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Methodology and Supporting Documentation for the Measurement of Noise from Medium and Heavy Trucks

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and

T. L. Quindry

Applied Acoustics Section
Mechanics Division
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National Bureau of Standards
Washington, D. C. 20234

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Final Report

Prepared for

Office of Noise Abatement and Control
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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Executive Summary

Vehicular traffic noise continues to be a major source of complaint and many consider trucks to be the major offender. Truck noise can be categorized as the noise produced by the power plant [including the engine, exhaust, intake, cooling fan, etc.] and by the tire-road interaction. The noise from the power plant increases as the engine speed (and power) increases while the noise from tires increases as the vehicle speed increases. Maximum power-plant noise usually occurs when the engine is delivering maximum power at its maximum operating speed. The percentage of time a vehicle spends at maximum noise conditions is determined by the vehicle power-to-weight ratio and operating conditions such as acceleration, speed, load, grade and, to some extent, the manner in which the vehicle is driven. Medium and heavy trucks [GVWR of 10,001 pounds or greater] operate near their horsepower limit a high percentage of the time. The exact speed at which the tire-roadway noise starts to predominate power-plant-associated noise is a highly complicated function of tire characteristics, engine-exhaust characteristics, road surface, vehicle condition, etc.

In general, the truck manufacturer's product is a two- or three-axle prime mover equipped with six or ten wheels. The "truck" is built up by the addition of van enclosures, platforms and stakes, dump bodies, concrete mixer bodies, semi-trailers, multiple combinations of trailers and many other types of equipment. The types and numbers of tires are dependent on the use and loads which the purchaser determines and the equipment which is later installed on the truck.

The EPA is charged with taking strong, comprehensive action to protect public health and welfare from increasing noise, thus ensuring a quieter environment. In the case of trucks, it is the consensus of the NBS and the members of its task force that the following regulation strategy, which is based on a systems approach to the truck noise problem, will ensure a decrease in community noise.

- Identify trucks and tires separately as major noise sources.
- Establish a level, or set of levels, in conjunction with an appropriate measurement methodology, to be met by the truck (prime mover) manufacturers.
- Establish a level, or set of levels, in conjunction with an appropriate measurement methodology, to be met by the tire manufacturer.
- Label tires in order that the user can choose tires for his single-chassis and combination vehicles which will maintain or reduce overall truck noise and will meet Federal interstate motor carrier regulations or State regulations.

If such a strategy were followed, a truck could be certified for sale and a subsequent tire change (maybe upon initial sale of the vehicle) or changes in the type of trailer pulled, would not result in an increase in community noise levels.

This report develops a measurement methodology which defines the procedure by which the noise from medium and heavy trucks, excluding tire noise, may be accurately and repeatably measured to ascertain whether the noise emitted is in compliance with noise-emission standards to be promulgated by the EPA.* The methodology is based on a low-speed acceleration passby (high engine speed, low vehicle speed) procedure similar to that specified in SAE Standard J366b - Exterior Sound Level for Heavy Trucks and Buses. Numerous modifications and additions have been made in order to reduce variability and improve repeatability of the test results. It should be pointed out, however, that this test procedure has some limitations. Since the test is performed outdoors, it is weather dependent. If large numbers of vehicles are to be tested, severe production holdups would result. Passby tests require considerable space (which makes location of suitable test sites difficult for some manufacturers) and cannot be easily performed at the end of an assembly line. The major advantage of this procedure is, of course, that it is the only existing test method that is backed with an extensive data base.

Alternative test procedures such as the stationary run-up test, dynamometer test or indoor tests -- which would eliminate some of the difficulties associated with the passby test -- were considered; however due to the time constraints on EPA and the lack of a data base and facilities, these methods could not be considered further at this time. This is not to say that there should not be a concentrated effort in the future to develop a simple, repeatable, accurate test procedure that would be independent of weather and site influences and would correlate with what the community hears as "truck" noise. Such a procedure, if properly developed and validated, would be welcomed by both government and industry.

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*A methodology that could be utilized for tire certification is presently being developed by DOT and NBS and will be available in final form in the very near future.

Acknowledgements

The National Bureau of Standards (NBS) gratefully acknowledges the assistance of many individuals and organizations whose contributions have helped make it possible to produce this report.

Of great assistance to the NBS was the task group of experts assembled by NBS to provide technical expertise and back-up data -- both acoustic and vehicle. The task group included: Mr. John U. Damian (Ford Motor Company), Mr. Frederick W. Krey (GMC Truck and Coach), Dr. Ben H. Sharp (acoustical consultant, Wyle Laboratories), and Mr. Richard L. Staadt (International Harvester Company).

In addition, between March 19, 1974 and April 2, 1974, a series of meetings was conducted by NBS with representatives of truck manufacturers to obtain input prior to the completion of this report. During these meetings the existing data base, typical operational modes and use statistics were reviewed and the problems associated with the technical capability of industry to utilize particular measurement methodologies and the possible economic impact associated with alternative measurement requirements was discussed. Truck manufacturers visted included: F.W.D., Clintonville, Wisconsin; Freightliner, Portland, Oregon; Pacific Car and Foundry (Kenworth and Peterbilt) Seattle, Washington; White, Cleveland, Ohio; Ford, Dearborn, Michigan and Louisville, Kentucky; Chevrolet/GMC, Pontiac, Michigan; and International Harvester, Fort Wayne, Indiana.

We thank all of these people for their cooperation and contributions.

Methodology and Supporting Documentation for the Measurement of Noise from Medium and Heavy Trucks

W. A. Leasure, Jr.
T. L. Quindry

This report contains a measurement methodology which defines the procedures by which the noise from medium and heavy duty trucks, excluding tire noise, may be measured to ascertain whether the noise emitted is in compliance with noise emission standards to be promulgated by the U. S. Environmental Protection Agency pursuant to Section 6 of the Noise Control Act of 1972 (P.L. 92-574). Associated supporting technical documentation for the methodology is included.

Key Words: Acoustics (sound); measurement methodology; noise emission standard; noise measurement; truck.

1. Introduction

At the request of the U. S. Environmental Protection Agency (EPA), the National Bureau of Standards (NBS), with the cooperation of industry, has developed a measurement methodology which defines the procedure by which the noise from medium and heavy duty trucks, excluding tire noise, may be measured to ascertain whether the noise emitted is in compliance with noise emission standards to be promulgated by the EPA pursuant to Section 6 of the Noise Control Act of 1972 (Public Law 92-574).

The method is applicable to complete and incomplete trucks and truck tractors (as defined in Section 2.0) having a gross vehicle weight rating (GVWR) of 10,001 pounds or greater. The measurement method provides for the determination of the maximum A-weighted sound level output of a vehicle during a low speed acceleration passby (high engine speed, low vehicle speed) as measured in the free-field over a reflecting plane. It should be noted that tire noise is negligible at low vehicle speeds.

The methodology is based on a consideration of truck operational modes and the noise emission characteristics associated with each mode. The methodology includes the method in which the vehicle is to be operated during testing, a complete test site description and other necessary descriptors to ensure a reliable and repeatable test.

A detailed discussion of the rationale for selection of this particular measurement methodology is presented in conjunction with associated supporting documentation.

2. Technical Backup

Webster's definition of the word "truck" is as follows: "An automotive vehicle for hauling loads along highways, street, etc." The Federal Highway Administration, U. S. Department of Transportation, Motor Safety Regulations[1]1/ make a distinction between "truck" and "truck tractor." A truck is defined as "any self-propelled motor vehicle, except a truck tractor, designed and used, or exclusively used whether or not so designed, for the transportation of property." A truck tractor, on the other hand, is defined as "a self-propelled motor vehicle designed and used primarily for drawing other vehicles and not so constructed as to carry a load other than a part of the weight of the vehicle so drawn."

It is also important to review the definition of "completed vehicle" according to the National Highway Traffic Safety Administration, U. S. Department of Transportation[2]. A completed vehicle is defined as "a vehicle that requires no further manufacturing operations to perform its intended function, other than the addition of readily attachable components, such as mirrors or tire and rim assemblies, or minor finishing operations such as painting." Since most "truck" manufacturers do not manufacture truck bodies and since "truck tractor" manufacturers do not mount the fifth wheels (devices used principally to connect a truck tractor to a semitrailer) in all cases, the majority of "trucks" and "truck tractors" coming off the assembly line do not meet the criterion to be called complete vehicles. Such vehicles are termed "incomplete vehicles" and are defined as "an assemblage consisting as a minimum, of frame and chassis structure, power train, steering system, suspension system, and braking system, to the extent that those systems are to be part of the completed vehicle, that requires further manufacturing operations, other than the addition of readily attachable components, such as mirrors or tire and rim assemblies, or minor finishing operations such as painting to become a completed vehicle"[2]. For the purposes of this report, complete and incomplete trucks and truck tractors will be considered and will be referred to simply as trucks.

2.1. Product Classification

Before we consider the problem further we must develop a reasonable product classification breakdown, i.e., we must be able to define exactly what we mean when we speak of medium and heavy trucks. Since trucks are designed to haul loads, a classification can conveniently be made according to the load a truck is capable of handling. The logical breakpoint between light trucks and medium and

1/ Numbers in brackets indicate the literature references at the end of this report.

heavy trucks appears to be a gross vehicle weight rating (GVWR)2/ of 10,001 pounds. Trucks with a GVWR of 10,000 pounds or less (termed light trucks) include 1/2, 3/4 and 1 ton pick-up and van vehicles which have recently become very popular for personal use. According to statistics of the Motor Vehicle Manufacturers Association [4], about 74 percent of the light trucks in use today are personal vehicles. These trucks use gasoline engines (exclusively) very similar to those used for automobiles and operate below their horsepower limit a vast majority of the time. Trucks with a GVWR of 10,001 pounds or greater (termed medium and heavy trucks) utilize both gasoline and diesel engines and because of their characteristic weight/horsepower ratio, they operate near their horsepower limit a high percentage of the time. Trucks in this category are utilized nearly 100 percent for commercial purposes.

Medium-duty trucks are popular for short haul jobs as in agriculture, intracity delivery, and construction. These vehicles are predominantly powered by gasoline engines (see Table 1). The heavy-duty trucks are usually diesel powered and are generally designed to haul semitrailer, full trailer or combinations of trailers. Dump trucks and cement mixers are also included in this category. Despite the vast amount of freight moved by trucks (motor trucks accounted for 78 percent of the 1971 freight dollar) from manufacturers, only 30 percent of truck trips are between cities. The great majority are local in nature.

Table 1. Truck sales as a function of weight category and type of fuel for 1973 [5].

	MEDIUM				HEAVY	
CLASS	3	4	5	6	7	8
GVWR (Pounds)	10,001-14,000	14,001-16,000	16,000-19,500	19,501-26,000	26,001-33,000	Over 33,000
Gasoline	44,724	7,181	18,921	198,404	25,006	19,937
Diesel	------	296	20	4,896	17,194	145,983
Total	44,724	7,477	18,941	203,300	42,200	165,920
PERCENT GASOLINE	98%				22%	
PERCENT DIESEL	2%				78%	

2.2. Normal Use Conditions (and Range)

In order to develop an appropriate, reliable and repeatable test or series of tests, it is necessary to consider the range of possible truck operational modes. The general operations discussed above such as delivery, long haul, etc., are not of sufficient detail for the purpose of defining normal truck operation. What is needed is definition of the percentage of time which a truck typically spends at idle, accelerating, decelerating, at low speed cruise, at high speed cruise, at wide open throttle, etc. Such typical usage data do not presently exist for trucks.

A program known as the CAPE 21 Study (sponsored jointly by the U. S. Environmental Protection Agency and the Coordinating Research Council, Inc.) is presently underway to define typical truck operation. Although the primary objective of the study is to define typical truck cycles for air emission purposes, the defined typical cycle might also be applicable in the noise arena. A knowledge of the percent of time spent in each operational mode coupled with the noise level generated during that mode would provide guidance as to the appropriate operational modes which the measurement methodology should specify.

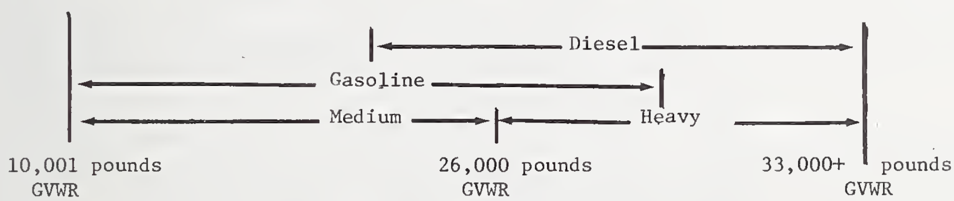
2/ The gross vehicle weight rating (GVWR) is defined [3] as the value specified by the manufacturer as the loaded weight of a single vehicle. This should not be confused with the gross combination weight rating (GCWR) which is defined as the value specified by the manufacturer as the loaded weight of a combination vehicle.

Phase I of the CAPE 21 Study has been completed and one report [6] has been prepared which presents data collated from various sources which identify the composition, function and travel behavior of urban truck travel in New York City. A similar report is presently in preparation for the Los Angeles Basin area. From these data, various stratifications have been organized to permit the characterization of mission, function and use patterns of trucks operating over urban streets.

On the basis of these data, a sample of 50 medium and heavy trucks (gross vehicle weight rating of 10,001 pounds or greater), representative of the total truck population in these urban areas, has been selected. The New York sample includes 10 percent diesel powered vehicles and 90 percent gasoline powered vehicles. In Los Angeles the mix is to be 40 percent diesel and 60 percent gasoline. The trucks are to be instrumented and operated in normal fashion to collect detailed operating profile data of truck operation. The data will include recordings of engine torque, engine temperature, throttle-valve closure and other parameters. Additionally, the onboard observer will be able to input into the instrumentation the road type -- expressway, arterial roadway, local street -- and prevailing traffic conditions manually. One data scan of the measured variables is to be accomplished each 0.8 second. The data is converted from analog sensor voltages to digital output in binary coded decimal (BCD) form and recorded on magnetic tape for later data processing and statistical analysis.

The plan is for the instrumented vehicles to be put into normal service by its owner/operator and monitored for one to five days. A total of 172 truck-days of data are to be accumulated in each area. The resultant data will provide truck operating profiles, or usage patterns, broken into periods of truck operation such as acceleration, cruise, deceleration, idle, etc. Although the typical truck operational cycle resulting from this study will have been developed for air emmisions purposes and is restricted to only urban areas, the progress of the CAPE 21 Study should be closely monitored.

One could assume that medium duty trucks spend a different percentage of their time operating at or near full power and at engine speeds near maximum than heavy duty trucks or that gasoline powered trucks operate differently than diesel powered trucks and therefore different test procedures might be considered appropriate to each class. Upon further investigation, however, a logical breakpoint separating medium and heavy duty trucks on any basis other than operation is difficult, if not impossible to define. For example, the breakpoint based on GVWR and that based on engine type are different as summarized in the following chart. International Harvester[7] 3/ for example, offers diesel engines in their 21,200 pound GVWR cab-over Cargostar model and 19,700 pound GVWR Loadstar 1750 model while also offering a gasoline engine in their 54,000 pound GVWR Fleetstar vehicle.



Since at the present time the data are not available to distinguish between medium and heavy duty trucks according to normal operation considerations, the same measurement methodology should be applied to all trucks of 10,001 pounds or greater. When the results of the CAPE 21 Study are available, it would be appropriate to see if there is any basis for modification of the present thinking.

2.3. Effects of Noise and Parties Affected

It is also important to identify the parties affected by truck noise and the nature of the effects. Operators and passengers are affected and the nature of the effects range from annoyance and task interference to possible hearing loss. Although hearing loss is not a potential problem for neighbors and bystanders near highways due to truck traffic, they certainly can have their tasks interfered with or be annoyed.

The interior truck noise problem is, in general, covered under the Bureau of Motor Carrier Safety Regulations[8] which establish a maximum interior sound level for commercial trucks (trucks of 10,001 pounds GVWR or greater are nearly 100 percent commercial) operated in interstate commerce. For this reason, the methodology to be developed will be applicable only to the exterior noise of vehicles which contributes to community noise levels.

3/ Commercial vehicles are identified in order to adequately define the basis for the examples cited as part of the technical backup in this report.

2.4. Major Truck Noise Sources

It is important to identify the major sources of noise in trucks and the effect of normal operation on the noise levels associated with each of these sources. Basically the sources are as follows:

- Engine (mechanical) Noise - is primarily produced by the combustion process which produces rapid changes in pressure in the cylinder which in turn results in excited mechanical vibrations in the engine structure. Some of this vibrational energy is subsequently radiated to the atmosphere as acoustic energy.

- Fan Noise - is the result of air flow past the fan blades which results in rotational (associated with pressure differences across the fan blades) and turbulent noise (associated with the eddy flows and vortices shed at the blade edges). Such noise is related to fan tip speed and air distribution which is governed by the fan configuration and environment.

- Exhaust Noise - is created when high pressure exhaust gases, released through the engine exhaust valves, excite oscillations in the exhaust system which are radiated to the atmosphere at the tail pipe, through the pipe surfaces and through the muffler shell. The noise is a function of engine type, engine timing, valve duration time, intake system type, muffler type, size and location, pipe diameter, pipe bends, dual or single system, etc.

- Air-Intake Noise - is created by the opening and closing of the intake valve which causes the volume of air in the system to pulsate. Associated noise levels are dependent upon whether the engine is gasoline or diesel, turbocharged or naturally aspirated, 2-cycle or 4-cycle the number of cylinders, the engine displacement, engine rpm, engine load, etc.

- Tire-Road Interaction Noise - is related to tire and tread configuration, highway road surface, vehicle speed, load and state of tire wear. Vibration of the tire carcass and the entrapment and release of air from tread pavement interstices (air pumping) appear to be the major mechanisms for tire noise generation.

- Transmission Noise - arises from the meshing of gear teeth in transmission systems and may be apparent under load, no load, or reverse load conditions. The noise may be aggravated by resonance of the gearbox casing or by structure born components that excite large body surfaces that form efficient radiators.

  Although subjectively noticeable to the pedestrian, gear noise components are unlikely to contribute significantly to objective measurements of emitted noise at the present time; however, as noise levels of other sources are reduced in the future, transmission noise could become a problem in certain vehicles.

- Noise From Accessories - is created by blowers, brakes (squeal, air brake release), generators, air conditioning equipment or miscellaneous equipment such as stake racks, tie down chains, tailgates, etc.

Appendix A contains a more detailed discussion of the component noise sources.

2.5. Rationale for Methodology

There is no such thing as a "typical" truck from a noise source standpoint. Many component combinations, which can affect the noise output of a given vehicle, exist in trucks due to the need to perform various tasks in different geographical and political climates. Such requirements as maximum allowable truck width, truck length, truck height, axle weights, etc., which vary from state to state represent political constraints. Owner preference also has a significant impact on final truck configurations since the owner specifies the options. To establish the complexity of the problem the following example is developed. The International Harvester Company[9] markets six basic models having a GVWR of 10,001 pounds or greater -- Fleetstar, Loadstar, Paystar, Conventional Transtar, Cab-Over Transtar, and the Cargostar. With the exception of the Cargostar (for which data were not compiled), 4298 options which can have an effect on noise levels are purchasable in the remaining basic model lines.

To explain the basis for these numbers a discussion of the Fleetstar options is presented. For example, 360 combinations are possible for the Fleetstar 2050 series. This series has four engine choices [IH diesels - DV550 (200 HP) and DV550 (180 HP), Cummins V555 and Caterpillar 1160], two transmission options [manual or automatic], five exhaust configurations, a choice of two hood types [fiberglass tilt hood or a steel butterfly hood], and can be purchased with or without shutters and a standard radiator or one designed to accommodate a power take-off. These options represent 320 combinations. In addition, two of these engines -- the DV550 (200 HP) and the DV550 (180 HP) -- are also available in eight special vehicles designed to haul steel; thus, an additional sixteen combinations exist. An additional engine (Detroit Diesel 6V53) is offered with three injector configurations, two hood options, two exhaust options and the choice of a standard radiator or one designed to accommodate a power take-off. This adds another 24 combinations. Therefore, a total of 360 combinations exist for the Fleetstar 2050 series. The Fleetstar 2010 series has 293 combinations while the 2070 series has 140 combinations. Similar calculations for the other models yield the following results: Loadstar, 2700 combinations; Paystar, 369 combinations; Conventional Transtar, 62 combinations; and Cab-Over Transtar, 374 combinations. This is not to say that all of the 4298 combinations discussed in this example are sold, but very few trucks built are identical.

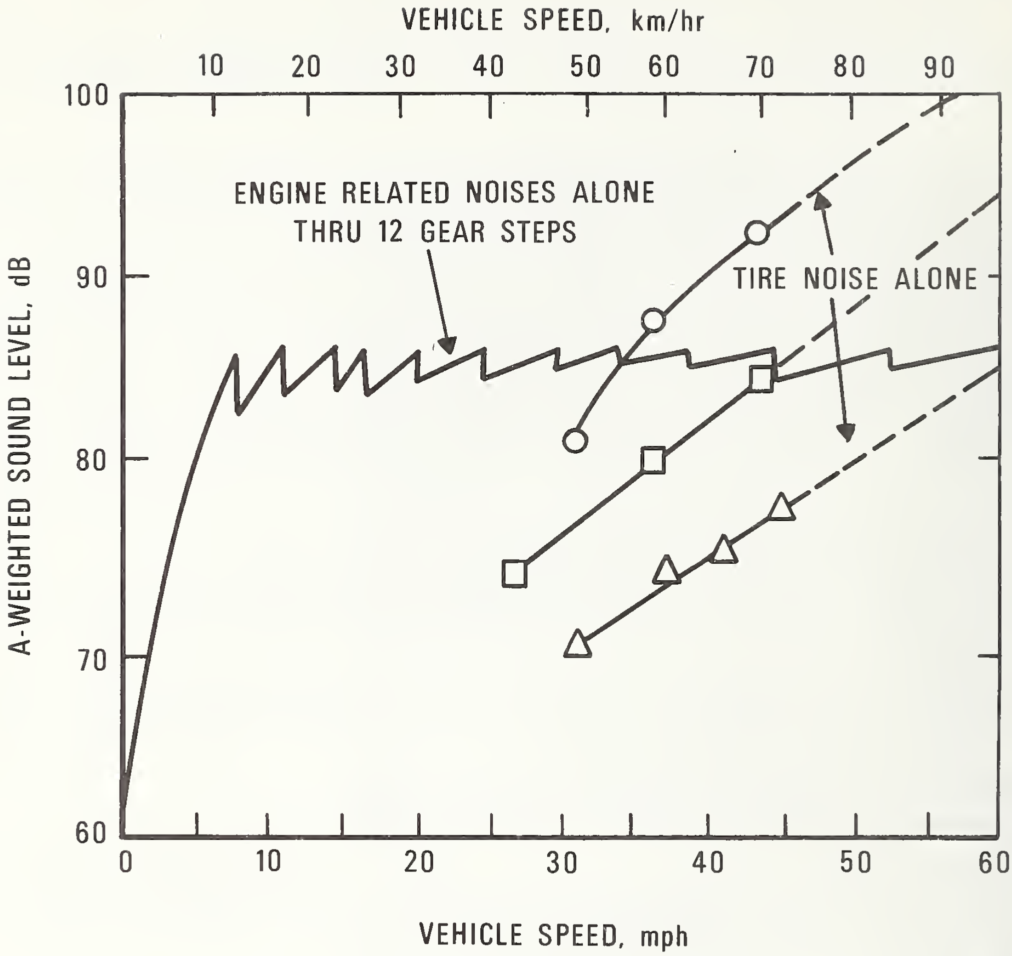
Even though an enormous number of different trucks exist on the market, the major noise in trucks can be categorized as the noise produced by the propulsion system (including the engine, exhaust, intake, cooling fan, etc.) and by the tire-road interaction. The noise from the propulsion system increases as the engine speed increases while the noise from tires increases as the vehicle speed increases (see Figure 1).

On this basis, one must consider the possibility of (1) regulating the total truck, including tires or (2) regulating the truck and tires separately. The proposed methodology in this report is a variation of the second of these alternatives.

- Identify trucks and tires separately as major noise sources.
- Establish a measurement methodology and a level or set of levels to be met by the truck (prime mover) manufacturer.
- Establish a measurement methodology and a level or set of levels to be met by the tire manufacturer.
- Label tires in order that the user can choose tires for his single-chassis and combination vehicles which will reduce the overall truck noise and will meet Federal interstate motor carrier regulations or State regulations.

The benefit from regulating the total truck, including tires, is simplicity; however, pursuit of this option will not ensure a decrease in overall noise levels since the high speed noise generated by these vehicles depends on the number of tires on the road, the tread design and state of wear, the load, vehicle speed and highway pavement surface -- variables which are out of the control of the truck (prime mover) manufacturer. If the entire truck were certified, the owner, under Section 10 requirements of the Noise Control Act of 1972, would be restricted to the purchase of identical tires or tires that were known to produce lower noise levels. Without a labeling system, this knowledge will not exist. Also it is the fleet owner who decides what tires are mounted on the tractor and trailer. These tires will dictate the high speed noise levels produced by the combination vehicle if the truck is fairly well maintained and has an adequate exhaust muffler. Without a knowledge of typical tire noise levels (which would be known if tires were identified as a major noise source and were included in a labeling program) the fleet owner must base his decision on experience and little data. An incorrect decision on his part could result in an expensive citation. Also, on what basis does the individual tractor owner decide whether or not he will be in violation of Federal interstate motor carrier regulations or State regulations when he agrees to pull a given trailer? He must be provided tire noise information to make such a decision since (1) he may pull a different trailer every trip and (2) he does not decide what tires are placed on the trailer. In addition, the following reasons form the basis for our recommendation that the tires be handled separately from the remainder of the truck's components:

- The purchaser may send the truck manufacturer new or used tires to be mounted on his vehicle or may specify the tires which should be purchased.
- If the manufacturer mounts "quiet" tires on the vehicle, at the time of delivery, he has no control over the purchaser who might immediately replace these tires with others more suited to his needs.



TIRE NOISE

	STEERING AXLE	DRIVE AXLE	TRAILER AXLE
○	NEW RIBS	½ WORN X-BARS	NEW POCKET RETREAD
□	NEW RIBS	NEW X-BARS	NEW RIB RETREAD
△	NEW RIBS	NEW RIBS	NEW RIB RETREAD

Figure 1. Engine related and tire noise for an 18-wheel tractor-trailer as measured 50-feet from the centerline of the lane of travel of the vehicle[10].

- The noise generation mechanisms are totally different for truck tires than they are for the propulsion system. Propulsion system noise is engine rpm dependent. Tire noise is road surface and vehicle speed dependent.

- In the case of the truck tractor, the truck manufacturer does not sell trailers and he does not know the type of trailer which his tractor will pull, the number of axles nor the number of tires.

- In the case of single-chassis vehicles, the truck manufacturer may or may not know the type of body which the truck will have (which would define in general terms the typical usage) and cannot control the addition of tack-on axles, a practice which is quite common with single-chassis vehicles (depending on state load/axle restrictions).

- Tire noise is load dependent and generally trucks cannot practically be loaded at the factory since they have no bodies (in the case of single-chassis vehicles) and may not have fifth wheels (in the case of truck tractors) by which the load can be carried or pulled, respectively.

- Historically, original equipment manufacturers equipment is utilized in replacement truck parts with the exception of tires. An owner never returns to the truck manufacturer to buy tires or for a recommendation as to which tires to buy.

- The breakdown of shipments of new truck tires in 1973 indicates 36.7 percent were for original equipment, 62 percent were for after-market replacement and 1.3 percent were for export[11]. It should be noted that these figures include tires for trailer use. When one takes into consideration the number of retreads on the road, it is obvious that the number of original equipment tires on the road is small. So, regulating total truck noise would not be a very effective means for controlling tire noise.

- It is possible to buy tires by specification in the safety area but the equivalent is not available in the noise area.

- There exists a practical restriction on tire noise testing in that quite a bit of room -- on the order of 1.5-2 miles for a fully loaded combination vehicle -- is necessary to allow a truck to attain speeds of 50-60 mph for a high speed certification test and then be able to stop the vehicle safely.

Therefore, the remainder of this report will concentrate on the development of measurement methodologies appropriate for the determination of the noise produced by the propulsion system. A methodology that would be appropriate for tire certification is presently being developed by DOT/NBS and will be available in final form in the very near future. Appendix B contains a discussion of alternative methodologies that were evaluated prior to the selection of the low speed acceleration test procedure discussed below.

2.5.1. Methodology Development

The existing Society of Automotive Engineers (SAE) test method for measuring the noise produced by motor vehicles (SAE J366b[12] for medium and heavy trucks) was designed to extract the maximum noise that can be produced by the propulsion system without considering the problems of tire noise. Accordingly, the tests are conducted at high engine speed and fairly low vehicle speed. The noise level produced during such a test represents the worst-case noise level for a truck operating under urban driving conditions. Such a test would, in addition, represent the worst-case propulsion-system noise contribution to the over-all noise levels produced by the vehicle at high speeds.

An extensive data base utilizing this test method exists today. A similar data base does not exist at the present time for alternative methodologies that might be utilized for measuring the noise of medium and heavy trucks. Alternative methods that specified stationary test modes rather than passbys and allowed for measurements that were not weather dependent would certainly be attractive and should be pursued in the future; however, the present legislative time constraints under which EPA must operate coupled with the lack of data for these alternative methods does not allow for their consideration at this time.

Although the major concepts of SAE J366b have been adopted as the basis for the methodology described in this report, modifications have been made in an effort to decrease the site-to-site variability due to test site and environmental considerations and to increase the repeatability of the test itself. Major emphasis will be placed on the modifications and the rationale for them.

The present SAE J366b procedure establishes the method for measuring the maximum exterior sound level for highway motor trucks, truck tractors and buses. Test site requirements limit measurements to a flat open space, free of large reflecting objects within 30 metres of either the vehicle path or the microphone. The measuring microphone is located 15 metres from the centerline of the vehicle path. The vehicle approaches the microphone in a gear ratio selected such that at a point (acceleration point)

15 metres before the microphone, the vehicle is at no more than two-thirds of maximum rated or governed engine speed. At this point the vehicle is accelerated at wide open throttle such that maximum rated or governed engine speed is achieved between 3 and 15 metres (the end zone) beyond the microphone without exceeding 56 km/hr at the end point.

2.5.1.1. Acoustic Environment

2.5.1.1.a. Test Site

Modifications have been made to the existing test site requirements contained in SAE J366b. The proposed modifications are aimed at decreasing the variability of the test results due to test site, meteorological and operational factors without invalidating the existing data base.

Vehicle position within the present end zone -- that area in which the vehicle is to reach maximum rated or governed engine speed -- is a significant variable which is affected by vehicle configuration, driver technique, etc. To gain a clearer understanding of how the component noise sources contribute to total truck noise during a J366b test, consider the following illustrative example, which might be considered typical for a fan dominated vehicle. For this particular truck, the exhaust and engine noises are about equal and dominate the total truck noise for about the first 11 metres. The engine noise levels off and remains essentially constant for the remainder of the passby. Exhaust noise continues to increase, reaching a maximum about 6 metres beyond the microphone point. The exhaust is the predominant source during the central portion of the drive-by. The cooling fan speed has been increasing throughout the test and near the end of the end zone it reaches maximum speed where it also produces maximum noise. At this point, the contribution of the other sources has decreased, and the cooling fan is the predominant source. It is here where the total truck noise also reaches a maximum. Thus, it is evident that variation in overall truck noise according to SAE J366b procedures can be expected depending on whether maximum rated or governed engine speed is reached near the beginning or end of the end zone.

Mathematically, assuming a constant intensity omni-directional point source in a free field, one would predict a maximum variation in A-weighted sound level of 2.9 dB over the extremes of the present 12.2 metre end zone. Measurements[13] made with a Ford LNT-9000 truck equipped with a Cummins NTC-335 diesel engine showed a 2.3 dB variation in A-weighted sound level on the basis of whether the vehicle reached governed engine speed at the beginning or end of the end zone. For this reason, the end zone has been reduced to 4.6 metres. Practical reasons associated with a truck reaching maximum rated or governed engine speed in a limited end zone precluded shortening the end zone further. Since the end zone is a fixed location and shorter than that specified in J366b, the acceleration point must now be allowed to float within an acceleration zone located 11.4 to 19 metres before the microphone point (rather than being fixed at 15 metres as in J366b) so that a beginning speed and proper gear ratio can be determined which will ensure that a vehicle reaches maximum rated or governed speed within the end zone.

The question still remains as to the proper location of the shortened end zone (4.6 metres in length) within the limits of the end zone which is presently specified in J366b (12.2 metres in length). The consensus of the NBS task force is that the shortened end zone should be located approximately in the middle of the existing zone; in other words, the present end zone would shrink 3.8 metres on either end. At first it was thought that the optimum location would be at the beginning of the existing end zone (closest to the microphone location); however, limited data indicated that the sound level measured under this configuration would be lower than that measured according to J366b procedures. Obviously comparative data between this newly developed procedure and J366b procedures are needed with special emphasis paid to determining the optimum location of the shortened end zone to ensure the preservation of the extensive existing data base.

At present a single microphone location is utilized and no readings are made after the truck has left the end zone. Before accepting this concept two questions need to be addressed: (1) Is there a need to replace the single microphone with an array of microphones located parrallel to the path of the vehicle and simply read the maximum noise level that occurs during a passby regardless of microphone location? (2) If a single microphone is sufficient, is the presently specified location appropriate?

In order to address the first question, data previously taken by NBS[14] according to J366a (the changes made between J366a and J366b are mainly editorial in nature) procedures utilizing an array of microphones have been reevaluated. Figure 2 shows a view of the test section and placement of all microphones in the array. In addition to the J366 location (microphone number 3), four additional microphones were located along a line parallel to the vehicle path at locations 4.6 metres and 9.2 metres on either side of microphone number 3. As shown in Figure 2, the microphones are located on the right side of the vehicle. A mirror image provides the proper view for left side measurements; that is, microphone number 1 is nearest the acceleration point regardless of the direction of travel.

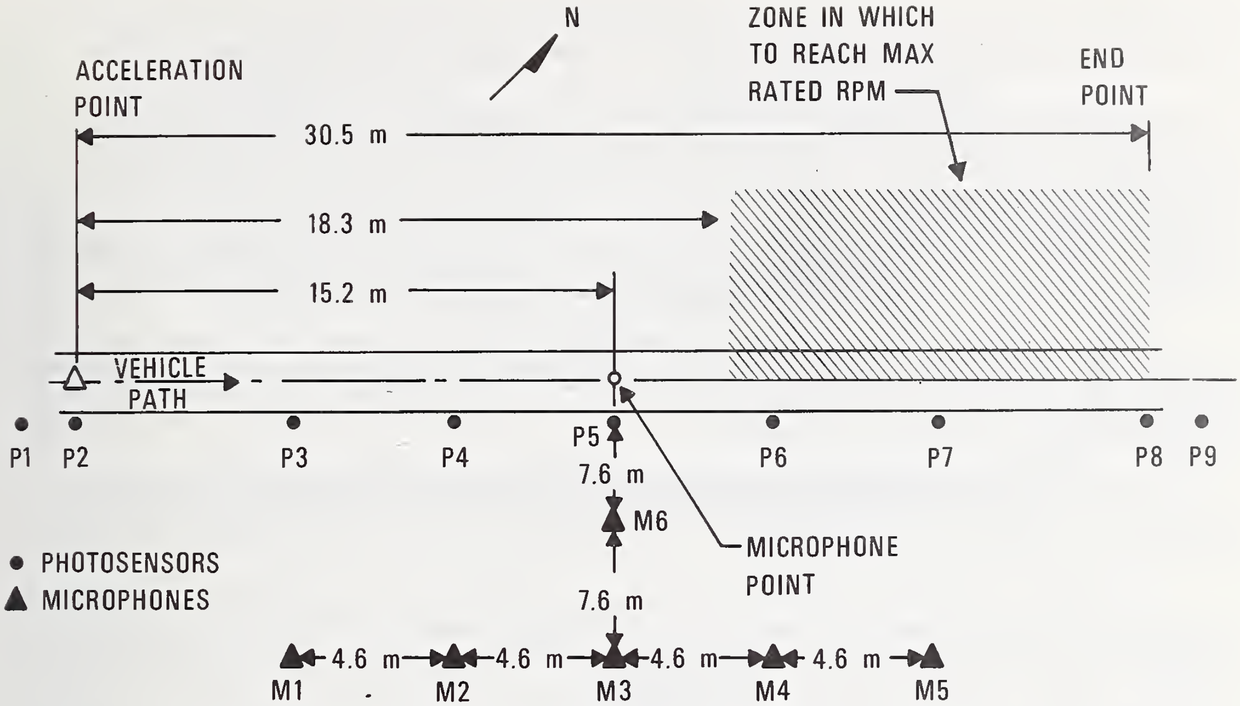


Figure 2. View of test section showing placement of microphones (M1-M6), photosensors (P1-P9), acceleration point, end point, microphone point, and the zone in which the maximum rpm is to be reached[14].

Table 2 shows the results of subtracting the sound level observed at the J366 microphone from those observed at the remaining microphones in the array (excluding the microphone located 7.6 metres from the centerline of vehicle travel). Minus and zero differences indicate that the maximum was read by the J366 microphone. Positive differences indicate that the maximum sound level was measured at a microphone other than the J366 microphone. These data show that 70 percent of the time the maximum sound level was measured at the J366 location and 94 percent of the time the reading at the J366 microphone location was within 1 dB of the maximum sound level which was observed at one of the other microphones in the array. On the basis of these 224 test runs, the use of an array of microphones does not appear to be justified in view of the cost and complexity associated with them -- especially when one considers the small manufacturers.

Table 2. A-weighted sound level differences observed between the J366 microphone and the remaining 15.2 metre microphones in the array shown in Figure 2.

Microphones Involved	Number of Occurrences						
	A-weighted Sound Level Differences						
	-3 dB	-2 dB	-1 dB	0 dB	1 dB	2 dB	3 dB
1 - 3	3	4	20	12	12	5	--
2 - 3	--	1	16	19	18	1	1
4 - 3	--	3	12	23	15	3	--
5 - 3	2	10	11	21	9	2	1

In answer to the second question posed -- namely the suitability of the J366 microphone location -- it appears, on the basis of these data, that the present location is better than any of the others investigated during the test program under discussion.

Another question which deserves consideration is whether measurements should terminate when the vehicle leaves the end zone or should continue for a limited time thereafter. The basis of the question is the speculated "peanut shell" directionality patterns to the front and rear for fan dominated vehicles. Although the question cannot fully be answered on the basis of these data [no attempt was made in this program to identify the predominate component noise sources], the fact that the maximum

A-weighted sound level was not observed more often at any one single microphone located on either side of the J366 microphone seems to indicate that there is no justification for continuing the meter reading after the truck has left the end zone.

Tolerances have been added to the specifications of the height of the microphone above the ground plane and the distance between the source and microphone. Acoustically these changes should make negligible differences [15] but it provides a little flexibility to the person performing the test and ensures that the data will not be legally dismissed because a given dimension is not exactly what it should have been. In addition guidance is provided to allow for the proper orientation of the microphone with respect to the sound source. The microphone should 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 flattest frequency response characteristic over the frequency range of interest.

A recent study[16] suggests locating the measuring microphone at ground level rather than at a height of 1.2 metres above the ground. However, experimental data are too limited to support such a change at the present time especially since (1) the present data base would be invalidated and (2) problems encountered due to meteorologically induced variations (shadow zones) are possibly more severe at ground level than at other heights.

Manufacturers, in conducting SAE J366b tests, have observed that the porosity of the surface of the test pad is critical as well as the planar smoothness of the surface in the measurement area. Additional specifications have been added to this methodology to control these parameters as required to limit the variability in test results.

For example, International Harvester Company observed that noise levels taken on their new test pad were significantly lower than those taken on the surfaces previously used. (The two surfaces, both asphalt, were thought to be identical.) An impedance tube[4/] placed directly on the surface of the test pad was utilized to acquire data such that the absorption characteristics of the two surfaces might be compared. Figure 3 shows the results of this investigation. The discontinuity at 1800 Hz is due to a change in the diameter of the impedance tube utilized (from 10 cm to 3 cm). A comparison of the datum point on either side of the discontinuity provides some indication of the accuracy of the measurement. Although the measurements were rather crude and were for normal incidence (whereas almost grazing incidence occurs in the truck passby measurements), the percent absorption below 2000 Hz was clearly different for the two asphalt surfaces. The new asphalt surface was 35-40% absorptive compared to the old asphalt which was found to be 2% absorptive. The solution in this case was simply to seal the new asphalt with commercial driveway sealer. Following the sealing operation, comparable sound levels were obtained for identical vehicles regardless of the test pad utilized. The conclusion that can be drawn from this experience is that, due to its porous nature fresh asphalt is highly absorptive. Old surfaces that have borne much traffic have evidently been sealed by the wear pattern much as the driveway sealer does on a new surface.

For practical reasons we do not limit the surface to concrete. Resurfacing is a problem with concrete since the entire test pad has to be dug up and a new pad laid. With asphalt a new surface can be laid fairly quickly and relatively inexpensively. We do not require the surfaces to meet given absorption restrictions either (present in-situ measurement techniques are not well defined), but simply require the hard surface area to be of smooth concrete or smooth sealed asphalt.

The effect of test site topography is another important aspect of passby site noise test variability. Researchers at General Motors[19] conclude that variations of a few inches in surface flatness (of the plane containing the vehicle path and the measuring microphone) may cause significant differences in overall sound levels and spectral content. GM looked at this problem as a result of consistent differences in sound level of 0.5 to 2 dB observed for identical vehicles on two test sites. (The two sites were measurement areas on opposite sides of the same vehicle test path.) An investigation of the topography was made with the intent being to make whatever modifications were necessary to the site geometry to force results of future vehicle passby noise tests to agree between sides within instrumentation accuracy.

The modifications to the pads were made in the form of a repaving to achieve uniform flatness over both test pads. Before repaving, the south side showed a "dished out" geometry while the north side showed substantial crowning. The repaving was successful, the measurement differences, based on measured data, being reduced to typically 0.5 dB. Unfortunately it is not possible to separate the effect of the resurfacing from that of correcting the surface topography since both influencing factors were changed as a result of the modification. However, it is felt that a practical flatness restriction is needed to lessen site-to-site sound level measurement variations. Therefore, this methodology requires that the plane containing the vehicle path (acceleration point to end point) and the microphone location be flat within $\pm$ 0.05 metres.

[4/] For a description of the impedance tube and its use reference should be made to ASTM Standard C-384-1972 -- Test for Impedance and Absorption of Acoustical Materials by the Tube Method[17].

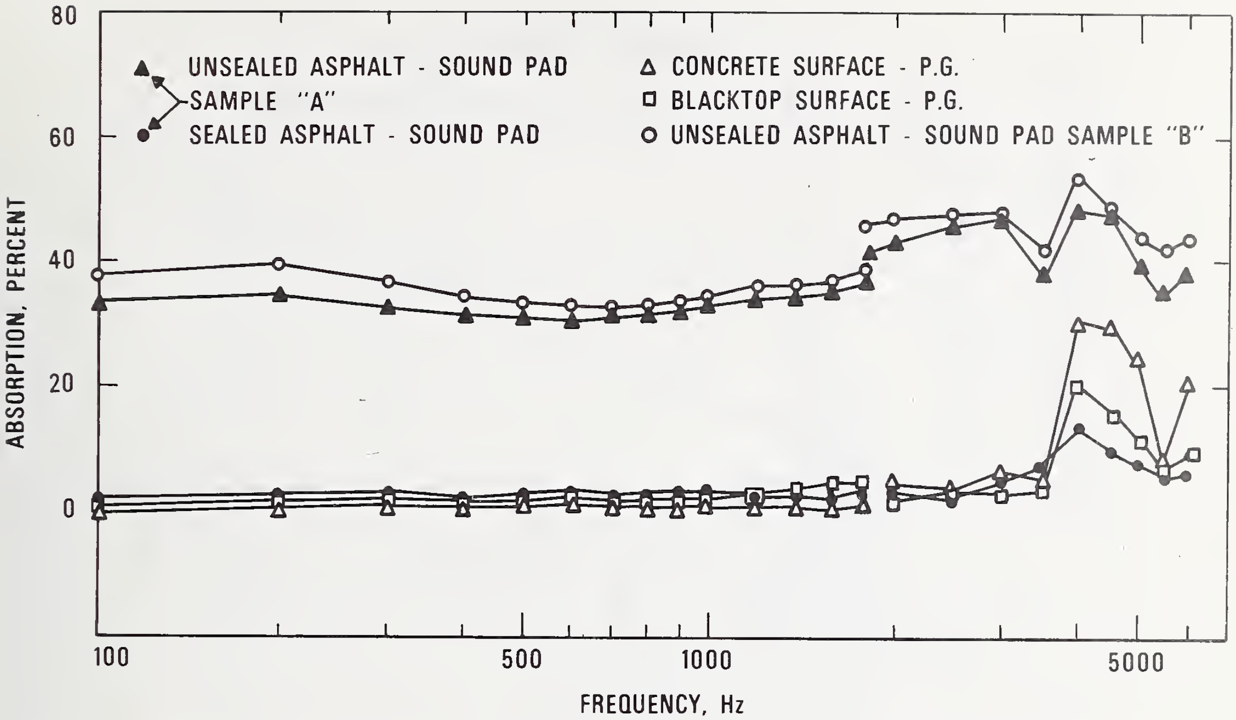


Figure 3. Comparison of sound absorption characteristics of various surfaces meeting the present requirements of SAE J366b[18].

2.5.1.1.b. Weather Conditions

The only modifications to the existing requirements contained in J366b are the following:

- Testing is restricted to times when the wind speed is less than 5 metres/second (acceptable since only A-weighted measurements are being made).

- Corrections are required for barometric or altimetric changes (effects on calibration devices that are ambient pressure dependent).

It is the consensus opinion of the NBS task force that all measurements should be corrected to a standard temperature and barometric pressure (e.g., 1 atm and 20°C) so that data taken in Michigan in winter can be compared with that taken in Arizona in summer, for instance.

The Ford Motor Company routinely applies a temperature correction to its data of 1 dB/27.8°C (1 dB/50°F) (see Figure 4). The correction factor is based on theoretical considerations of the effect of temperature on noise generation by individual truck components.

General Motors Corporation has compiled data on six identical passenger cars. Although automobiles typically have different noise characteristics than trucks, it was felt by GM[21] that variations in noise level due to temperature changes observed for these vehicles (air bag test vehicles) would be similar to what would be expected for trucks. These vehicles were equipped with 350CID 4-BBC engines, thermostatic clutch fans, automatic transmission, 3.42 to 1 rear axle ratios and dual exhaust systems. Much scatter can be seen in the data (Figure 5) but the trend shows that the A-weighted sound level decreases by 1 dB for an increase in temperature of 24.7°C (44.5°F).

Data [Figures 6 and 7] are also available to indicate that 20°C should be selected as the standard temperature. Some SAE procedures presently utilize 20°C as a reference temperature.

At this time, no consideration of a barometric pressure correction has been made by the truck manufacturers. Theoretical considerations indicate that for a constant volume-velocity source (which may be representative of selected truck component noise sources but probably not total truck noise) barometric pressure and temperature influence ρc and therefore affect the sound power measured. For instance a constant volume-velocity source will emit 2.2 dB less sound power at the top of Pike's Peak than at sea level. In this case, changes in barometric pressure are more influential than changes in temperature. It is possible that some of the scatter thought to be a result of vehicle configuration might possibly be partly attributable to barometric pressure variations.

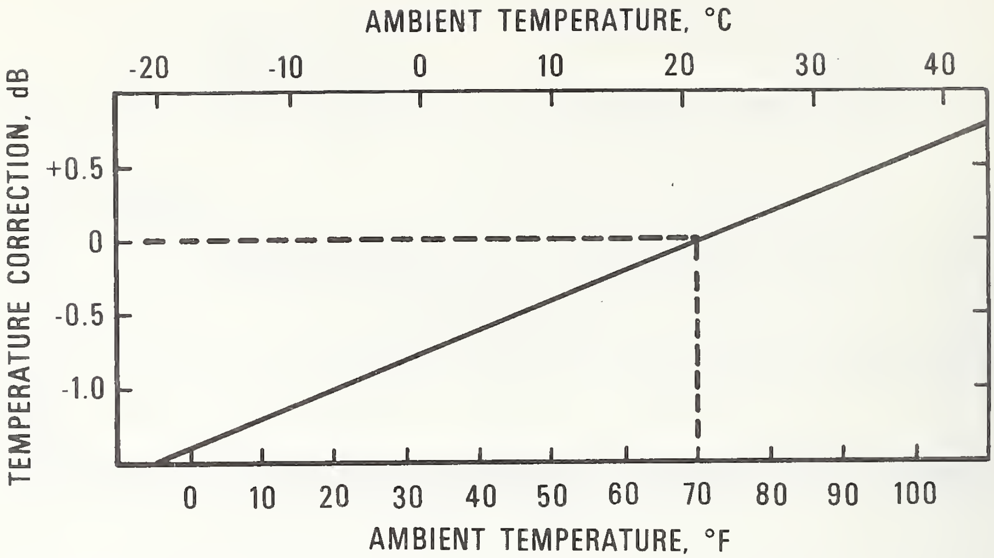


Figure 4. Ambient temperature correction factors for truck exterior noise tests[20].

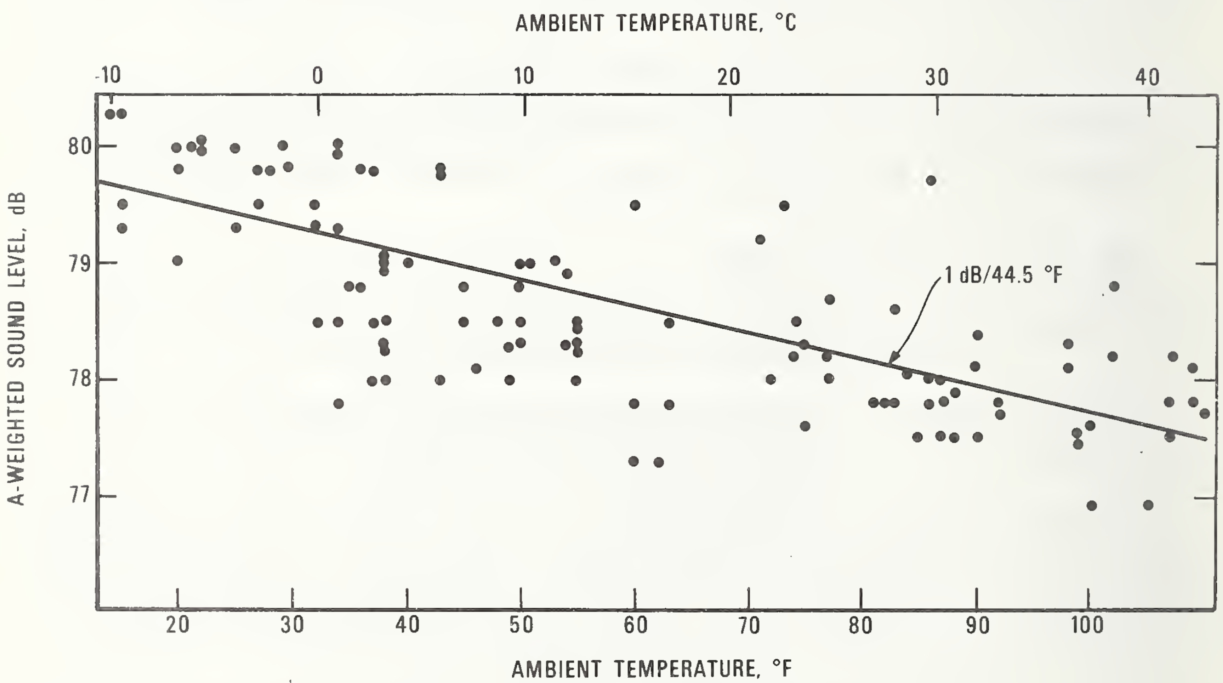


Figure 5. A-weighted sound level versus ambient temperature measured during air bag vehicle variability study[21].

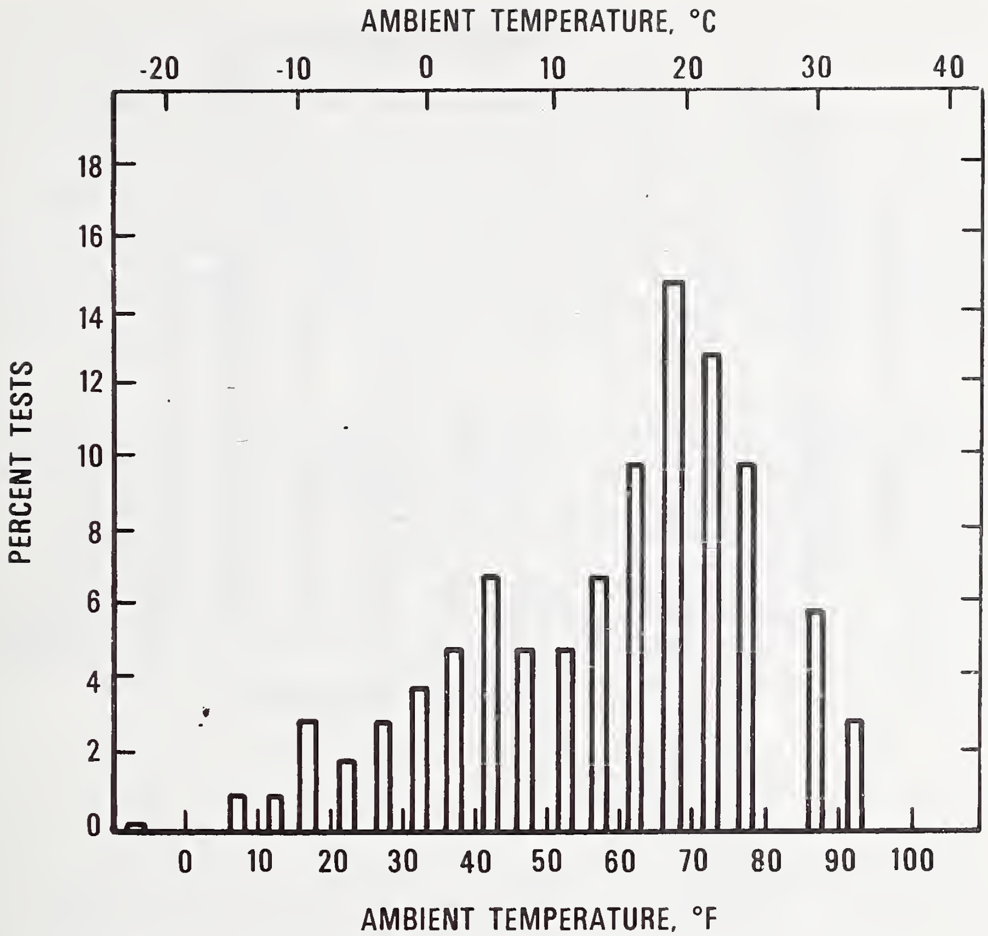


Figure 6. Temperature distribution for J366a noise tests conducted by International Harvester during calendar year 1973[18].

At the present time the data base is such that correction factors for temperature and barometric pressure cannot be defined. Such corrections are needed and research to provide definition of such factors should be given a high priority.

2.5.1.1.c. Background Noise

To be a valid test the existing background noise at the test site must be at least 10 dB below the regulated level.

2.5.1.2. Instrumentation

The response of instrumentation to transient signals, e.g., vehicle passbys, is not well defined in existing instrumentation standards. In an attempt to tighten the requirements as much as possible at this time, the instrumentation to be used while making measurements according to this methodology are required to meet the Type 1 requirements of American Standard Specifications for Sound Level Meters, S1.4-1971[22]. In addition, pertiment sections of American National Standard Methods for the Measurement of Sound Pressure Levels, S1.13-1971[23] have been incorporated as part of this methodology.

Calibration requirements -- both single point in the field and complete calibrations (to determine compliance with precision, Type 1 Specifications) -- are specified in detail and allowable tolerances are defined for calibrators.

Requirements are given for the use of a windscreen and the allowable effect of the windscreen on the sensitivity of the microphone.

Anemometers, thermometers and barometers are required as additional instrumentation and the required accuracy is spelled out in the methodology.

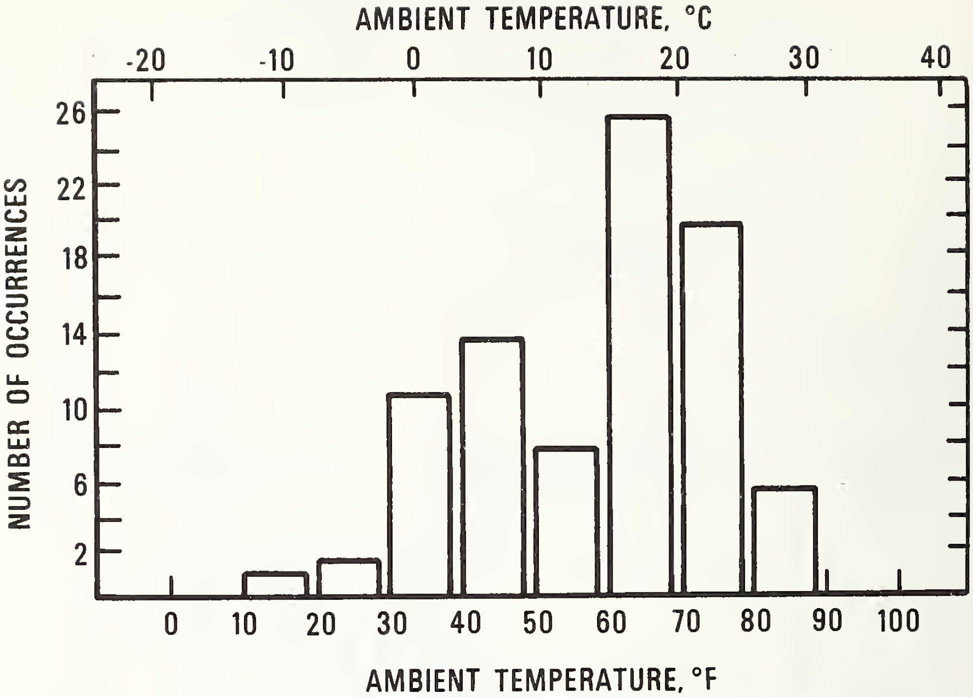


Figure 7. Test (J366a) temperature histogram for Ford Motor Company 1973 noise test program[20].

2.5.1.3. Vehicle Operation

The deceleration test procedure now specified in J366b was added to the original procedure to address the problems of engine brakes. These devices, when in use, essentially convert the engine into an air compressor which causes the exhaust valve to open at the top of the compression stroke allowing the compressed air to blow down through the exhaust system instead of working against the piston on the subsequent down stroke as per normal operations[24]. When one considers the total truck population the numbers of such brakes are quite small; however, in certain geographical areas they are quite popular. Although improvements have been made in the engine brakes themselves and in exhaust mufflers, the engine brake noise may still be the limiting factor on lowering the overall noise level for some vehicles. For this reason we retain this test procedure, but only require that it be performed for those vehicles equipped with engine brakes.

The recommendation to go to the unloaded configuration is a practical one. Tractors are typically sold without fifth wheels; therefore, no load can be pulled and it is not practical to load such a vehicle in another manner. Single-chassis vehicles are typically sold without bodies so loading this vehicle is also not practical. The J366b test procedure is such that the engine is inertially loaded during the acceleration so that there is no apparent need for pulling and/or carrying a load.

The present J366b procedure implys that governed engines, be they gasoline or diesel, should be tested at their governed speed and ungoverned gasoline engines at their maximum rated speed. This methodology turns this implication into a requirement.

Today's trucks typically utilize direct drive fans designed for "worst case" cooling demands -- heat rejection at maximum engine power with little or no ram air. Because of this it is not surprising that the cooling fan is not necessary to maintain engine cooling under many conditions. Available on the market today, but in limited use, are clutched fan drives which operate only when there is a cooling demand. High initial cost, space and maintenance problems have limited more widespread use of these devices. In addition to being attractive from a noise reduction standpoint, the usage of the clutched fan also saves the otherwise wasted power utilized to drive the fan when it actually is not needed.

Much speculation has been made on the actual percentage of time that a fan is needed to maintain engine cooling for trucks in normal operation. International Harvester Company is currently conducting a study to determine actual fan-on time. The study is a part of the DOT "quiet truck" program. At the present time 23 vehicles have been equipped with either on-off or modulating fan clutch systems. The on-off unit is either full-on or full-off while the speed of the modulating fan is variable and is determined by the cooling demand. The 23 vehicles are equipped with diesel engines ranging from 250-350 horsepower, are of conventional and cab-over designs, and represent 8 fleets which operate throughout the United States. Each vehicle is instrumented so that the following data result: (1) engine speed versus time, (2) fan engagement, (3) total engine revolutions, (4) hours of engine-on time and (5) hours of fan-on time. A log is also kept indicating the fleet, truck model, engine type as well as a compilation of times and destinations.

On the basis of present data[25,26], resulting from 700,000 miles and 18,800 hours of engine operation, the projected fan operation (total fan-on percent) would be 4 percent of the annual vehicle operation time. During only 2.6 percent of the annual vehicle operation would the fan speed by high enough (during fan-on time) to be significant from a noise standpoint. Significant fan-on time is defined as that time the fan is engaged while the engine is above 1600 rpm. 1600 rpm is the speed at which the fan noise would be 8-10 dB less than the noise at governed engine speed for the majority of the trucks involved in the program. The fan would not contribute to vehicle noise at engine speeds less than 1600 rpm. Details of the projection method for predicting significant fan operating time for a year are presented in Appendix C. The present projection is based on data from 8 of the 23 vehicles. Data acquisition with all 23 vehicles is continuing at present and the projections will be updated as more data become available.

It should be pointed out that the existing data (measured) are for diesel engines only and cover operation over an ambient temperature range from -4°C to 27°C. Also the present projections do not include any modulating fan data since the modulating fans in the study have not operated, as yet, above 1600 rpm. Even though the percentages may increase slightly for other engine types or when additional hot weather data are acquired, the net benefit provided by such fans outweighs the small portion of the time when they contribute significantly to overall noise levels. The economic feasibility of these devices hinges on the acceptance of higher noise levels during that small percentage of the time when the heat rejection demand on the cooling system is high in order to achieve lower noise emissions the remainder of the time. To provide some inducement for the utilization of such devices (assuming mechanical reliability can be demonstrated), this methodology proposes that the fan be declutched during tests for those vehicles equipped with on-off or modulating fan units. In addition to noise reduction, they also offer such advantages as fuel savings due to the fan not being on all the time -- an important consideration in light of the fuel shortage, less noise in the cab and more power.

Many trucks today are equipped with radiator shutters for temperature control. The J366b procedure requires the measurement of maximum noise; therefore, in general, the test is run with fan-on and shutters closed. Since this may not be the typical condition occurring during actual service, this methodology simply requires that the test be run with the shutters in the position producing the highest noise level that occurs when the vehicle is brought to its normal operating temperature.

2.5.1.4. Measurements

All things considered, it is proposed for practical reasons to utilize the A-weighted sound level as the basic measure for truck noise. The choice of the fast meter response is made to allow accurate readings to be made on the rapidly changing sound level associated with acceleration tests.

Selection of a single-number descriptor of the loudness or the noisiness of a sound is complicated by the relatively complex system by which humans hear and discriminate sounds. The frequency response of the hearing mechanism and the ability of humans to extract varying characteristics of noise have generated extensive research into the human reaction to noise and the means for specifying this reaction.

Present research provides two methods for determining subjective reaction to noise -- direct psychological judgements such as paired comparisons or jury (group) decisions and indirect measures such as the use of simple weighting networks in direct measuring instrumentation which are based on data from psycho-acoustic measurements. Such methods provide numerous measures for subjective reaction to noise including loudness, loudness level by the Stevens or Zwicker methods, perceived noise level, speech interference level and C- and A-weighted sound level.

The subjective response of subjects to vehicle noise has been evaluated during two comprehensive studies[27,28]. A comparison has been made between the results utilizing the psychologically derived and physical measures of sound. The Armour Research Foundation (now the Illinois Institute of Technology Research Institute) study utilized diesel truck spectra as the stimulus while the Motor Industry Research Association study included the noise of gasoline and diesel trucks, automobiles and motorcycles. The results of these studies, summarized in Figures 8 and 9, show that with the exception of the C-weighted sound level and the speech interference level the remaining psychologically derived and physical measures of sound studied could reasonably serve as predictors of human response to motor vehicle noise, in particular trucks.

Since the A-weighted sound level is the only measure having high correlation with subjective reaction that can also be read directly on a commercially available meter having standardized performance, it is proposed that the A-weighted sound level be selected as the basic measure for truck noise at this time. Should new types of propulsion systems become practical for widescale use in trucks, such as the gas turbine engine, it may be necessary to reconsider the present proposal in light of the different frequency characteristics of the sound produced.

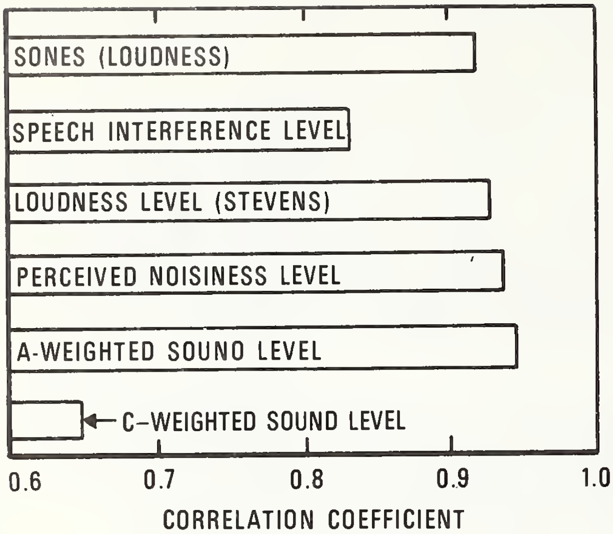


Figure 8. Correlation coefficients for various measures of subjective reaction to diesel truck noise. At the time this study was conducted, sound level meters meeting the requirements of American Standard ASA Z24.3-1944 were used. These meters had relatively wide tolerances for microphones and circuitry. The A-weighted sound levels reported in this figure were computed from the original tapes utilizing instruments meeting American Standard ASA S1.4-1961[29].

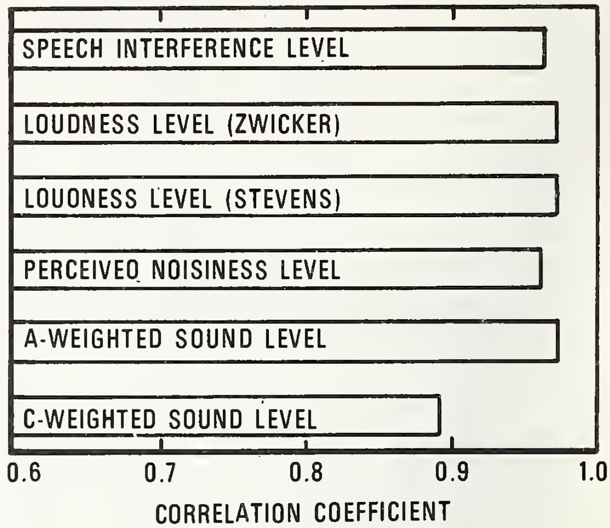


Figure 9. Correlation coefficients for various measures of subjective reaction to motor vehicles. The test included automobiles, light trucks, diesel trucks and motorcycles[29].

2.5.1.5. Measurement Uncertainty

SAE Standard J366b describes a test procedure which places restrictions on many variables -- such as limits on windspeed, reflecting surfaces, etc. -- so that the measured variable, the sound level of the test vehicle, can be accurately determined. In spite of these restrictions, it has been the experience of many individuals that there are still variabilities in the test method that result in different noise levels being measured with the same vehicle on different days (or even on the same day) and at different sites. Many attempts have been made to quantify the variabilities and/or develop correction factors [13,15,16,19,30, and 31], but very little success has been achieved to date.

The probable sources of measurement variance, which affect the generation, radiation and/or propagation of motor vehicle noise, are not difficult to identify. They include:

- Meteorological Effects
  - air temperature
  - humidity
  - atmospheric pressure
  - wind velocity and direction
  - temperature gradients
  - wind gradients
- Instrumentation Effects
  - Calibration and instrument variances (including transient response)
  - Microphone orientation
  - Windscreens
- Test Site Effects
  - Vehicle position within the end zone
  - Absorption of the surface of the test pad
  - Planar smoothness of that portion of the test site containing the microphone location and the vehicle path
- Vehicle
  - Driver technique
  - Truck-to-truck assembly differences (nominally identical vehicles)

These are just some of the known influencing factors. J366b recommends a 2 dB allowance over the sound level limit to provide for variations in test site, temperature gradients, test equipment, and inherent differences in nominally identical vehicles. Studies[13,30,31] indicate that the 2 dB allowance is not large enough to account for all the variables.

What is required is either a test that is independent of test site and environmental variables or a means of accounting for changes in the measured noise levels resulting from such variables, e.g., through site calibration techniques or the application of correction factors. At present, neither of these options is available; therefore, the attempt has been made in this methodology to tighten the test restrictions as much as possible in those areas which are controllable. It is imperative, however, that one be aware of the possible magnitude of uncertainty associated with a given test procedure so that the compliance procedures are practical.

3. Medium and Heavy Duty Truck Measurement Methodology

3.1. Purpose and Applicability

This methodology defines an acceptable procedure by which the noise from medium and heavy duty trucks (gross vehicle weight rating of 10,001 pounds or greater) may be measured to ascertain whether the noise emitted is in compliance with the noise emission standards promulgated by the U.S. Environmental Protection Agency pursuant to Section 6 of the Noise Control Act of 1972 (Public Law 92-574). For the purpose of this methodology, trucks include complete and incomplete trucks and truck tractors as defined in the Code of Federal Regulations, Title 49, Transportation (U.S. Department of Transportation, Federal Highway Administration, Part 390 -- Motor Carrier Safety Regulations and National Traffic Safety Administration, Part 568 -- Vehicles Manufactured in Two or More Stages).

3.2. Acoustic Environment

3.2.1. Test Site

3.2.1.1. The test site shall be such that the truck radiates sound into a free field over a reflecting plane. This condition may be considered fulfilled if the test site consists of an open space free of large reflecting surfaces, such as parked vehicles, signboards, buildings or hillsides, located within 30 metres of either the vehicle path or the microphone (see Figure 10).

3.2.1.2. The microphone shall be located 15.2 ± 0.3 metres from the centerline of truck travel and 1.2 ± 0.1 metres above the ground plane. The microphone 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 flattest frequency response characteristic over the frequency range 100 Hz to 10 kHz.

3.2.1.3. In order to establish the critical dimensions of the test site the following reference points are established (see Figure 10).

3.2.1.3.a. The microphone location is that point on the ground plane established by the normal from the microphone to the ground plane.

3.2.1.3.b. The normal from the microphone location to the centerline of vehicle travel shall establish the datum point.

3.2.1.3.c. The end zone begins 6.8 metres past the datum point and ends 11.4 metres past the datum point.

3.2.1.3.d. An acceleration zone shall be established on the vehicle path 11.4 to 19.0 metres before the datum point. The final choice for the acceleration point, within the acceleration zone, should be such that the vehicle (vehicle reference point is defined in Section 3.2.1.3.f.) under test reaches maximum rated speed (for ungoverned engines) or governed speed (for governed engines) within the end zone.

3.2.1.3.e. An end line shall be established on the vehicle path 19 metres past the microphone point.

3.2.1.3.f. 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. If the engine is located rearward of the center of the chassis, the rear of the vehicle shall be used as the reference point. If the horizontal distance from the reference point of the vehicle to the exhaust outlet is more than 5.1 metres, tests shall be run using both the front and rear of the vehicle as reference points.

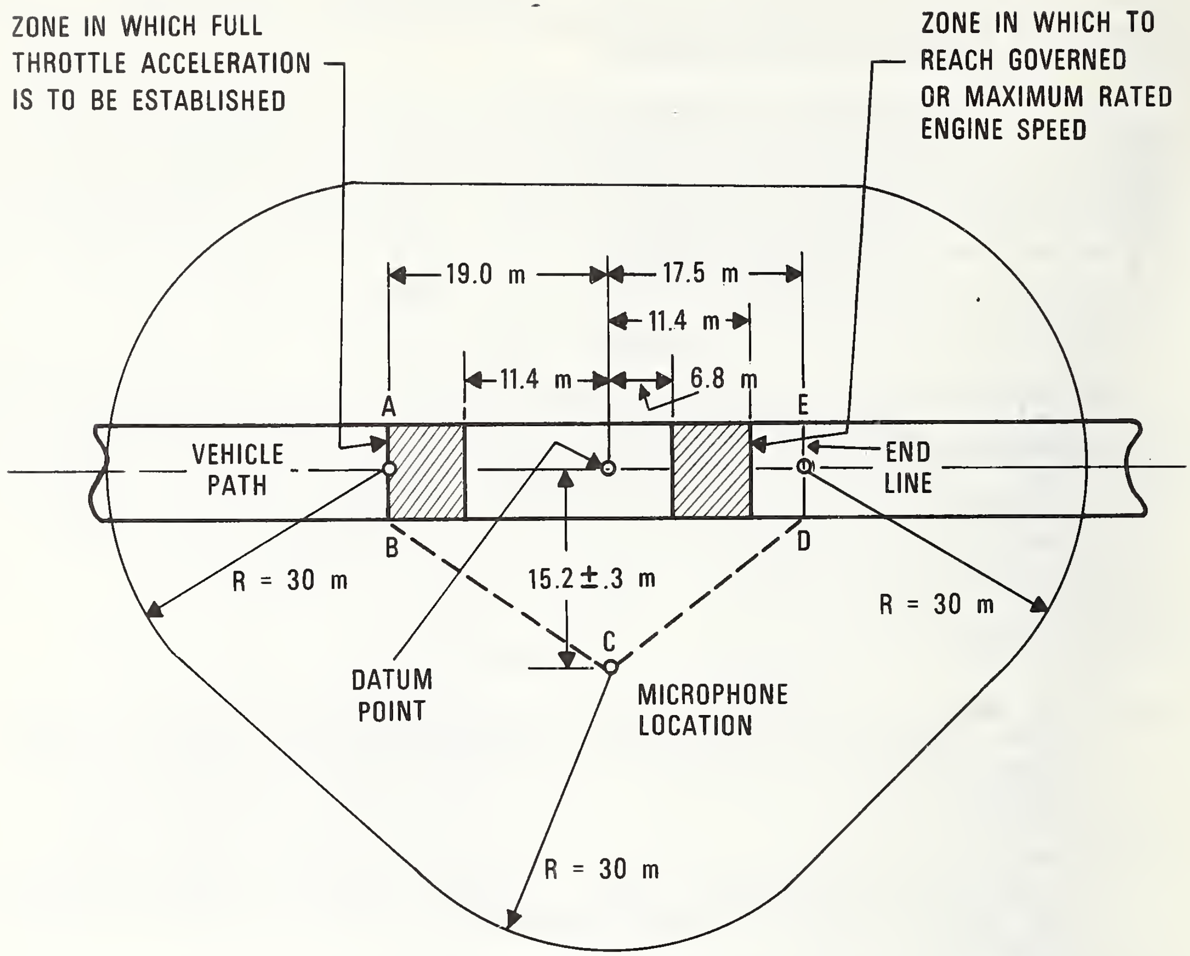


Figure 10. Minimum test site.

3.2.1.4. The road surface within the test site upon which the vehicle travels, and, at a minimum, the measurement area (BCD in Figure 10) shall be smooth concrete or smooth sealed asphalt, free of extraneous material such as gravel.

3.2.1.5. The plane containing the vehicle path and the microphone location (plane ABCDE in Figure 10) shall be flat within ± 0.05 metres.

3.2.2. Weather Conditions

3.2.2.1. Measurements shall not be made when the wind velocity exceeds 5 metres/second.

3.2.2.2. If calibration devices are utilized which are not independent of ambient pressure (e.g., a pistonphone) corrections must be made for barometric or altimetric changes according to the recommendation of the instrument manufacturer.

3.2.2.3. Measurements shall not be made when the road surface is wet, covered with snow, or during precipitation.

3.2.3. Background Noise

3.2.3.1. The maximum A-weighted fast response sound level observed at the test site immediately before and after the test shall be at least 10 dB below the regulated level.

3.3. Instrumentation

3.3.1. The measurement system utilized shall conform to the requirements of American National Standard S1.4-1971 "Specifications for Sound Level Meters" for a Type 1 instrument over the frequency range 50 Hz-10 kHz.

3.3.2 A windscreen shall be used when the average wind noise is within 20 dB of the regulated level, provided that the sensitivity change does not exceed ±0.5 dB to 5 kHz and ±2.0 dB to 10 kHz.

3.3.3. The sound level meter, or equivalent system, shall be calibrated (e.g., by means of an acoustical calibrator) at one or more frequencies in the range 250 to 1000 Hz, at the beginning and end of each series of measurements. The calibrator shall produce a sound pressure level, at the microphone diaphragm, that is known to within an accuracy of ±0.5 dB. The calibrator shall be checked annually to verify that its output has not changed.

3.3.4. A complete calibration of the instrumentation over the entire frequency range of interest shall be performed at least annually using methodology of sufficient precision and accuracy to determine compliance with the standards cited in Section 3.3.1.

3.3.5. Additional Instrumentation Requirements

3.3.5.1. An anemometer or other device for measurement of ambient wind speed accurate within ±10% at 5 m/sec.

3.3.5.2. A thermometer for measurement of ambient temperature accurate within ±1°C.

3.3.5.3. A barometer for measurement of ambient pressure accurate within ±1%.

3.4. Vehicle Operation

3.4.1. A full throttle acceleration test is to be utilized. A beginning speed, proper gear ratio and the location of the acceleration point within the acceleration zone shall be determined for each vehicle for use during measurements.

3.4.2. All vehicles tested shall be unloaded.

3.4.3. Trucks equipped with on-off or modulating fans shall be tested with the fan off.

3.4.4. The truck shall be brought to its normal operating temperature prior to commencement of testing.

3.4.5. For those trucks equipped with radiator shutters, tests shall be conducted with shutters in that position producing the highest noise level that occurs when the vehicle is brought to its normal operating temperature.

3.4.6. 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 (which must be previously established within the acceleration zone for the particular test vehicle) under the following conditions: (a) starting at two thirds of maximum rated (for ungoverned engines) or governed engine speed, (b) reaching maximum rated or governed engine speed within the end zone, (c) without exceeding 15.7 metres/second before leaving the end zone.

3.4.7. Should maximum rated or governed engine speed be attained before reaching the end zone, alter the location of the acceleration point within the acceleration zone maintaining an approach rpm of two thirds of maximum rated or governed engine speed. Should maximum rated or governed engine speed still be attained before reaching the end zone, decrease the approach rpm in 100 rpm increments until maximum rated or governed engine speed is attained within the end zone.

3.4.8. Should maximum rated or governed engine speed not be attained until beyond the end zone, alter the location of the acceleration point within the acceleration zone maintaining an approach rpm of two thirds of maximum rated or governed engine speed. Should maximum rated or governed engine speed still not be attained until beyond the end zone, select the next lower gear until maximum rated or governed engine speed is attained within the end zone. Should the lowest gear still result in reaching maximum rated or governed engine speed beyond the end zone, increase the approach rpm in 100 rpm increments until the maximum rated or governed engine speed is reached within the end zone.

3.4.9. The vehicle should approach the acceleration point using the engine speed and gear ratio selected according to the above procedure (Sections 3.4.6 - 3.4.8) and at the acceleration point wide-open throttle should be rapidly established. Acceleration shall continue until maximum rated or governed speed is reached.

3.4.10. Wheel slip which affects the maximum sound level must be avoided.

3.4.11. For trucks equipped with an engine brake the following additional tests shall be run. The vehicle shall 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 engine brake shall be full on immediately following closing of the throttle.

3.5. Measurements

3.5.1. The quantity to be measured, under the test conditions described above, is the A-weighted sound level with fast meter response as defined in the American National Standard S1.4-1971.

3.5.2. Bystanders have an appreciable influence on meter response when they are in the vicinity of the vehicle or microphone; therefore not more than one person, other than the observer reading the meter, shall be within 15.2 metres of the vehicle path or instrument and the person shall be directly behind the observer reading the meter, on a line through the microphone and observer. To minimize the influence of the observer on the measurements, a cable should be used between the microphone and the sound level meter.

3.5.3. A minimum of two test runs shall be made for each side of the vehicle. The meter shall be observed during the period while the vehicle is accelerating or decelerating prior to leaving the end zone. The applicable reading for each run shall be the maximum sound level to the nearest decibel obtained for the run. Tests shall be rerun if unrelated peaks occur due to extraneous ambient noises.

3.5.4. 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. The noise level for the side of the vehicle with the highest reading shall be utilized to determine compliance with this regulation.

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

3.5.6. The wind velocity, barometric pressure and ambient temperature shall be measured at the microphone height and within at least 3 metres of the microphone location.

3.6. Data to be Recorded

The maximum A-weighted sound level, using the fast response characteristic, shall be recorded for each measurement.

The following additional data shall also be recorded.

- General Data
  - Date of test
  - Test report number (manufacturer)
  - Other
- Truck Data
  - Manufacturer
  - Model
  - Serial number
  - Other
- Test Conditions
  - Manufacturer's test site identification
  - Ambient temperature, °C
  - Ambient wind velocity during sound level measurement, m/sec
  - Atmosphere pressure, mm Hg
  - Other

- Instrumentation

  - A calibration history of all equipment shall be maintained.
  - Microphone/serial number
  - Sound level meter/serial number
  - Calibrator/serial number
  - Other/serial number
  - Windscreen on/off

- Sound Level Data

4. Appendix A. A Discussion of Truck Subsource Noise[5/]

Gasoline engines power 65 percent (based on 1973 new truck sales) of the trucks in operation with a GVWR of 10,001 pounds or more. The remaining 35 percent are powered by diesel engines. The major contributing subsources of truck noise include engine (mechanical) and transmission, exhaust, cooling system, intake and tires.

- Engine (mechanical)

The engine and transmission form a complex acoustical system composed of a large number of sources, the most important of which result from the increase in pressure within the cylinder during combustion of the fuel. This rapid rise of cylinder pressure excites mechanical vibrations in the engine structure. Some of this vibrational energy is subsequently radiated into the atmosphere as acoustic energy. The gas forces are also transmitted through the piston and crank mechanism to the main bearings and hence excite flexible or mobile structures coupled to the crankshaft. Most of the noise generated by these mechanisms is radiated by the crankcase, oil pan, clutch housing and valve covers. The noise level produced by both gasoline and diesel engines depends upon engine size, speed and load. The noise level depends more on engine speed than on size, so that for a given horsepower, the quieter engines are associated with a larger displacement and slower engine speed. In practice there is a significant range in engine (mechanical) noise levels for a given engine size. Calculating the effect of engine noise on the overall vehicle noise level is difficult because the noise produced by a given engine depends upon the way in which it is mounted so that the level varies with the type of truck in which it is installed.

Gasoline engines initiate combustion with a flame which smoothly spreads throughout the cylinder until the fuel-air mixture is burned. Diesel engines, on the other hand, rely on much higher compression ratios to produce spontaneous combustion which rapidly oxidizes the fuel. This causes a more rapid change in pressure in the cylinder which in turn results in increased engine vibration and hence higher noise levels.

The primary combustion forces occur at the relatively low fundamental firing frequencies but the structure responds to the higher harmonics as well. Fuel injection equipment, pistons, valve train, gearing and accessories, all integral with or attached to the engine frame, contribute at various frequencies to deflect or vibrate the engine structure.

The engine itself contains several areas which vibrate and radiate noise. The blocks of V engines act as tuning forks while in-line engine blocks vibrate as beams. The motion of these relatively thin case block surfaces as well as sheet-metal components such as the oil pan, rocker arm cover, oil sumps, etc., which are attached to the vibrating structure, all increase the noise radiated to the atmosphere.

The character of the combustion forces can be changed advantageously by turbocharging. Turbocharging, which increases the pressure of the inlet air above atmospheric pressure, reduces the combustion force impact by making the pressure rise more gradual; thus, decreasing the noise radiated. Sheet-metal parts may be vibration isolated from the movement of the engine by use of soft gaskets and rubber washers at the mounting bolts. Engine covers using high density barrier materials lined with absorbent materials are the most effective way of reducing engine noise but have the disadvantages of reduced accessibility to the engine, reduced cooling efficiency, added weight, and potential fire hazards due to leaking oil being absorbed by the acoustical liners (which also destroys the noise absorption characteristics). Shielding under the engine can be effective in blocking the reflected path of noise from the engine to the receiver by way of a paved surface.

[5/] The material in this appendix was mainly derived from Wyle Laboratory reports to EPA [32,33] on transportation noise and a cost-effectiveness study of medium and heavy trucks and material presented in the SAE Twentieth L. Ray Buckendale Lecture on truck noise control [34].

• Exhaust System Noise

Exhaust noise is generated by the rapid release of high pressure combustion gases when the exhaust valve opens. In addition to the discharge noise -- noise radiated to the atmosphere at the tail pipe outlet -- this rapid release of pressure excites oscillations of the muffler shell and exhaust and tail pipe surfaces which are radiated in the atmosphere as noise. Transmission loss through the pipes and flexible connections and gas leaks are additional noise sources within the exhaust system. In the past, the outlet noise has overshadowed the other exhaust system sources; however, as the outlet noise is reduced by use of improved mufflers, the pipe and shell noise become more significant contributors.

The primary frequency components of exhaust noise are dependent upon engine speed, number of cylinders, exhaust system configuration (single or dual exhausts) and whether the engine is a 2-cycle or 4-cycle engine. Its amplitude is dependent upon ignition timing, throttle setting and engine load (pressure in the cylinder when the valve opens).

Mufflers or resonators are typically utilized to control exhaust discharge noise. The performance of these devices is very dependent upon other acoustic elements within the system such as the engine and the length and diameter of both the exhaust and tail pipes. In addition to providing effective noise reduction, mufflers must be designed to produce a tolerable back pressure on the engine.

Muffler shell noise and pipe-radiated noise are similar in nature. General approaches to pipe and shell noise reduction include reducing the distance between the muffler and the manifold by utilizing a shorter exhaust pipe, by concealing pipes with shielding or by routing the pipes behind other truck components, or by utilizing damping materials to reduce muffler and pipe vibration.

Noise also can be produced by engine brakes which, when in use essentially convert a power producing diesel engine into a power absorbing air compressor. This is accomplished through a master-slave piston arrangement which opens cylinder exhaust valves near the top of the normal compression stroke releasing the compressed air charge to the exhaust manifold. The blowdown of compressed air to atmospheric pressure prevents the return of energy to the engine piston on the expansion stroke, the effect being a net energy loss since the work done in compressing the cylinder charge is not returned during the expansion process. Since the diesel engine is turned over by the driving wheels of a vehicle descending a hill through the vehicle drive line and transmission, application of the engine brake retards the "free-wheeling" effect of the driving wheels and a braking action results. Advantages such as elimination of continual braking with the vehicle service brakes, ability to maintain engine operating temperatures on down grades, increased life of brake components and tires and added safety make this device a popular option in certain geographical areas. The noise produced by the blowdown of the compressed air to the atmosphere is generally controlled by making improvements to the engine brake itself or through the use of improved mufflers.

• Cooling System Noise

The cooling system is a major noise source on trucks due to the severity of the cooling requirements at full engine power and low road speeds. The fan must move enough air to maintain the required coolant temperature when ram air is not available.

The fan is the predominant noise source in the cooling system. The fan, as an air moving device, creates lift forces to cause air motion. Since the lift force is the result of a pressure difference across the fan blade, the lift force actually rotates with the blades and relative to a fixed point, fluctuates each time a blade passes setting up pulsations in the surrounding area. Such pulsations result in the generation of a fundamental tone, associated with the blade passage frequency, and higher order harmonics. Non-uniform air flow across the face of the fan (due to improper distribution of the air from the radiator) and obstructions near the fan such as hoses, alternators, etc., which create air flow irregularities intensify the fan noise problem. In addition, random pressure fluctuations, resulting in broadband noise, are caused by the non-coherent shedding of vortices from trailing edges of the blades and by turbulence generated upstream of the fan arising from the passage of the cooling air over the tube and fin surfaces of the radiator.

Fan noise can further be aggravated for trucks utilizing radiator shutters for engine temperature control. By blocking the air flow through the radiator, shutters cause the pressure rise across the fan blade to increase resulting in an increase in noise level.

An obvious approach to reduce cooling system noise is to increase cooling efficiency and thus allow for decreased fan speed. A larger fan turning at a slower speed which can be swept over a larger radiator core area with possibly a lower tip speed has obvious advantages. Fan shrouds can also be used to prevent air recirculation through the fan thereby ensuring that all of the air pumped by the fan has passed through the radiator to provide cooling. The clearance between the outer edges of the fan blades and the shroud (tip clearance) can also be a major factor. To ensure optimum noise reduction the tip clearance should be as small as practical.

Cooling systems are designed for "worst case" situations which seldom occur. In actual service conditions, the heat load is such that full fan speed is not required much of the time. The critical condition for trucks, from a cooling demand standpoint, is when the vehicle is pulling a heavy load up a long grade at full engine power but low road speed. Fans operating at full speed are necessary during this period to provide necessary cooling in the absence of the ram air effect. Additionally, fans are usually operating when the vehicle is idling; however, the fan is not operating at its maximum rpm and therefore the noise generation is not significant. At fan speeds of less than 1600 rpm the fan noise is sufficiently less than the fan noise at governed engine speed (usually about 2100 rpm) and therefore the contribution to the overall noise level of the vehicle is not significant.

On the basis of the previous discussion, it appears that the obvious approach to the fan noise problem would be the utilization of a demand fan in place of a direct drive fan. Clutched fan drives -- either on-off or modulating -- do exist on the market today (in limited quantities); however, they are not widely utilized in trucks at the present time. Such fans are thermostatically controlled and operate only when needed. On-off fans are either full-on or full-off, in other words, when cooling is needed the fan comes full-on and remains on until the cooling demand has been satisfied. The speed of the modulating fan varies to compensate for the heat rejection demands of the engine and seldom is at "full-on" condition.

Present limited data (discussed earlier in this report) utilizing trucks equipped with demand fans indicate that actual fan "on time" is on the order of a few percent of engine on time under actual over-the-road conditions. Such fan clutches are not prevalent at the present time; however, the promulgation of new noise regulations which accept the higher noise levels during that small percentage of the time when the heat rejection demand on the cooling system is high in order to achieve lower noise emissions the remainder of the time should alter this situation.

- Air Intake Noise

Engine air-intake noise is produced by the intake pulsations on 4-cycle naturally aspirated engines, by blower blades on a turbocharged engine, and by blower lobe passage disturbances on pressure scavenged 2-cycle engines.

Intake systems are similar to exhaust systems in that the components and problems are much the same; however, each intake system must be treated individually since both the frequency and amplitude of intake noise varies with engine type. Low frequency intake noise is generally controlled by the use of properly designed and located large volume air-cleaners matched to the intake pipe. Tuned silencers are usually required to reduce the high frequency components of intake noise. Location of the air intake openings, e.g., toward the front of the vehicle rather than to the side, can also be effective in controlling intake noise as observed by a bystander along the road.

At present, the air intake system is not a major contributor to overall truck noise levels for most manufacturers; however, as overall noise levels are reduced the intake system will have to be re-evaluated.

- Tire-Road Interaction Noise

The physical mechanisms of the production of noise by the tire-road interaction process are not well understood. The general consensus is that air pumping (entrapment and release of air from the tire tread cavities) and vibration of the tire carcass are the major mechanisms contributing to the generation and radiation of acoustic energy. However, the effect of tread design (rib, crossbar), effect of road surface, effect of wear, and the effect of load on the noise levels produced are known. The existing data do not provide the basis for the design of quieter tires.

Truck tread designs for highway usage can be classified basically into two categories -- rib and cross-bar. Rib type tires, with the major tread elements oriented in the circumferential direction, possess characteristics that are suitable for all wheel locations. These tires are noted for their lateral traction and uniform wear characteristics. Although they can be used on all axle positions, rib tires typically are seen on steering and trailer axles. Cross-bar tires are used primarily on the drive axles. This design, with the major tread elements oriented in the lateral direction, gives maximum driving traction and provides a much more rigid tread structure plus added original design tread depth. The final choice of which type of tire is utilized depends on many factors, some of which include the original cost of the tire, a concept of the safety provided by a given tire and a knowledge of the company's policy on retreading. The true cost of a tire (cost/mile) is dependent, for instance, on the number of times a carcass -- be it a rib or cross-bar tread design originally -- will be retreaded.

Although the mechanisms of tire noise generation are not well understood, influencing variables such as wear, load, speed and pavement surface are known to affect tire noise levels.

Cross-bar tires, as a generic group, are noisier than the rib-tread tires. The difference between the quietest cross-bar tire and the noisiest rib tire is typically 4-8 dB. Also of interest is the fact that only a 1 to 2 dB decrease is observed between the quietest rib tire and a completely smooth tread. Therefore, a breakthrough in basic tire design appears to be needed before tires exhibiting significantly lower noise levels could be manufactured. Such a breakthrough does not appear to be imminent.

Road surface conditions do influence tire noise levels; however, the effect depends on the tire type, for instance, cross-bar tires generally produce higher noise levels when running on a rougher surface but in any case the influence is not very significant. Rib tires tend to get noisier as the surface gets rougher. It should be noted at this point that no method now exists for quantitatively characterizing the surface roughness or texture of pavements typical on today's roads. Until the surface texture can be physically characterized, little can be known about the effect of surface roughness on the generation of tire noise.

It is known that sound levels rise with increasing speed for all tires, but at slightly different rates. Empirically, tires are characterized by an increase of 6 to 12 dB for a doubling of vehicle speed in the range of 30 to 60 mph. Theoretical considerations supporting relationships in which sound level increases as either $30 \log_{10} V$ or $40 \log_{10} V$, or where V is speed, have been developed. This is within the range of the empirical data.

Load is also an important parameter. The increase in sound level that exists between the unloaded and loaded condition is significant for cross-bar tires. As the load is increased for tread designs of the cross-bar type, more of the tire load is carried on the outer sections of the tread where the most drastic interruptions in tread pattern exist.

Rib tires are relatively unaffected by load. In this case the rib pattern is the same across the width of the tire and, hence, it is not important how much load is carried on the outer edges of the tire.

Tread wear is another variable that can greatly affect the sound level generated by tires. Tire noise generally increases between the new and half-worn states and depending on the tire type either increases or decreases with additional wear. It appears that the factor controlling the change in noise level with wear is the change in tread curvature.

Other factors -- inflation pressure, tire temperature, etc. -- also can influence tire noise but their effect is not thought to be as great as those parameters discussed above.

5. Appendix B. Discussion of Alternative Low Speed Acceleration Measurement Procedures

The low speed acceleration test procedure discussed in this report is a very detailed and repeatable test procedure. A wealth of data now exist utilizing this type of procedure and it has been shown that the test does produce the maximum noise level which a truck is capable of making at low speeds. It is basically a test of propulsion system noise. Because of the space, weather and time constraints of this procedure, it seems appropriate to investigate alternative procedures which would be simpler yet correlatable with the more detailed test procedure discussed in this report. The correlation as we speak of it here is not whether the simple test gives the same answers as the more detailed test but rather that vehicles which fail the simple test would also fail the detailed test. In other words, a double jeopardy situation would not be created for the manufacturer to cope with.

5.1. Stationary Run-Up Test

One immediate candidate for consideration is the stationary run-up test utilized as one of the tests in the present draft of the Federal noise certification procedures for interstate motor carriers.

The basic components of a stationary run-up procedure are as follows:

1. Park the vehicle at a location so that no large reflecting surfaces such as other vehicles, signboards, buildings, or hills, are within 24.4 metres of the vehicle under test.

2. Locate the microphone 12 metres above the ground plane and 15.2 metres from the fore to aft centerline of the truck in such a manner that the measuring microphone is on a line with the exhaust outlet.

3. With the vehicle transmission in neutral gear, accelerate the engine with wide open throttle to its governed engine speed as rapidly as possible.

4. A minimum of two measurements shall be made for each side of the truck. 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. The noise level for the side of the vehicle with the highest readings shall be utilized to determine compliance.

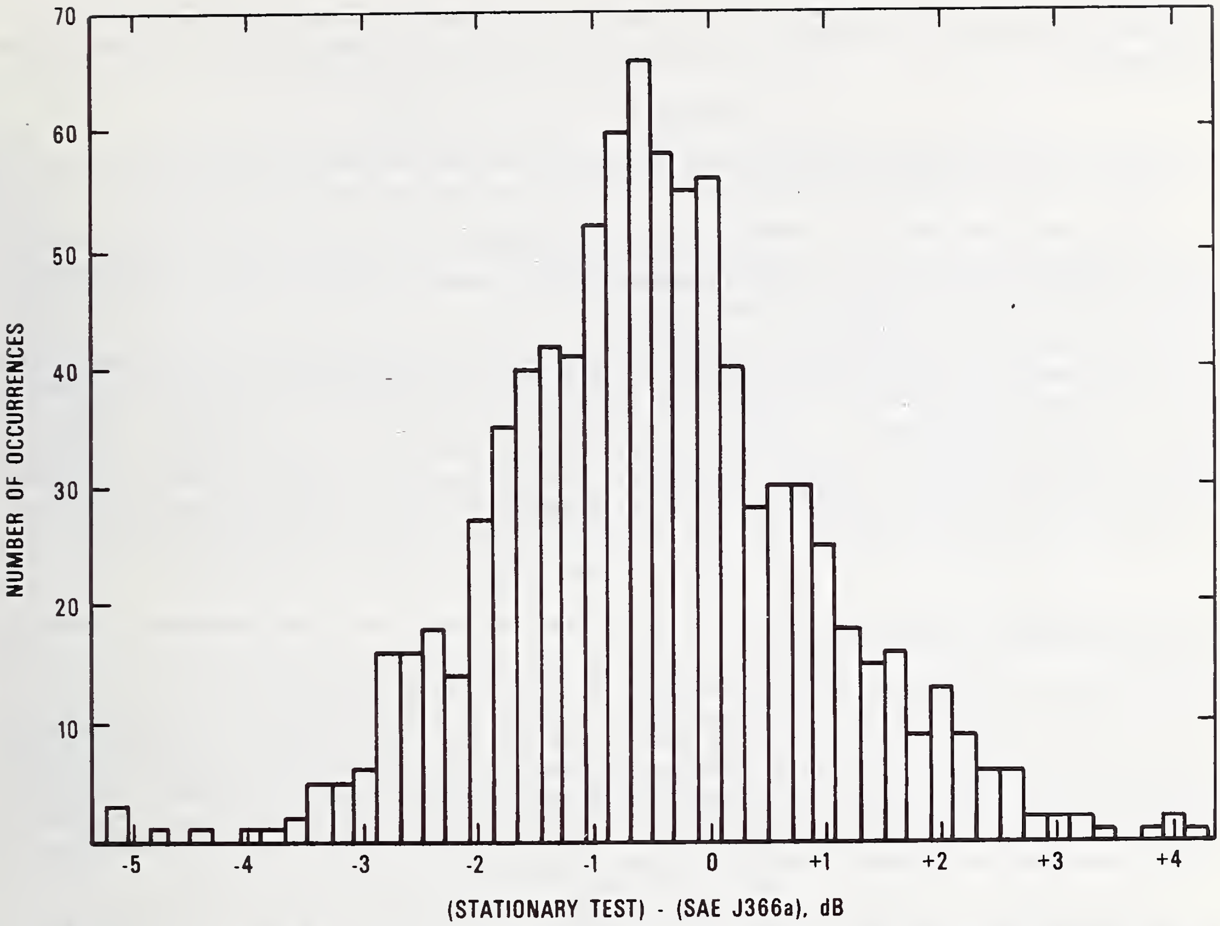


Figure B-1. Comparison of stationary run-up and vehicle acceleration (SAE J366) test results [35].

Only the highlights of the stationary run-up test procedure are discussed here. All of the meteorological and background noise constraints of the previously discussed measurement methodology would be applicable as well as the sections on purpose and applicability, quantities to be measured and measurement instrumentation. The test site specifications and the detailed vehicle operation of course would have to be modified.

Some data exist utilizing this procedure. Figure B-1 shows the results of a study of over 800 different trucks in which a comparison was made between the sound level obtained for the J366a procedure and that for the stationary run-up procedure. The results are promising; however, due to difficulties associated with the test, it has not been considered further as a candidate measurement methodology for new trucks at this time.

The two main difficulties with the test procedure is that gear train associated noise is not evaluated in a stationary test and the procedure is only applicable to governed engines. The test sample shown in Figure B-1 included governed engines only -- gasoline engines and turbocharged and naturally aspirated diesel engines. The number of ungoverned engines sold by each individual manufacturer varies but a large proportion, estimated to be about 40-50 percent, are sold ungoverned. Since the governor, or lack of a governor, is a problem only for gasoline engines -- for safety reasons all diesel engines are governed -- the adoption of the procedure as is would result in a distinction according to engine type. As discussed earlier, this separation may have no merit and may be a false and unrealistic division criterion.

This procedure offers little in the way of improvement over the passby procedure discussed earlier. It would probably take less time to run the test and the amount of space necessary to conduct the test would be slightly reduced, however, all of the weather constraints which limit testing when the passby method is utilized would also be a problem with the stationary run-up test.

Another question which must be addressed is whether one tests vehicles with this procedure or merely the accuracy or inaccuracy of the particular governor. The maximum noise level recorded during the stationary run-up test corresponds to that point where the engine hits the governor, overshoots and then settles down to the governed engine speed (or high idle). Because of the safety factor with diesel engines the speculation is that diesel governors are usually more accurate than those utilized on gasoline engines.

5.2. Dynamometer or Inertial Loading

On the basis of the difficulties associated with the low speed acceleration test and the stationary run-up test the next logical step would be to look for a means to load an engine externally.

It has been shown that it is possible to disconnect the drive shaft of the truck at the universal joint and connect it directly to a shaft/flywheel assembly which if properly sized can simulate the inertial load on the engine that would be observed during a J366b acceleration test. At present only limited experience exists with such a test setup.

Dynamometers, on the other hand, do exist and are in use in some parts of the motor vehicle industry. They tend to be noisy devices in themselves; however, the operating machinery could be remotely located. Finally, tire noise, of possibly greater magnitude than normal for a J366b test, would be introduced into the measurement. Tires on dynamometer rolls tend to heat up and deform in a manner which is different than when in normal operation. In addition, the tires are in a different situation on a dynamometer roll (with a radius) than they are in actual service on a highway (with a flat surface). The noise levels in or near existing facilities on the grounds of a truck manufacturing plant, where dynamometers are typically located, preclude the measurements being made in existing facilities.

5.3. Indoor Tests

Since the weather is a major limiting factor for all outdoor tests, it would be logical to investigate the possibility of indoor testing.

If indoor testing were to be chosen as part of the standard requirements, a testing facility would have to be specified in great detail and identical facilities would have to be constructed by each manufacturer -- be he small or large. It would appear to be prohibitively expensive to construct a facility to allow for 15.2 metre measurements; yet, measurements any closer than 15.2 metre would be questionable without extensive research to provide insight into the near field/far field effects and to establish the correlation between the results obtained according to such procedures with what the community experiences when a truck passes by on a nearby highway. Also, the practical problem of removing the heat and exhaust fumes from the operating vehicle would have to be dealt with.

The legislative time constraints which EPA is working under do not allow for consideration of such alternative methodologies at the present time. They each have pros and cons associated with them; but, they have almost no data base or experience base to back them up. Much research would be necessary before such procedures could be utilized as the measurement methodology for the new truck regulation.

6. Appendix C. Projection Method for Predicting Significant Fan Operating Time [26]

Step I - Fan-On Yearly Projection

A. Plot monthly normal temperatures from World Almanac for area of truck operation.

B. Plot percent of fan-on time data for each truck versus the monthly normal temperature curve from A above. Draw best-fit line.

C. Establish projected percent fan-on time for each month by selecting normal temperature at mid-point of each month, going to curve in B, and reading back the percent of fan-on time for the monthly normal temperature.

Step II - Significant Fan-On Time

A. Establish average engagement time per truck by counting number of engagements over two randomly selected one week data periods. Divide the fan-on time data by the number of engagements to give the average time per engagement. The mean of the two data periods is used.

B. Count the number of engagements for all data periods where the engine speed is above 1600 rpm. Where time frame includes variable and constant engine speed operation, count period as above 1600 rpm if more than 50% of the time is at constant speed and below 1600 rpm if more than 50% of the time is not at constant speed.

C. To establish the amount of time for fan operation greater than 1600 rpm multiply A above x B above.

D. The percent fan-on time greater than 1600 rpm is C above divided by the total fan-on time for the data period. The average for all reporting periods available is considered representative for the year. No trend could be seen versus temperature.

E. To establish the significant fan-on time for the year, multiply the projected percent fan-on time (I;C) by the percent fan-on time greater than 1600 rpm (II;D) for each month, then determine the yearly average for each truck.

7. Appendix D. Research Needs

The following is a list of projects which are needed to fill the gaps in existing knowledge as they pertain to the accurate and repeatable characterization of the noise levels of medium and heavy trucks. The fact that uncertainties are associated with the test method has exceedingly important consequences on the manufacturer of motor vehicles. If a manufacturer is required to certify that the vehicles sold by him comply with certain noise emission regulations, then uncertainty in the measurement procedure can be costly -- increasingly so as the regulations become more exacting.

- There exists a need to develop comparative data utilizing J366b procedures and the newly developed procedure to evaluate the effect of the proposed modifications on the existing data base. Of utmost concern is the proper location of the shortened end zone (4.6 metres in length) within the present end zone (12.2 metres in length) specified in J366b. That is, should the shortened end zone be located at the beginning, middle, or end of the present end zone to ensure that the existing data base is not invalidated?

- There exists a need to attempt to define the barometric pressure and temperature correction factors to be applied to the measured results so that all data will be reported at a standard reference temperature and barometric pressure (e.g., 1 atm and 20°C). Present data (noise level versus temperature) exhibit a great deal of scatter due to differences in vehicle components such as engine, fan, exhaust, etc.

- There exists a need to measure the response of existing instrumentation (sound level meters, real-time analyzers, etc.) to actual transient signals in order to establish the interrelationships among the various precision instruments, to supply data to strengthen existing standards, and to establish a data base so that the technical community, manufacturers, lawmakers and enforcement agencies will have a common basis for comparison of results obtained using supposedly comparable equipment.

- There is a need for the various environmental and test site effects on noise measurements to be systematically investigated and correction factors developed so that measurements made under any conditions may be corrected to a single standard set of conditions. If correction factors are not feasible then there is a need for a site calibration procedure or definition of limiting test conditions.

- There exists a need to develop a test procedure that is simpler to perform and is less dependent on weather and test site variables. Correlation must also be proven between the results obtained utilizing such a test and human response to motor vehicle noise.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report contains a measurement methodology which defines the procedures by which the noise from medium and heavy trucks, excluding tire noise, may be measured to ascertain whether the noise emitted is in compliance with noise emission standards to be promulgated by the U.S. Environmental Protection Agency pursuant to Section 6 of the Noise Control Act of 1972 (P.L. 92-574). Associated supporting technical documentation for the methodology is included.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*
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