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PRELIMINARY COST AND TECHNOLOGY INFORMATION ON MEDIUM AND HEAVY DUTY TRUCKS

JUNE 1974

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL
WASHINGTON, D.C. 20460

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FOREWORD

This document contains preliminary cost and technology information that is being used to develop noise regulations for newly manufactured medium and heavy duty trucks. The information presented here does not represent an EPA position nor does it represent all the technical information that will be used to develop the regulation.

Medium and heavy duty trucks have been identified as a major source of noise, and public participation in the regulatory process is desired by EPA. Accordingly, comments on all aspects of medium and heavy duty truck regulation are welcome.

Alvin F. Meyer, Jr.
Deputy Assistant Administrator
for Noise Control Programs

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SECTION 1
INTRODUCTION

The general objectives of this document are to provide an estimate of technological requirements for truck propulsion system noise control and the attendant costs. These costs refer to the manufacture of new trucks and are not appropriate estimates for noise reduction through retrofit of existing trucks.

Because the costs are nonuniform, variations among companies rather than only average figures are examined. Consequently, this information has a natural bias toward those manufacturers who provided data. Data on nonparticipating manufacturers have been gathered from the open literature.

Most truck (and engine) manufacturers were contacted directly and data were obtained on the noise of present production trucks, estimates of noise levels that could be achieved, and attendant costs. However, total truck noise levels and costs are inadequate for our purpose for two reasons. First, noise control is a relatively new requirement for most manufacturers, several of whom have not yet assessed the technological requirements and costs of reaching levels much beyond those which will be required by certain cities and states in the near future. Secondly, most truck manufacturers rely on the same component suppliers, whose products differ substantially in noise level. Thus, the impact of truck noise regulations is likely to be felt by certain suppliers perhaps to a greater degree than by truck manufacturers. Accordingly, data were obtained on truck components to analyze treatments that might be performed to quiet trucks using various components.

In this document, Section 2 provides a brief overview of the truck industry, including the MVMA categories by which trucks are classified. Section 3 presents baseline noise and performance data, discussing (1) various test procedures and their relevance to environmental noise, and (2) variations in noise levels attributable to unit-to-unit variations, test site nonuniformities, and instrument error. Section 4 examines the major sources of truck noise, present quieting techniques, and demonstrated technology. In Section 5, curves of noise level vs cost are developed for various truck and engine types. These curves are based on estimates provided by manufacturers and EPA contractors.

For the purpose of evaluation, the costs of meeting noise levels of 86, 83, 80, and 75 dBA as measured according to SAE J366a, are estimated in this document. The first level represents a baseline that all manufacturers are now reaching with "off-the-shelf" hardware for new trucks marketed in jurisdictions that enforce noise standards, such as the state of California. (Trucks marketed elsewhere often exceed 86 dBA.) The second level, 83 dBA, is significant because some new trucks will be able to achieve it easily while other new trucks will require engine or under-hood treatment. Nevertheless, truck manufacturers could achieve this level with most engines and off-the-shelf hardware. The third level, 80 dBA, is one that could be reached with some diesel engines but not with others, even using off-the-shelf hardware. Accordingly, an 80 dBA level would require either (1) the use of a minority of presently available diesel engines, (2) the development of quieter engines by major engine manufacturers, or (3) the development and application of engine enclosures to most new diesel trucks in present production. Finally, 75 dBA is approximately the level that may be achieved with the application of presently available technology. To meet a 75 dBA level, every diesel truck currently being manufactured would require an engine enclosure.

In this document, the term "off-the-shelf" is used to designate hardware that has been thoroughly tested and produced at least in small quantities. An assessment of the capability of industry to produce such hardware in volume is beyond the scope of this document.

SECTION 2

CURRENT TRUCK CLASSES AND OPERATIONS

DESIGN TYPES

There are three major truck designs which reflect the three major uses for trucks. A truck-tractor for pulling heavy semitrailers is called a line haul truck. A ruggedly built cab-chassis for mounting dump beds or concrete mixers is a construction truck, and a light cab-chassis for mounting van bodies is a general delivery truck.

In addition to these use designations, trucks can be classified by cab style. The two main types are conventional cab and cab-over-engine. In a conventional cab (sometimes termed a "fixed" cab) the driver sits behind an engine which is covered by a hood. Conventional cab styles are further subdivided into "short" (Figure 1) and "long" depending on the length of the hood. The cab-over-engine style (COE) has the driver positioned above (and to the side of) the engine. COE styles are also divided into two subcategories, "low" (Figure 2) and "high", depending on the distance of the deck (or floor of the cab) above the ground. The deck of a low deck COE is less than 40 in. above the ground, and the driver can step directly into the cab (typically a general delivery truck). High deck COE's require the driver to climb up a ladder to enter the cab.

Trucks are further classified by drive line, the manner of transmitting the engine power as traction at the road surface. For trucks with two axles, one of which drives the truck (as in an automobile), the designation is 2 x 4, that is, two out of four wheels driving (dual tires only count as one wheel). Similarly, a tandem axle truck-tractor is a 4 x 6 and an all-wheel drive is a 4 x 4 or 6 x 6. Finally, current production trucks are normally powered by either gasoline or diesel fuel, although in the future, it is anticipated that gas turbine engines

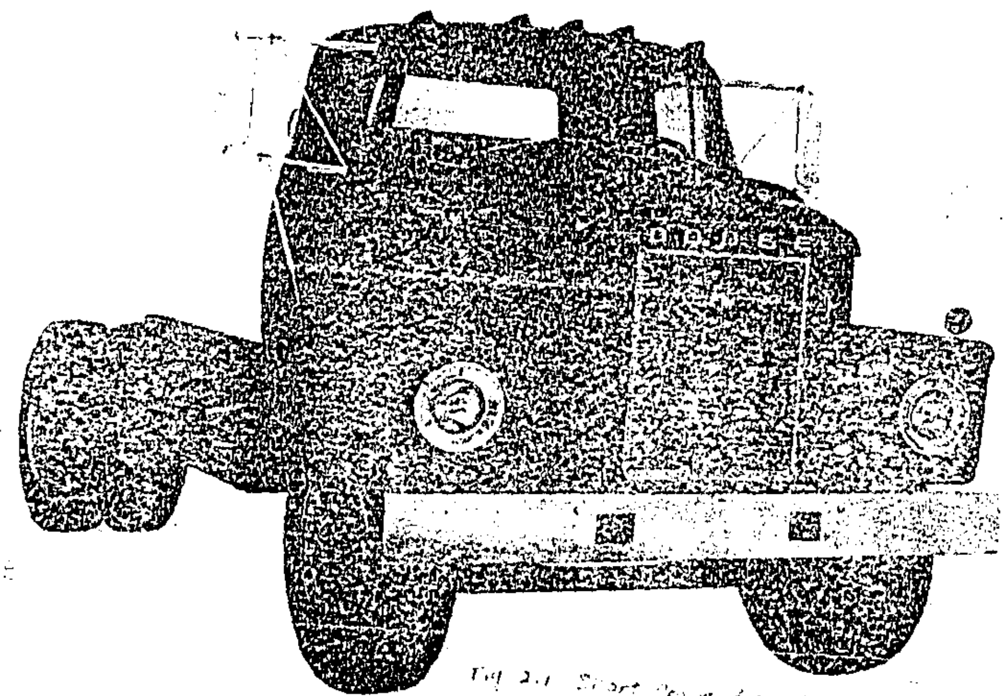

Figure 1. Short Conventional Cab

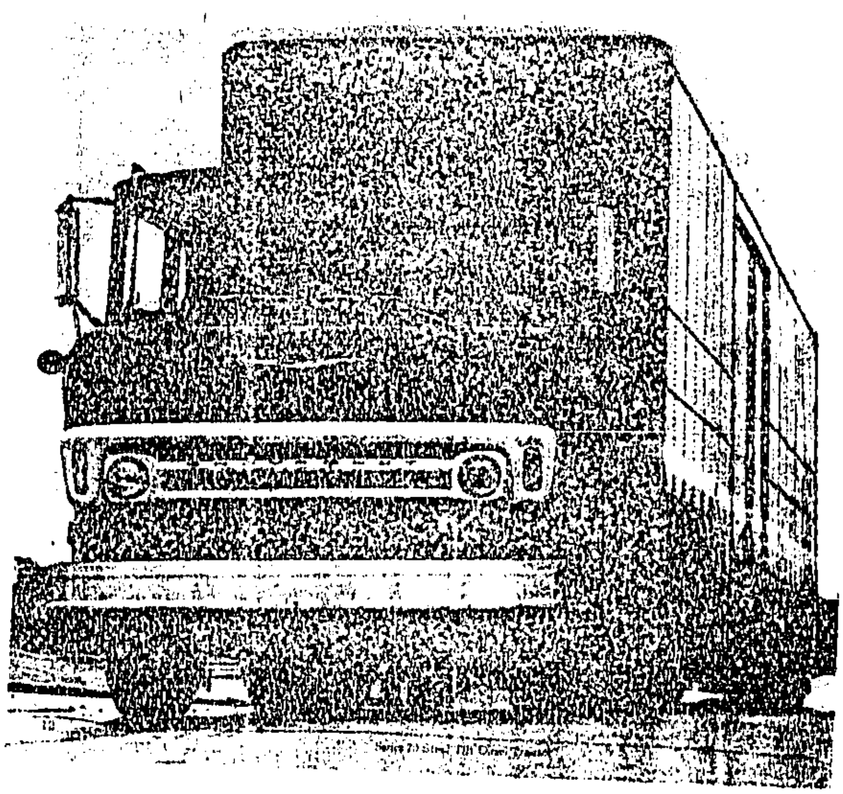

Fig 2.2 Low Deck Cab-Over-Engine

Figure 2. Low Deck Cab-Over-Engine

will enter the market in increasing numbers. Table 1 lists the major truck configurations and styles in use today.

TABLE 1

TRUCK CONFIGURATIONS AND STYLES

Type of Truck	Cab Style	Type of Engine	Drive Line
Line-haul	Long Conventional	Gasoline	2 x 4
Construction	Short Conventional	Diesel	4 x 4
General Delivery	Low-Deck COE		4 x 6
	High-Deck COE		6 x 6

DISTRIBUTION OF TRUCKS BY WEIGHT CLASS AND ENGINE TYPE

Load-bearing capacity is yet another basis for classifying trucks. The present MVMA weight classifications are given in Table 2. A truck's gross vehicle weight rating (GVWR) is based on its rated axle capacity. Thus, the net payload capacity of a truck is its GVWR minus its tare or "street weight." In this document trucks are divided into two classes: medium-duty trucks weighing 10,001 - 26,000 lb GVWR and heavy-duty trucks of over 26,000 lb GVWR. Table 2 gives the Motor Vehicle Manufacturers Association (MVMA) totals of domestic truck production in 1972 by weight class and engine type.

TABLE 2

FACTORY TRUCK SALES IN THE UNITED STATES - 1972

	Class	Weight (GVWR)	No. Gasoline	% Gasoline	No. Diesel	% Diesel
Medium Duty	3	10,001 - 14,000	44,221	100	0	0
	4	14,001 - 16,000	9,397	98	215	2
	5	16,001 - 19,500	26,330	100	41	0
	6	19,501 - 26,000	147,315	97	4,789	3
		TOTAL	227,263	98	5,045	2
Heavy Duty	7	26,001 - 33,000	25,364.	65	13,563	35
	8	Over 33,000	16,630	12	124,481	88
		TOTAL	41,994	23	138,044	77
		GRAND TOTAL	269,257	65	143,089	33

Table 3 gives the weight and engine types of trucks produced by various manufacturers in 1972. Information about the distribution of diesel engines by truck manufacturers is contained in Table 4. These tables indicate the distribution of truck production in 1972 and show the relative market share of manufacturers by weight and fuel.

TABLE 3

NUMBER OF TRUCKS BY MANUFACTURER, WEIGHT AND ENGINE TYPE

Manufacturer	Medium Duty			Heavy Duty		
	Total	Gasoline	Diesel	Total	Gasoline	Diesel
Chevrolet	53,857	53,722	135	5,298	1,602	3,696
Diamond Reo	37	37	-	4,251	1,044	3,207
Dodge	45,320	44,042	278	5,103	3,623	1,480
FWD	12	4	8	897	291	606
Ford	66,554	63,544	3101	32,776	13,952	18,824
GMC	26,014	25,568	446	24,143	8,126	16,017
IHC	40,229	39,064	1165	41,541	12,230	29,311
Mack[1]	0	0	0	26,356	25	26,331
White[2]	3	0	3	22,607	753	21,854
Others	282	282	0	17,056	338	16,718

[1] Includes Brockway.

[2] Includes Freightliner, Autocar, Western Star.

TABLE 4

DIESEL ENGINES USED BY U.S. TRUCK MANUFACTURERS - 1972

Manufacturers	Allis-Chalmers	Caterpillar	Cummins	Detroit Diesel	GMC	IHC	Mack	Perkins	Scania Vabis	Total
Chevrolet			308	3,388	135					3,831
Diamond Reo		129	2,038	1,040						3,207
Dodge			1,046	434				278		1,758
FWD		1	165	448						614
Ford		9,336	4,759	7,739						21,834
GMC			1,255	14,599	609					16,463
IHC		747	11,830	14,475		2742		682		30,476
Mack	22	331	2,612	1,584			21,121		661	26,331
White	44	799	15,513	5,501						21,857
Others		3,736	8,983	3,999						16,718
Total	66	15,079	48,509	53,207	744	2742	21,121	960	661	143,089

SECTION 3

BASELINE NOISE CHARACTERISTICS

In this section baseline noise data is given for present production trucks. This is the starting point from which noise regulations will impact truck noise emissions. The section begins with a brief discussion of the relationship between environmental noise and noise measured under carefully controlled conditions according to existing standard measurement procedures. Then current data on trucks is presented from which noise levels are identified for use in subsequent evaluations of noise control vs cost. Also, distributions of truck noise and corresponding engine noise data are presented to indicate the levels that have been achieved without the application of significant engine treatment.

TRUCK NOISE AND MEASUREMENT STANDARDS

Ideally, a measurement standard for a motor vehicle (or vehicle component) prescribes a test that is simple to conduct, reliable, but--above all--correlates well with the parameter that the test result is supposed to indicate. Thus, test standards for truck exterior noise levels should correlate well with the environmental noise generated by trucks in normal service; test standards for measuring engine noise in the laboratory should yield numerical ratings that can be interpreted in terms of the engine's contribution to truck noise. SAE J366a is currently being used by the motor vehicle industry, and forms the basis for much of the data reported here.

TRUCK NOISE

The noise generated by trucks on the road depends in part on the way in which they are operated. In general terms, truck operation may be classified as highway cruise (i.e., high speed), medium- and low-speed cruise, acceleration and hill climbing, and braking.

During highway cruise (typically at 55-65 mph), the engine and drive train* are fully loaded most of the time. The engine operates at maximum rpm, thereby generating maximum noise; the tires also generate maximum noise. However, at high speeds, tire noise generally exceeds drive train noise.

During acceleration and hill-climbing, the drive train is fully loaded and producing maximum noise, since most trucks have transmissions with a large number of gear steps to permit engine operation at near maximum engine speed and power. Under these conditions the tires turn more slowly and are a lesser contributor to overall truck noise.

MEASUREMENT STANDARDS

The existing standard that has been widely used in the past for the measurement of low-speed truck noise is the SAE J366a recommended practice, which is appended to this document. The SAE J366a procedure is aimed at measuring drive train noise and requires a truck to accelerate at full throttle and low speed past a microphone placed 50 feet from the center line of the truck's path. The truck drives past the microphone several times in both directions, and the peak noise level in dBA is noted for each passby. The level reported is the average of the two highest peak levels corresponding to the noisiest side of the vehicle.

<u>NOISE OF CURRENT TRUCKS</u>

Trucks may be classified by load-carrying capacity (as discussed in Section 2) and according to whether they have gasoline or diesel engines. From the point of view of noise, the load-carrying capacity of a truck is not especially relevant. However, whether a truck is powered by a gasoline or diesel engine is crucial. Diesel engines tend to radiate substantially higher levels of noise from their structures than do gasoline engines as a result of the fundamentally different combustion processes. Quieting engine structural sound is generally far more expensive than quieting other sources (e.g., the exhaust) and merits

*"Drive train" in this document means the engine and all its accessories, including the fan, transmission, and rear axle(s).

special attention. On the other hand, the heat rejection rates per horsepower are greater for gasoline than diesel engines. Accordingly, for equal horsepower, trucks with gasoline engines require more cooling air flow that is often achieved with higher-speed noisier fans. For these reasons it is desirable to categorize trucks by engine type.

Figure 3 is a histogram of the noise level of all new diesel trucks (for which it was possible to collect data) measured according to the SAE J366a test procedure. From a sample of 384 vehicles, the mean noise level is 84.7 dBA and the standard deviation is 2.24 dBA. The data in Figure 3 include models from eight manufacturers which account for approximately 85 percent of the diesel trucks sold in 1972. Not included are experimental models, such as those developed under the DOT quiet truck program or with internal funds from various manufacturers. The data set in Figure 3 is not necessarily an unbiased sample. Some manufacturers supplied a great deal more data than others. No attempt was made to weight these data by the sales volume of each model for each manufacturer, since such statistics are not available.

Figure 4 shows a cumulative distribution corresponding to the histogram in Figure 3. It is interesting to note that approximately 1 percent of the diesel trucks are 80 dBA or less, 30 percent are under 83 dBA, and 85 percent are under 86 dBA. Nevertheless, several diesel trucks are rated in excess of 90 dBA.

Data on trucks with gasoline engines are shown in Figure 5. Data are grouped in terms of medium and heavy duty vehicles. The mean value of 84.7 dBA for the heavy duty gasoline trucks is less than 2 dBA higher than the mean of the medium duty gasoline trucks. However, the sample size is not sufficiently large to regard this difference as particularly significant.

It is interesting to note that the difference between the mean noise levels of gasoline and diesel trucks is only 1.2 dBA. The reason for the small difference between noise emissions from gasoline and diesel trucks is not the difference in engine noise, which is significantly greater than 1.2 dBA. Noise control

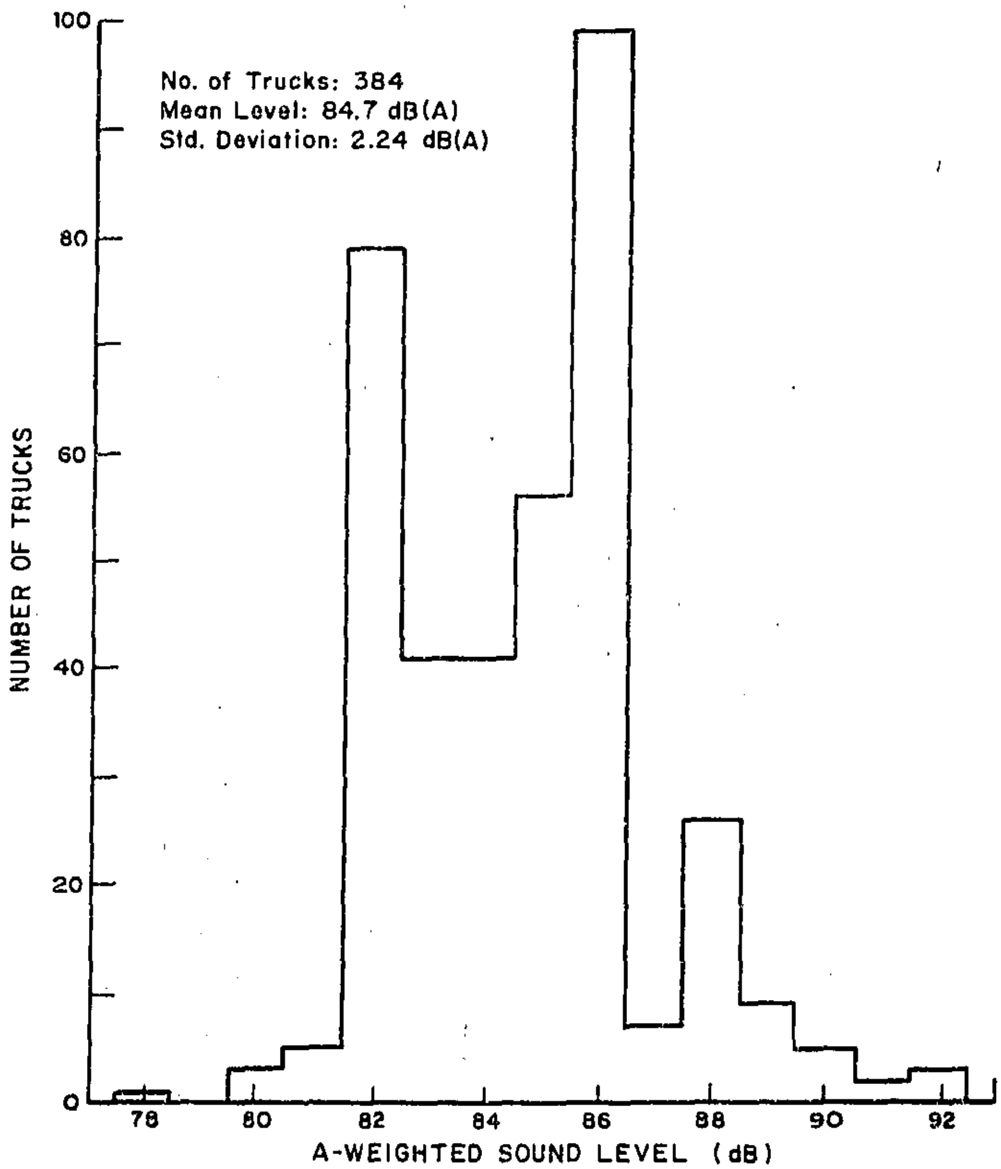

Figure 3. Histogram of New Diesel Truck Noise Levels Measured According to the SAE J366a Recommended Practice

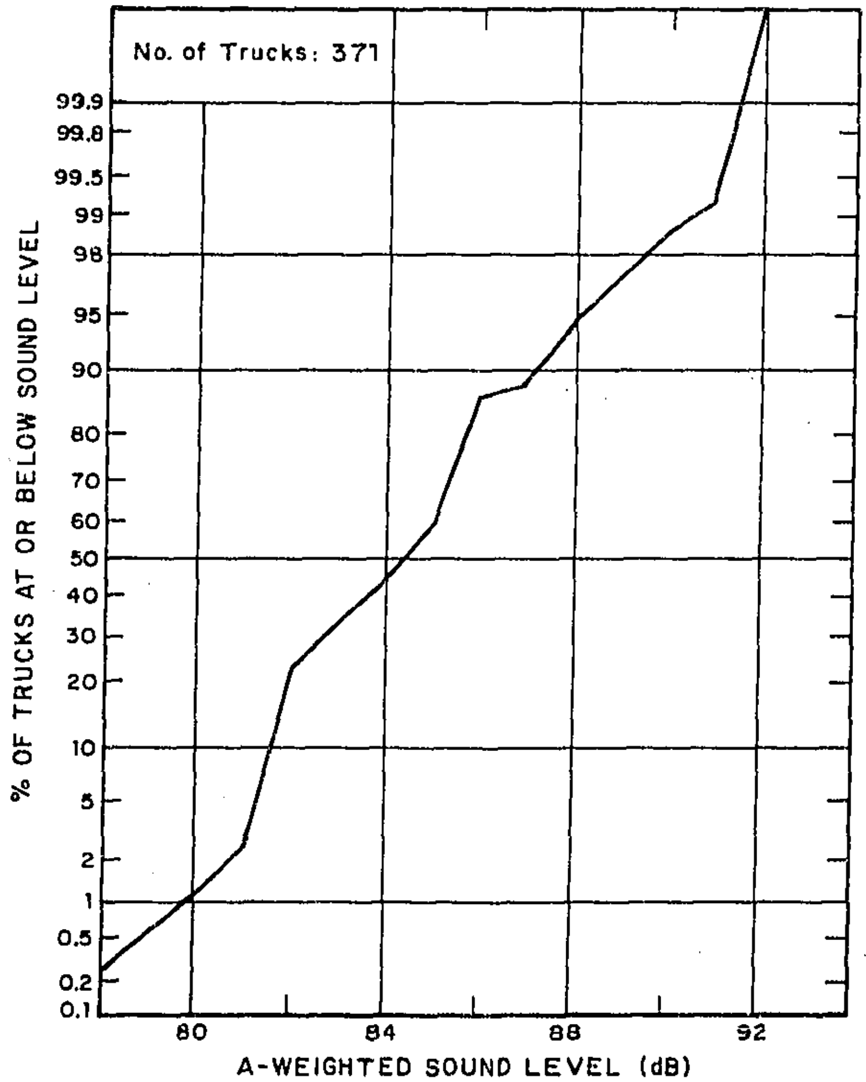

Figure 4. Cumulative Distribution of New Diesel Truck Noise Levels Measured According to SAE J366a Recommended Practice

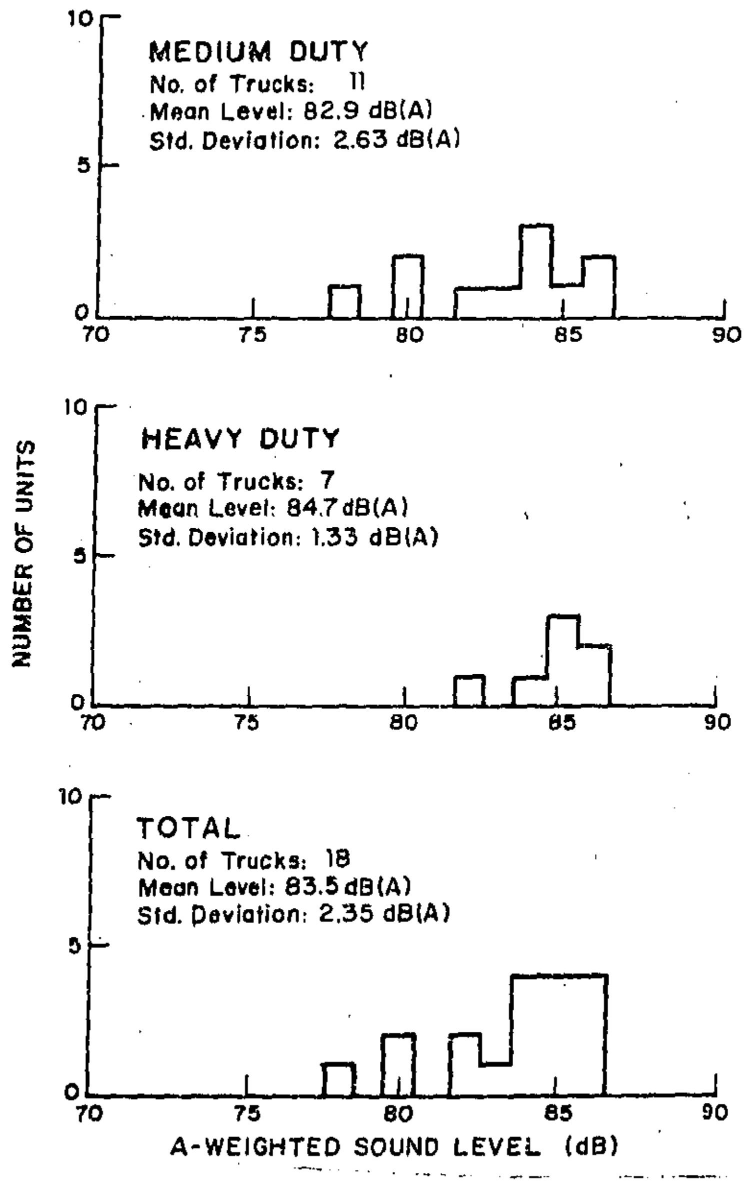

Figure 5. Histograms of Noise Levels of Medium and Heavy Duty Gasoline-Powered Trucks

generally requires greater manufacturing cost, and presently there is little marketplace demand for trucks that are quieter than 86 dBA, regardless of whether they are gasoline or diesel.

NOISE OF CURRENT DIESEL ENGINES

As indicated earlier, diesel engine noise is a key element in overall truck noise control because of the relatively large costs of quieting these engines. In this subsection data is presented on the noise of some current production diesel engines and the noise of trucks using them. The engine data are divided into four horsepower ranges (200-250, 251-300, 301-350, and 351-400) to permit an evaluation of engine interchangeability for purposes of noise control. (Obviously, considerations of cost, durability, ease of maintenance, and many other factors are involved in engine selection and must be accounted for in any detailed study of interchangeability.)

The data on engines and truck noise for the above four horsepower categories are displayed in Figure 6-9. Several histograms are shown in each figure. Each histogram corresponds to a specific diesel engine model (which is not identified owing to the proprietary nature of the data). Along with engine noise levels are total noise levels of trucks using corresponding engines. These data indicate several trends. First, there is a significant range in truck noise levels--as much as 8 dBA--for a given model of engine. This range is substantially greater than the range of noise levels within a given model line which, owing to imprecisions in diagnostic techniques, generally appears greater than it would actually be. The range in truck noise levels results principally from the use of nonuniform muffler and cooling systems with different exhaust and fan noise contributions.

SECTION 4

COMPONENT CONTRIBUTIONS, NOISE CONTROL, AND COST

Many truck components contribute significantly to total truck noise levels. The low-frequency sound often heard from highway trucks typically emanates from the exhaust. Higher frequency sound is generally caused by radiation from the engine inlet, the engine structure, and the fan. At high speeds, tires often dominate the total truck noise level. Other sources, such as the differential(s), transmission, air compressor, and other accessories contribute noise, but generally at lower levels. In this section, noise level data are presented for major truck component sources (the engine structure, exhaust, intake, and fan), and the abatement technology and cost of quieting each component is evaluated.

ENGINE STRUCTURE

Noise radiated externally from the engine structure is created by the vibration of the engine surface and appended covers. The relative magnitude of the noise varies with the engine type and design. Engine size or power is not a determining factor in engine noise. Figure 10 shows engine noise source levels in trucks as a function of engine horsepower. Figure 11 is a histogram of these source levels. The three gasoline-fueled engines are in the 75-77 dBA range, indicating that total gasoline-truck noise levels of approximately 80 dBA are attainable without engine enclosures involving major cab redesign. Diesel engine noise levels, however, range from 76 to 85 dBA with groupings at 76-77, 79-81, and 85 dBA. For trucks using these engines, reaching a total noise level of 83 dBA without major cab redesign will require the use of engine quieting packages now marketed by certain manufacturers of noisier engines. Note, however, that two diesel engines have a source level of 82 dBA even with the quieting package installed. For these engines additional noise control

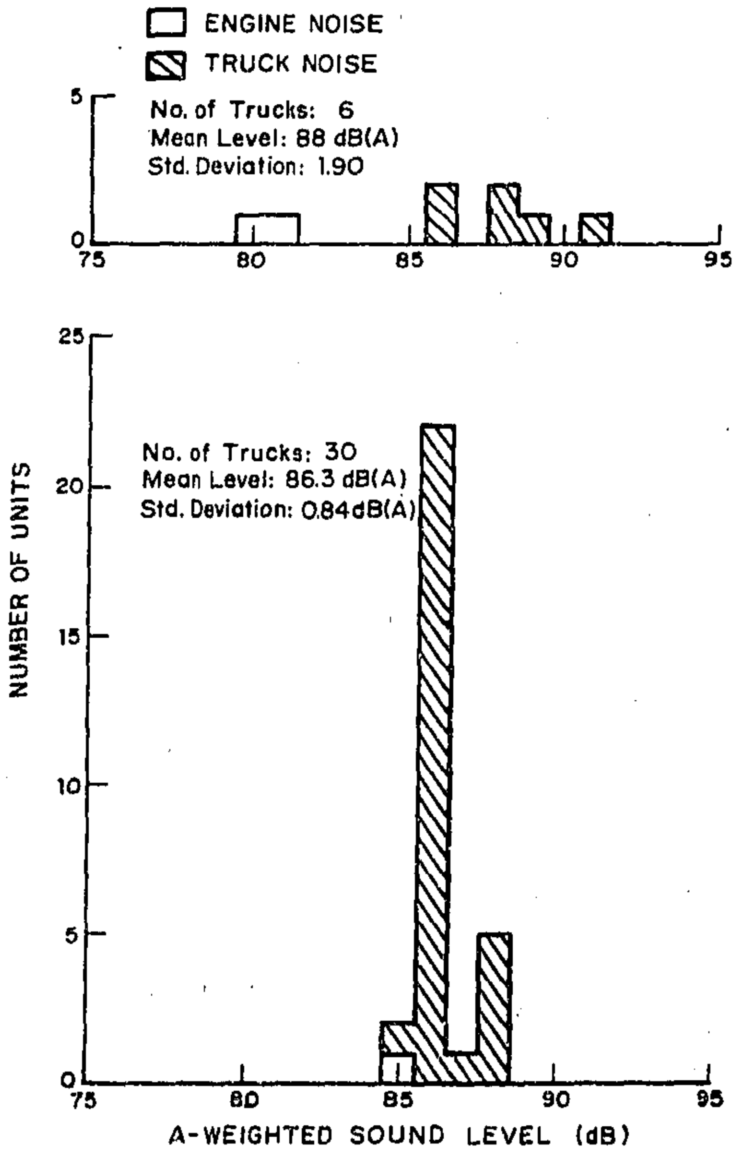

Figure 6. Histograms of Noise Levels of Two Diesel Engines in the 200-250 HP Class and Trucks Using these Engines

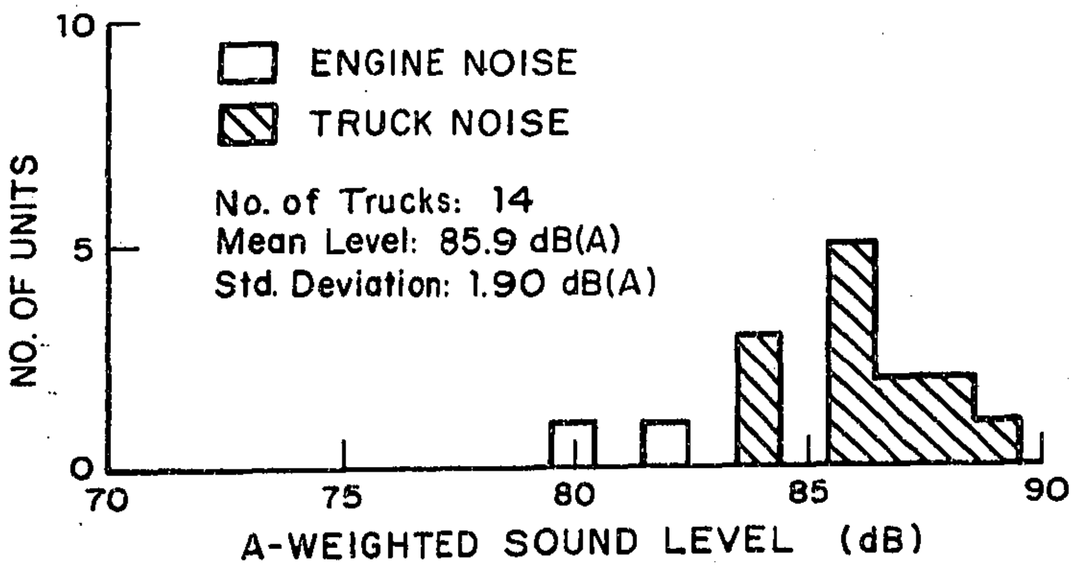

Figure 7. Histograms of Noise Levels of One Diesel Engine in the 251-300 HP Class and Trucks Using this Engine

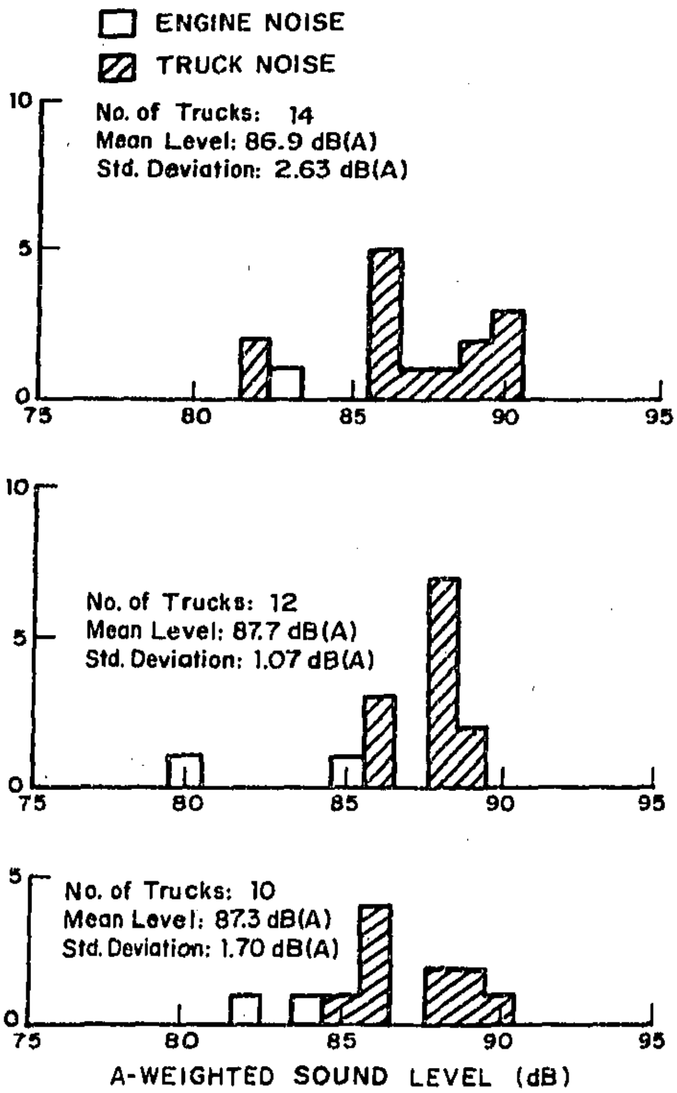

Figure 8. Histograms of Noise Levels of Three Diesel Engines in the 301-350 HP Class and Trucks Using these Engines

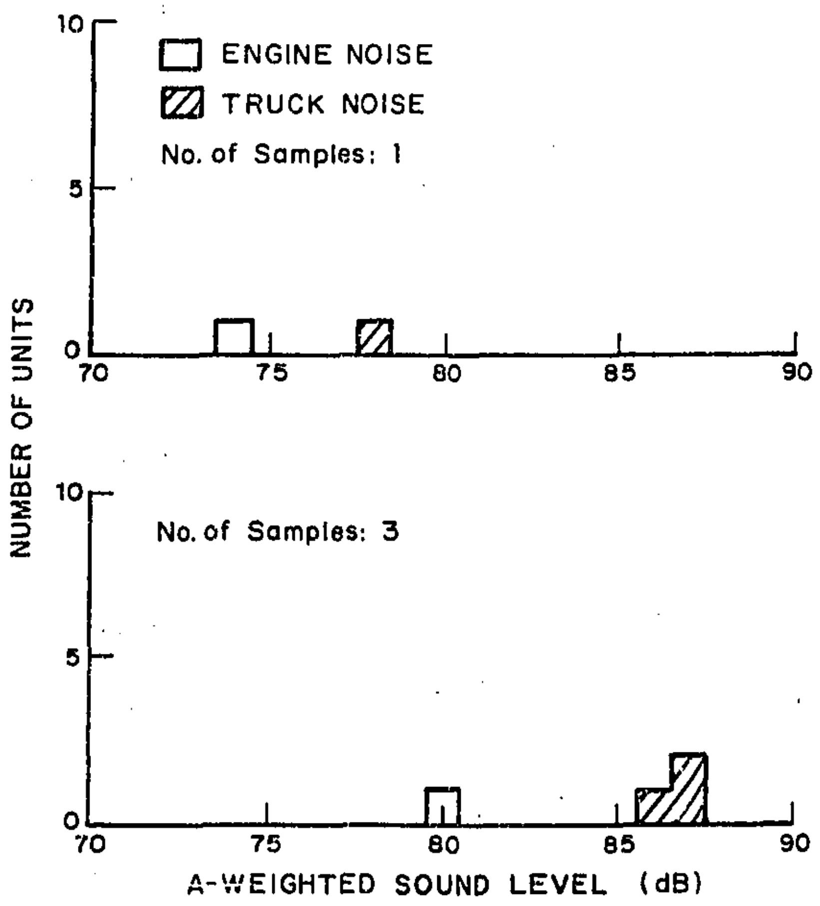

Figure 9. Histograms of Noise Levels of Two Diesel Engines in the 351-400 HP Class and Trucks Using these Engines

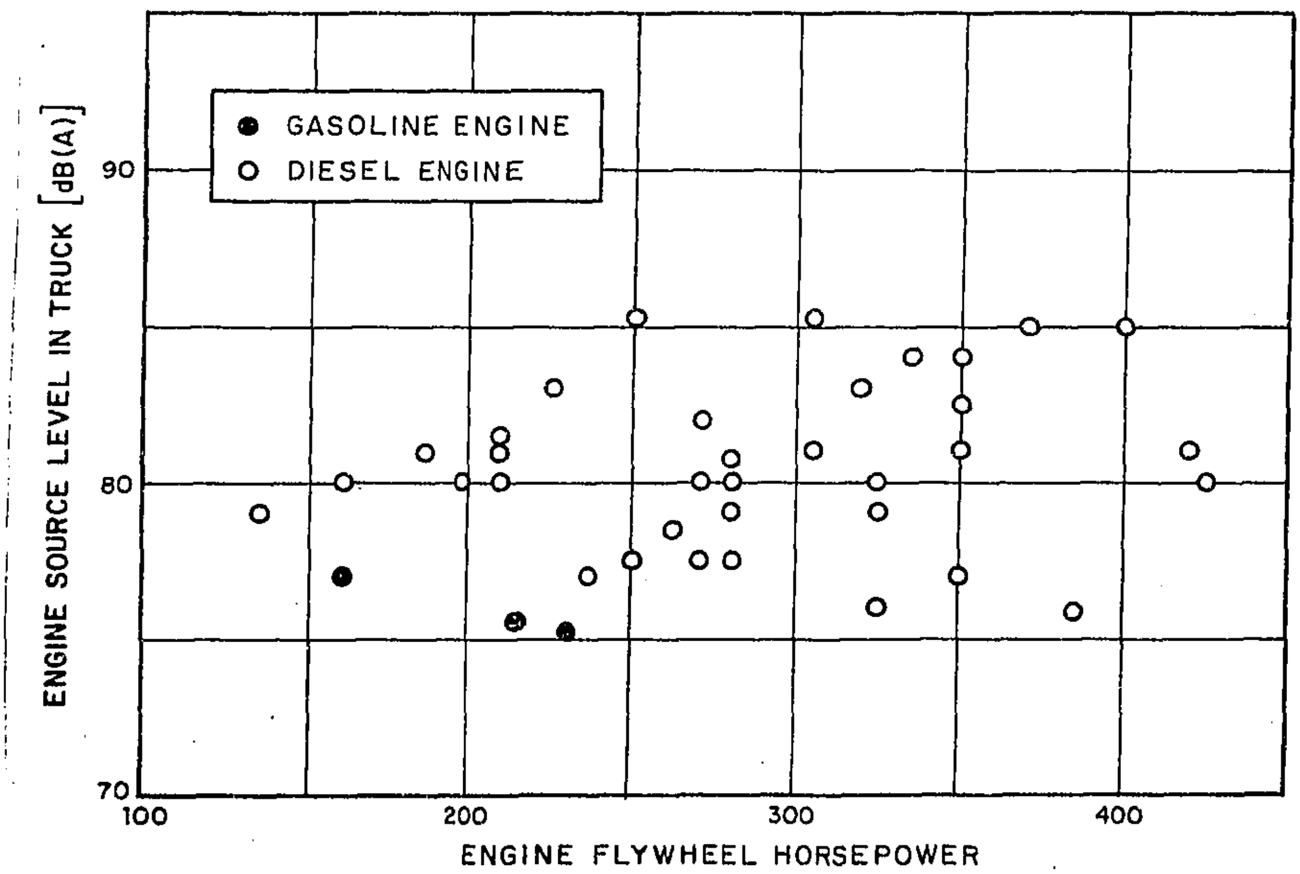

Figure 10. Engine Noise as a Function of Horsepower

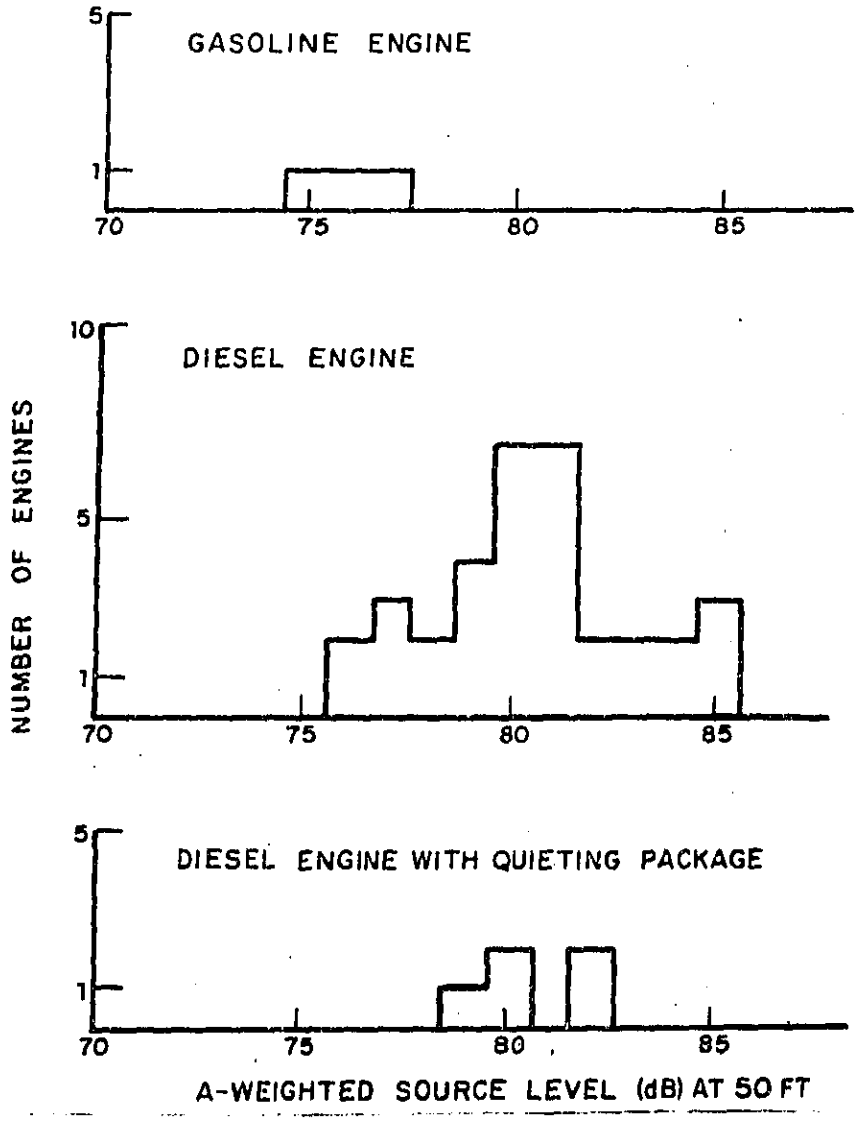

Figure 11. Histograms of Heavy Truck Engine Structure Noise (Engine in Truck)

measures will be required of the truck builder, including some cab redesign such as side shields, with sound absorbing lining either under the hood of conventional tractors or on tunnel surfaces of COE tractors. Alternative measures include the design of better engine quieting packages by the engine manufacturers. Thus, engine structural noise is an important consideration in quieting overall truck noise. To explain further the mechanism and control of engine structural noise, present production engines must be examined.

MECHANISM OF ENGINE STRUCTURAL NOISE

Internal combustion engines convert the chemical energy of fuels to mechanical energy. This conversion is accomplished through the controlled combustion of the fuels in a cylinder to push a piston connected to a crankshaft. The motion of engine components, such as pistons and fuel injectors, and the sudden increase in cylinder pressure occurring during combustion excites the engine structure, causing vibration of the external surfaces and attendant noise radiation.

The machinery-related forces are caused by the oscillating pistons slapping the cylinder walls (Ungar and Ross, 1965), by the oscillating moments generated by the linkage translating lateral motion to rotating motion, and by the valves and gear trains inherent in the system (Hanaoka and Fukumura, 1973). Other mechanical linkages and components such as fuel pumps, superchargers, and turbochargers are additive sources of vibratory forces and motions.

The combustion-related forces are generated by the rapid combustion of the fuel in the cylinder. Combustion (actually a detonation or explosion) creates a pressure force on the piston, the cylinder wall, and the cylinder head. These exposive pressures are periodic at a rate corresponding to one-half of the crankshaft rotational rate per cylinder for 4-stroke cycle engines and at the crankshaft rotational rate for 2-stroke cycle engines. The relation between the cylinder pressures and engine noise has been investigated (Priede et al, 1967; Anderton and Baker, 1973; Tiede and Kubele, 1973). In present production diesel engines, the combustion process involves a rapid pressure rise in the cylinder, generating mid- to high-frequency forces. Thus, the general reason for higher source levels in diesel engines than gasoline engines is the greater relative strength of the combustion forces, especially in the mid- to high-frequencies where resonant structural vibration modes are present in the engine. Reducing the combustion forces to achieve noise reduction also reduces the pressure on the piston with attendant power reduction. The pressure parameter that is closely related to the power output of the engine is the brake mean effective pressure or BMEP.* Any noise control method which reduces the BMEP will also reduce the power output of the engine. Therefore, the object of combustion-related noise reduction should be to smooth the pressure-time history of cylinder pressure such that the rapid rise in pressure is reduced (Tiede and Kubele, 1973). Controlling the fuel delivery rate in diesels is possible but at present difficult to achieve with production tolerances in the injection system. An alternative solution is to use a turbocharger on 4-stroke cycle engines. Turbocharging consists of an exhaust gas-drive impeller coupled to another impeller which pumps induction air into the cylinders. With the increased induction air supply, the peak cylinder pressures are higher but the rate of pressure rise is slower with attendant reduction in spectral pressure forces in the mid- to high-frequencies. Another technique is to redesign the combustion chamber and injector spray pattern to smooth the cylinder pressure-time history (Priede et al, 1967). At present, all of the above solutions are being tested by the major engine manufacturers. Turbocharging in particular is being used; one major manufacturer is phasing all naturally aspirated engines out of production, replacing them with turbocharged models.

Control of machinery forces in present engines is aimed primarily at reducing or changing the structural response of the engine. Investigators are experimenting with better ways to support the piston in the cylinder and are trying to obtain better balance and closer tolerances in production engines. One manufacturer designed and built a truck having an overall noise level of 75 dBA without an enclosure by using a turbocharged diesel engine with

*BMEP is defined according to the power output and is not an actual measure of the cylinder pressure.

balanced parts and closer tolerances. Mass production of this truck would be difficult at present, but it is an example of how a quiet engine can result in a quiet truck without the major cab redesign required to reduce the noise of present engines.

AVAILABLE TECHNOLOGY FOR ENGINE NOISE CONTROL

As discussed in the previous section, the presently available (off-the-shelf) technology for the control of engine structural noise is centered on the turbocharging as a means of reducing the rate of cylinder pressure rise. In addition, most manufacturers are currently marketing close-fitting engine covers to attenuate this noise. Although the covers do not control the source of engine structural noise, they do alter its transmission to external observers.

Depending on the particular cover used and the truck configuration, engine noise reduction ranges from 0 to 4 dBA. Most of the engine quieting packages provide about 2-3 dBA of engine noise reduction. These packages consist of covers for the sides of the engine block and the oil pan, vibration isolation of the valve covers or air intake manifolds and crossovers, and possibly damping treatment on sheet metal covers (Jenkins and Kuehner, 1973). Thien (1973) reports even greater reduction, on the order of 15-20 dBA, in laboratory studies of close fitting covers that extend over the entire engine structure. Discussions with one major engine manufacturer indicate that the actual noise reduction for the whole truck would be about 10-15 dBA. This is a significant reduction and means that 75-dBA trucks could be built (equipped with advanced fan and muffling systems) without requiring major cab redesign. The engine manufacturers also indicated that these covers were not presently acceptable because of cooling and service access problems.

To reach the 75 dBA overall truck noise level, most engine manufacturers would prefer to use an enclosure built into the truck cab rather than fitted to the engine. Such external enclosures have been investigated by three truck manufacturers (International Harvester Corp., White Motor Co., Freightliner, Inc.) under the auspices of the DOT quiet truck program. All of the enclosure designs were of a tunnel configuration with the cooling fan at the enclosure entrance. Air flows through the enclosure and around the engine via acoustically lined ducts. At present, design and operation cost information are available only for the Freightliner truck (Averill and Patterson, 1973). The Freightliner quiet truck uses a large frontal area radiator to provide a low pressure drop and high flow rates of air moving through the radiator core. Increased "ram air" dur to forward motion of the truck reduces cooling fan requirements. In addition, a larger engine tunnel formed by the underside of the cab gives more room for the cooling air to flow past the engine.

In summary, then, full or partial enclosures built into the cab structure are technologically feasible as a noise reduction technique. The enclosures will be necessary to reduce the overall noise of trucks equipped with standard diesel engines to 75 dBA. Fewer trucks will require enclosures to meet an 80-dBA goal.

ENGINE VIBRATION

The significance of engine vibration transmitted to the cab and exhaust piping structure as a source of truck noise has been documented during the quiet truck program (Averill and Patterson, 1973; Bender and Patterson, 1973). The estimated noise level radiated from an exhaust pipe excited by engine vibration is 71 dBA. For a truck with a completely enclosed engine, energy transmitted through the engine mounts resulted in radiation from the truck structure of 65-70 dBA. For overall truck noise levels of 83 to 80 dBA, these sources are not considered to be a major problem; however, to achieve 80 dBA, some trucks will require vibration isolation of the exhaust system. Before an overall level of 75 dBA can be attained, the transmission path of engine vibration to the frame and cab as well as the exhaust system must be evaluated. Reducing engine vibration transmission requires better isolators and/or different mounting points for attaching the engine to the frame. Most truck builders do not have the equipment or the staff to do this, but the technology is available.

EXHAUST SYSTEMS

Exhaust-related noise actually consists of two distinct sources: outlet noise and shell radiation. Outlet noise emanates from the exhaust system terminus and is generated by the pressure pulses of exhaust gases from the engine. The amplitude of these pressure pulses is such that unmuffled exhaust outlet noise for diesel engines can range from 82 to 105 dBA at 50 feet (see Table 5) (Hunt et al, 1973). Exhaust shell-related noise consists of radiation from the external surfaces of the pipes and mufflers of the exhaust system. Exhaust shell noise is generated by two mechanisms, the transmission and subsequent radiation of engine vibration to the exhaust system and the transmission of internal sound to the exterior of the pipe. For the Freightliner quiet truck, Bender and Patterson (1973) found that the vibration path was dominant for the exhaust pipe and that some vibration isolation was required for noise reduction. For the muffler, the internal sound is the dominant source of shell noise and double walls are required to reduce the noise. The relative magnitude of exhaust shell noise is such that very few trucks will require modification to reach overall noise levels of 83 dBA at 50 feet. To achieve 80 dBA, most trucks will require mufflers with an outer wrapping and vibration-isolated exhaust clamps to mount the exhaust pipe to the engine. To achieve the 75 dBA level, all exposed exhaust pipes must be wrapped to increase the transmission loss and isolate the shell vibration.

One factor which must be considered in the selection of a muffler is the back pressure it creates. Some of the work that the engine performs during operation is expended on pushing exhaust gasses out the exhaust port. When a muffling system is installed, higher exhaust gas pressure (hence, more engine work) is usually required to overcome the added resistance. Back pressure is the parameter which defines the magnitude of this added work in the pipe leading from the exhaust manifold. The pressure is usually defined in terms of inches of water or mercury (Hg). A comparison of the back pressure developed by several muffler systems shows that some quiet systems have the same flow resistance as noisier ones; therefore, systems are available with source levels

TABLE 5

UNMUFFLED EXHAUST OUTLET NOISE SOURCE LEVELS

Diesel Engine Type	Hp	Sound Level, dBA at 50 ft
Naturally Aspirated 4-Stroke	250	95
Turbocharged 4-Stroke	350	93
Roots Blown 2-Stroke (6)	238	105
Roots Blown 2-Stroke (8)	318	104
Turbocharged 4-Stroke	237	82

of 75 dBA that do not degrade engine performance. Section 5 discusses the expected yearly increase in operating costs due to engine back pressure. However, when assessing truck price increases, only the initial purchase price of the muffler system need be considered.

Muffled exhaust system source levels for the various truck engines used in industry today are well documented in two DOT publications, Truck Noise VI A & B (Hunt et al, 1973; DOT Draft, 1973). A graph of source level vs retail price of various mufflers for 6-cylinder, in-line, turbocharged diesel engines is given in Figure 12. Note that the source levels range from 70 to 87.5 dBA and that many mufflers are available which muffle the source levels to less than 75 dBA at no increase in retail price. Figure 13 shows the source levels and prices of mufflers for naturally aspirated 4-stroke diesels. Mufflers are available to reduce their exhaust noise to about 75 dBA at 50 feet. The cost of quieting, for this class of engines, is the net increase in price required to purchase the 75-dBA system. Figure 14 displays the source levels and corresponding retail prices of mufflers on 4-stroke, turbocharged, Vee engines. Here again, a muffling system is available to provide a 75-76 dBA exhaust source level at no significant price increase.

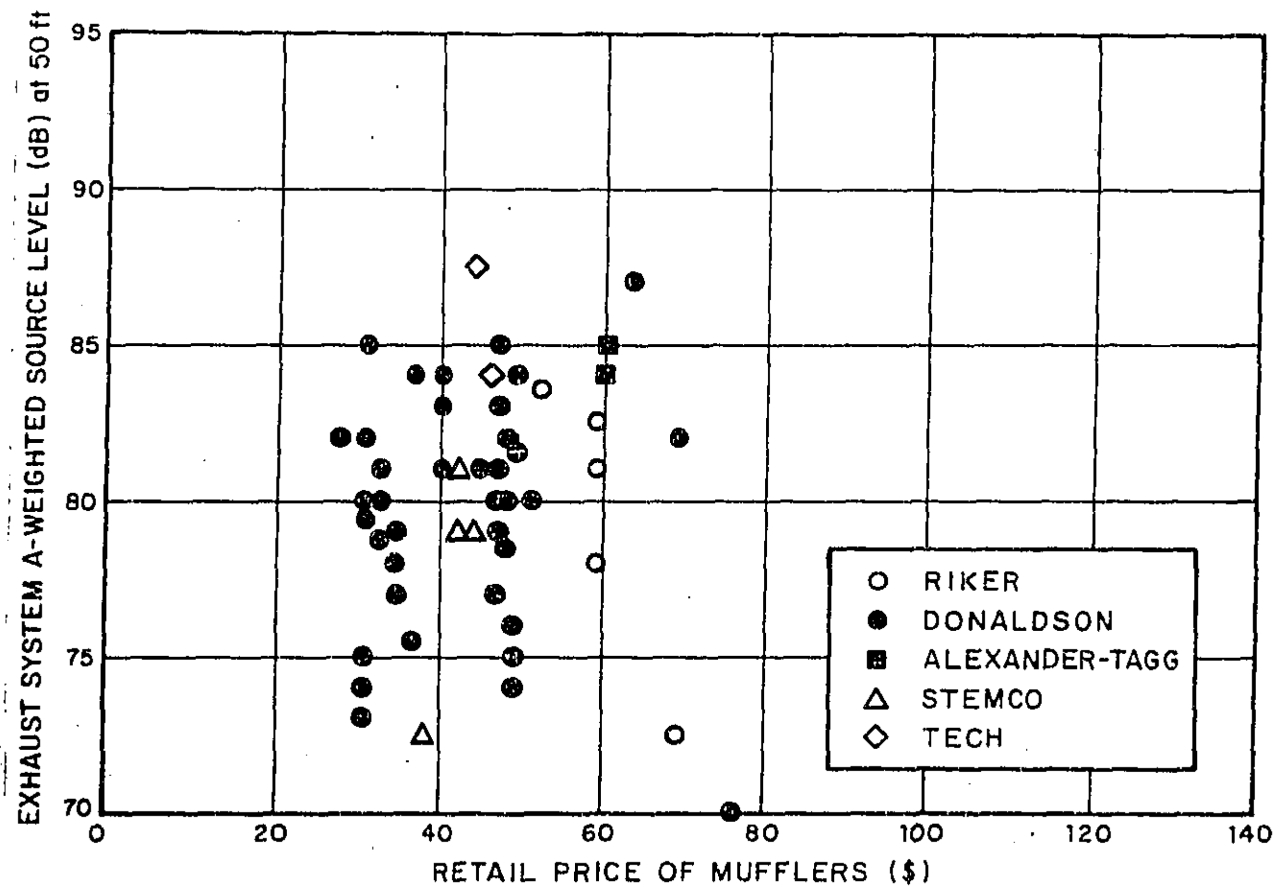

Figure 12. Exhaust System Source Levels for Turbocharged, In-Line, 4-Stroke Diesel Engines

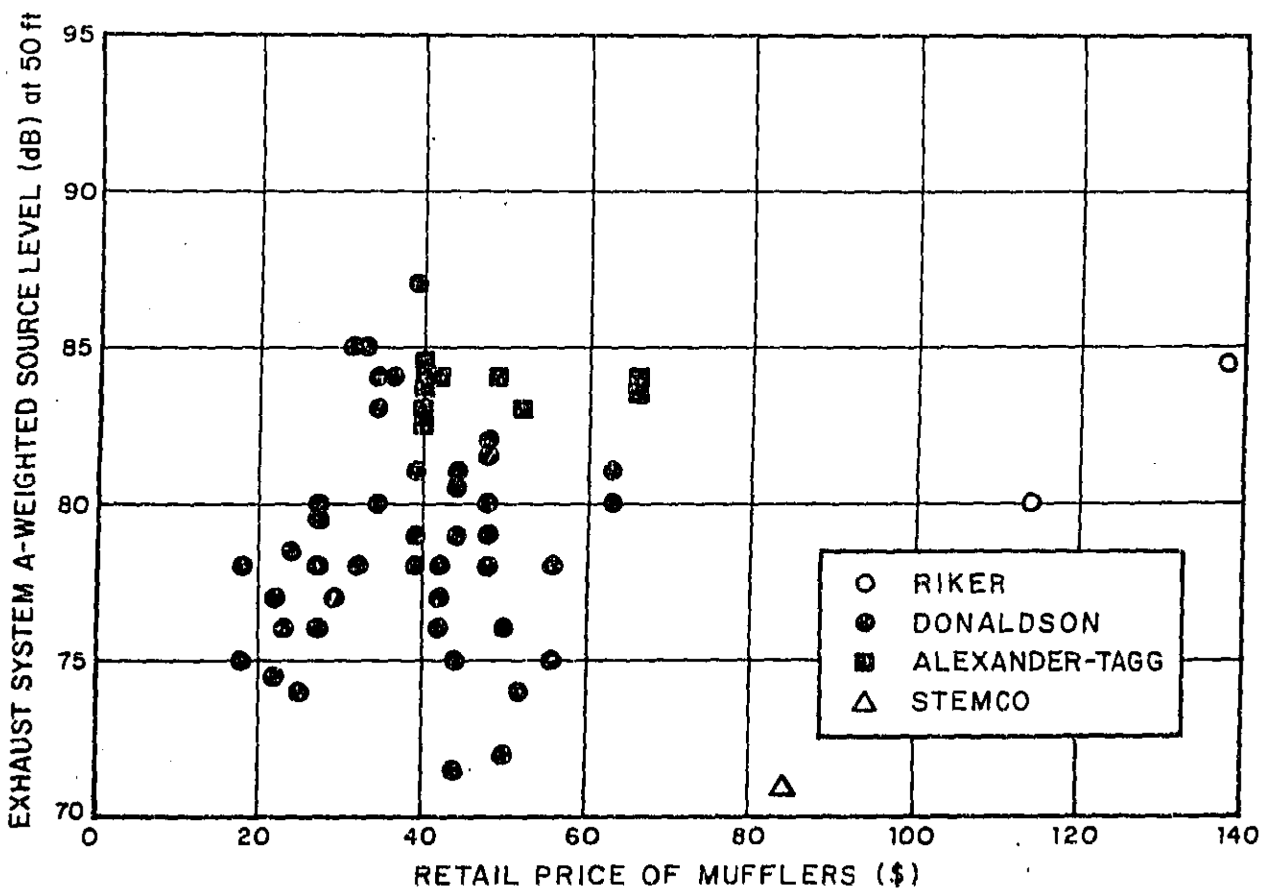

Figure 13. Exhaust System Source Levels for Naturally Aspirated 4-Stroke Diesel Engines

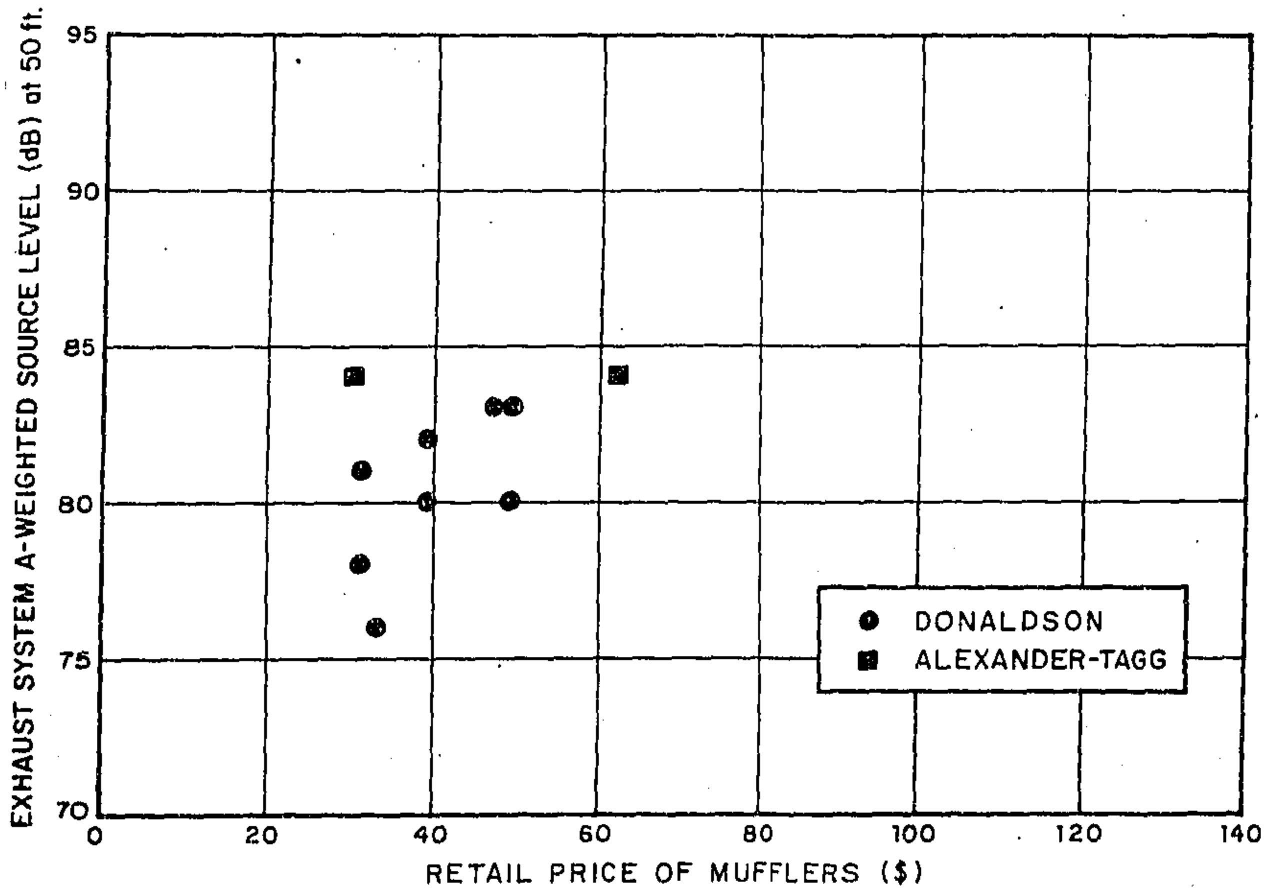

Figure 14. Exhaust System Source Levels for Turbocharged, Vee, 4-Stroke Diesel Engines

The unmuffled source levels of 2-Stroke engines, given in Table 5 are at least 10 dBA higher than the others. It would seem that the muffling systems for this class of engines would be more expensive to provide the same overall noise level. Figure 15 shows the sound level/price relation for 6-cylinder, 2-stroke diesel engines. The graph shows certain commonalities with the previous ones. The price range is about the same as before, but the source levels are higher. This indicates that similar mufflers have been used in both cases. Thus, while no muffler is presently available which will yield a 75 dBA system, the muffler manufacturers could design mufflers tailored to these engines or combine present designs into dual configurations. Again, the increase in price is the net difference in the acquisition price of the mufflers.

Figure 16 displays the source levels of exhaust systems for the 8-cylinder, 2-stroke models. Here again, the source levels are above 75 dBA, but dual or series type systems could bring them down to that level. A recent trend in the design of truck engines is the use of a turbocharger to increase engine power output. As discussed previously, turbocharging 4-stroke diesel engines also tends to reduce their combustion-related noise. In addition, the turbocharger reduces the unmuffled exhaust noise; noise reductions on the order of 5-10 dBA have been reported. As an example, Figure 17 shows the exhaust source levels for 8-cylinder, 2-stroke, turbocharged diesel engines. A comparison of these data with Figure 16 indicates that lower source levels are obtained with cheaper mufflers than for the same engines without the turbocharger. Thus, the addition of turbochargers to present 2-stroke engines will reduce the costs required to quiet the exhaust system to 75 dBA.

Finally, Figure 18 shows the available mufflers and prices for 12-cylinder, 2-stroke diesel engines. Some progress in muffler technology is required to provide the exhaust systems needed to obtain an 83 or 80 dBA overall truck noise level using these engines. The anticipated method of reducing the exhaust noise of 12-cylinder engines is by using dual or series mufflers; thus, retail prices of exhaust systems for these engines will probably double (see Section 5).

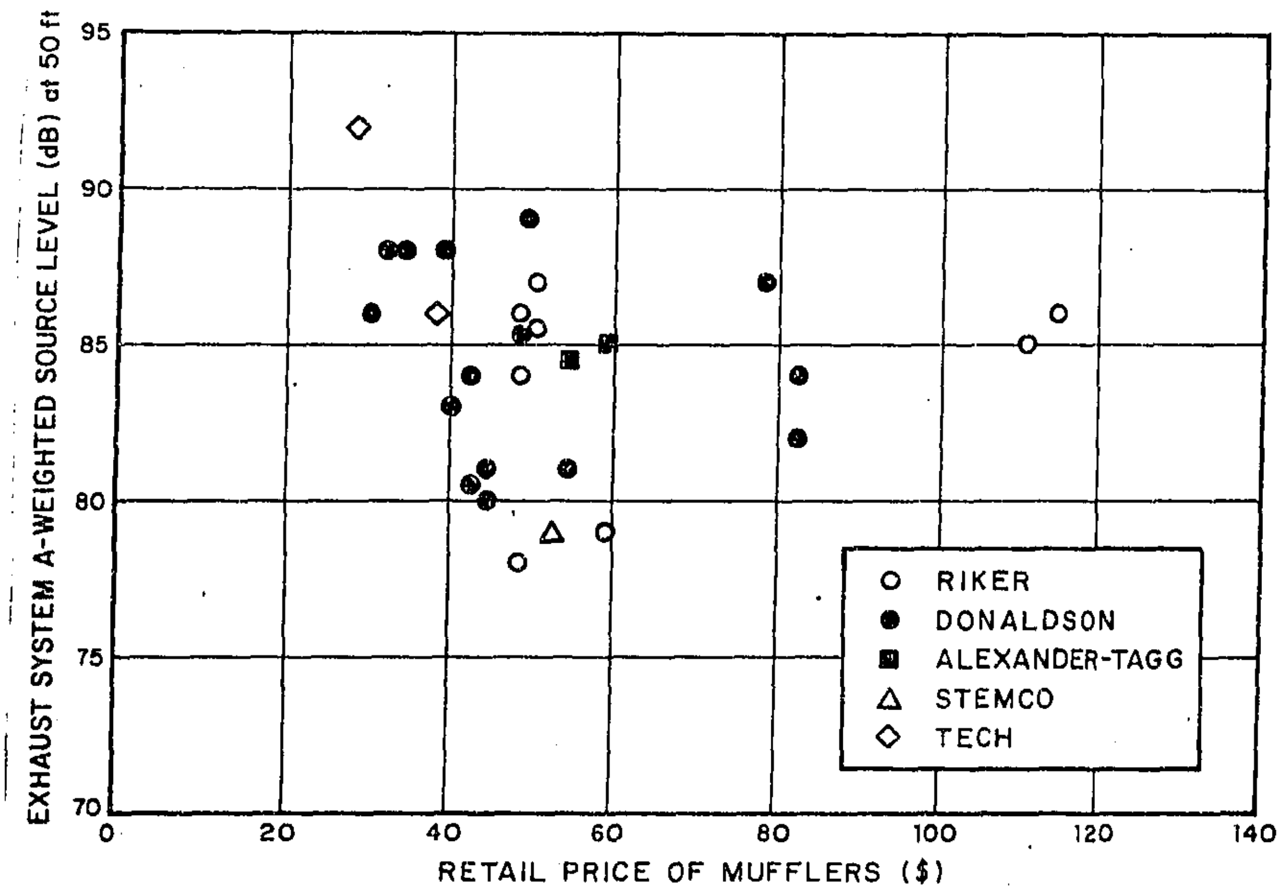

Figure 15. Exhaust System Source Levels for 6-Cylinder, 2-Stroke Diesel Engines

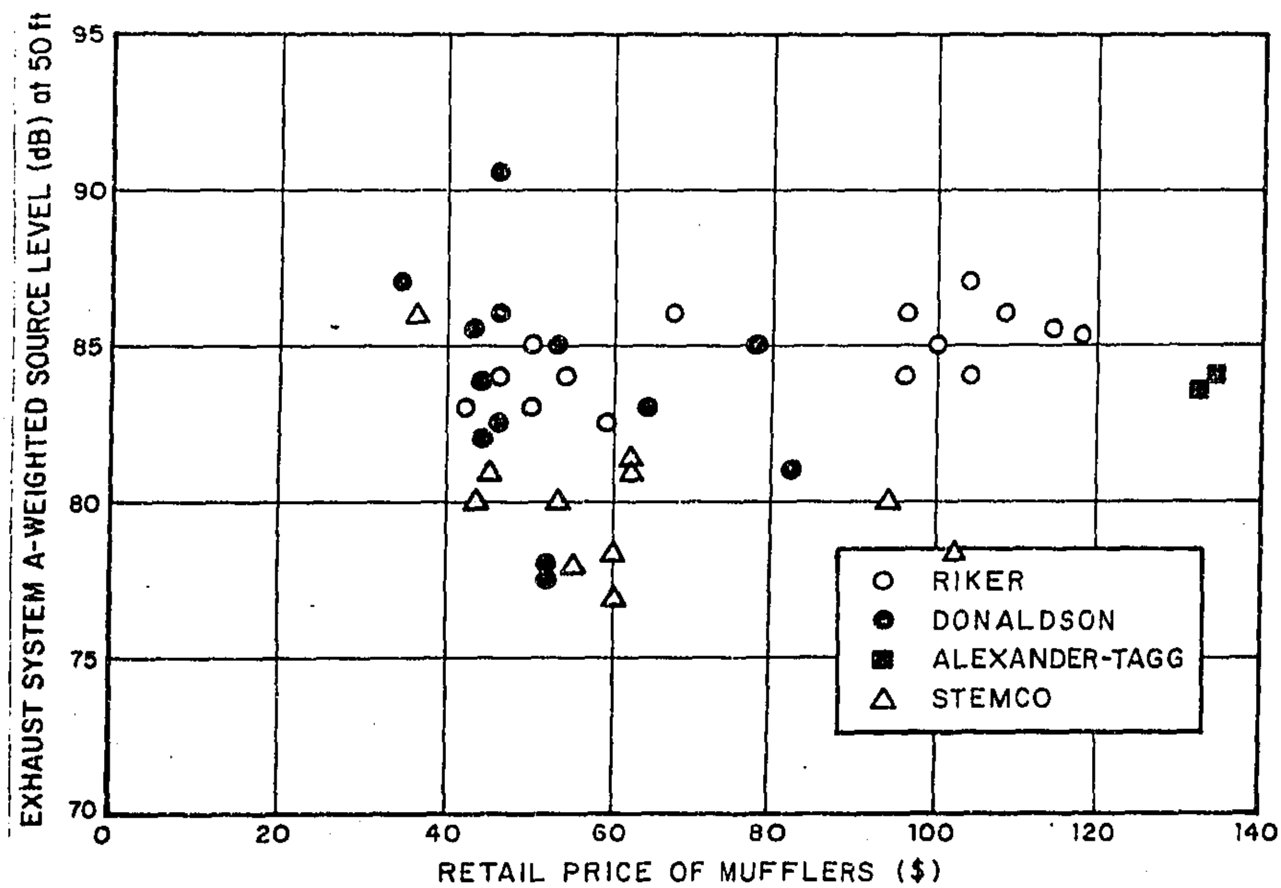

Figure 16. Exhaust System Source Levels for 8-Cylinder, 2-Stroke Diesel Engines

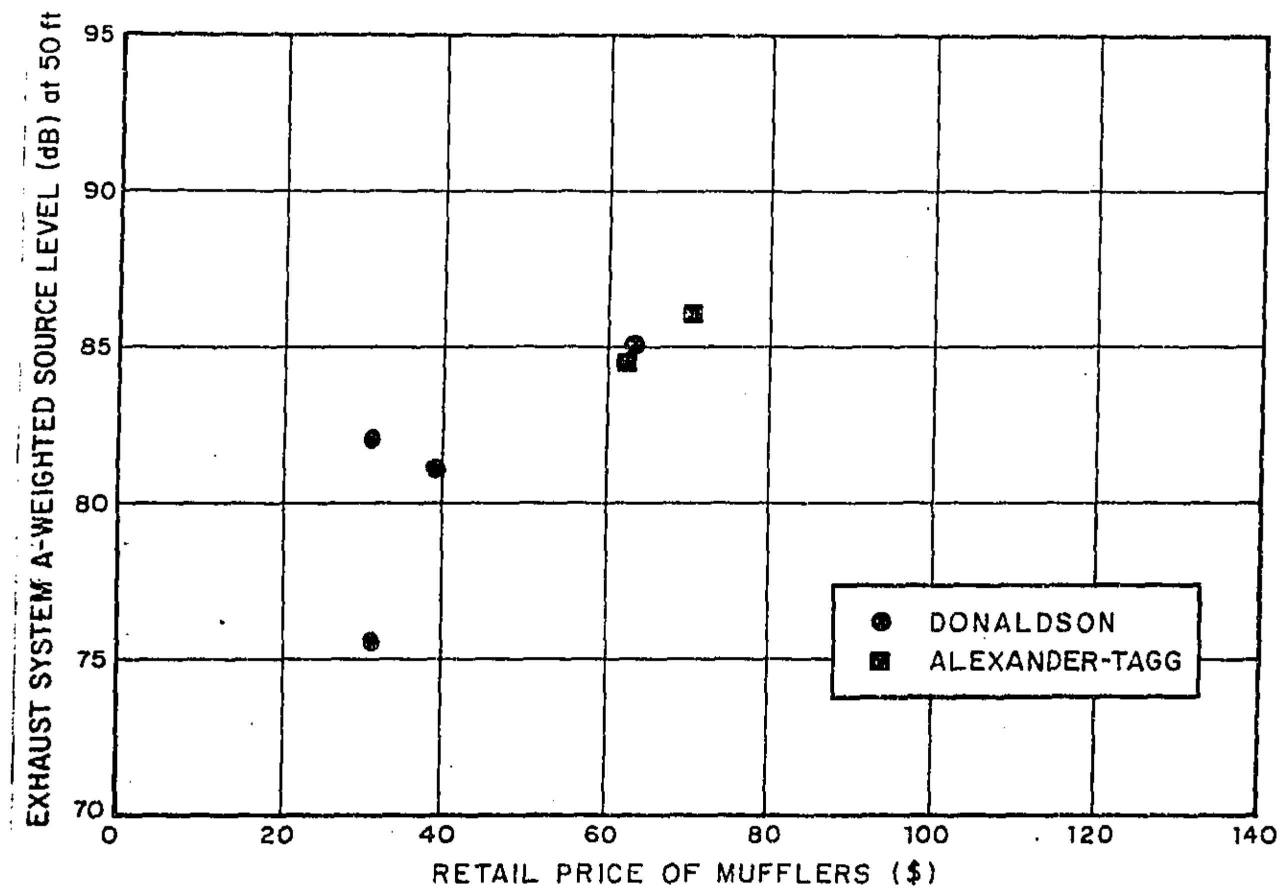

Figure 17. Exhaust System Source Levels for Turbocharged, 8-Cylinder, 2-Stroke Diesel Engines

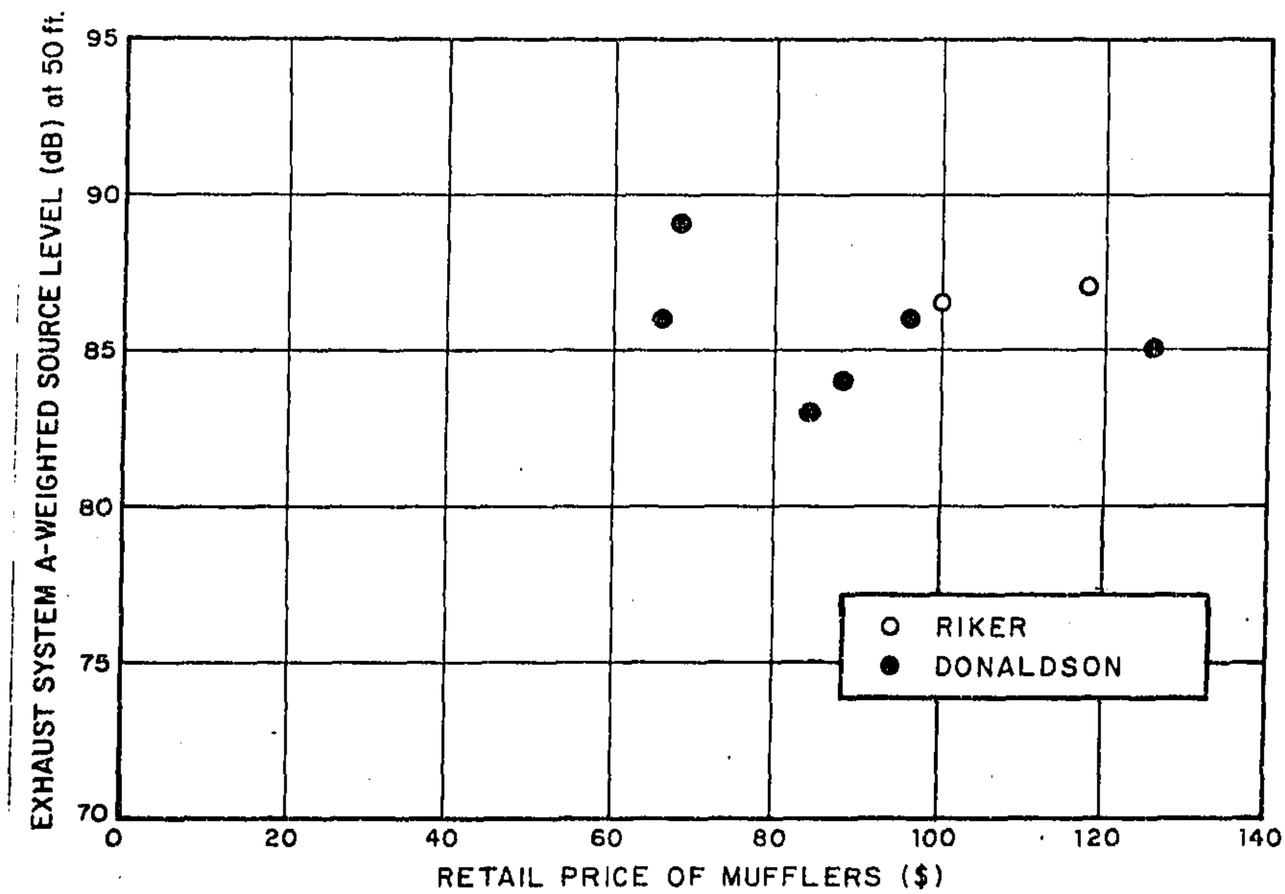

Figure 18. Exhaust System Source Levels for 12-Cylinder, 2-Stroke Diesel Engines

Almost all of the noise control efforts in the trucking industry have centered on the heavy diesel truck as a "worst first" consideration. Consequently, little information is available on exhaust source levels for gasoline-fueled trucks. Source levels that have been measured indicate that present gasoline truck engines have muffled exhaust-related noise levels of about 80 dBA at 50 feet. However, considering the success achieved by the industry in quieting diesel engine exhaust noise, a reduction of gasoline engine exhaust noise to less than 75 dBA at 50 feet should be feasible.

AIR INTAKE SYSTEMS

Internal combustion engines require a continuous supply of air to provide the oxygen for combustion of fuel. The system used in trucks to supply the required clean air is termed the air intake or induction system. The complexity and size of the system can range from a simple air filter mounted on top of a carburetor to an externally mounted air filter with large diameter ducts leading to the engine and a cab mounted snorkel unit. The DOT reports on exhaust systems referred to earlier include studies of air intake systems on certain diesel engines. The unmuffled sound levels are listed in Table 6. The DOT reports also list the air intake source levels when various air filters are installed on these engines. In all cases, the intake system could be quieted to source levels below 75 dBA and even to below 65 dBA for some engines. The prices of these quiet systems were essentially the same as for noisier models with air filters. Thus, to quiet diesel trucks to overall levels of 83 or 80 dBA, no price or performance change due to the air intake system is anticipated. Essentially the same reasoning holds for trucks with gasoline engines, as source levels for air intake systems that have been measured are all less than 69 - 72 dBA at 50 feet. To achieve 75 dBA for total truck noise, some additional quieting will be required for some engines. The results of the DOT quiet truck program indicate that intake noise is not difficult to reduce and will not constitute a severe quieting problem.

TABLE 6

UNMUFFLED AIR INTAKE SOURCE LEVELS

Diesel Engine Type	hp	Air Intake Source Level at 50 Ft
Naturally Aspirated 4-Stroke	250	81.5 dBA
Turbocharged 4-Stroke	350	70.0 dBA
Roots Blown 2-Stroke (6)	238	82.0 dBA
Roots Blown 2-Stroke (8)	318	85.5 dBA
Turbocharged 4-Stroke	237	82.5 dBA

FAN NOISE

Truck cooling fans have evolved with a fair degree of emphasis on purchase price but little consideration for noise or aerodynamic efficiency. Accordingly, most fans are made of stamped sheet metal blades riveted to a hub that is turned by means of a belt and pulley arrangement connected to the engine. The cross section of the fan blade is not usually aerodynamically shaped, and the blade pitch angle does not vary with radius as it should to develop uniform flow through all portions of the radiator. Owing to legal length limitations on trucks, truck designers try to maximize trailer volume by positioning the engine very close to the radiator with the fan sandwiched in between. Under favorable conditions the fan would move air axially; in the usually cramped engine compartment the flow is mostly radial, with a nonuniform velocity distribution.

BASELINE DATA — DIESEL TRUCKS

Noise data for various diesel truck fans are shown in Figure 19 as a function of engine flywheel horsepower. These data correspond to trucks from four manufacturers and to a range of engine power from 175 to 475 hp. The brackets on the five points in the 300 - 400 hp region designate limits of uncertainty owing to ±0.5 dBA levels of uncertainty in the measurements used

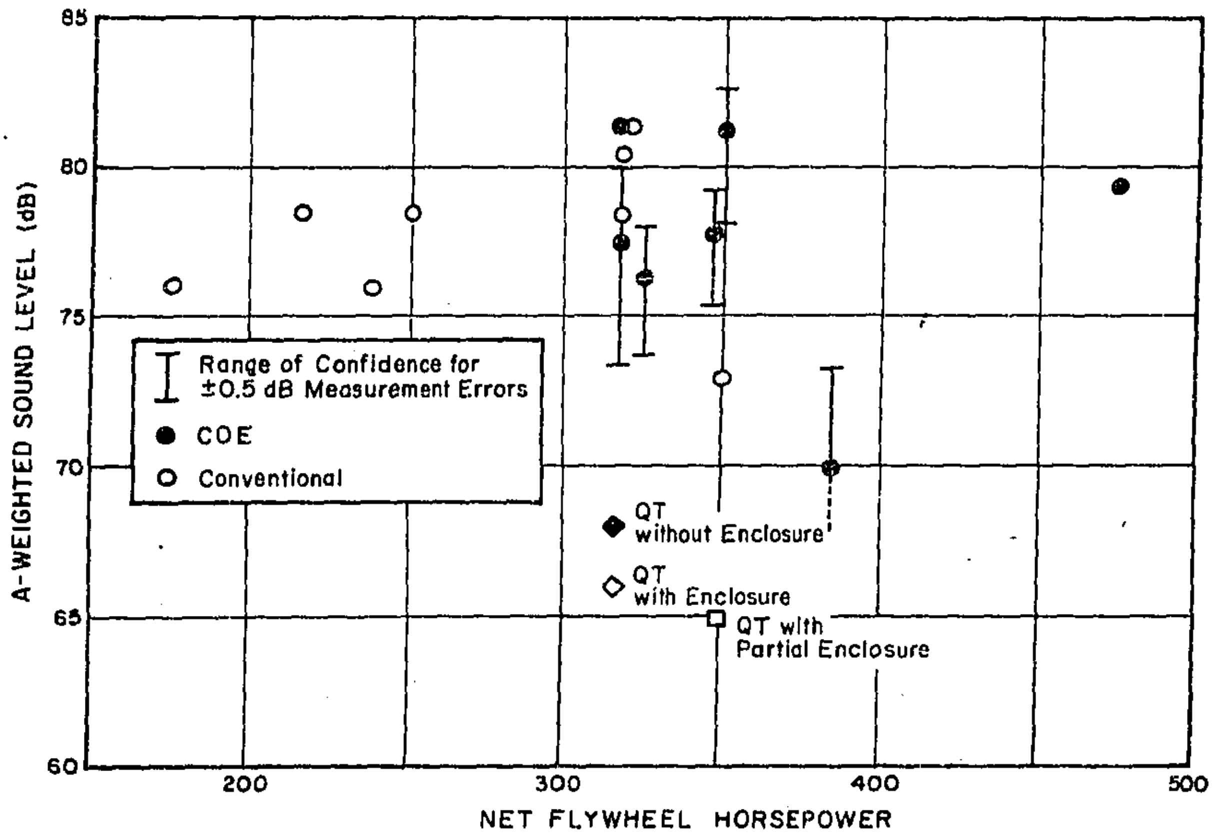

Figure 19. Diesel Truck Fan Noise Levels as a Function of Engine Horsepower

to estimate the fan noise levels. These points correspond to the five trucks measured for purposes of this report. The circled points correspond to trucks that have been quieted under an on-going Quiet Truck Program sponsored by the DOT Office of Noise Abatement.

A distinction is made between conventional truck tractors (where the engine is in front of the cab as with automobiles) and cab-over-engine (COE) tractors. The reason for the distinction is that a COE tractor, because of its large blunt front, tends to develop a higher average dynamic head (pressure rise) in front of the radiator caused by the foreward motion of the truck alone. This pressure supplements the flow created by the fan and allows the use of a slower, quieter fan.

Despite the differences in cab type and the rather large range in engine power level, neither cab nor engine appear to have a significant impact on the noise level of present-production truck fans. One may speculate that the reason for the rather uniform noise level is that cooling systems have been designed for minimum cost, i.e., by using a small radiator and a high-speed (noise) fan. Quite clearly, the fan noise from at least the low-powered trucks can be reduced by using larger (more expensive) radiators and larger, slower fans. Unfortunately, presently available data are inadequate to quantify the relation between radiator size (and cost), heat transfer coefficient, and fan noise.

The circled points in Figure 19 indicate the fan noise levels that can be achieved with a significant engineering effort for COE trucks in the 300 - 350 hp region. The point at 65 dBA corresponds to a quiet truck with a partial enclosure which ducts air from the radiator over the engine and out the rear of the truck. For this truck, a large radiator with a frontal area of 2000 sq. in. is used. Interestingly, the fan, which is thermostatically controlled, operates for only about 1 percent of the time. For the remainder of the time, the forward motion of the truck is adequate to force sufficient cooling air through the radiator. The result is a quiet fan and a conservation of the power ordinarily needed to drive it.

BASELINE DATA — GASOLINE TRUCKS

Fan noise data on gasoline-powered trucks are not as abundant as for diesel trucks. However, noise levels for three trucks are known and are shown in Figure 23 as a function of horsepower. (These data cannot be compared to fans for diesels with the same horsepower since the heat rejection/hp of gasoline engines is higher.) The noise from these fans is quite high owing principally to their small diameter and high speed.

FAN NOISE CONTROL

The control of fan noise must be viewed in terms of cooling system design. Some noise reduction can be achieved by modifying the radiator, the shutters, fan shroud, and, of course, the fan itself.

Radiator design is intimately coupled to fan performance, noise, and truck cost. Thick radiators that are densely packed with tubes and fins do not require a great deal of air flow but create substantial pressure drops and are costly to manufacture. Low flow requirements allow for slower-turning fans which are

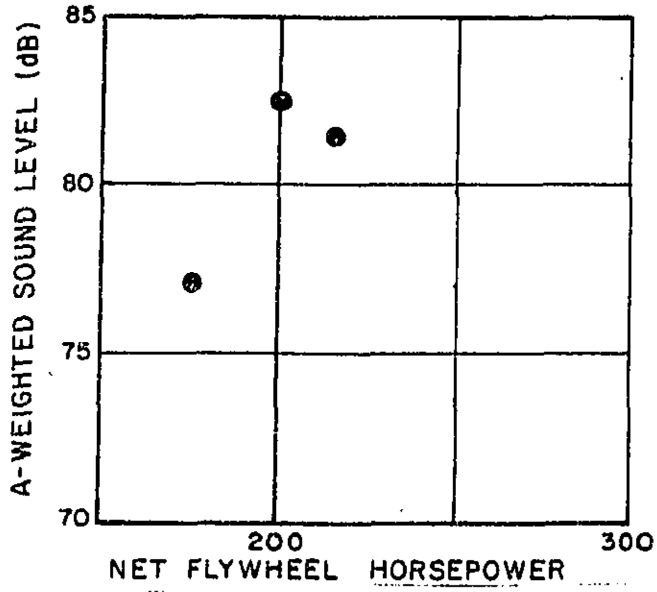

Figure 20. Gasoline Truck Fan Noise Levels as a Funtion of Horsepower.

quieter. The amount of noise reduction achievable by radiator modification depends on the initial radiator configuration. Even well-designed cooling systems can often be quieted by 2 - 3 dBA just by modifying radiator design (Shrader, 1973).

Thermostatically controlled shutters are used on a great many trucks to control the air flow through the radiator. The shutters, which are like venetian blinds, are placed in front of the radiator and are controlled by the temperature of the water that is about to return to the engine from the bottom of the radiator or by the temperature of the air that has passed through the radiator. The primary purpose of shutters is to prevent cold water from overcooling the engine, which could happen on very cold days. Unfortunately, shutters significantly influence fan noise. When the shutters are closed and air flow to the fan is substantially reduced, the fan blades stall and generate more noise. A 5 dBA increase in fan noise owing to closed shutters is reported by Shrader (1973). One manufacturer has reported approximately a 2 - 3 dBA increase in total truck noise for his entire line of models because of closed shutters. Several manufacturers believe that shutters could be eliminated with temperature control provided by thermostats and bypass tubing. However there is a strong marketplace demand for shutters which continue to be offered on new trucks.

The fan shroud ducts air from the radiator to the fan and is quite important in maximizing fan effectiveness and preventing recirculation of hot air back through the radiator. Shrouds which do not channel this air smoothly into the fan can lead to stalled blade tips with an attendant increase in noise and decrease in fan efficiency. Shrader (1973) claims a 3 - 5 dBA decrease in fan noise levels resulting from improved shroud design.

The fan itself can often be changed to reduce noise. One of the most effective changes is to increase the fan diameter and decrease the fan speed. A 2 - 3 inch increase in fan diameter typically allows a 3 - 5 dBA reduction in noise for a constant volume flow rate. Of course, there are limitations on the extent to which the fan diameter may be increased, determined primarily by the configuration of the radiator and essential structural members of the truck.

Changing the radiator height or width typically requires a major cab redesign involving numerous other constraints and engineering trade-offs and, consequently, a long lead time.

FAN NOISE LEVELS AND COSTS

To project total truck noise reductions and costs associated with fan noise control, the following estimates are used:

Fan Noise Level	Incremental Cost
80 dBA	0
75	$100
65	150

The data in Figures 19 and 20 indicate that most fans generate less than 80 dBA. Those that are higher can certainly be quieted to 80 dBA for negligible cost by using a slightly different fan model and fan/engine speed ratio. Further reduction to 75 dBA may require somewhat larger radiator cores and larger, slower fans. The estimated incremental cost is $100 per truck. Levels can be reduced to 65 dBA with larger radiator cores, larger and slower fans, careful design of fan shrouds, and a thermostatically-controlled fan clutch that is phased with a shutter thermostat to prevent fan operation while the shutters are closed. Estimated cost for this treatment is $150.

TRANSMISSIONS AND DRIVE LINES

In all medium and heavy trucks now in production, the transmission is connected to the engine at the flywheel. The drive line for these trucks consists of a drive shaft (or shafts in combination) and the drive axles. While all of these components are usually relatively minor noise sources (on the order of 60 - 70 dBA at 50 feet), some configurations are noisier. In particular, some drive shafts have been measured with a source level of about 80 dBA during the acceleration run required by the SAE J366a Recommended Practice. Reducing this noise requires dampeners like those presently used on automobile drive shafts for noise and vibration control. The technology is available in the automotive industry and the associated costs would be minimal.

Highway trucks usually have differential drives with hypoid gears. These axles are not a noise problem, because the high speeds and loadings require excellent gear finishes and tolerances which yield quiet operation. For all-wheel drive trucks, the transfer cases and final gearing at the wheel are typically much noisier, especially for the heavy duty, small production units. Noise control on these models would require better gear finishes and closer tolerances. Estimates of price increases on this type of treatment are usually about 40 percent. Consequently, a transfer case normally selling for $2,000 would cost $2,800 with better gears and bearings.

Measurements of transmission noise under dynamometer loading indicate that most transmissions do not generate significant noise levels but act as a sounding board for engine structural noise. No transmission treatment is required to achieve overall truck noise levels of 83 or 80 dBA. However, transmissions must be appropriately treated (e.g., shielded) to reduce heavy truck noise to 75 dBA.

SECTION 5

TOTAL TRUCK NOISE CONTROL

To assess the cost of quieting trucks, all of the component noise control measures described in Section 4 must be combined such that overall noise levels of trucks are within specified limits. The noise control measures selected depend on the primary noise source in each truck. Usually, engine noise is very significant and is also the most difficult and costly to treat. Thus, to provide the clearest picture of the methods and price increases required to quiet trucks, the classification should be based on the engine to be installed in the truck rather than on other secondary factors such as the truck's rated load-bearing capacity or cab style.

COMPONENT SOURCE LEVELS FOR QUIET TRUCKS

The important sources of truck noise are the engine, exhaust, and cooling system fan. The present source levels of components are typically such that most trucks just meet the California limit of 86 dBA, although a few truck manufacturers are now aiming at 83 dBA. The various source levels currently encountered in gasoline and diesel trucks are presented in Table 7.

TABLE 7

RANGE OF COMPONENT SOURCE LEVELS FOR PRESENT TRUCKS

Truck	Engine	Fan	Exhaust	Measured Total Truck Noise Levels
Gasoline	75-77 dBA	80-85 dBA	80 dBA	83-86 dBA
Diesel	76-85 dBA	75-85 dBA	75-85 dBA	83-86 dBA

Note the wide variation in diesel truck source levels and the relatively equal total levels of both classes of trucks. To reach the 86 dBA total level, the diesel truck manufacturers have concentrated on quieting the noisiest trucks first. Thus, trucks with noisy engines having source levels of 80 - 85 dBA have quieter fans and exhaust systems than trucks with quieter engines.

Table 8 shows combinations of component source levels that will yield a truck whose overall noise level is less than 83 dBA (Level 1).

Naturally, to achieve the 83 dBA level on a not-to-exceed basis, all of the component source levels must also be on a not-to-exceed basis. The guaranteed attainment of the component levels would be part of a quality control program with tolerances to be placed on each component. Then to provide an 81 dBA source level for the engine, the average engine source level would be 79 dBA with a 2 dBA tolerance. Similar tolerances will be required for the

TABLE 8
COMPONENT SOURCE LEVELS FOR AN
83-dBA TRUCK

Component	Noise Level	Total
Engine*	≤81 dBA	≤83 dBA
Fan	≤75 dBA	
Exhaust	≤75 dBA	
All Others	≤70 dBA	
or Engine*	≤78 dBA	≤83 dBA
Fan	≤80 dBA	
Exhaust	≤75 dBA	
All Others	≤70 dBA	

*Engine includes the transmission.

other components. Table 9 lists the expected tolerances required for the main components. These tolerances must be subtracted from the required component source level when designing the truck. Assuming that the component tolerances represent the maximum variance in source levels, the total variance in overall truck noise would be about 2 dBA. That is, the mean noise level for all trucks would be about 2 dBA less than the noise level limit.

Table 10 gives the component source levels required for a truck having an overall noise level of 80 dBA (Level 2). The same tolerances for the component source levels apply as at Level 1. Naturally, some engine manufacturers will be able to quiet their exhaust systems to lower levels to compensate for a slightly noisier engine. Most diesel-powered trucks will require engine noise control packages to reduce the engine contribution to acceptable levels.

TABLE 9

TOLERANCES FOR COMPONENT NOISE SOURCES

Component	Tolerance
Engine	2 dBA
Fan	1 dBA
Exhaust	2 dBA

TABLE 10

COMPONENT SOURCE LEVELS FOR AN 80-dBA TRUCK

Component	Noise Level	Total
Engine	≤75 dBA	≤80 dBA
Fan	≤74 dBA	
Exhaust	≤75 dBA	
All Others	≤70 dBA	

Level 3 trucks at 75 dBA will require component source noise levels in approximately the ranges given in Table 11. To achieve this overall level, most diesel trucks will require some sort of engine enclosure built into the cab. In addition, the other components will require the application of the best available technology to reduce their source levels to within the given limits. Because the noise control methods and their cost vary greatly according to the engine used, we shall evaluate costs for three engine types: gasoline, quiet diesel, and noisy diesel.

TABLE 11

COMPONENT SOURCE LEVELS FOR A 75-dBA TRUCK

Component	Noise Level	Total
Engine	≤70 dBA	
Fan	≤65 dBA	≤75 dBA
Exhaust	≤68 dBA	
All Others	≤70 dBA	

COST OF QUIET TRUCKS

Table 12 gives the anticipated customer price increases to achieve the three overall truck noise levels. All of the cost relations are based on known noise control techniques and hardware or are projected on the basis of Freightliner's prototype Quiet Truck. Parentheses enclose engineering estimates based on similar noise control work or on manufacturers' estimates. "M. D." and "H. D." refer to medium and heavy duty engines (according to severity of service), and substitution of a quieter engine for a noisy one is possible within the medium duty and heavy duty classes. Gasoline engines are considered in a single class because their structural noise is already in the 75-dBA range without the use of quieting techniques. Substitution of gasoline engines for medium duty diesel engines is possible although not recommended as a viable means of noise control. Specific methods for controlling noise from components in trucks are referred to by code in Table 12 (i. e., a1-3, b1-b3, c1-c3). Table 13 is the key to these methods. Finally, to provide additional insight into the relative impact of the noise control measures, Table 12 shows the relative market share of each family of medium and heavy duty engines installed in trucks.

COST OF COMPLIANCE TESTING

An additional influence on customer price increases for noise control will be the added manufacturers' costs for internal noise testing on production trucks to ensure end-product compliance. The cost will depend upon the enforcement procedure used by EPA. A thorough evaluation of possible procedures requires a level of study that is beyond the scope of this document.

OPERATIONAL COSTS

Adding noise control devices to trucks has the effect of changing physical parameters of the trucks, including the gross vehicle weight (GVW), the backpressure imposed on the engine by the muffling system, and the power required to run accessories (primarily the fan). Changes in these parameters will, in general, change the truck's fuel consumption per mile,

TABLE 12

ESTIMATED CUSTOMER PRICE INCREASES FOR QUIETED TRUCKS

Engine Class[1]	Market Share[2]	Level 1, 83 dBA Fan	Exhaust	Engine	Cab	Total	Level 2, 80 dBA Fan	Exhaust	Engine	Cab	Total	Level 3, 75 dBA Fan	Exhaust	Engine	Cab	Total
Gasoline Engines	68%	a1	-	-	-		$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 50 b2	-	$100 d1	$ 300
H.D. Diesel Engines Manufacturer A	12%	$100 a2	$ 50 b1	-	-	$150	$100 a2	$ 50 b1	$200 c1	-	$ 350	$150 a3	$100 b2	-	$750-1250 d2	$1000-1500
H.D. Diesel Engines Manufacturer B	6%	$100 a2	$ 50 b1	$275 c1	-	$425	$100 a2	$ 50 b1	-	$550 d2	$1000	$150 a3	$100 b2	-	$850-1250 d2	$1100-1500
H.D. Diesel Engines Manufacturer D	6%	$100 a2	$ 25 b1	$200 c1	-	$325	$100 a2	$ 25 b1	-	$675 d2	$ 800	$150 a3	$ 75 b2	-	$775 d2	$1000
H.D. Diesel Engines Manufacturer C	4.8%	-	-	-	-	$ 0	$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 75 b2	$200 c1	$100 d1	$ 625
M.D. Diesel Engine Manufacturer D	2.2%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$ 85 c1	-	$ 210	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
H.D. Diesel Engines Manufacturer D	1.5%	a1	-	-	-		$100 a2	$ 50 b1	-	-	$ 150	$150 a3	$100 b2	-	$750-1250 d2	$1000-1500
H.D. Diesel Engines Manufacturer A	0.9%	$100 a2	$100 b2	-	-	$200	$100 a2	$100 b2	$200 c1	-	$ 400	$150 a3	$150 b2	-	$800-1300 d2	$1100-1500
M.D. Diesel Engines Manufacturer E	0.77%	$100 a2	-	-	-	$100	$100 a2	$ 25 b1	$175 c1	-	$ 300	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
H.D. Diesel Engines Manufacturer C	0.47%	$100 a2	-	-	-	$100	$100 a2	$ 25 b1	$175 c1	-	$ 400	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
H.D. Diesel Engines Manufacturer F	0.225%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$200 c1	-	$ 325	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
M.D. Diesel Engines Manufacturer G	0.17%	$100 a2	$ 25 b1	-	-	$125	$100 a2	$ 25 b1	$150 c1	-	$ 275	$150 a3	$ 75 b2	-	$775-1275 d2	$1000-1500
H.D. Diesel Engines Manufacturer H	0.015%	-	-	-	-	$ 0	$100 a2	$ 25 b1	-	-	$ 125	$150 a3	$ 75 b2	$200 c1	$100 d1	$ 525

NOTES:

[1]M.D. = medium duty, H.D. = heavy duty. M.D. and H.D. refer to severity of service. Exchange of a noisy engine by a quiet engine is possible within M.D. and H.D. classes.

[2]Percent of medium and heavy trucks powered by indicated engine family, 1972.

TABLE 13

NOISE CONTROL KEY

System	Code (See Figure 29)	Description of Noise Control Measure	Source Level or Noise Reduction
Fan	a1	Use of larger-slower turning fan with shrouding	80 dBA
	a2	Larger-slower turning fan with thermostat control to eliminate shutters or control their opening	75 dBA
	a3	Best technology fan system	65 dBA
Exhaust	b1	Best available system	75 dBA
	b2	Advanced system better than presently available	75 dBA
	b3	Best technology exhaust system	65 dBA
Engine	c1	Close fitting covers and isolated or damped exterior parts supplied by engine manufacturer	2-3 dBA NR
Cab	d1	Under hood treatment such as acoustic absorbing material, side shields, recirculation panels, etc.	2-4 dBA
	d2	Partial or full engine enclosures	10-15 dBA NR

and hence the annual fuel costs incurred. The change in fuel costs, and the incremental cost of maintaining the modified truck are the major changes in annual operating costs that occur.

Other potential effects of noise abatement are reduction of the truck's maximum speed by decreasing the engine power available to drive the wheels, and reduction of the truck's maximum payload by increasing the tare (empty) weight.

A thorough evaluation of changes in operating costs due to the use of noise control devices on trucks of various types is beyond the scope of this document.

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APPENDIX

EXTERIOR SOUND LEVEL FOR HEAVY TRUCKS AND BUSES
SAE J366a
SAE Recommended Practice

INTRODUCTION

This SAE Recommended Practice establishes the maximum exterior sound level for highway motor trucks, truck tractors, and buses, and describes the test procedure, environment, and instrumentation for determining the maximum sound level.

SOUND LEVEL LIMIT

The sound level produced by trucks and buses over 6000 lb GVW shall not exceed 88 dB on an A-weighted at 50 feet when measured in accordance with the procedure described herein (see General Comments).

INSTRUMENTATION

The following instrumentation shall be used, where applicable, for the measurement required:

1. A sound level meter which meets the requirements of International Electrotechnical Commission Publication 179, "Precision Sound Level Meters."

   Alternatively, a microphone/magnetic tape recorder, indicating meter system whose overall response is equivalent to the above may be used.
2. A sound level calibrator (see General Comments).
3. A calibrated windscreen (see General Comments).
4. An engine-speed tachometer (see Procedure).

TEST SITE

A suitable test site shall consist of a level open space free of large reflecting surfaces, such as parked vehicles, signboards, buildings, or hill-sides, located with 100 feet of either the vehicle path or the microphones.

The microphone shall be located 50 feet from the centerline of the vehicle path and 4 feet above the ground plane. The normal to the vehicle path from the microphone shall establish the microphone point on the vehicle path.

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

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

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

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

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

1. If the horizontal distance from the front of the vehicle to the exhaust outlet is more than 200 inches, tests shall be run using both the front and rear of the vehicle as reference points.
2. If the engine is located rearward of the center of the chassis, the rear of the vehicle shall be used as the reference point.

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

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

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

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

PROCEDURE

VEHICLE OPERATION

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

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

1. Starting at no more than two-thirds of maximum rated or of governed engine speed.
2. Reaching maximum rated or governed engine speed within the end zone.
3. Without exceeding 35 mph before reaching the end point
   - Should maximum rated or governed rpm be attained before reaching the end zone, decrease the approach rpm in 100 rpm increments until maximum rated or governed rpm is attained within the end zone.
   - Should maximum rated or governed rpm not be attained until beyond the end zone, select the next lower gear until maximum rated or governed rpm is attained within the end zone.
   - Should the lowest gear still result in reaching maximum rated or governed rpm beyond the permissible end zone, unload the vehicle and/or increase the approach rpm in 100 rpm increments until the maximum rated or governed rpm is reached within the end zone.

For the acceleration test, approach the acceleration point using the engine speed and gear ratio selected as discussed above and at the acceleration point rapidly establish wide-open throttle. The vehicle reference shall be as indicated under Test Site. Acceleration shall continue until maximum rated or governed engine speed is reached.

Wheel slip which affects maximum sound level must be avoided.

For the deceleration test, approach the microphone point at maximum rated or governed engine speed in the gear selected for the acceleration test. At the microphone point, close the throttle and allow the vehicle to decelerate to one-half of maximum rated or of governed engine speed. The vehicle reference shall be as indicated under Test Site.

MEASUREMENTS

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

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

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

GENERAL COMMENTS

It is essential that technically qualified personnel select equipment and that tests be conducted only by persons trained in the current techniques of sound measurement.

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

Instrument manufacturer's specifications for orientation of the microphone relative to the source of sound and the location of the observer relative to the meter should be adhered to.

When a windscreen is required, a previously calibrated windscreen should be used. It is recommended that measurements be made only when wind velocity is below 12 mph.

Instrument manufacturer's recommended calibration practice of instruments should be made at appropriate times. Field calibration should be made immediately before and after each test sequence. Either an external calibrator or internal calibration is accomplished immediately before and after field use.

REFERENCE MATERIAL

Suggested reference material is as follows:

USASI S1.1 — 1960, Acoustical Terminology.

USASI S1.2 — 1962, Physical Measurement of Sound.

International Electrotechnical Commission Publication 179, Precision Sound Level Meters.

Application for copies of these documents should be addressed to U.S.A. Standards Institute, 10 East 40th Street, New York, New York 10016.