DI	5.00 X 5.50	864	####	####	#####	####	87-102
ENDT865	8	325@2100	4	72-75	T	DI	5.25 X 5.00	866	####	####	#####	####	85- 96
MERCEDES-BENZ *************													
OM314	I-4	86@2800	4	66-75	N	DI	3.81 X 5.03	231	####	####	#####	####	87-102
OM346	I-6	####@####	4	66-68	N	DI	5.03 X 5.52	660	####	####	#####	####	87-102
OM352	I-6	130@2800	4	66-75	N	DI	3.81 X 5.03	346	####	####	#####	####	87-102
OM352A	I-6	165@2800	4	71-75	N	DI	3.81 X 5.03	346	####	####	#####	####	87-102
OM355	I-6	200@2000	4	71-75	N	DI	5.03 X 5.91	707	####	####	#####	####	87-102
OM360	I-6	19@2500	4	71-71	N	DI	4.53 X 5.52	532	####	####	#####	####	87-102
OM401	V-6	195@2500	4	74-75	N	DI	4.92 X 5.13	584	####	####	#####	####	87-102
OM402	V-8	260@2500	4	72-75	N	DI	4.92 X 5.13	779	####	####	#####	####	87-102
OM403	V10	325@2500	4	71-75	N	DI	4.92 X 5.13	973	####	####	#####	####	87-102
OM404	V12	430@2500	4	##-75	N	DI	4.92 X 5.59	1276	####	####	#####	####	87-102

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MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
MINNEAPOLIS MOLINE *****************													
D206	I-4	52@1750	4	63-72	N	EC	3.63 X ####	206	####	####	#####	####	87-102
DHD2364A	I-4	65@1800	4	69-73	N	EC	3.88 X 5.00	236	####	####	#####	####	87-102
D3364A	I-4	71@1600	4	62-69	N	EC	4.63 X 5.00	336	####	####	#####	####	87-102
D336A-4A	I-4	82@1600	4	70-73	N	EC	4.63 X 5.00	336	####	####	#####	####	87-102
D425	I-6	89@1500	4	##-61	N	EC	4.25 X 5.00	425	####	####	#####	####	87-102
D425-6A	I-6	89@1600	4	62-69	N	EC	4.25 X 5.00	426	####	####	#####	####	87-102
DHD504-6A	I-6	139@1800	4	67-74	N	EC	4.63 X 5.00	504	####	####	#####	####	87-102
PERKINS *******													
4-99	I-4	55@4000	4	65-70	N	PC	3.00 X 3.50	99	####	####	#####	####	87-102
4-107	I-4	57@4000	4	64-71	N	PC	3.13 X 3.50	107	####	####	#####	####	87-102
4-108	I-4	60@4000	4	69-75	N	PC	3.13 X 3.50	107	3.00	10.0	#####	####	87-102
D3-152	I-3	52@2500	4	69-71	N	DI	3.61 X 5.00	153	####	####	#####	####	87-102
4-154	I-4	80@3600	4	69-75	N	PC	3.50 X 4.00	154	3.00	10.0	#####	####	87-102
4-203	I-4	63@2600	4	64-75	N	PC	3.61 X 5.00	203	3.00	10.0	#####	####	87-102
4-236	I-4	80@2800	4	64-75	N	DI	3.88 X 5.00	236	3.00	10.0	2.50	####	87-102
4-248	I-4	85@2500	4	69-73	N	DI	3.97 X 5.00	249	3.00	10.0	2.50	####	87-102
4-270	I-4	62@2000	4	64-68	N	DI	4.25 X 4.75	270	####	####	#####	####	87-102
4-300	I-4	90@2200	4	66-69	N	DI	4.50 X 4.75	302	####	####	#####	####	87-102
4-302	I-4	76@2300	4	67-70	N	DI	4.50 X 4.75	302	####	####	#####	####	87-102
6-305	I-6	89@2600	4	64-65	N	PC	3.61 X 5.00	305	####	####	#####	####	87-102

NOTES:
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- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BP(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED PERKINS *****************													
4-318	I-4	75@2000	4	71-74	N	##	#### X ####	318	####	####	#####	####	87-102
6-354	I-6	120@2800	4	64-75	N	DI	3.88 X 5.00	354	3.00	10.0	2.75	####	87-102
T6-354	I-6	150@2400	4	65-71	T	DI	3.88 X 5.00	354	####	####	#####	####	85- 96
T6-354-3	I-6	140@2500	4	72-73	T	DI	3.88 X 5.00	354	####	####	#####	####	85- 96
6-372	I-6	121@2500	4	72-75	N	##	3.98 X 5.00	372	3.00	10.0	#####	####	87-102
V8-510	V-8	185@2800	4	66-75	N	DI	4.25 X 4.50	511	3.00	10.0	#####	####	87-102
V8-540	V-8	166@2500	4	##-75	N	##	4.25 X 4.75	540	3.00	10.0	2.00	####	87-102
V8-605	V-8	200@2500	4	##-72	N	##	4.50 X 4.75	605	####	####	#####	####	87-102
WAUKESHA ********													
VRD232	I-6	68@2200	4	74-75	N	DI	3.62 X 3.75	232	1.50	25.0	#####	####	87-102
190DLC	I-6	84@2800	4	61-62	N	TC	3.75 X 4.00	265	1.00	####	#####	####	87-102
VRD283	I-6	76@2200	4	74-75	N	DI	3.88 X 4.00	283	1.50	25.0	#####	####	87-102
197DLC	I-6	91@2800	4	61-66	N	TC	4.00 X 4.00	302	1.00	####	#####	####	87-102
197DLCS	I-6	131@2800	4	61-66	T	PC	4.00 X 4.00	302	.50	####	#####	####	85- 96
VRD310	I-6	106@2400	4	74-75	N	DI	3.88 X 4.38	310	1.50	25.0	#####	####	87-102
D317D	I-4	118@2400	4	72-73	N	DI	4.53 X 4.92	317	4.60	12.0	#####	####	87-102
D317DS	I-4	142@2400	4	72-73	T	DI	4.53 X 4.92	317	1.50	12.0	#####	####	85- 96
F475D	I-6	182@2400	4	72-75	N	DI	4.53 X 4.92	475	4.60	12.0	#####	####	87-102
F475DS	I-6	216@2400	4	72-75	T	DI	4.53 X 4.92	475	1.50	12.0	#####	####	85- 96
F674D	I-6	226@2200	4	72-75	N	DI	5.00 X 4.72	673	4.60	12.0	#####	####	87-102

NOTES:
- ### HASH MARKS: Indicate information is unavailable or does not apply.
- (1) BHP@RPM: Rating listed is maximum brake horsepower at the given RPM.
- (2) YEARS: Gathered data indcates the engine was produced during these years.
- (3) ASPIRATION: N-Naturally Aspirated; B-Mechanically Blown; T-Turbocharged; I-Intercooled.
- (4) FUEL INJECTION: PC-Pre Combustion;DI-Direct Injection; EC-Energy Cell; TC-Turbulence Chamber.
- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

MODEL	TYPE	BHP@ RPM(1)	CYCLE	YEARS (2)	ASPIR (3)	FUEL INJ (4)	BORE AND STROKE	CID	BF(5)	IR(6)	RECOMMENDED PIPE SIZE SINGLE	DUAL	EXH. N.L. (7)
CONTINUED WAUKESHA ******************													
F674DS	I-6	299@2200	4	72-75	T	DI	5.00 X 5.72	673	1.50	12.0	#####	####	85- 96
H866DS	V-8	384@2300	4	72-75	T	DI	5.00 X 5.52	866	1.50	12.0	#####	####	85- 96
H1077D	V-8	346@2400	4	67-75	N	DI	5.75 X 5.19	1077	1.30	####	#####	####	87-102
H1077DS	V-8	522@2400	4	67-75	T	DI	5.75 X 5.19	1077	.90	####	#####	####	85- 96
H1077DSI	V-8	557@2400	4	70-75	TI	DI	5.75 X 5.19	1077	.90	####	#####	####	85- 96
WAKD	I-6	258@1800	4	61-63	N	TC	6.25 X 6.50	1197	1.00	####	#####	####	87-102
WAKDS	I-6	400@1800	4	61-63	T	TC	6.25 X 6.50	1197	.50	####	#####	####	85- 96
F1197D	I-6	258@1800	4	64-71	N	TC	6.25 X 6.50	1197	1.30	####	#####	####	87-102
F1197DS	I-6	400@1800	4	64-71	T	TC	6.25 X 6.50	1197	.90	####	#####	####	85- 96
F1197DSI	I-6	462@2400	4	70-71	TI	DI	6.25 X 6.50	1197	.90	####	#####	####	85- 96
L1616D	V12	520@2400	4	67-75	N	DI	5.75 X 5.19	1616	1.30	####	#####	####	87-102
L1616DS	V12	785@2400	4	67-75	T	DI	5.75 X 5.19	1616	.90	####	#####	####	85- 96
L1616DSI	V12	836@2400	4	70-75	TI	DI	5.75 X 5.19	1616	.90	####	#####	####	85- 96
NKDC	I-6	297@1200	4	61-63	N	TC	7.00 X 8.50	1905	1.00	####	#####	####	87-102
NKDCS	I-6	390@1200	4	61-63	T	TC	7.00 X 8.50	1905	.50	####	#####	####	85- 96
F1905D	I-6	297@1200	4	64-71	N	DI	7.00 X 8.50	1905	1.30	####	#####	####	87-102
F1905DS	I-6	390@1200	4	64-71	T	DI	7.00 X 8.50	1905	.90	####	#####	####	85- 96
F1905DSI	I-6	514@2200	4	70-71	TI	DI	7.00 X 8.50	1905	.90	####	#####	####	85- 96
P2154D	V16	592@2200	4	72-75	N	DI	5.75 X 5.13	2154	1.30	####	#####	####	87-102
P2154DS	V16	1017@2200	4	72-75	T	DI	5.75 X 5.13	2154	.90	####	#####	####	85- 96
P2154DSI	V16	1077@2200	4	72-75	TI	DI	5.75 X 5.13	2154	.90	####	#####	####	85- 96

NOTES:
- ### HASH MARKS: Indicate information is unavailable or does not apply.
- (1) BHP@RPM: Rating listed is maximum brake horsepower at the given RPM.
- (2) YEARS: Gathered data indcates the engine was produced during these years.
- (3) ASPIRATION: N-Naturally Aspirated; B-Mechanically Blown; T-Turbocharged; I-Intercooled.
- (4) FUEL INJECTION: PC-Pre Combustion;DI-Direct Injection; EC-Energy Cell; TC-Turbulence Chamber.
- (5) B.P.: Engine Back Pressure Limit (In. HG).
- (6) I.R.: Intake Restriction Limit (In. water), clean system.
- (7) EXHAUST NOISE LEVEL: Straight pipe noise level in DB'A' at 50 ft. at maximum rated load and speed, vertical tailpipe.

APPENDIX B
MUFFLER HORSEPOWER GUIDE

NATURALLY ASPIRATED AND
TURBOCHARGED ENGINES

MANUFACTURER: COWL

MUFFLER	PIPE	STYLES	ATTENUATION 2-	ATTENUATION 4-	HP @ 20 IN. H2O
SINGLE INLET	2.00	TR,TL,SP,SL,PR,PL	20	18	56
SINGLE INLET	2.50	TR,TL,SP,SL,PR,PL	20	18	88
SINGLE INLET	3.00	TR,TL,SP,SL,PR,PL	25	22	126
SINGLE INLET	3.50	TR,TL,SP,SL,PR,PL	25	22	172
SINGLE INLET	4.00	TR,TL,SP,SL,PR,PL	25	22	225
SINGLE INLET	4.50	TR,TL,SP,SL,PR,PL	30	28	285
SINGLE INLET	5.00	TR,TL,SP,SL,PR,PL	30	28	350
SINGLE INLET	6.00	TR,TL,SP,SL,PR,PL	30	28	504
DUAL INLET	2.00	PV,SV	25	22	126
DUAL INLET	2.50	PV,SV	25	22	172
DUAL INLET	3.00	PV,SV	25	22	225
DUAL INLET	3.50	PV,SV	30	28	285
DUAL INLET	3.50	PV,SV	30	28	350
DUAL INLET	4.00	PV,SV	30	28	504

NATURALLY ASPIRATED ENGINES

MANUFACTURER: DONALDSON

MUFFLER	PIPE	STYL	ATTEN 2-	ATTEN 4-	MAX HP @ BP 2.0 2-	2.0 4-	2.5 2-	2.5 4-	3.0 2-	3.0 4-	4.0 2-	4.0 4-
MAM04-5193	1.68	3	22	17	26	33	29	36	31	40	36	46
MAM06-0158	2.00	3	22	17	43	56	48	62	52	68	60	79
MZM06-0054	2.00	2	20	15	51	66	57	73	62	80	72	93
MZM06-0055	2.00	2	18	13	51	66	57	73	62	80	72	93
MFM04-5045	2.00	1	13	8	55	72	61	80	67	88	77	101
MOM06-0149	2.38	1	27	22	64	83	71	92	78	101	90	117
MUM06-0013	2.41	1	12	4	99	129	110	144	121	157	140	182
MFM06-0005	2.50	1	13	8	63	82	70	91	77	100	89	115
MFM05-5009	2.50	1	13	8	67	87	74	97	82	106	94	123
MAM06-5044	2.50	3	22	17	69	89	77	99	84	109	97	125
MTM06-5015	2.50	2	20	15	69	89	77	99	84	109	97	125
MOM09-0273	2.50	2	37	32	69	90	77	100	84	110	97	127
WOM08-[illegible]045	2.50	2	27	22	76	99	84	110	93	121	107	140
MZM06-50[illegible]4	2.50	2	22	17	79	103	88	115	96	126	111	145
MZM06-[illegible]34	2.50	2	20	15	79	103	88	115	96	126	111	145
MTM06-[illegible]42	2.50	2	28	23	81	105	90	117	94	128	114	148
MZM08-50[illegible]4	2.50	2	27	[illegible]	104	136	116	152	127	166	147	192
MZM07-0043	2.75	2	22	17	78	101	87	112	95	123	110	142

NATURALLY ASPIRATED ENGINES

MANUFACTURER: DONALDSON

			ATTEN		MAX HP @ BP							
					2.0		2.5		3.0		4.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
WDM09-0159	3.00	2	32	27	94	122	105	136	115	149	132	172
MDM09-0170	3.00	2	30	25	94	122	105	136	115	149	132	172
MAM08-5090	3.00	3	20	15	96	125	107	139	117	153	135	176
WAM08-5094	3.00	3	22	17	96	125	107	139	117	153	135	176
MBM08-5083	3.00	6	25	20	98	128	109	143	120	156	138	181
MFM08-0018	3.00	1	16	11	99	129	110	144	121	157	140	182
MTM08-5078	3.00	2	28	23	110	144	122	160	134	176	155	203
WTM08-5106	3.00	2	30	25	110	144	122	160	134	176	155	203
MFM07-0008	3.00	1	13	8	119	155	133	173	145	189	168	219
MZM08-5023	3.00	2	25	20	121	157	135	175	148	192	171	222
MZM08-5056	3.00	2	18	13	122	159	136	177	149	194	172	224
MZM07-0076	3.25	2	20	15	97	126	108	140	118	154	137	178
MAM08-5084	3.50	3	24	19	99	129	110	144	121	157	140	182
WSM09-0211	3.50	1	32	27	116	151	129	168	142	184	164	213
MSM09-0146	3.50	1	28	23	119	155	133	173	145	189	168	219
MFM07-0028	3.50	1	13	8	122	158	136	176	149	193	172	223
MDM09-0301	3.50	5	26	21	131	171	146	191	160	209	185	241
MZM08-5008	3.50	2	23	18	135	175	150	195	165	214	190	247
MZM08-5064	3.50	2	20	15	139	181	155	202	170	221	196	255
MDM09-0140	3.50	2	22	17	152	198	169	221	186	242	214	280

NATURALLY ASPIRATED ENGINES

MANUFACTURER: DONALDSON

			ATTEN		MAX HP @ BP							
					2.0		2.5		3.0		4.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
MDM09-0158	3.50	2	27	22	152	198	169	221	186	242	214	280
WDM09-0210	3.50	2	29	24	152	198	169	221	186	242	214	280
MSM09-0157	3.50	1	27	22	155	201	173	224	189	246	219	284
MFM07-0050	3.50	1	13	8	156	204	174	228	191	249	220	288
MPM09-0115	3.50	1	21	13	198	258	221	288	242	315	280	364
MUM09-0015	3.50	1	16	8	307	399	343	446	375	488	434	564
WZM10-0067	4.00	2	35	30	106	139	118	155	129	170	149	196
WDM12-0230	4.00	2	37	32	112	146	125	163	137	178	158	206
WTM10-0104	4.00	1	34	29	112	146	125	163	137	178	158	206
WSM09-0212	4.00	1	30	25	127	165	141	184	155	202	179	233
MSM09-0135	4.00	1	26	21	133	173	148	193	162	211	188	244
MDM09-0168	4.00	2	27	22	155	202	173	225	189	247	219	285
WDM09-0213	4.00	2	29	24	155	202	173	225	189	247	219	285
WDM12-0241	4.00	2	37	32	167	218	186	243	204	266	236	308
WDM12-0197	4.00	2	36	31	167	218	186	243	204	266	236	308
WZM10-0145	4.00	1	34	29	173	225	193	251	211	275	244	318
MAM10-0146	4.00	3	22	17	173	225	193	251	211	275	244	318
MBM10-0049	4.00	5	20	15	174	227	194	253	213	278	246	321
MSM09-0142	4.00	1	23	18	177	230	197	257	216	281	250	325
WSM09-0216	4.00	[illegible]	25	20	177	230	197	[illegible]	216	281	250	325
MDM12-0154	4.00	[illegible]	26	21	179	233	[illegible]	260	219	285	253	329
WDM12-0183	4.00	[illegible]	28	23	179	233	[illegible]	260	219	285	253	329
WTM10-0066	4.00	2	34	29	186	242	[illegible]	270	227	296	263	342
MTM10-0148	4.00	2	33	28	186	242	[illegible]	270	227	296	263	342

NATURALLY ASPIRATED ENGINES

MANUFACTURER: DONALDSON

MUFFLER	PIPE	STYL	ATTEN 2-	ATTEN 4-	MAX HP @ BP 2.0 2-	2.0 4-	2.5 2-	2.5 4-	3.0 2-	3.0 4-	4.0 2-	4.0 4-
MOM14-0001	4.00	2	30	25	194	252	216	281	237	308	274	356
WOM14-0011	4.00	2	32	27	194	252	216	281	237	308	274	356
MOM09-0124	4.00	2	20	15	196	255	219	285	240	312	277	360
MKM09-0055	4.00	2	13	8	199	259	222	289	243	317	281	366
MBM10-0002	4.00	6	18	13	199	259	222	289	243	317	281	366
MTM10-0048	4.00	2	22	17	200	260	223	290	244	318	282	367
MFM09-0009	4.00	1	13	8	202	263	225	294	247	322	285	371
MTM10-0043	4.00	2	25	20	204	266	228	297	249	325	288	376
WTM10-0089	4.00	2	26	21	204	266	228	297	249	325	288	376
MTM10-0006	4.00	2	20	15	219	285	244	318	268	349	309	403
MOM12-0100	4.00	2	20	15	231	301	258	336	282	368	326	425
WOM12-0184	4.00	2	22	17	231	301	258	336	282	368	326	425
MOM12-0200	4.00	2	20	15	231	301	258	336	282	368	326	425
MPM09-0063	4.00	1	21	13	232	302	259	337	284	369	328	427
MPM08-5069	4.00	1	18	10	251	327	280	365	307	400	354	462
MOM12-1000	4.00	6	17	12	252	328	281	366	308	401	356	463
WKM10-0064	4.00	2	23	18	252	328	281	366	308	401	356	463
MKM10-0147	4.00	2	24	19	252	328	281	366	308	401	356	463
MPM09-0141	4.00	1	23	15	269	350	300	391	329	428	380	494
MUM09-0022	4.00	1	19	11	325	423	363	472	398	518	459	598
MUM09-0071	4.00	1	9	1	360	468	402	523	440	573	509	661
MUM07-0011	4.00	1	14	6	386	503	431	562	472	616	545	711
MUM09-0008	4.00	1	12	4	401	521	448	582	491	638	567	736
MUM07-0054	4.00	1	12	4	410	533	455	595	502	652	579	753
MTM10-0038	5.00	2	22	17	229	298	256	333	280	364	323	421

NATURALLY ASPIRATED ENGINES

MANUFACTURER: DONALDSON

MUFFLER	PIPE	STYL	ATTEN 2-	ATTEN 4-	MAX HP @ BP 2.0 2-	2.0 4-	2.5 2-	2.5 4-	3.0 2-	3.0 4-	4.0 2-	4.0 4-
WTM10-0065	5.00	2	24	19	229	298	256	333	280	364	323	421
MDM12-0189	5.00	6	24	19	249	324	278	362	304	396	352	458
MFM10-0165	5.00	1	26	21	255	332	285	371	312	406	360	469
MDM12-0176	5.00	6	19	14	261	339	291	379	319	415	369	479
MDM12-0235	5.00	3	22	17	268	348	299	389	328	426	379	492
MDM12-0108	5.00	2	18	13	280	364	313	406	342	445	395	514
WDM12-0182	5.00	2	18	13	280	364	313	406	342	445	395	514
MDM12-0186	5.00	2	23	18	291	379	325	423	356	464	411	535
MDM14-0002	5.00	2	24	19	318	413	355	461	389	505	449	584
WDM14-0012	5.00	2	26	21	318	413	355	461	389	505	449	584
MFM09-0249	5.00	1	21	16	334	434	373	485	409	531	472	613
WFM09-0275	5.00	1	23	18	334	434	373	485	409	531	472	613
MKM10-0149	5.00	1	18	13	362	471	404	526	443	576	511	666
WKM10-0105	5.00	1	20	15	362	471	404	526	443	576	511	666
MDM12-0225	5.00	2	19	14	372	484	415	541	455	592	526	684
MDM12-0131	5.00	6	16	11	387	504	432	563	473	617	547	712
MPM09-0197	5.00	1	22	14	393	511	439	571	481	625	555	722
MPM10-0106	5.00	1	24	16	393	511	439	571	481	625	555	722
WPM10-0107	5.00	1	26	18	393	511	439	571	481	625	555	722
MFM09-0013	5.00	1	10	5	402	522	449	583	492	639	568	738
MUM09-0074	5.00	1	18	10	413	537	461	600	505	657	584	759
MPM09-0161	5.00	1	20	12	493	642	551	717	603	786	697	907
WPM09-0272	5.00	1	22	14	493	642	551	717	603	786	697	907
MPM10-0108	5.00	1	25	17	493	642	551	717	603	786	697	907
WPM10-0109	5.00	1	27	19	493	642	551	717	603	786	697	907
MPM10-0127	5.00	1	22	14	493	642	551	717	603	786	697	907

NATURALLY ASPIRATED ENGINES

MANUFACTURER: DONALDSON

MUFFLER	PIPE	STYL	ATTEN 2-	ATTEN 4-	MAX HP @ BP 2.0 2-	2.0 4-	2.5 2-	2.5 4-	3.0 2-	3.0 4-	4.0 2-	4.0 4-
MUM09-0072	5.00	1	8	0	594	773	664	864	727	946	840	1093
MDM12-2300	6.00	2	14	9	451	587	504	656	552	718	637	830
MDM17-0101	6.00	2	24	19	498	647	556	723	609	792	704	914
WDM17-0106	6.00	2	26	21	498	647	556	723	609	792	704	914
MDM17-0100	8.00	2	16	11	766	996	856	1113	938	1219	1083	1408
MDM19-0002	8.00	2	22	17	781	1016	873	1135	956	1244	1104	1436
MDM19-0001	10.00	2	18	13	1021	1328	1141	1484	1250	1626	1443	1878

TURBOCHARGED ENGINES

MANUFACTURER: DONALDSON

			ATTEN		MAX HP @ BP							
					1.5		2.0		2.5		3.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
MAM04-5193	1.68	3	19	16	18	23	20	26	23	29	25	32
MAM06-0158	2.00	3	19	16	30	39	34	45	38	50	42	55
MZM06-0054	2.00	2	17	14	35	45	40	51	45	58	49	63
MZM06-0055	2.00	2	15	12	35	45	40	51	45	58	49	63
MFM04-5045	2.00	1	10	7	39	50	45	57	50	64	55	70
MDM06-0149	2.38	1	24	21	44	57	50	65	56	73	62	80
MUM06-0013	2.41	1	9	6	69	89	79	102	89	114	97	125
MFM06-0005	2.50	1	10	7	44	57	50	65	56	73	62	80
MFM05-5009	2.50	1	10	7	47	60	54	69	60	77	66	84
MAM06-5044	2.50	3	19	16	48	62	55	71	61	80	67	87
MTM06-5015	2.50	2	17	14	48	62	55	71	61	80	67	87
MDM09-0273	2.50	2	34	31	48	62	55	71	61	80	67	87
WDM08-0045	2.50	2	24	21	53	69	61	79	68	89	74	97
MZM06-5024	2.50	2	19	16	56	71	64	81	72	91	79	100
MZM06-5034	2.50	2	17	14	56	71	64	81	72	91	79	100
MTM06-5042	2.50	2	25	22	57	73	65	84	73	94	80	103
MZM08-5024	2.50	2	24	21	73	94	84	108	94	121	103	132
MZM07-0043	2.75	2	19	16	55	[illegible]	63	80	71	90	77	98

TURBOCHARGED ENGINES

MANUFACTURER: DONALDSON

MUFFLER	PIPE	STYL	ATTEN 2-	ATTEN 4-	MAX HP @ BP 1.5 2-	1.5 4-	2.0 2-	2.0 4-	2.5 2-	2.5 4-	3.0 2-	3.0 4-
WDM09-0159	3.00	2	29	26	66	84	76	96	85	108	93	118
MDM09-0170	3.00	2	27	24	66	84	76	96	85	108	93	118
MAM08-5090	3.00	3	17	14	67	86	77	99	86	111	94	121
WAM08-5094	3.00	3	19	16	67	86	77	99	86	111	94	121
MBM08-5083	3.00	6	22	19	69	88	79	101	89	113	97	124
MFM08-0018	3.00	1	13	10	69	89	79	102	89	114	97	125
MTM08-5078	3.00	2	25	22	77	99	88	114	99	127	108	140
WTM08-5106	3.00	2	27	24	77	99	88	114	99	127	108	140
MFM07-0008	3.00	1	10	7	83	107	95	123	107	138	117	151
MZM08-5023	3.00	2	22	19	85	108	98	124	109	139	120	152
MZM08-5056	3.00	2	15	12	85	109	98	125	109	140	120	154
MZM07-0076	3.25	2	17	14	68	87	78	100	87	112	96	123
MAM08-5084	3.50	3	21	18	69	89	79	102	89	114	97	125
WSM09-0211	3.50	1	29	26	81	104	93	120	104	134	114	147
MSM09-0146	3.50	1	25	22	84	107	96	123	108	138	118	151
MFM07-0028	3.50	[illegible]	10	7	85	109	98	125	109	140	120	154
MDM09-0301	3.50	3	[illegible]	20	92	118	106	136	118	152	130	166
MZM08-5008	3.50	2	[illegible]	17	94	121	106	139	[illegible]	156	132	171
MZM08-5064	3.50	2	17	14	97	125	112	[illegible]	125	161	137	176
MDM09-0140	3.50	2	[illegible]	[illegible]	107	137	123	[illegible]	[illegible]	176	151	193

TURBOCHARGED ENGINES

MANUFACTURER: DONALDSON

MUFFLER	PIPE	STYL	ATTEN		MAX HP @ BP 1.5		2.0		2.5		3.0	
			2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
MDM09-0158	3.50	2	24	21	107	137	123	158	138	176	151	193
WDM09-0210	3.50	2	26	23	107	137	123	158	138	176	151	193
MSM09-0157	3.50	1	24	21	108	139	124	160	139	179	152	196
MFM07-0050	3.50	1	10	7	110	140	127	161	142	180	155	197
MPM09-0115	3.50	1	18	15	139	178	160	205	179	229	196	251
MUM09-0015	3.50	1	13	10	215	276	248	318	277	356	304	390
WZM10-0067	4.00	2	32	29	75	96	86	110	96	123	106	135
WDM12-0230	4.00	2	34	31	78	100	90	115	100	129	110	141
WTM10-0104	4.00	1	31	28	78	101	90	116	100	130	110	142
WSM09-0212	4.00	1	27	24	89	114	102	131	114	147	125	161
MSM09-0135	4.00	1	23	20	93	119	107	137	120	153	131	168
MDM09-0168	4.00	2	24	21	109	139	125	160	140	179	154	196
WDM09-0213	4.00	2	26	23	109	139	125	160	140	179	154	196
WDM12-0241	4.00	2	34	31	117	150	135	173	151	193	165	212
WDM12-0197	4.00	2	33	30	117	150	135	173	151	193	165	212
WZM10-0145	4.00	1	31	28	121	155	139	178	156	200	171	219
MAM10-0146	4.00	3	19	16	121	155	139	178	156	200	171	219
MBM10-0049	4.00	6	17	14	122	157	140	181	157	202	172	222
MSM09-0142	4.00	1	20	17	124	159	143	183	160	205	175	224
WSM09-0216	4.00	1	22	19	124	159	143	183	160	205	175	224
MDM12-0154	4.00	6	[illegible]	20	125	161	144	185	161	207	176	227
WDM12-0183	4.00	6	[illegible]	[illegible]	125	161	144	185	161	207	176	227
WTM10-0066	4.00	2	[illegible]	[illegible]	131	167	151	192	169	215	185	236
MTM10-0148	4.00	2	[illegible]	[illegible]	131	167	151	192	169	215	185	236

TURBOCHARGED ENGINES

MANUFACTURER: DONALDSON

MUFFLER	PIPE	STYL	ATTEN 2-	ATTEN 4-	MAX HP @ BP 1.5 2-	1.5 4-	2.0 2-	2.0 4-	2.5 2-	2.5 4-	3.0 2-	3.0 4-
MDM14-0001	4.00	2	27	24	136	174	157	200	175	224	192	246
WDM14-0011	4.00	2	29	26	136	174	157	200	175	224	192	246
MDM09-0124	4.00	2	17	14	137	176	158	203	176	227	193	248
MKM09-0055	4.00	2	10	7	139	178	160	205	179	229	196	251
MBM10-0002	4.00	6	15	12	140	179	161	206	180	231	197	253
MTM10-0048	4.00	2	19	16	140	179	161	206	180	231	197	253
MFM09-0009	4.00	1	10	7	142	181	163	209	183	233	200	255
MTM10-0043	4.00	2	22	19	143	183	165	211	184	236	202	258
WTM10-0089	4.00	2	23	20	143	183	165	211	184	236	202	258
MTM10-0006	4.00	2	17	14	153	196	176	226	197	253	216	277
MDM12-0100	4.00	2	17	14	162	208	187	240	209	268	229	294
WDM12-0184	4.00	2	19	16	162	208	187	240	209	268	229	294
MDM12-0200	4.00	2	17	14	162	208	187	240	209	268	229	294
MPM09-0063	4.00	1	18	15	163	209	188	241	210	269	230	295
MPM08-5069	4.00	1	15	12	176	226	203	260	227	291	248	319
MDM12-1000	4.00	6	14	11	177	226	204	260	228	291	250	319
WKM10-0064	4.00	2	20	17	177	227	204	262	228	293	250	321
MKM10-0147	4.00	2	21	18	177	227	204	262	228	293	250	321
MPM09-0141	4.00	1	20	17	189	242	218	279	243	312	267	342
MUM09-0022	4.00	1	16	13	228	292	263	337	294	376	322	412
MUM09-0071	4.00	1	6	3	253	323	292	372	326	416	357	456
MUM07-0011	4.00	[illegible]	11	8	271	347	312	400	349	447	383	490
MUM09-0003	4.0[illegible]	[illegible]	9	6	281	360	324	415	362	464	397	509
MUM07-0054	[illegible]	[illegible]	9	6	287	368	331	424	[illegible]	[illegible]	405	520
MTM10-0038	5.00	2	19	16	160	205	184	236	206	264	226	289

TURBOCHARGED ENGINES

MANUFACTURER: DONALDSON

					MAX HP @ BP							
			ATTEN		1.5		2.0		2.5		3.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
WTM10-0065	5.00	2	21	18	160	205	184	236	206	264	226	289
MOM12-0189	5.00	6	21	18	175	224	202	258	225	289	247	316
MFM10-0165	5.00	1	23	20	179	229	206	264	231	295	253	323
MOM12-0176	5.00	6	16	13	183	234	211	270	236	302	258	330
MOM12-0235	5.00	3	19	16	188	240	217	277	242	309	265	339
MOM12-0108	5.00	2	15	12	196	251	226	289	253	324	277	354
WOM12-0182	5.00	2	15	12	196	251	226	289	253	324	277	354
MOM12-0186	5.00	2	20	17	204	261	235	301	263	336	288	369
MOM14-0002	5.00	2	21	18	223	285	257	329	287	367	315	403
WOM14-0012	5.00	2	23	20	223	285	257	329	287	367	315	403
MFM09-0249	5.00	1	18	15	234	300	270	346	302	387	330	424
WFM09-0275	5.00	1	20	17	234	300	270	346	302	387	330	424
MKM10-0149	5.00	1	15	12	254	325	293	375	327	419	359	459
WKM10-0105	5.00	1	17	14	254	325	293	375	327	419	359	459
MOM12-0225	5.00	2	16	13	261	334	301	385	336	431	369	472
MOM12-0131	5.00	6	13	10	272	348	314	401	351	449	384	492
MPM09-0197	5.00	1	19	16	276	353	318	407	356	455	390	499
MPM10-0106	5.00	1	21	18	276	353	318	407	356	455	390	499
WPM10-0107	5.00	1	23	20	276	353	318	407	356	455	390	499
MFM09-0013	5.00	1	7	4	282	361	325	416	364	466	398	510
MUM09-0074	5.00	1	15	12	290	371	334	428	374	478	410	524
MPM09-0161	5.00	1	17	14	346	443	399	511	446	571	489	626
WPM09-0272	5.00	1	19	16	346	443	399	511	446	571	489	626
MPM10-0108	5.00	[illegible]	22	19	346	443	399	511	446	571	489	626
WPM10-0109	5.00	[illegible]	24	21	346	443	399	511	446	571	489	626
MPM10-0127	5.00	1	19	16	346	443	399	511	446	571	489	626

TURBOCHARGED ENGINES

MANUFACTURER: DONALDSON

			ATTEN		MAX HP @ BP							
					1.5		2.0		2.5		3.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
MUM09-0072	5.00	1	5	2	417	534	481	616	538	689	589	755
MOM12-2300	6.00	2	11	8	317	405	366	467	409	522	448	572
MOM17-0101	6.00	2	21	18	349	447	402	516	450	577	493	632
WOM17-0106	6.00	2	23	20	349	447	402	516	450	577	493	632
MOM17-0100	8.00	2	13	10	537	688	620	794	693	888	759	972
MOM19-0002	8.00	2	19	16	548	702	632	810	707	906	774	992
MOM19-0001	10.00	2	15	12	717	917	827	1058	925	1183	1013	1296

NATURALLY ASPIRATED ENGINES

MANUFACTURER: NELSON MUFFLER

			ATTEN		MAX HP @ BP							
					2.0		2.5		3.0		4.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
U-41107	1.05	1	18	14	19	27	21	30	23	33	27	38
U-41207	1.05	1	23	19	19	27	21	30	23	33	27	38
U-41307	1.05	1	29	25	19	27	21	30	23	33	27	38
U-42107	1.05	5	18	14	19	27	21	30	23	33	27	38
U-42207	1.05	5	23	19	19	27	21	30	23	33	27	38
U-42307	1.05	5	29	25	19	27	21	30	23	33	27	38
U-43107	1.05	3	18	14	19	27	21	30	23	33	27	38
U-43207	1.05	3	23	19	19	27	21	30	23	33	27	38
U-43307	1.05	3	29	25	19	27	21	30	23	33	27	38
U-41110	1.32	1	18	14	30	43	34	48	37	53	42	61
U-41210	1.32	1	23	19	30	43	34	48	37	53	42	61
U-42110	1.32	5	18	14	30	43	34	48	37	53	42	61
U-42210	1.32	5	23	19	30	43	34	48	37	53	42	61
U-42310	1.32	5	29	25	30	43	34	48	37	53	42	61
U-43110	1.32	3	18	14	30	43	34	48	37	53	42	61
U-43210	1.32	3	23	19	30	43	34	48	37	53	42	61
U-43310	1.32	3	29	25	30	43	34	48	37	53	42	61
U-41113	1.66	1	18	14	55	77	61	86	67	94	78	109
U-41213	1.66	1	23	19	55	77	61	86	67	94	78	109
U-41313	1.66	1	29	25	55	77	61	86	67	94	78	109
U-42113	1.66	5	18	14	55	77	61	86	67	94	78	109
U-42213	1.66	5	23	19	55	77	61	86	67	94	78	109
U-42313	1.66	5	29	25	55	77	61	86	67	94	78	109
U-43113	1.66	3	18	14	55	77	61	86	67	94	78	109
U-43213	1.66	3	23	19	55	77	61	86	67	94	78	109
U-43313	1.66	3	29	25	55	77	61	86	67	94	78	109
U-41115	1.90	1	18	14	74	104	83	116	91	127	105	147
U-41215	1.90	1	23	19	74	104	83	116	91	127	105	147
U-41315	1.90	1	29	25	74	104	83	116	91	127	105	147
U-42115	1.90	5	18	14	74	104	83	116	91	127	105	147
U-42215	1.90	5	23	19	74	104	83	116	91	127	105	147
U-42315	1.90	5	29	25	74	104	83	116	91	127	105	147
U-43115	1.90	3	18	14	74	104	83	116	91	127	105	147
U-43215	1.90	3	23	19	74	104	[illegible]	[illegible]	91	127	105	147
U-43315	1.90	3	29	25	74	104	[illegible]	[illegible]	91	127	105	147

NATURALLY ASPIRATED ENGINES

MANUFACTURER: NELSON MUFFLER

MUFFLER	PIPE	STYL	ATTEN		MAX HP @ BP 2.0		2.5		3.0		4.0	
			2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
U-41120	2.38	1	18	14	124	174	139	195	152	213	175	246
U-41220	2.38	2	23	19	124	174	139	195	152	213	175	246
U-41320	2.38	1	29	25	124	174	139	195	152	213	175	246
U-42120	2.38	5	18	14	124	174	139	195	152	213	175	246
U-42220	2.38	5	23	19	124	174	139	195	152	213	175	246
U-42320	2.38	5	29	25	124	174	139	195	152	213	175	246
U-43120	2.38	3	18	14	124	174	139	195	152	213	175	246
U-43220	2.38	3	23	19	124	174	139	195	152	213	175	246
U-43320	2.38	3	29	25	124	174	139	195	152	213	175	246
U-41125	2.88	1	18	14	198	278	221	311	243	341	280	393
U-41225	2.88	2	23	19	198	278	221	311	243	341	280	393
U-41325	2.88	1	29	25	198	278	221	311	243	341	280	393
U-42125	2.88	5	18	14	198	278	221	311	243	341	280	393
U-42225	2.88	5	23	19	198	278	221	311	243	341	280	393
U-42325	2.88	5	29	25	198	278	221	311	243	341	280	393
U-43125	2.88	3	18	14	198	278	221	311	243	341	280	393
U-43225	2.88	3	23	19	198	278	221	311	243	341	280	393
U-43325	2.88	3	29	25	198	278	221	311	243	341	280	393
U-41130	3.50	1	18	14	274	384	306	429	336	470	387	543
U-41230	3.50	2	23	19	274	384	306	429	336	470	387	543
U-41330	3.50	1	29	25	274	384	306	429	336	470	387	543
U-42130	3.50	5	18	14	274	384	306	429	336	470	387	543
U-42230	3.50	5	23	19	274	384	306	429	336	470	387	543
U-42330	3.50	5	29	25	274	384	306	429	336	470	387	543
U-43130	3.50	3	18	14	274	384	306	429	336	470	387	543
U-43230	3.50	3	23	19	274	384	306	429	336	470	387	543
U-43330	3.50	3	29	25	274	384	306	429	336	470	387	543
U-44130	3.50	6	18	14	274	384	306	429	336	470	387	543
U-44230	3.50	6	23	19	274	384	306	429	336	470	387	543
U-44330	3.50	6	29	25	274	384	306	429	336	470	387	543
U-41135	4.00	1	18	14	364	510	407	570	446	625	515	721
U-41235	4.00	2	23	19	364	510	407	570	446	625	515	721
U-41335	4.00	1	29	25	364	510	407	570	446	625	515	721
U-42135	4.00	5	18	14	364	510	407	570	446	625	515	721
U-42235	4.00	5	23	19	364	510	407	570	446	625	515	721

NATURALLY ASPIRATED ENGINES

MANUFACTURER: NELSON MUFFLER

			ATTEN		MAX HP @ BP							
					2.0		2.5		3.0		4.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
U-42335	4.00	5	29	25	364	510	407	570	446	625	515	721
U-43135	4.00	3	18	14	364	510	407	570	446	625	515	721
U-43235	4.00	3	23	19	364	510	407	570	446	625	515	721
U-43335	4.00	3	29	25	364	510	407	570	446	625	515	721
U-44135	4.00	6	18	14	364	510	407	570	446	625	515	721
U-44235	4.00	6	23	19	364	510	407	570	446	625	515	721
U-44335	4.00	6	29	25	364	510	407	570	446	625	515	721
U-41140	4.00	1	18	14	469	656	524	733	575	804	663	928
U-41240	4.00	2	23	19	469	656	524	733	575	804	663	928
U-41340	4.00	2	29	25	469	656	524	733	575	804	663	928
U-42140	4.00	5	18	14	469	656	524	733	575	804	663	928
U-42240	4.00	5	23	19	469	656	524	733	575	804	663	928
U-42340	4.00	5	29	25	469	656	524	733	575	804	663	928
U-43140	4.00	3	18	14	469	656	524	733	575	804	663	928
U-43240	4.00	3	23	19	469	656	524	733	575	804	663	928
U-43340	4.00	3	29	25	469	656	524	733	575	804	663	928
U-44140	4.00	6	18	14	469	656	524	733	575	804	663	928
U-44240	4.00	6	23	19	469	656	524	733	575	804	663	928
U-44340	4.00	6	29	25	469	656	524	733	575	804	663	928
U-41150	5.00	1	18	14	743	1040	831	1163	910	1274	1051	1471
U-41250	5.00	2	23	19	743	1040	831	1163	910	1274	1051	1471
U-41350	5.00	2	29	25	743	1040	831	1163	910	1274	1051	1471
U-42150	5.00	5	18	14	743	1040	831	1163	910	1274	1051	1471
U-42250	5.00	5	23	19	743	1040	831	1163	910	1274	1051	1471
U-42350	5.00	5	29	25	743	1040	831	1163	910	1274	1051	1471
U-43150	5.00	3	18	14	743	1040	831	1163	910	1274	1051	1471
U-43250	5.00	3	23	19	743	1040	831	1163	910	1274	1051	1471
U-43350	5.00	3	29	25	743	1040	831	1163	910	1274	1051	1471
U-44150	5.00	6	18	14	743	1040	831	1163	910	1274	1051	1471
U-44250	5.00	6	23	19	743	1040	831	1163	910	1274	1051	1471
U-44350	5.00	6	29	25	743	1040	831	1163	910	1274	1051	1471
U-41160	6.00	1	18	14	1054	1475	1178	1649	1291	1807	1490	2086
U-41260	6.00	2	23	19	1054	1475	1178	1649	1291	1807	1490	2086
U-41360	6.00	2	29	25	1054	1475	1178	1649	1291	1807	1490	2086
U-42160	6.00	5	18	14	1054	1475	1178	1649	1291	1807	1490	2086

NATURALLY ASPIRATED ENGINES

MANUFACTURER: NELSON MUFFLER

			ATTEN		MAX HP @ BP							
					2.0		2.5		3.0		4.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
U-42260	6.00	5	23	19	1054	1475	1178	1649	1291	1807	1490	2086
U-42360	6.00	5	29	25	1054	1475	1178	1649	1291	1807	1490	2086
U-43160	6.00	3	18	14	1054	1475	1178	1649	1291	1807	1490	2086
U-43260	6.00	3	23	19	1054	1475	1178	1649	1291	1807	1490	2086
U-43360	6.00	3	29	25	1054	1475	1178	1649	1291	1807	1490	2086
U-44160	6.00	6	18	14	1054	1475	1178	1649	1291	1807	1490	2086
U-44260	6.00	6	23	19	1054	1475	1178	1649	1291	1807	1490	2086
U-44360	6.00	6	29	25	1054	1475	1178	1649	1291	1807	1490	2086

TURBOCHARGED ENGINES

MANUFACTURER: NELSON MUFFLER

			ATTEN		MAX HP @ BP 1.5		2.0		2.5		3.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
U-41107	1.05	1	20	16	13	17	15	20	17	22	18	25
U-41207	1.05	1	25	21	13	17	15	20	17	22	18	25
U-41307	1.05	1	31	27	13	17	15	20	17	22	18	25
U-42107	1.05	5	20	16	13	17	15	20	17	22	18	25
U-42207	1.05	5	25	21	13	17	15	20	17	22	18	25
U-42307	1.05	5	31	27	13	17	15	20	17	22	18	25
U-43107	1.05	3	20	16	13	17	15	20	17	22	18	25
U-43207	1.05	3	25	21	13	17	15	20	17	22	18	25
U-43307	1.05	3	31	27	13	17	15	20	17	22	18	25
U-41110	1.32	1	20	16	21	27	24	31	27	35	29	38
U-41210	1.32	1	25	21	21	27	24	31	27	35	29	38
U-42110	1.32	5	20	16	21	27	24	31	27	35	29	38
U-42210	1.32	5	25	21	21	27	24	31	27	35	29	38
U-42310	1.32	5	31	27	21	27	24	31	27	35	29	38
U-43110	1.32	3	20	16	21	27	24	31	27	35	29	38
U-43210	1.32	3	25	21	21	27	24	31	27	35	29	38
U-43310	1.32	3	31	27	21	27	24	31	27	35	29	38
U-41113	1.66	1	20	16	37	49	43	57	48	64	53	70
U-41213	1.66	1	25	21	37	49	43	57	48	64	53	70
U-41313	1.66	1	31	27	37	49	43	57	48	64	53	70
U-42113	1.66	5	20	16	37	49	43	57	48	64	53	70
U-42213	1.66	5	25	21	37	49	43	57	48	64	53	70
U-42313	1.66	5	31	27	37	49	43	57	48	64	53	70
U-43113	1.66	3	20	16	37	49	43	57	48	64	53	70
U-43213	1.66	3	25	21	37	49	43	57	48	64	53	70
U-43313	1.66	3	31	27	37	49	43	57	48	64	53	70
U-41115	1.90	1	20	16	50	67	58	77	65	86	71	94
U-41215	1.90	1	25	21	50	67	58	77	65	86	71	94
U-41315	1.90	1	31	27	50	67	58	77	65	86	71	94
U-42115	1.90	5	20	16	50	67	58	77	65	86	71	94
U-42215	1.90	5	25	21	50	67	58	77	65	86	71	94
U-42315	1.90	5	31	27	50	67	58	77	65	86	71	94
U-43115	1.90	3	20	16	50	67	58	77	65	86	71	94
U-43215	1.90	3	25	21	50	67	58	77	65	86	71	94
U-43315	1.90	3	31	27	50	67	58	77	65	86	71	94

TURBOCHARGED ENGINES

MANUFACTURER: NELSON MUFFLER

MUFFLER	PIPE	STYL	ATTEN 2-	ATTEN 4-	MAX HP @ BP 1.5 2-	1.5 4-	2.0 2-	2.0 4-	2.5 2-	2.5 4-	3.0 2-	3.0 4-
U-41120	2.38	1	20	16	84	112	97	129	108	144	119	158
U-41220	2.38	2	25	21	84	112	97	129	108	144	119	158
U-41320	2.38	1	31	27	84	112	97	129	108	144	119	158
U-42120	2.38	5	20	16	84	112	97	129	108	144	119	158
U-42220	2.38	5	25	21	84	112	97	129	108	144	119	158
U-42320	2.38	5	31	27	84	112	97	129	108	144	119	158
U-43120	2.38	3	20	16	84	112	97	129	108	144	119	158
U-43220	2.38	3	25	21	84	112	97	129	108	144	119	158
U-43320	2.38	3	31	27	84	112	97	129	108	144	119	158
U-41125	2.88	1	20	16	133	178	154	206	172	230	189	252
U-41225	2.88	2	25	21	133	178	154	206	172	230	189	252
U-41325	2.88	1	31	27	133	178	154	206	172	230	189	252
U-42125	2.88	5	20	16	133	178	154	206	172	230	189	252
U-42225	2.88	5	25	21	133	178	154	206	172	230	189	252
U-42325	2.88	5	31	27	133	178	154	206	172	230	189	252
U-43125	2.88	3	20	16	133	178	154	206	172	230	189	252
U-43225	2.88	3	25	21	133	178	154	206	172	230	189	252
U-43325	2.88	3	31	27	133	178	154	206	172	230	189	252
U-41130	3.50	1	20	16	184	246	213	284	238	318	261	348
U-41230	3.50	2	25	21	184	246	213	284	238	318	261	348
U-41330	3.50	1	31	27	184	246	213	284	238	318	261	348
U-42130	3.50	5	20	16	184	246	213	284	238	318	261	348
U-42230	3.50	5	25	21	184	246	213	284	238	318	261	348
U-42330	3.50	5	31	27	184	246	213	284	238	318	261	348
U-43130	3.50	3	20	16	184	246	213	284	238	318	261	348
U-43230	3.50	3	25	21	184	246	213	284	238	318	261	348
U-43330	3.50	3	31	27	184	246	213	284	238	318	261	348
U-44130	3.50	6	20	16	184	246	213	284	238	318	261	348
U-44230	3.50	6	25	21	184	246	213	284	238	318	261	348
U-44330	3.50	6	31	27	184	246	213	284	238	318	261	348
U-41135	4.00	1	20	16	245	327	283	378	316	423	347	463
U-41235	4.00	2	25	21	245	327	283	378	316	423	347	463
U-41335	4.00	1	31	27	245	327	283	378	316	423	347	463
U-42135	4.00	5	20	16	245	327	283	378	316	423	347	463
U-42235	4.00	5	25	21	245	327	283	378	316	423	347	463

TURBOCHARGED ENGINES

MANUFACTURER: NELSON MUFFLER

					MAX HP @ BP							
			ATTEN		1.5		2.0		2.5		3.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
U-42335	4.00	5	31	27	245	327	283	378	316	423	347	463
U-43135	4.00	3	20	16	245	327	283	378	316	423	347	463
U-43235	4.00	3	25	21	245	327	283	378	316	423	347	463
U-43335	4.00	3	31	27	245	327	283	378	316	423	347	463
U-44135	4.00	6	20	16	245	327	283	378	316	423	347	463
U-44235	4.00	6	25	21	245	327	283	378	316	423	347	463
U-44335	4.00	6	31	27	245	327	283	378	316	423	347	463
U-41140	4.00	1	20	16	315	421	364	486	407	543	446	595
U-41240	4.00	2	25	21	315	421	364	486	407	543	446	595
U-41340	4.00	2	31	27	315	421	364	486	407	543	446	595
U-42140	4.00	5	20	16	315	421	364	486	407	543	446	595
U-42240	4.00	5	25	21	315	421	364	486	407	543	446	595
U-42340	4.00	5	31	27	315	421	364	486	407	543	446	595
U-43140	4.00	3	20	16	315	421	364	486	407	543	446	595
U-43240	4.00	3	25	21	315	421	364	486	407	543	446	595
U-43340	4.00	3	31	27	315	421	364	486	407	543	446	595
U-44140	4.00	6	20	16	315	421	364	486	407	543	446	595
U-44240	4.00	6	25	21	315	421	364	486	407	543	446	595
U-44340	4.00	6	31	27	315	421	364	486	407	543	446	595
U-41150	5.00	1	20	16	501	667	578	770	646	861	708	943
U-41250	5.00	2	25	21	501	667	578	770	646	861	708	943
U-41350	5.00	2	31	27	501	667	578	770	646	861	708	943
U-42150	5.00	5	20	16	501	667	578	770	646	861	708	943
U-42250	5.00	5	25	21	501	667	578	770	646	861	708	943
U-42350	5.00	5	31	27	501	667	578	770	646	861	708	943
U-43150	5.00	3	20	16	501	667	578	770	646	861	708	943
U-43250	5.00	3	25	21	501	667	578	770	646	861	708	943
U-43350	5.00	3	31	27	501	667	578	770	646	861	708	943
U-44150	5.00	6	20	16	501	667	578	770	646	861	708	943
U-44250	5.00	6	25	21	501	667	578	770	646	861	708	943
U-44350	5.00	6	31	27	501	667	578	770	646	861	708	943
U-41160	6.00	1	20	16	709	947	819	1093	916	1222	1003	1339
U-41260	6.00	2	25	21	709	947	819	1093	916	1222	1003	1339
U-41360	6.00	2	31	27	709	947	819	1093	916	1222	1003	1339
U-42160	6.00	5	20	16	709	947	819	1093	916	1222	1003	1339

TURBOCHARGED ENGINES

MANUFACTURER: NELSON MUFFLER

			ATTEN		MAX HP @ BP							
					1.5		2.0		2.5		3.0	
MUFFLER	PIPE	STYL	2-	4-	2-	4-	2-	4-	2-	4-	2-	4-
U-42260	6.00	5	25	21	709	947	819	1093	916	1222	1003	1339
U-42360	6.00	5	31	27	709	947	819	1093	916	1222	1003	1339
U-43160	6.00	3	20	16	709	947	819	1093	916	1222	1003	1339
U-43260	6.00	3	25	21	709	947	819	1093	916	1222	1003	1339
U-43360	6.00	3	31	27	709	947	819	1093	916	1222	1003	1339
U-44160	6.00	6	20	16	709	947	819	1093	916	1222	1003	1339
U-44260	6.00	6	25	21	709	947	819	1093	916	1222	1003	1339
U-44360	6.00	6	31	27	709	947	819	1093	916	1222	1003	1339

APPENDIX C
MUFFLER COSTS

TABLE C-1. Costs for Donaldson Company Mufflers (Sheet 1 of 4)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of		
				1	10	100
DCI	MAM04-5193	1.68	3	--	$ 13.13	--
DCI	MAM06-0158	2.00	3	--	24.42	--
DCI	MZM06-0054	2.00	2	--	19.69	--
DCI	MZM06-0055	2.00	2	--	18.34	--
DCI	MFM04-5045	2.00	1	--	7.36	--
DCI	MOM06-0149	2.38	1	--	29.99	--
DCI	MUM06-0013	2.41	1	--	7.23	--
DCI	MFM06-0005	2.50	1	--	16.33	--
DCI	MFM05-5009	2.50	1	--	7.91	--
DCI	MAM06-5044	2.50	3	--	26.10	--
DCI	MTM06-5015	2.50	2	--	19.05	--
DCI	MOM09-0273	2.50	2	--	51.12	--
DCI	WOM08-0045	2.50	2	--	65.37	--
DCI	MZM06-5024	2.50	2	--	18.34	--
DCI	MZM06-5034	2.50	2	--	17.50	--
DCI	MTM06-5042	2.50	2	--	21.22	--
DCI	MZM08-5024	2.50	2	--	42.94	--
DCI	MZM07-0043	2.75	2	--	19.78	--
DCI	WOM09-0159	3.00	2	--	77.64	--
DCI	MOM09-0170	3.00	2	--	47.29	--
DCI	MAM08-5090	3.00	3	--	47.36	--
DCI	WAM08-5094	3.00	3	--	66.17	--
DCI	MBM08-5083	3.00	6	--	33.81	--
DCI	MFM08-0018	3.00	1	--	17.50	--
DCI	MTM08-5078	3.00	2	--	31.83	--
DCI	WTM08-5106	3.00	2	--	50.61	--
DCI	MFM07-0008	3.00	1	--	17.57	--
DCI	MZM08-5023	3.00	2	--	25.22	--
DCI	MZM08-5056	3.00	2	--	23.38	--
DCI	MZM07-0076	3.25	2	--	20.86	--
DCI	MAM08-5084	3.50	3	--	36.24	--
DCI	WSM09-0211	3.50	1	--	78.58	--
DCI	MSM09-0146	3.50	1	--	48.70	--
DCI	MFM07-0028	3.50	1	--	14.63	--
DCI	MOM09-0301	3.50	3	--	51.71	--
DCI	MZM08-5008	3.50	2	--	30.43	--

TABLE C-1. Costs for Donaldson Company Mufflers (Sheet 2 of 4)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of		
				1	10	100
DCI	MZM08-5064	3.50	2	--	$ 24.18	--
DCI	MOM09-0140	3.50	2	--	34.59	--
DCI	MOM09-0158	3.50	2	--	43.89	--
DCI	WOM09-0210	3.50	2	--	75.28	--
DCI	MSM09-0157	3.50	1	--	48.70	--
DCI	MFM07-0050	3.50	1	--	23.09	--
DCI	MPM09-0115	3.50	1	--	43.96	--
DCI	MUM09-0015	3.50	1	--	24.67	--
DCI	WTM10-0066	4.00	2	--	112.89	--
DCI	MTM10-0148	4.00	2	--	73.35	--
DCI	MOM14-0001	4.00	2	--	193.22	--
DCI	WOM14-0011	4.00	2	--	266.19	--
DCI	MOM09-0124	4.00	2	--	43.82	--
DCI	MKM09-0055	4.00	2	--	28.48	--
DCI	MBM10-0002	4.00	6	--	34.79	--
DCI	MTM10-0048	4.00	2	--	53.59	--
DCI	MFM09-0009	4.00	1	--	30.25	--
DCI	MTM10-0043	4.00	2	--	49.75	--
DCI	WTM10-0089	4.00	2	--	76.18	--
DCI	MTM10-0006	4.00	2	--	42.71	--
DCI	MOM12-0100	4.00	2	--	44.92	--
DCI	WOM12-0184	4.00	2	--	73.96	--
DCI	MOM12-0200	4.00	2	--	62.65	--
DCI	MPM09-0063	4.00	2	--	38.37	--
DCI	WZM10-0067	4.00	2	--	107.73	--
DCI	WOM12-0230	4.00	2	--	90.11	--
DCI	WTM10-0104	4.00	1	--	87.69	--
DCI	WSM09-0212	4.00	1	--	79.21	--
DCI	MSM09-0135	4.00	1	--	49.35	--
DCI	MOM09-0168	4.00	2	--	42.82	--
DCI	WOM09-0213	4.00	2	--	73.18	--
DCI	WOM12-0241	4.00	2	--	79.12	--
DCI	WOM12-0197	4.00	2	--	80.96	--
DCI	WZM10-0145	4.00	1	--	107.47	--
DCI	MAM10-0146	4.00	3	--	58.63	--
DCI	MBM10-0049	4.00	6	--	40.45	--

TABLE C-1. Costs for Donaldson Company Mufflers (Sheet 3 of 4)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of		
				1	10	100
DCI	MSM09-0142	4.00	1	--	$ 50.57	--
DCI	WSM09-0216	4.00	1	--	80.41	--
DCI	MOM12-0154	4.00	6	--	52.06	--
DCI	WOM12-0183	4.00	6	--	83.09	--
DCI	MPM08-5069	4.00	1	--	41.28	--
DCI	MOM12-1000	4.00	6	--	58.32	--
DCI	WKM10-0064	4.00	2	--	98.32	--
DCI	WKM10-0147	4.00	2	--	66.61	--
DCI	MPM09-0141	4.00	1	--	56.94	--
DCI	MUM09-0022	4.00	1	--	36.68	--
DCI	MUM09-0071	4.00	1	--	20.86	--
DCI	MUM07-0011	4.00	1	--	29.63	--
DCI	MUM09-0008	4.00	1	--	21.95	--
DCI	MUM07-0054	4.00	1	--	21.71	--
DCI	MTM10-0038	5.00	2	--	75.28	--
DCI	WTM10-0065	5.00	2	--	108.13	--
DCI	MOM12-0189	5.00	6	--	66.44	--
DCI	MPM10-0165	5.00	1	--	78.10	--
DCI	MOM12-0176	5.00	6	--	59.69	--
DCI	MOM12-0235	5.00	3	--	73.59	--
DCI	MOM12-0108	5.00	2	--	53.36	--
DCI	WOM12-0182	5.00	2	--	84.36	--
DCI	MOM12-0186	5.00	2	--	59.62	--
DCI	MOM14-0002	5.00	2	--	193.22	--
DCI	WOM14-0012	5.00	2	--	266.19	--
DCI	MFM09-0249	5.00	1	--	80.92	--
DCI	WFM09-0275	5.00	1	--	123.24	--
DCI	MKM10-0149	5.00	1	--	79.98	--
DCI	WKM10-0105	5.00	1	--	104.35	--
DCI	MOM12-0225	5.00	2	--	54.83	--
DCI	MOM12-0131	5.00	6	--	57.89	--
DCI	MPM09-0197	5.00	1	--	61.34	--
DCI	MPM10-0106	5.00	1	--	72.21	--
DCI	WPM10-0107	5.00	1	--	102.08	--
DCI	MFM09-0013	5.00	1	--	65.15	--
DCI	MUM09-0074	5.00	1	--	44.00	--

TABLE C-1. Costs for Donaldson Company Mufflers (Sheet 4 of 4)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of		
				1	10	100
DCI	MPM09-0161	5.00	1	--	$ 57.33	--
DCI	WPM09-0272	5.00	1	--	81.46	--
DCI	MPM10-0108	5.00	1	--	83.97	--
DCI	WPM10-0109	5.00	1	--	132.99	--
DCI	MPM10-0127	5.00	1	--	71.98	--
DCI	MUM09-0072	5.00	1	--	21.44	--
DCI	MOM12-2300	6.00	2	--	63.05	--
DCI	MOM17-0101	6.00	2	--	272.78	--
DCI	WOM17-0106	6.00	2	--	385.14	--
DCI	MOM17-0100	8.00	2	--	304.03	--
DCI	MOM19-0002	8.00	2	--	412.01	--
DCI	MOM19-0001	10.00	2	--	412.01	--

TABLE C-2. Costs for Nelson Mufflers (Sheet 1 of 6)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of 1	10	100
Nelson	U-41107 P&S	.75	1	$ 20.50	--	--
Nelson	U-41207 P&S	.75	1	24.00	--	--
Nelson	U-41307 P&S	.75	1	29.80	--	--
Nelson	U-42107 P&S	.75	5	22.60	--	--
Nelson	U-42207 P&S	.75	5	26.40	--	--
Nelson	U-42307 P&S	.75	5	32.80	--	--
Nelson	U-43107 P&S	.75	3	22.00	--	--
Nelson	U-43207 P&S	.75	3	25.80	--	--
Nelson	U-43307 P&S	.75	3	32.00	--	--
Nelson	U-41110 P&S	1.00	1	22.80	--	--
Nelson	U-41210 P&S	1.00	1	26.90	--	--
Nelson	U-41310 P&S	1.00	1	33.90	--	--
Nelson	U-42110 P&S	1.00	5	25.10	--	--
Nelson	U-42210 P&S	1.00	5	29.60	--	--
Nelson	U-42310 P&S	1.00	5	37.30	--	--
Nelson	U-43110 P&S	1.00	3	24.50	--	--
Nelson	U-43210 P&S	1.00	3	28.90	--	--
Nelson	U-43310 P&S	1.00	3	36.40	--	--
Nelson	U-41113 P&S	1.25	1	26.50	--	--
Nelson	U-41213 P&S	1.25	1	31.30	--	--
Nelson	U-41313 P&S	1.25	1	46.60	--	--
Nelson	U-42113 P&S	1.25	5	29.20	--	--
Nelson	U-42213 P&S	1.25	5	34.40	--	--
Nelson	U-42313 P&S	1.25	5	51.30	--	--
Nelson	U-43113 P&S	1.25	3	28.50	--	--
Nelson	U-43213 P&S	1.25	3	33.70	--	--
Nelson	U-43313 P&S	1.25	3	50.10	--	--
Nelson	U-41115 P&S	1.50	1	30.50	--	--
Nelson	U-41215 P&S	1.50	1	40.60	--	--
Nelson	U-41315 P&S	1.50	1	54.00	--	--
Nelson	U-42115 P&S	1.50	5	33.60	--	--
Nelson	U-42215 P&S	1.50	5	44.70	--	--
Nelson	U-42315 P&S	1.50	5	59.40	--	--
Nelson	U-43115 P&S	1.50	3	32.80	--	--
Nelson	U-43215 P&S	1.50	3	43.70	--	--
Nelson	U-43315 P&S	1.50	3	58.00	--	--

P - Pipe Fitting
S - Slotted
F - Flange

TABLE C-2. Costs for Nelson Mufflers (Sheet 2 of 6)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of 1	10	100
Nelson	U-41120 P&S	2.00	1	$ 34.20	--	--
Nelson	U-41220 P&S	2.00	2	48.20	--	--
Nelson	U-41320 P&S	2.00	1	66.60	--	--
Nelson	U-42120 P&S	2.00	5	37.60	--	--
Nelson	U-42220 P&S	2.00	5	53.00	--	--
Nelson	U-42320 P&S	2.00	5	73.30	--	--
Nelson	U-43120 P&S	2.00	3	36.80	--	--
Nelson	U-43220 P&S	2.00	3	51.80	--	--
Nelson	U-43320 P&S	2.00	3	71.60	--	--
Nelson	U-41125 P&S	2.50	1	40.50	--	--
Nelson	U-41125 S	2.50	1	38.50	--	--
Nelson	U-41225 P	2.50	2	53.00	--	--
Nelson	U-41225 S	2.50	2	51.00	--	--
Nelson	U-41325 P	2.50	1	81.00	--	--
Nelson	U-41325 S	2.50	1	79.00	--	--
Nelson	U-42125 P	2.50	5	44.60	--	--
Nelson	U-42125 S	2.50	5	42.40	--	--
Nelson	U-42225 P	2.50	5	58.30	--	--
Nelson	U-42225 S	2.50	5	56.10	--	--
Nelson	U-42325 P	2.50	5	89.10	--	--
Nelson	U-42325 S	2.50	5	86.90	--	--
Nelson	U-43125 P	2.50	3	43.50	--	--
Nelson	U-43125 S	2.50	3	41.40	--	--
Nelson	U-43225 P	2.50	3	57.00	--	--
Nelson	U-43225 S	2.50	3	54.80	--	--
Nelson	U-43325 P	2.50	3	87.10	--	--
Nelson	U-43325 S	2.50	3	84.90	--	--
Nelson	U-41130 P	3.00	1	52.20	--	--
Nelson	U-41130 S	3.00	1	47.20	--	--
Nelson	U-41230 P	3.00	2	69.40	--	--
Nelson	U-41230 S	3.00	2	64.40	--	--
Nelson	U-41330 P	3.00	1	99.20	--	--
Nelson	U-41330 S	3.00	1	94.20	--	--
Nelson	U-42130 P	3.00	5	57.40	--	--
Nelson	U-42130 S	3.00	5	52.40	--	--

P - Pipe Fitting
S - Slotted
F - Flange

TABLE C-2. Costs for Nelson Mufflers (Sheet 3 of 6)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of 1	10	100
Nelson	U-42230 P	3.00	5	$ 76.30	--	--
Nelson	U-42230 S	3.00	5	71.30	--	--
Nelson	U-42330 P	3.00	5	108.40	--	--
Nelson	U-42330 S	3.00	5	103.40	--	--
Nelson	U-43130 P	3.00	3	56.10	--	--
Nelson	U-43130 S	3.00	3	51.10	--	--
Nelson	U-43230 P	3.00	3	74.60	--	--
Nelson	U-43230 S	3.00	3	69.60	--	--
Nelson	U-43330 P	3.00	3	104.50	--	--
Nelson	U-43330 S	3.00	3	99.50	--	--
Nelson	U-44130 P	3.00	6	58.70	--	--
Nelson	U-44130 S	3.00	6	53.70	--	--
Nelson	U-44230 P	3.00	6	78.10	--	--
Nelson	U-44230 S	3.00	6	73.10	--	--
Nelson	U-44330 P	3.00	6	109.40	--	--
Nelson	U-44330 S	3.00	6	104.40	--	--
Nelson	U-41135 P	3.50	1	56.00	--	--
Nelson	U-41135 S	3.50	1	49.50	--	--
Nelson	U-41235 P	3.50	2	76.70	--	--
Nelson	U-41235 S	3.50	2	70.20	--	--
Nelson	U-41335 P	3.50	1	123.30	--	--
Nelson	U-41335 S	3.50	1	116.80	--	--
Nelson	U-42135 P	3.50	5	61.60	--	--
Nelson	U-42135 S	3.50	5	55.10	--	--
Nelson	U-42235 P	3.50	5	84.40	--	--
Nelson	U-42235 S	3.50	5	77.90	--	--
Nelson	U-42335 P	3.50	5	135.60	--	--
Nelson	U-42335 S	3.50	5	129.10	--	--
Nelson	U-43135 P	3.50	3	60.20	--	--
Nelson	U-43135 S	3.50	3	53.70	--	--
Nelson	U-43235 P	3.50	3	82.50	--	--
Nelson	U-43235 S	3.50	3	76.50	--	--
Nelson	U-43335 P	3.50	3	132.60	--	--
Nelson	U-43335 S	3.50	3	126.10	--	--
Nelson	U-44135 P	3.50	6	63.00	--	--
Nelson	U-44135 S	3.50	6	56.50	--	--

P - Pipe Fitting
S - Slotted
F - Flange

TABLE C-2. Costs for Nelson Mufflers (Sheet 4 of 6)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of		
				1	10	100
Nelson	U-44235 P	3.50	6	$ 86.30	--	--
Nelson	U-44235 S	3.50	6	79.80	--	--
Nelson	U-44335 P	3.50	6	138.70	--	--
Nelson	U-44335 S	3.50	6	132.20	--	--
Nelson	U-41140 P	4.00	1	71.00	--	--
Nelson	U-41140 S	4.00	1	65.00	--	--
Nelson	U-41140 F	4.00	1	82.60	--	--
Nelson	U-41240 P	4.00	2	94.40	--	--
Nelson	U-41240 S	4.00	2	88.40	--	--
Nelson	U-41240 F	4.00	2	106.20	--	--
Nelson	U-41340 P	4.00	2	131.30	--	--
Nelson	U-41340 S	4.00	2	125.30	--	--
Nelson	U-41340 F	4.00	2	143.10	--	--
Nelson	U-42140 P	4.00	5	61.60	--	--
Nelson	U-42140 S	4.00	5	55.60	--	--
Nelson	U-42140 F	4.00	5	90.90	--	--
Nelson	U-42240 P	4.00	5	103.80	--	--
Nelson	U-42240 S	4.00	5	97.80	--	--
Nelson	U-42240 F	4.00	5	116.80	--	--
Nelson	U-42340 P	4.00	5	144.40	--	--
Nelson	U-42340 S	4.00	5	138.40	--	--
Nelson	U-42340 F	4.00	5	157.40	--	--
Nelson	U-43140 P	4.00	3	76.30	--	--
Nelson	U-43140 S	4.00	3	70.30	--	--
Nelson	U-43140 F	4.00	3	88.80	--	--
Nelson	U-43240 P	4.00	3	101.50	--	--
Nelson	U-43240 S	4.00	3	95.50	--	--
Nelson	U-43240 F	4.00	3	114.20	--	--
Nelson	U-43340 P	4.00	3	141.20	--	--
Nelson	U-43340 S	4.00	3	135.20	--	--
Nelson	U-43340 F	4.00	3	153.80	--	--
Nelson	U-44140 P	4.00	6	79.90	--	--
Nelson	U-44140 S	4.00	6	73.90	--	--
Nelson	U-44140 F	4.00	6	92.90	--	--
Nelson	U-44240 P	4.00	6	106.20	--	--
Nelson	U-44240 S	4.00	6	100.20	--	--

P - Pipe Fitting
S - Slotted
F - Flange

TABLE C-2. Costs for Nelson Mufflers (Sheet 5 of 6)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of 1	10	100
Nelson	U-44240 F	4.00	6	$ 119.50	--	--
Nelson	U-44340 P	4.00	6	147.70	--	--
Nelson	U-44340 S	4.00	6	141.10	--	--
Nelson	U-44340 F	4.00	6	161.00	--	--
Nelson	U-41150 S	5.00	1	82.50	--	--
Nelson	U-41150 F	5.00	1	109.50	--	--
Nelson	U-41250 S	5.00	2	104.40	--	--
Nelson	U-41250 F	5.00	2	131.40	--	--
Nelson	U-41350 S	5.00	2	151.20	--	--
Nelson	U-41350 F	5.00	2	178.20	--	--
Nelson	U-42150 S	5.00	5	93.50	--	--
Nelson	U-42150 F	5.00	5	120.50	--	--
Nelson	U-42250 S	5.00	5	117.50	--	--
Nelson	U-42250 F	5.00	5	144.50	--	--
Nelson	U-42350 S	5.00	5	169.00	--	--
Nelson	U-42350 F	5.00	5	196.00	--	--
Nelson	U-43150 S	5.00	3	90.70	--	--
Nelson	U-43150 F	5.00	3	117.70	--	--
Nelson	U-43250 S	5.00	3	113.90	--	--
Nelson	U-43250 F	5.00	3	140.90	--	--
Nelson	U-43350 S	5.00	3	164.00	--	--
Nelson	U-43350 F	5.00	3	191.60	--	--
Nelson	U-44150 S	5.00	6	96.20	--	--
Nelson	U-44150 F	5.00	6	123.20	--	--
Nelson	U-44250 S	5.00	6	127.00	--	--
Nelson	U-44250 F	5.00	6	147.80	--	--
Nelson	U-44350 S	5.00	6	173.50	--	--
Nelson	U-44350 F	5.00	6	200.50	--	--
Nelson	U-41160 S	6.00	1	108.00	--	--
Nelson	U-41160 F	6.00	1	140.00	--	--
Nelson	U-41260 S	6.00	2	148.00	--	--
Nelson	U-41260 F	6.00	2	180.00	--	--
Nelson	U-41360 S	6.00	2	205.20	--	--
Nelson	U-41360 F	6.00	2	236.20	--	--
Nelson	U-42160 S	6.00	5	122.00	--	--
Nelson	U-42160 F	6.00	5	154.00	--	--

P - Pipe Fitting
S - Slotted
F - Flange

TABLE C-2. Costs for Nelson Mufflers (Sheet 6 of 6)

Manuf.	Muffler Part #	Inlet Dia.	Style	Unit Cost for Quantity of 1	10	100
Nelson	U-42260 S	6.00	5	$ 166.00	--	--
Nelson	U-42260 F	6.00	5	198.00	--	--
Nelson	U-42360 S	6.00	5	227.80	--	--
Nelson	U-42360 F	6.00	5	259.80	--	--
Nelson	U-43160 S	6.00	3	118.50	--	--
Nelson	U-43160 F	6.00	3	150.50	--	--
Nelson	U-43260 S	6.00	3	161.50	--	--
Nelson	U-43260 F	6.00	3	193.50	--	--
Nelson	U-43360 S	6.00	3	221.90	--	--
Nelson	U-43360 F	6.00	3	253.90	--	--
Nelson	U-44160 S	6.00	6	125.50	--	--
Nelson	U-44160 F	6.00	6	157.50	--	--
Nelson	U-44260 S	6.00	6	170.50	--	--
Nelson	U-44260 F	6.00	6	202.50	--	--
Nelson	U-44360 S	6.00	6	233.70	--	--
Nelson	U-44360 F	6.00	6	265.70	--	--

P - Pipe Fitting
S - Slotted
F - Flange

APPENDIX D
EXHAUST SYSTEM COSTS

TABLE D-1. Cost for Piece Part Exhaust Systems

Item		1	10	100
Elbows 90°	2	--	$ 7.75	--
	2-1/2	--	8.75	--
	3	--	10.45	--
	3-1/2	--	15.00	--
	4	--	15.30	--
	5	--	27.80	--
	6	--	53.60	--
Elbows 45°	2			
	2-1/2			
	3	--	9.85	--
	3-1/2	--	11.25	--
	4	--	12.00	--
	5	--	22.10	--
	6	--	41.15	--
U-Clamps	2	--	1.20	--
	2-1/2	--	1.25	--
	3	--	1.30	--
	3-1/2	--	1.40	--
	4	--	1.65	--
	5	--	2.35	--
	6	--	2.85	--
Tailpipes	2	--	4.15	--
	2-1/2	--	4.75	--
	3	--	5.60	--
	3-1/2	--	7.30	--
	4	--	8.15	--
	5	--	14.85	--
	6	--	23.95	--
St. Pipe 10'	2	--	7.40	--
	2-1/2	--	10.70	--
	3	--	12.10	--
	3-1/2	--	15.70	--
	4	--	20.70	--
	5	--	38.80	--
	6	--	50.30	--
Flex 25' Coil	2	--	15.70	--
	2-1/2	--	19.75	--
	3	--	65.00	--
	3-1/2	--	75.40	--
	4	--	82.85	--
	5	--	105.60	--
	6			

TABLE D-2. Typical Exhaust System Cost for Seven Configurations

SYSTEM SIZE							
Configuration	2	2-1/2	3	3-1/2	4	5	6
A 6'-St. Pipe 2-U-Clamps	$ 4.45 2.38	$ 6.41 2.52	$ 7.27 2.60	$ 9.40 2.74	$ 12.43 3.28	$ 23.29 4.68	$ 30.17 5.66
Total	6.83	8.93	9.87	12.14	15.71	27.97	35.83
B 6'-St. Pipe 3-U-Clamps 1-90° Elbow	4.45 3.57 7.76	6.41 3.78 8.73	7.27 3.90 10.45	9.40 4.11 15.01	12.43 4.92 15.32	23.29 7.02 27.80	30.17 8.49 53.57
Total	15.78	18.92	21.62	28.52	32.67	58.11	92.23
C 6'-St. Pipe 2-Clamps	4.45 2.38	6.41 2.52	7.27 2.60	9.40 2.74	12.43 3.28	23.29 4.68	30.17 5.66
Total	6.83	8.93	9.87	12.14	15.71	27.97	35.83
D 6'-St. Pipe 2-U-Clamps	4.45 2.38	6.41 2.52	7.27 2.60	9.40 2.74	12.43 3.28	23.29 4.68	30.17 5.66
Total	6.83	8.93	9.87	12.14	15.71	27.97	35.83
E 6'-St. Pipe 4-U-Clamps 2-90° Elbows	4.45 4.76 15.52	6.41 5.04 17.46	7.27 5.20 20.90	9.40 5.48 30.02	12.43 6.56 30.64	23.29 9.36 55.60	30.17 11.32 107.14
Total	24.73	28.91	33.37	44.90	49.63	88.25	148.63
F 6'-St. Pipe 3-U-Clamps 1-90° Elbows	4.45 3.57 7.76	6.41 3.78 8.73	7.27 3.90 10.45	9.40 4.11 15.01	12.43 4.92 15.32	23.29 7.02 27.80	30.17 8.49 53.57
Total	15.78	18.92	21.62	28.52	32.67	58.11	92.23
G 9'-St. Pipe 3-Clamps	6.68 3.57	9.62 3.78	10.90 3.90	14.10 4.11	18.64 4.92	34.93 7.02	45.26 8.49
Total	10.26	13.40	14.80	18.21	23.56	41.95	53.75

APPENDIX E

SAE J88A PROCEDURES AND RATIONALE FOR USING FAST RESPONSE FOR IMI TESTING

E.1 SAE J88A TEST PROCEDURE

Exterior Sound Level Measurement Procedure For Powered Mobile Construction Equipment — SAE J88a

SAE RECOMMENDED PRACTICE

APPROVED JUNE 1975

LAND
SEA
AIR
SPACE

SOCIETY OF AUTOMOTIVE ENGINEERS, INC.
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

EXTERIOR SOUND LEVEL MEASUREMENT
PROCEDURE FOR POWERED MOBILE
CONSTRUCTION EQUIPMENT - SAE J88a   SAE Recommended Practice

Report of Vehicle Sound Level Committee approved November 1972 and last revised June 1975.

1. SCOPE-This SAE Recommended Practice sets forth the instrumentation and procedure to be used in measuring exterior sound levels for powered mobile construction equipment of 20 rated bhp and over. It is not intended to cover operation of safety devices (such as backup alarms) air compressors, jack hammers, and machinery designed primarily for operation on highways or within factories, aircraft, or recreational vehicles such as snowmobiles and boats. The sound levels obtained by using the test procedures set forth in this SAE Recommended Practice are repeatable and are representative of the higher range of sound levels generated by the machinery under actual field operating conditions, but do not necessariliy represent the average sound level over a field use cycle.

2. INSTRUMENTATION

2.1 A sound level meter which meets the Type 1 or S1A requirements of the American National Standard Specification for Sound Level Meters, S1.4-1971.

2.2 As an alternative to making direct measurements using a sound level meter, a microphone or sound level meter may be used with a magnetic tape recorder and/or graphic level recorder or indicating instrument, providing the system meets the requirements of SAE Recommended Practice J184 QUALIFYING A SOUND DATA ACQUISITION SYSTEM.

2.3 An acoustical calibrator (see paragraph 4.2.4 – accuracy within $\pm$ 0.5dB).

2.4 A microphone windscreen shall be used that does not permit the effect on the microphone and frequency response to exceed $\pm$ 0.5 dB to 5kHz and $\pm$ 2.0dB to 12 kHz.

2.5 An anemometer or other device for measurement of ambient wind speed and direction (accuracy within $\pm$ 10%).

2.6 A power source rpm indicator (accuracy within $\pm$ 2%).

2.7 A thermometer for measurement of ambient temperature (accuracy within $\pm$ 1°).

2.8 A barometer for measuring atmospheric pressure (accuracy within $\pm$ 1%).

3.1 Test Site – The test area shall consist of a flat open space free of any large reflecting surfaces, such as a signboard, building or hillside, located within 30m (100ft) of either the microphone or the machinery being measured (see Fig.1). It is recommended that measurements be made only when the wind speed is below 19 km/h (12 mph).

3.1.1 The minimum measurement area (see Fig. 1) shall consist of the triangle formed by the microphone location, points A & B, and the rectangle formed by points A, B, C & D. Both designated areas shall be smooth concrete or smooth and sealed asphalt or a similar hard and smooth surface. The rectangle formed by points C, D, E & F shall consist of hard-packed earth. The planes between the microphone location and line AB and planes encompassed by points A, B, C, F, E & D shall form a continuous, uniform plane. If a minimum measurement area test site is used, it will require reorientation of the machine for each major surface measurement during the stationary tests, and the moving test will have to be run in two opposite directions. The other option is to have a larger measurement area test site and relocate the microphone for the series of prescribed test conditions with the machine in one position for stationary tests and driving by in only one direction for the moving tests.

3.1.2 Because bystanders have an appreciable influence on the meter response when they are in the vicinity of the construction machinery or

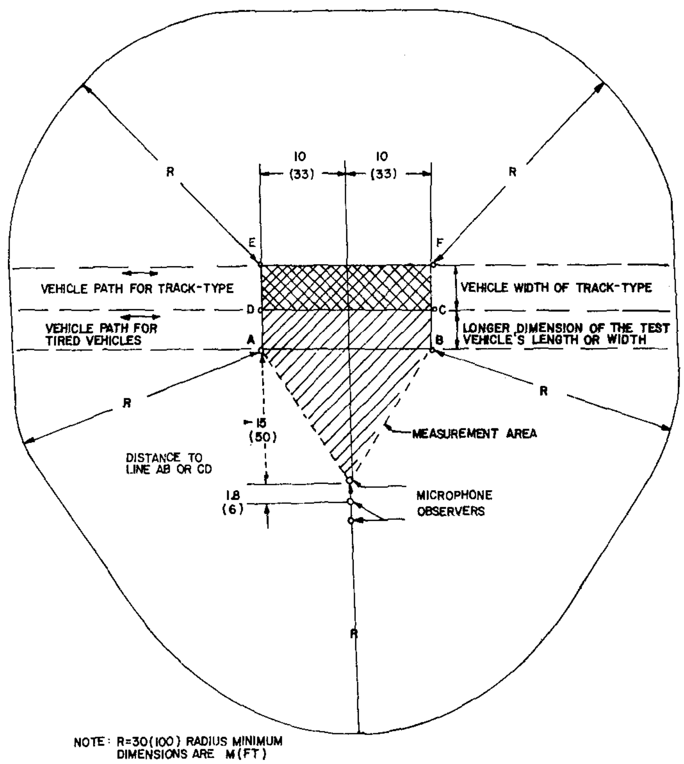


FIG. 1 - TEST SIT CONFIGURATION

microphone, not more than one person, other than the observer reading the meter, shall be within 17m (56 ft) of the construction machinery and 1.8m (6ft) of the measuring microphone, and that person shall be directly behind the observer who is reading the meter, on a line through the microphone and the observer (see Fig. 1).

3.1.3 The ambient sound level due to sources other than the construction machinery being measured (including wind effects) shall be at least 10 dB lower than the sound level of the machinery being measured. (see paragraph 3.3.3).

3.1.4 The surface between and under the construction machinery and microphone shall be smooth and free of acoustically absorptive material, such as snow or grass.

3.1.5 For all stationary tests the machinery shall be located on the hard surface area formed by points A,B,C&D in Fig 1.

3.1.6 Moving Tests

3.1.6.1 For moving tests of all rubber tired machines, the path of travel shall be across the area defined by points A, B, C & D in the directions shown in Fig. 1.

3.1.6.2 For moving tests of all steel wheel, steel drum or track-type of machines the path of travel shall be across the area defined by C, D, E & F in the direction shown in Fig. 1.

3.2 Tests Required

(a) For mobile construction machinery that is used primarily in a stationary mode, test per paragraphs 3.2.1.1, 3.2.1.2, and if applicable 3.2.1.3.

(b) For self-propelled construction machinery that is used primarily in a mobile mode, test per paragraphs 3.2.1.1, 3.2.1.2, 3.2.1.3, and 3.2.2. For construction machines which have an auxiliary power source, such as a truck mounted crane, the main engine and auxiliary engine shall be run separately during tests 3.2.1.1 and 3.2.1.2 with the other engine shut down. During test 3.2.1.3 only the auxiliary engine shall be run and only the main propulsion engine run during the test prescribed in 3.2.2. For combined construction machinery (such as small loader with backhoe) test per paragraphs 3.2.1.1, 3.2.1.2, 3.2.1.3 and 3.2.2.

3.2.1 Stationary Tests with Ground Propulsion Transmission Shift Selector in Neutral Position.

3.2.1.1 Operate all mobile construction machinery engines at no load with all component drive systems in neutral position and maximum governed speed (high idle at no load) at a stabilized condition.

3.2.1.2 Operate all mobile construction machinery engines at no load with all component drive systems in neutral position through the cycle "low idle-maximum governed speed (high idle at no load) low idle" as rapidly as possible, but allowing the engine to stabilize for at least 10 sec at maximum governed/ speed (high idle at no load) before it is permitted to return to low idle.

3.2.1.3 With the engine at the maximum governed speed (high idle at no load) in a stabilized condition, activate the appropriate hydraulic circuits, mechanical, electrical, hydrostatic, or torque converter drive systems to cycle the major components or component from the most retracted and/or lowered position to fully extended and/or maximum height position and then back to orginal position. This cycling should be done as fast as practical, taking into consideration all the pertinent safety factors/that can be accomplished without blowing relief valves. For safety reasons and undesirability of change of location of major noise source in relation to microphone, a major portion of the mobile machine, such as the tractor of a scraper unit, drum of a compactor, or the upper rotational structure of an excavator, shall not be moved or placed in a vibratory mode of operation during this stationary machine test.

3.2.2 *Constant speed moving Test* – Self-propelled construction machinery shall be operated in a forward intermediate gear ratio at no load at a location as specified in paragraphs 3.1.6.1 or 3.1.6.2. The power source shall be operated at full governor control setting. Intermediate is intended to mean second gear ratio for machines with three or four gear ratios, third gear ratio for machines with five or six gear ratios. fourth gear ratio for machines with seven or eight gear ratios, etc. (Gear ratio refers to overall gear reductions.) If there is a problem with the transmission shifting up or down in this phase of this test, one gear lower or higher may be used to eliminate the problem. Hydrostatic or electric drive machinery will be operated as near as possible to one-half its maximum ground speed. Machinery that has major noise-generating components which could be used at the above ground speed, such as on an elevating scraper or on a vibrating compactor, shall have these major components in operation during this moving test.

3.2.3 Construction machinery that has a major attachment that is normally used for the main operating function shall be equipped with this attachment. Examples of this are buckets on loaders and dozers on either wheel or track-type tractors. For all tests these attachments shall be in a minimum transport position of 0.15m (6 in) to 0.3 m (12 in) for dozers, scrapers, etc., and for loaders use carry position as specified by SAE Standard J732 SPECIFICATIONS DEFINITIONS-FRONT END LOADER.

3.3 MEASUREMENTS

3.3.1 The microphone shall be located at a height of 1.2m (4 ft) above the ground plane.

3.3.2 The sound level meter shall be set for slow response and the A-weighting network.

3.3.3 The ambient wind speed and direction, ambient temperature, atmospheric pressure, and ambient A-weighted sound level shall be measured and recorded at the height of 1.2m (4 ft) and within at least 3m (10 ft) of the one specified location of the microphone as shown in Fig. 1.

3.3.4 The stabilized maximum governed engine speed shall be measured and recorded.

3.3.5 The sound level meter needle movement shall be observed during each test sequence at the specified microphone location. The highest value observed, disregarding sounds of short duration that are out of character with the test on the machine, (example) impact sound such as bucket rack against stops, shall be recorded for each test sequence. For stabilized test conditions (3.2.1.1) a single reading shall be recorded for each measurement point. For cycling and moving test conditions (3.2.1.2, 3.2.1.3 and 3.2.2) a minimum of three readings shall be taken for each measuring point. If none of these readings are within 2 dB of each other, then additional readings shall be taken until there are two that are within 2 dB of each other. The reported value shall be the average of these two values that are within 2 dB of each other. If there are two pairs of readings that are within 2 dB of each other, report the average of the higher pair. The final reported result for each test mode shall be the highest reading for stabilized test conditions and the highest average for the cyclic or moving tests and must include the location of the microphone.

3.3.6 For stationary tests, record the sound level obtained at a distance of 15m (50 ft) normal to the centers of the four major surfaces of the equipment at the microphone height. Generally, four major surfaces refer to front, rear, and sides of an imaginary box that would just fit over the machine but does not include attachment items such as buckets, dozers, and booms (see Fig. 2). In the case of a crane or an ex-

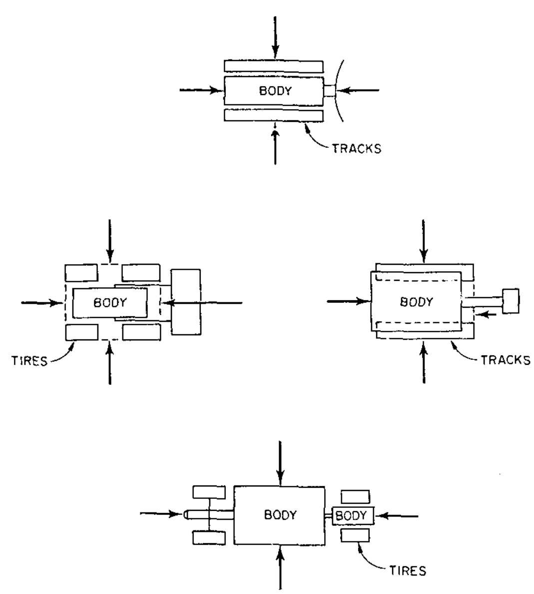


FIG. 2 - MAJOR SURFACE OUTLINES

cavator, the upper (revolving superstructure) fore-and-aft centerline should be in line with the lower fore-and-aft centerline. Operate the machine in a manner as specified in paragraphs 3.2.1.1, 3.2.1.2 and 3.2.1.3.

3.3.7 For moving tests, take measurements at a distance of 15m (50 ft) measured in a direction normal to a major side surface which is parallel to the machine path, as shown in Fig. 1. Operate the machine in a manner specified in paragraph 3.2.2.

3.3.8 The final reported sound level per this SAE Recommended Practice shall be the highest of the reported values obtained in paragraphs 3.3.6 and 3.3.7; the test report shall include the test mode, the machine operating conditions during the reported test mode, the stabilized maximum governed engine speed, the location of the microphone in relation to the construction machine, the surface description over which the machine operated and the sound level measurements were made.

4.1 It is recommended that persons technically trained and experienced in the current techniques of sound measurements select the instrumentation and conduct the tests.

4.2 Proper use 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:

4.2.1 The type of microphone which shall be oriented with respect to the source so that the sound strikes the diaphragm at the angle for which the microphone was calibrated to have the flatest frequency response characteristic over the frequency range of interest.

4.2.2 The effects of ambient weather conditions on the performance of all instruments (for example: temperature, humidity, and barometric pressure). Instrumentation can be influenced by low temperature, and caution should be exercised.

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

4.2.4 Proper acoustical calibration procedure, to include the influence of extension cables, etc. Field acoustical calibration shall be made immediately before and after each test sequence of a piece of construction machinery.

5. REFERENCES

5.1 ANSI S1.1-1960 (R1971), Acoustical Terminology

5.2 ANSI S1.2-1962 (R1971), Physical Measurement of Sound

5.3 ANSI S1.4-1971, Specification for Sound Level Meters

5.4 ANSI S1.13-1971, Methods for the Measurement of Sound Pressure Levels

5.5 ISO R362, Measurement of Noise Emitted by Vehicles

5.6 SAE Recommended Practice J184, Qualifying a Sound Data Acquisition System

5.7 SAE Standard J732c-Specification Definitions-Front End Loader

5.8 C.A.G.I. - PNEUROP Test Code for Measurement of Sound for Pneumatic Equipment

E.2 Rationale for Using Fast Response for IMI Testing

Although SAE J88a calls for the use of slow response in taking sound level measurements, we have employed the use of fast response in our testing performed during this contract and recommend its use during IMI tests. This recommendation is based on our background and extensive testing on overhighway trucks per SAE J1096 "Measurement of Exterior Sound Levels for Heavy Trucks Under Stationary Conditons" and Interstate Motor Carrier Noise Emission Standards (49 CFR 325), both of which use the "fast" meter response mode for IMI tests. These tests have shown that peaks measured during an IMI test ("fast" response) have good correlation with the sound level at rated load. This correlation occurs due to the inertial loading created as the engine rpm increases rapidly from idle to maximum governed speed during the initial run-up of the IMI test. Test results and our experience indicate that such a correlation does not exist if the "slow" response mode of the sound level meter is used during an IMI test. Data indicates that the "slow" response mode does not measure the short duration transient sound level peaks present in the run-up phase of the IMI test and as such was not considered for one work on this contract.

APPENDIX F

PRECISE TECHNIQUE FOR NOISE SOURCE IDENTIFICATION

F.1 Noise Source Elimination Process

The noise contribution of each of the major noise sources, i.e., (a) exhaust, (b) fan, (c) intake, (d) mechanical and hydraulic, (e) track, can be determined by a step-by-step noise source elimination process.

Step 1: Measure the overall noise level of the original equipment (according to SAE J88a measurement procedures modified to use fast response for the IMI tests) (Ref. Appendix A).

Step 2: By silencing the exhaust system, the noise contribution can be determined. The exhaust system can be silenced by the use of several mufflers in series and by wrapping exhaust pipes. The exhaust pipes are wrapped to eliminate shell-radiated noise and noise caused by exhaust leaks. The equipment noise level is then measured and subtracted from the overall level to find the exhaust level.

Step 3: The contribution of the fan is determined by disengaging the fan belts and with exhaust silenced, measuring the equipment noise level. The fan noise level is then found by subtracting this level from the level measured in Step 2. Care must be taken to avoid overheating the engine in this and succeeding tests.

Step 4: With the fan and exhaust silenced, the contribution of the intake can be determined by silencing the intake with the addition of commercially-available intake silencers to the intake system. The equipment level is then remeasured and subtracted from the level found in Step 3.

Step 5: The level measured in Step 4 in the stationary tests, with exhaust, fan, and intake silenced, can be attributed to mechanical and hydraulic noise sources. This noise level is measured by overall noise level minus exhaust noise minus fan noise minus intake noise.

Step 6: For tracked vehicles operating on hard surfaces, the track noise can be determined by securing sound insulating panels around the engine (and other remaining noise sources) and with the exhaust, fan and intake silenced, measuring the equipment level in a moving test mode. Since all other sources are silenced, the measured level can be attributed to track noise.

F.2 Subtracting dB(A) Levels

Because described levels are logarithmic, they cannot be subtracted directly. They must be subtracted according to the formula,

$$X(dB(A)) - Y(dB(A)) = 10 \log_{10} \left(\text{antilog}_{10} \frac{X}{10} - \text{antilog}_{10} \frac{Y}{10}\right)$$

The numerical difference between the levels being subtracted is located on the left or bottom axis, and by proceeding across to the upper curve and down (or up and across), the numerical difference between the total level and unknown level is determined.

F.3 Example of Noise Source Identification

Using the excavator test results (Appendix G). the noise source identification procedure following the steps outlined in Section B.1, is:

Step 1

Overall excavator level (measured on left side during IMI test:

77.5 dB(A) @ 50 ft.

Step 2

Equipment level with silenced exhaust:

76 dB(A)

Overall excavator level-equipment level with silenced exhaust

$$77.5 - 76 = 1.5$$

Using Figure G-1; locate 1.5 on the vertical axis and proceed across to the curve. The value at this point on the horizontal axis is 5.3. Subtract to get exhaust noise level:

$$77.5 - 5.3 = 72.2 \text{ dB(A)}$$

Step 3

Measured noise level after disconnecting fan:

74.5

Exhaust noise level - noise level after disconnecting fan

$$76 - 74.5 = 1.5$$

$$76 - 5.3 = 70.7 \text{ dB(A)} = \text{Fan noise level}$$

Step 4

Noise level after silencing the intake:

74 dB(A)

Intake noise level:

74.5 - 74 = 0.5

74.5 - 9.0 = 65.5 dB(A)

Step 5

Noise level of the mechanical and hydraulic sources:

Overall level	77.5
less exhaust	– 72.2
less fan	– 70.7
less intake	– 65.5
Equals mechanical - hydraulic 74 dBA	

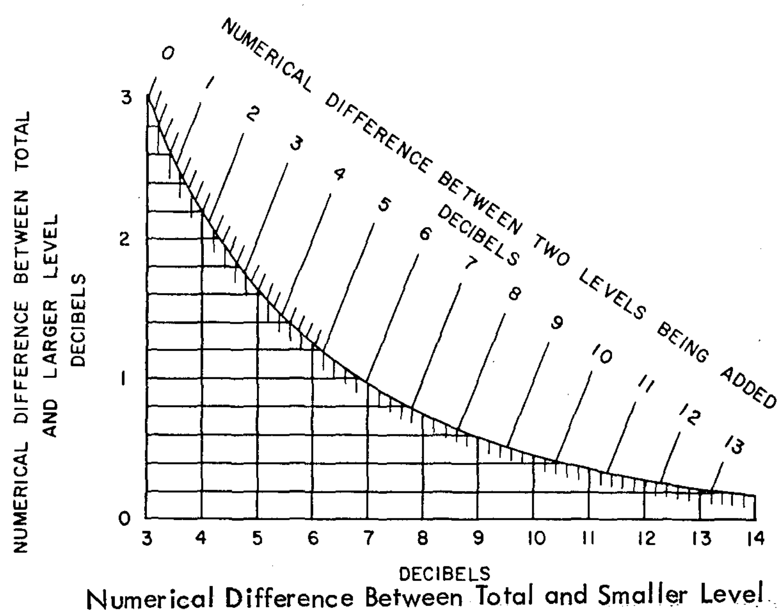


Figure F-1. Chart for Adding or Subtracting Noise Levels*

*Reproduced by permission from Handbook of Noise Measurement, published by GenRad Inc. (chart developed by R.S. Musa, Westinghouse Research Laboratories).

APPENDIX G

RESULTS OF NOISE SOURCE IDENTIFICATION

The following pages give the complete results of the source identification tests on the four pieces of equipment. Included are the actual test results for each microphone position under the three test modes.

Equipment Type: Excavator

Manufacturer: Warner & Swasey

Model: H-550 TT

Original Equipment:

Engine: Detroit Diesel 4-53
115 hp @ 2400 rpm
Hydraulics: Pump - 115 gpm @ 2400 rpm
Motor 25 hp
Fan - 5 blades @ 2400 rpm
Muffler-Donaldson #MZM08-5023
Air Cleaner and Pre-Cleaner
Crawler Drive - 49 hp Motor
Travel Speed - 1 mph

Test Site: Ryan Construction Company

Ambient Noise Level - 55-60 dB(A)

Test Procedure: The vehicle noise levels were measured at 50 feet from each side, according to SAE J88a measurement procedures modified to use fast response for IMI tests. Sound levels were recorded at each side, for (a) idle-max rpm-idle, (b) unloaded maximum rpm, and (c) loaded maximum rpm tests. Moving tests were not conducted since this was not a typical operating mode. Microphone locations were numbered as follows: (1) left side of vehicle, (2) rear, (3) right side, (4) front. Measurements from position (4), front, were not continued throughout the test because it was the quietest side and the position of the bucket influenced the level significantly.

Overall Excavator Noise Levels: Test Condition - Test Procedure

	Idle-max rpm-idle (dB(A))	Unloaded max rpm (dB(A))	Hydraulically Loaded max rpm (dB(A))
Original Equipment			
Location 1:	77.5	76.5	76
2:	80.5	80	79
3:	78.5	77	77
4:	76	76.5	75
Silenced Exhaust			
Location 1:	76	76	74.5
2:	80.5	80.5	78
3:	76.5	75.5	74.5
4:			
Silenced Exhaust and Fan			
Location 1:	74.5	74.5	73
2:	80	80	77.5
3:	76	76	75
4:			
Silenced Exhaust, Intake and Fan			
Location 1:	74	74	73
2:	78.5	78.5	76.5
3:	75	74.5	73.5
4:			
w/Batts around engine compartment*			
Location 1:	69	68	68
2:	71.5	70.5	68.5
3:	69.5	68.5	67.5
4:			
Open Exhaust			
Location 1:	95.5	87	94
2:	96.5	88	96
3:	96.5	87	95
4:	87.5	80.5	88

*See Figure 20

Excavator Noise Source Levels

	Idle-max rpm-idle (dB(A))	Unloaded max rpm (dB(A))	Hydraulically Loaded max rpm (dB(A))
Fan			
Location 1:	70.5	70.5	69
2:	71	71	68.5
3:	65	65	65
4:			
Intake			
Location 1:	65.5	65	65
2:	74.5	74.5	70.5
3:	69	70.5	67.5
4:			
Mechanical & Hydraulic			
Location 1:	74	74	73
2:	78.5	78.5	76.5
3:	75	74.5	73.5
4:			
Original Exhaust			
Location 1:	73	67	70.5
2:	70	70	72
3:	74		73.5
4:			
Open Exhaust			
Location 1:	95.5	87	94
2:	96.5	87.5	96
3:	96.5	87	95
4:			

Equipment Type: Front End Loader

Manufacturer: Michigan

Model: 275B

Original Equipment:

Engine: Cummins NTC 380
380 hp @ 2100 rpm
Muffler: Nelson 6P 73

Use: 1970, Est. 4000 hours

Test Site: Edward Kraemer & Sons, Inc.

Ambient Noise Level: 50 - 55 dB(A)

Test Procedure: The vehicle noise levels were measured at 50 feet from each side according to SAE J88a measurement procedures modified to use fast response for IMI tests. Sound levels were recorded at each side for (a) idle-max rpm-idle, (b) unloaded maximum rpm, and (c) loaded maximum rpm tests. Moving tests were conducted with original equipment only.

Microphone locations were numbered as follows: (1) left side of vehicle, (2) rear, (3) right side, (4) front.

Overall Front-End Loader Noise Levels: Test Condition - Test Procedure

	Idle-max rpm-idle (dB(A))	Unloaded max rpm (dB(A))	Hydraulically Loaded max rpm (dB(A))
Original Equipment			
Location 1:	89	86	85.5
2:	87.5	86	85.5
3:	89	86.5	86
4:	78	73	78
Silenced Exhaust			
Location 1:	87	85	85
2:	86	86	84.5
3:	87.5	85	86
4:	77.5	75	77
Silenced Exhaust and Intake			
Location 1:	87	85.5	85.5
2:	86	86	86
3:	87.5	85.5	85
4:	77.5	74	77
Silenced Exhaust, Intake and Fan			
Location 1:	87.5	82	83.5
2:	86	83	82
3:	87.5	83	83
4:	77	70.5	77
w/Batts			
Location 1:	79.5	79	78
2:	80	79	78
3:	80.5	79.5	80
4:	77	70	77
Open Exhaust			
Location 1:	94.5	92	92.5
2:	92.5	88	89.5
3:	95	93	92.5
4:	82	80	81.5

Front-End Loader Noise Source Levels

	Idle-max rpm-idle (dB(A))	Unloaded max rpm (dB(A))	Hydraulically Loaded max rpm (dB(A))
Fan			
Location 1:	75	82	81
2:	75	83	81
3:	75	82	80.5
4:	72.5	71.5	65
Intake			
Location 1:	75	75	75
2:	75	75	75
3:	75	75	79
4:	65	75	65
Mechanical and Hydraulic			
Location 1:	87	82	83.5
2:	86	83	82
3:	87	83	83
4:	76.5	70.5	77
Original Exhaust			
Location 1:	84.5	79	76
2:	84	75	78.5
3:	84	81	75
4:	70.5	65	71
Open Exhaust			
Location 1:	93.5	91	91.5
2:	91.5	85.5	88
3:	94	92	91.5
4:	81	79	79.5

Equipment Type: Crawler Dozer

Manufacturer: Terex

Model: 82 - 40

Original Equipment:
Engine: Detroit Diesel 8V-71 NA
318 hp @ 2100 rpm

Use: 1967, Est. 13,426 hours

Test Site: Road construction site, 5 miles south of Shakopee.

Ambient Noise Level: 45 dB(A)

Test Procedure: The vehicle noise levels were measured at 50 feet from each side, according to SAE J88a measurement procedures modified to use fast response for IMI tests. Sound levels were recorded at each side for (a) idle-max rpm-idle, (b) unloaded maximum rpm, and (c) loaded maximum ,m tests. Moving tests were conducted for original equipment and quietest configuratio only.

Microphone locations were numbered as follows: (1) left side of vehicle, (2) rear, (3) right side, (4) front.

Crawler Dozer Overall Noise Source Levels: Test Condition - Test Procedure

	Idle-max rpm-idle (dB(A))	Unloaded max rpm (dB(A))	Hydraulically Loaded max rpm (dB(A))
Original Equipment			
Location 1:	84.5	83.5	85
2:	82	82	81
3:	86	85	86.5
4:	79	78	86.5
Silenced Exhaust			
Location 1:	83.5	83	85
2:	81	80	80.5
3:	84	83	85
4:	75.5	75	86
Silenced Exhaust and Intake			
Location 1:	83.5	83	85
2:	80.5	80	80.5
3:	83.5	83	84
4:	75	74.5	86
Silenced Exhaust, Intake and Fan			
Location 1:	83	82	84
2:	73.5	73	76
3:	83.5	81.5	83
4:	76	73	85
w/Batts			
Location 1:	80	78	79.5
2:	70.5	69.5	74
3:	77	76.5	78
4:	72	72.5	
Open Exhaust,			
Location 1:			
2:			
3:			
4:			

Crawler-Dozer Noise Source Levels

	Idle-max rpm-idle (dB(A))	Unloaded max rpm (dB(A))	Hydraulically Loaded max rpm (dB(A))
Fan			
Location 1:	74.5	76	78
2:	79.5	79	78.5
3:	72	77.5	77
4:	65	69	79
Intake			
Location 1:	72	70	75
2:	72	70	70
3:	74	70	78
4:	66	64.5	75
Mechanical and Hydraulic			
Location 1:	83	82	84
2:	73.5	73	76
3:	83.5	81.5	83
4:	75	73	85
Original Exhaust			
Location 1:	78.5	74	75
2:	76	77.5	71.5
3:	83.5	80.5	81
4:	76.5	75	77
Open Exhaust			
Location 1:			
2:			
3:			
4:			

Equipment Type: Tractor

Manufacturer: Ford

Model: 4400

Original Equipment:

Engine: Ford 201D
59 hp @ 2200 rpm

Muffler: (Part No. Unknown)

Test Site: Donaldson Company, Inc.

Ambient Noise Level: 50 - 55 dB(A)

Test Procedure: The vehicle noise levels were measured at 50 feet from each side, according to SAE J88a measurement procedures modified to use fast response for IMI tests. Sound levels were recorded at each side for (a) idle-max rpm-idle, (b) unloaded maximum rpm, and loaded maximum rpm tests.

Microphone locations were numbered as follows: (1) left side of vehicle, (2) rear, (3) right side, and (4) front.

Tractor Noise Source Levels: Test Condition - Test Procedure

	Idle-max rpm-idle (dB(A))	Unloaded max rpm (dB(A))	Hydraulically Loaded max rpm (dB(A))
Original Equipment			
Location 1:	83	76.5	78.5
2:	78	73	74.5
3:	83.5	77.5	79
4:	83.5	77	80
Silenced Exhaust			
Location 1:	81.5	75.5	77.5
2:	76.5	72	73.5
3:	82	76	78.5
4:	80	74.5	78.5
Silenced Exhaust and Fan			
Location 1:	80	74	76
2:	75	70	71
3:	80.5	74.5	77
4:	79	72.5	77.5
Silenced Exhaust, Intake and Fan			
Location 1:	80	73.5	75.5
2:	75	70	72
3:	80	74.5	76
4:	78.5	72	77
w/Batts			
Location 1:	69	64	67
2:	64.5	60.5	64
3:	69	64.5	65.5
4:	69.5	66	
Open Exhaust			
Location 1:	90	82.5	84
2:	83.5	77	79
3:	89.5	81.5	83.5
4:	90	81.5	85.5

Tractor Noise Source Levels

	Idle-max rpm-idle (dB(A))	Unloaded max rpm (dB(A))	Hydraulically Loaded max rpm (dB(A))
Fan			
Location 1:	76	70	72
2:	71	69.5	70
3:	76.5	70.5	73
4:	74	70	71.5
Intake			
Location 1:	70	64.5	66.5
2:	65	60	60
3:	71	65	70
4:	69.5	63	68
Mechanical and Hydraulic			
Location 1:	80	73.5	75.5
2:	75	70	72
3:	80	74.5	76
4:	78.5	72	77
Original Exhaust			
Location 1:	77.5	69.5	71.5
2:	72.5	66	67.5
3:	78	72	69.5
4:	81	73.5	74.5
Open Exhaust			
Location 1:	89.5	81.5	83
2:	82.5	75.5	77.5
3:	88.5	80	81
4:	89.5	80.5	84.5

From these tests, it appears that the idle-max rpm-idle test measured using fast response gives the best equipment noise evaluation in a single test. The idle-max rpm-idle test accelerates the engine rapidly through its operating speeds and approximates a fully-loaded engine. The peak idle-max rpm-idle test also yielded the highest sound level in most cases. On the average, exhaust noise levels were 6 dB(A) higher and mechanical and hydraulic levels were 3 dB(A) higher in the idle-max rpm-idle tests as compared with the unloaded max rpm tests. Loaded max rpm tests were more inconsistent than idle-max rpm-idle tests, since the fully-loaded condition was not guaranteed by lifting auxiliary equipment. Loaded maximum rpm tests averaged 2 dB(A) higher than unloaded max rpm tests for both exhaust and mechanical and hydraulic levels.

APPENDIX H

BACK PRESSURE CORRECTION PROCEDURES

D.1 Wye Correction Adjustment Factor

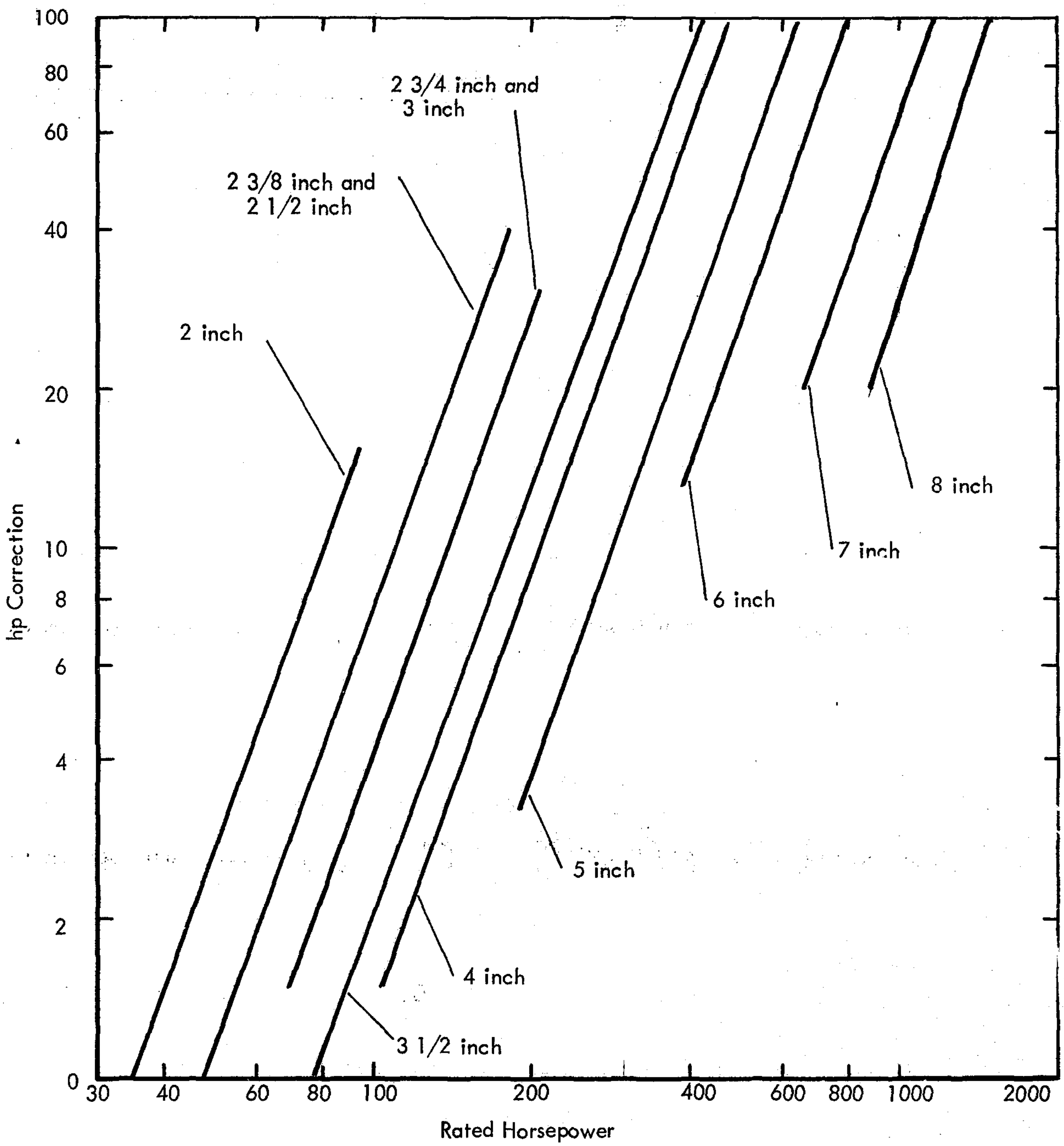
Verification of the Muffler-Horsepower Guide (Ref. Section 3.4.2) indicated that use of a wye connector on a Vee engine affected the exhaust system back pressure and was dependent on the pipe size and exhaust flow. An average horsepower-airflow relationship was determined using as a base the information presented on Table 18. Based on this value a correlation was developed between rated horsepower and back pressure. This back pressure was converted to a horsepower correction and the adjustment curve is shown in Figure D-1. The adjusted horsepower factor is added to the rated horsepower. This sum is then used when selecting a muffler from the Muffler-Horsepower Guide.

D.2 Pressure Drop Per Foot of Pipe

Maximum horsepower values for each muffler included six feet of piping when correlating horsepower to back-pressure limits. If the exhaust system length is substantially greater than six feet, the piping may add a significant amount of back pressure. Shown in Figure D-2 is a back pressure correction for different pipe diameters at a typical exhaust flow (velocity = 250 ft/sec). This curve is developed for smooth-walled pipes. If the piping is old and scales have developed on the walls increase the back pressure correction by a factor of 1.5.

D.3 Pressure Drop Per Elbow

Maximum horsepower values for each muffler included one 90 degree and one 45 degree elbow. If there are more elbows in the system, a back pressure correction should be determined. There are a great variety of 90 degree elbows, i.e., the radius at which the elbows are formed. However, generally exhaust system elbows have a r/d of 2 (r = radius of bend and d = diameter of elbow). For these elbows, the back pressure added by the elbow is equivalent to the back pressure added by one foot of pipe of the same diameter.



Note: To use, add hp corrections to rated hp.

Figure H-1. Wye Connector Correction Curve

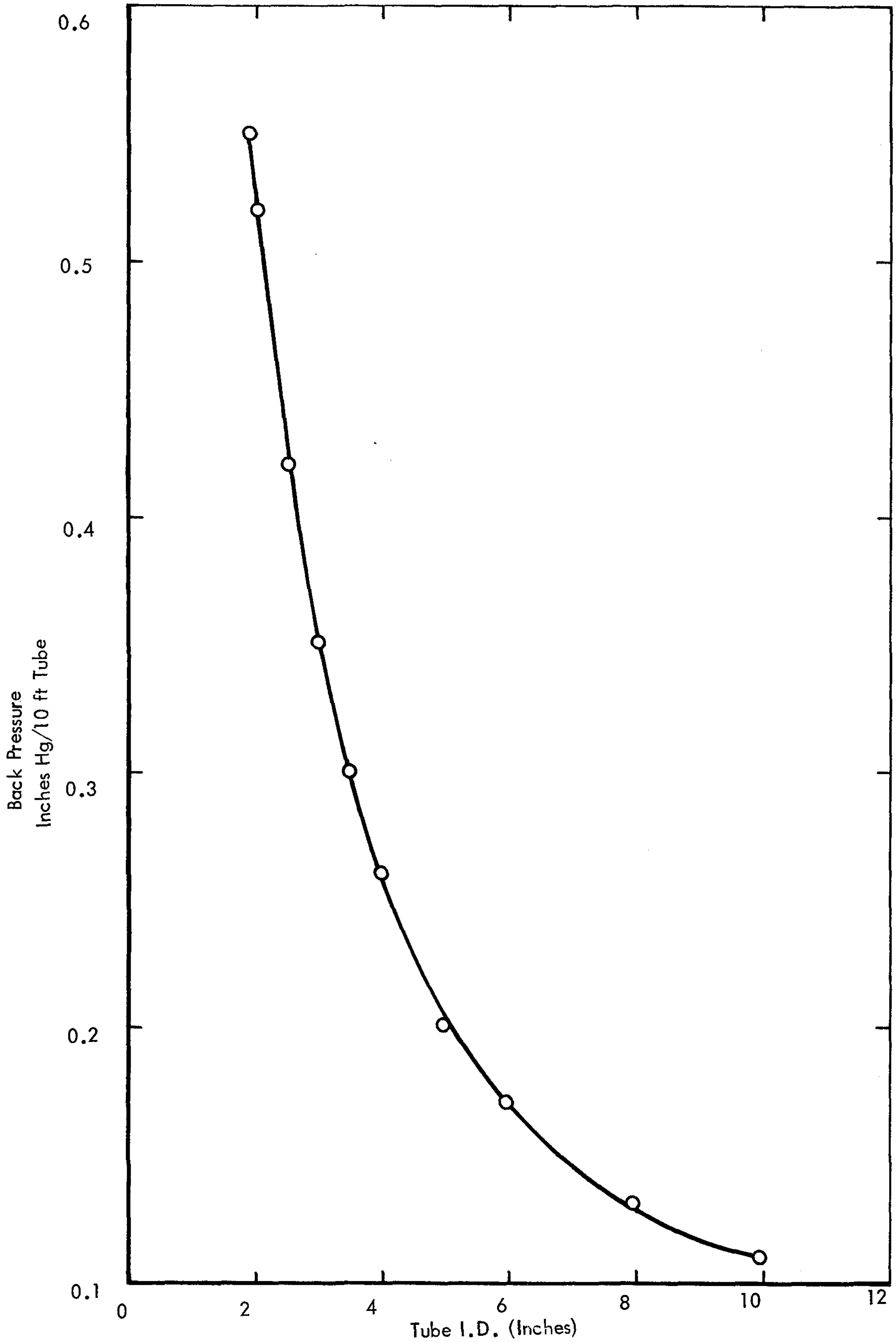


Figure H-2. Back pressure vs Exhaust Pipe Length (Gas Velocity 250 ft/sec.)

1.4 Back Pressure Measurement Procedure

Often in complex systems, it is necessary to measure the back pressure to insure that back pressure does not exceed the limit. In order to obtain the most meaningful readings, locate the tap as close to the manifold as possible at least one pipe diameter downstream from any change in flow area or flow direction. Weld an 1/8" pipe coupling to the exhaust tubing at a neutral flow plane, then drill through the tubing with an 1/8" bit and deburr. Mount a 90 degree Weatherhead fitting to coupling and use 3 feet of 1/8" copper tubing to dissipate heat. Connect this assembly to a slack tube mercury manometer (such as Dwyer Model #1211-16) with ten feet of 3/16" i.d. rubber hose. Disconnect Weatherhead when not in use and seal coupling with 1/8" pipe plug. Figure D-3 is a schematic of a proper measurement set-up.

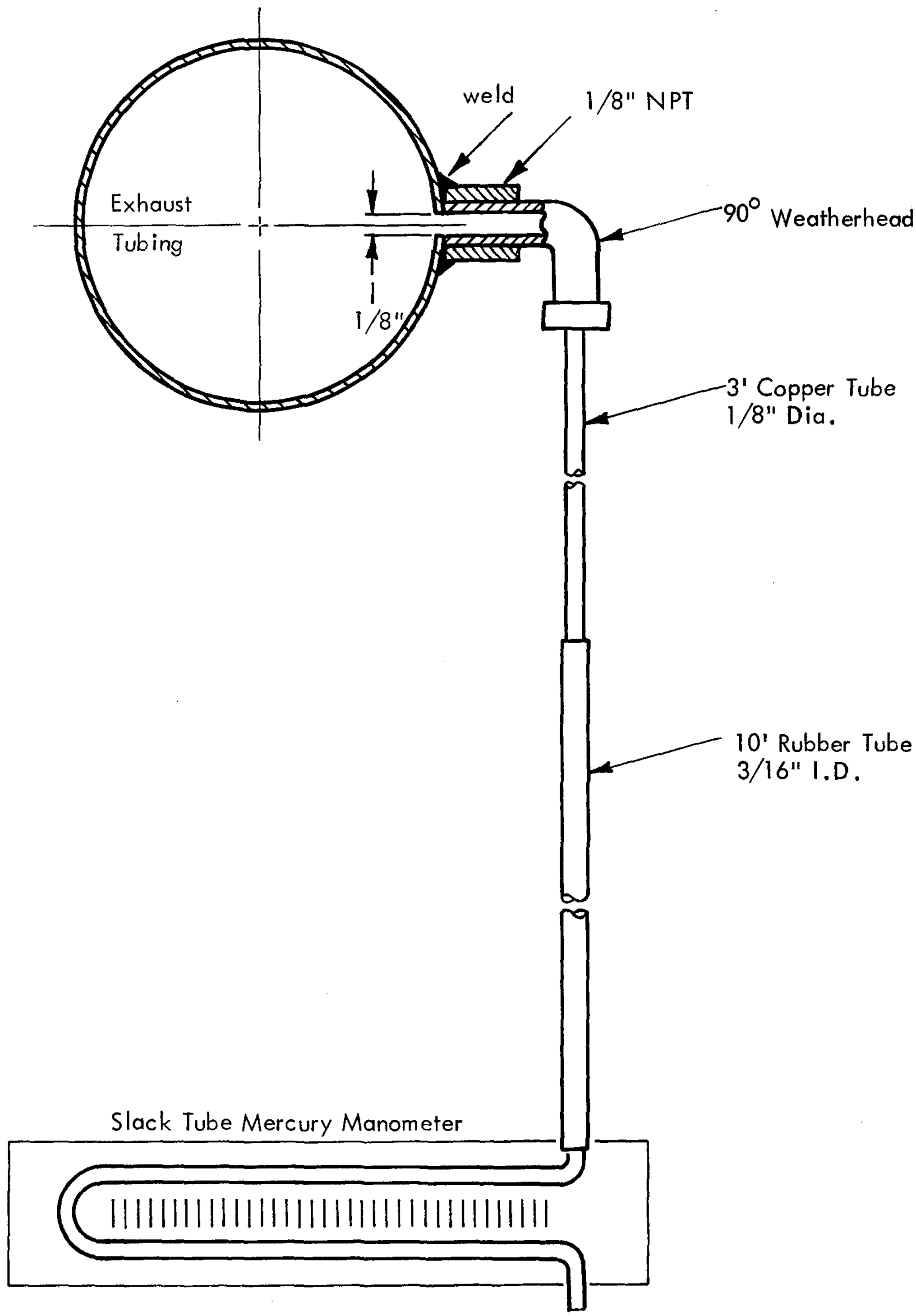


Figure H-3. Schematic of Recommended Back Pressure Measurement Set-up

APPENDIX I

REPORT OF NEW TECHNOLOGY

After a diligent review of the work performed under the contract on Noise Abatement Techniques for Transportation Construction Equipment, it has been determined that no innovation, discovery, or invention has been made. However, Section 4 of the report can be used as a handbook for construction equipment owners and operators. This handbook is designed to carry personnel through a systematic process for determining if exhaust noise is a problem, to selecting and installing a complete exhaust system. Tests on equipment with factory installed mufflers indicate that improved muffling will generally lower overall equipment levels by one (1) to three (3) DB(A). In cases where a particular piece of equipment either does not have or has a poor muffler, application of a good muffler will reduce overall noise by six (6) to twelve (12) DB(A).

(See Section 3.5 and Appendix G)

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