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TRUCK NOISE 1-D

EMPIRICAL MODEL FOR PREDICTING IN-SERVICE TRUCK TIRE NOISE LEVELS

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16. Abstract

SAE Recommended Practice J57 -- Sound Level of Highway Truck Tires -- specifies a simple, practical noise certification test procedure for tires which results in a single-number rating -- maximum A-weighted sound level -- of the coastby sound level measured according to prescribed procedures. Such a rating by itself, however, does not allow prediction of in-service noise levels. This report discusses the basic assumptions and necessary input data for a DOT/NBS developed empirical model which utilizes the certification test results to predict in-service noise levels. The usefulness and expected accuracy of the predictive model are shown through a comparison of measured versus predicted maximum A-weighted sound levels for a variety of truck/tire combinations.

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Abstract

SAE Recommended Practice J57 -- Sound Level of Highway Truck Tires -- specifies a simple, practical noise certification test procedure for tires which results in a single-number rating -- maximum A-weighted sound level -- of the coastby sound level measured according to prescribed procedures. Such a rating by itself, however, does not allow prediction of in-service noise levels. This report discusses the basic assumptions and necessary input data for a DOT/NBS developed empirical model which utilizes the certification test results to predict in-service tire noise levels. The usefulness and expected accuracy of the predictive model are shown through a comparison of measured versus predicted maximum A-weighted sound levels for a variety of truck/tire combinations.

1. Introduction

Initial interest in truck noise can be traced to the early 1950's; however, in the test procedures developed by industry and the Society of Automotive Engineers (SAE) for the measurement of exterior truck noise, the speed of the vehicle under test was maintained below 35 mph (56.3 km/hr) in order to limit the noise contribution of the tires. The first input to the open literature that identified the relative contributions of tire noise to total truck noise was a report published in 1964 which documented tests conducted by the American Trucking Associations, Inc.[1] [1/]. On the basis of this study, industry data, and subsequent studies -- principally those by the Rubber Manufacturers Association [2/] and General Motors[4] -- the SAE Vehicle Sound Level Committee established a Truck Tire Noise Subcommittee charged with developing a test procedure and a recommended maximum sound level for truck tires consistent with the SAE recommended practice for maximum exterior sound levels of heavy duty trucks and buses. At essentially the same time, the Department of Transportation initiated a wide ranging study of tire noise variables through an interagency agreement with the National Bureau of Standards. An extensive series of truck tire noise tests were conducted at Wallops Island, Virginia during 1970 and 1971[5,6].

The Truck Tire Noise Subcommittee -- composed of personnel from tire manufacturers, auto and truck manufacturers, and government -- accumulated a wide variety of test results (both objective and subjective data) and on this basis formulated a test procedure applicable to highway truck tires which they felt was adequate for their purposes; namely, "qualification of tires for radiated sound levels by (tire) manufacturers and recappers"[3]. They realized that many issues were not resolved and that further research was necessary to address the remaining issues; however, they also realized that the need for a standard precluded further delay. Therefore, SAE Recommended Practice J57 -- Sound Level of Highway Truck Tires -- was approved and issued in 1973[7] [3/]. This standard specifies a simple, practical noise certification test procedure for tires which results in a single-number rating -- maximum A-weighted sound level -- of the coastby sound level measured according to prescribed procedures. Such a rating by itself, however, does not allow the prediction of in-service noise levels. For this reason, a predictive scheme which allows one to utilize the certification test results to predict in-service noise levels is needed. Utilizing the extensive Wallops Island truck tire noise data base, which was developed following procedures essentially identical to SAE J57 [4/], DOT/NBS developed a simple empirical model to satisfy this need.

[1/] Figures in brackets refer to references at the end of this report.

[2/] The data obtained in this study were never published, however, the results are summarized in references [2,3].

[3/] The complete text of SAE J57 is reproduced in Appendix B.

[4/] The DOT/NBS data were obtained utilizing "fast" meter response while SAE J57 specifies use of "slow" meter response.

The basic assumptions and necessary data for application of the model are as follows:

(1) The necessary input data are A-weighted sound level versus time data which can be converted to A-weighted sound level versus distance data. Such data are relatively simple to acquire without the necessity for extensive instrumentation.

(2) The basic assumptions are:

-- The data for a given axle can be represented by the certification data assuming (a) the number of tires mounted on the axle, (b) the tread design, and (c) the state of tread wear of the tires are comparable.

-- For vehicles with numerous axles and axle locations, the certification data representative of each axle (a) can be adjusted to account for load differences (between certification and in-service), (b) can be shifted spatially according to the geometric arrangement of the axles of the particular vehicle of interest, and (c) can be added together on an energy basis.

In the remainder of this report the usefulness and expected accuracy of the predictive model is shown through a comparison of measured versus predicted maximum A-weighted sound levels for a variety of truck/tire combinations. Application of the model is illustrated by means of an example computation in Appendix A.

2. Feasibility Study

In order to test the hypothesis of the predictive model, the DOT/NBS single-chassis [4 x 2[5/]] Wallops Island data[5,6] were used to predict the maximum A-weighted sound level and the A-weighted sound level versus distance data for seventy-six (76) test conditions which corresponded to runs actually made with a 6 x 4 tractor with a double-axle trailer [6 x 4 DAT]. This was the only vehicle configuration that could be tested on the basis of the Wallops Island data.

These seventy-six conditions corresponded to coastbys at vehicle speeds ranging from 25 to 60 mph (40.2 to 96.6 km/hr). [The test matrix called for test runs to be made in 5 mph (8.0 km/hr) increments from 30 to 60 mph (48.3 to 96.6 km/hr).] Nine new and retreaded tires of various tread designs -- four ribs, four cross-bars and one pocket tread -- were tested.

[5/] The nomenclature 4 x 2 relates to the number of wheel positions -- 4, and the number of driven positions -- 2, but has no relationship to the number of tires -- 6. Therefore, a 6 x 4 would have 10 tires mounted at 6 wheel positions, 4 of which are driven.

Before the raw tire noise data could be utilized as input to the model, it was necessary to correct the A-weighted sound level versus distance data for any given axle to account for any differences which existed between the loading conditions for the 6 x 4 tractor with double-axle trailer and the single-chassis vehicle[6/]. The load-corrected 4 x 2 single-chassis data were then utilized to predict the noise levels corresponding to the actual test runs of the 6 x 4 tractor with double-axle trailer.

The results of the feasibility study are listed in Table 1. The trial numbers listed in the table refer to the tractor-trailer test matrix utilized in the DOT/NBS truck tire noise study[5,6]. It should be noted that only data measured at 50 feet (15.2m) for test runs on the concrete surface were used in this feasibility study.

A graphical comparison of the measured versus the predicted maximum A-weighted sound levels is presented in Figure 1. A band of ± 4 dB on the line would encompass 90 percent of the data points. A recheck of some of the individual data points for which there was the greatest discrepancy between the measured and calculated values revealed that many of these data points were out of character when compared with the data points at vehicle speeds lower and higher than the datum point at 50 mph (80.5 km/hr) -- i.e., individual datum points deviated significantly from the expected approximate 40 log V relationship between noise level and vehicle speed. The danger of utilizing the data for a single test run to establish the noise level corresponding to a given vehicle speed is pointed out by this exercise.

As further evidence of the validity of the model, comparisons are presented (Figures 2 and 3) between the A-weighted sound level versus distance data predicted by the model and those actually measured for two of the seventy-six conditions. These particular conditions were selected to test the capability of the model to predict accurately the shape of the A-weighted sound level versus distance curve. In one case the difference between the predicted and measured maximum A-weighted sound level was small (approximately 0.6 dB), while in the other case the difference was quite large (approximately 5.3 dB). It is clear from the data that the model predicts the shape of the A-weighted sound level versus distance (or time) curve very well, even for those cases where the maximum A-weighted sound level is not as well predicted.

[6/] Very little data on the effect of load on tire noise levels are published in the literature. The data that are available deal only with selected tires -- a circumferential rib, one typical continuous rib, one typical cross-bar and one type of pocket tread -- and only two loading conditions -- loaded, 17,720 pounds per axle (8038 kg per axle); and unloaded, 6120 pounds per axle (2776 kg per axle) [5,6]. In this current study it is assumed that the noise level changes linearly with load and that any rib or cross-bar tire behaves with load changes exactly like the typical rib and cross-bar for which data exist. The load corrections are determined from Figure A-1 which is a plot of maximum A-weighted sound level versus load difference (certification loading minus in-service loading) for the typical rib and cross-bar tires.

Table 1. Results of the feasibility study given in terms of the measured and calculated maximum A-weighted sound level at 50 feet (15.2 m) for the seventy-six test conditions corresponding to runs of a 6 x 4 tractor with double-axle trailer[5,6].

Trial Number	Test Vehicle Speed, mph (km/hr)	Maximum A-weighted Sound Level, dB		Sound Level Difference, (Calculated - Measured), dB
		Measured	Calculated	
1	25.8 (41.5)	68.8	69.5	0.7
	35.0 (56.3)	71.8	71.4	-0.4
	44.2 (71.1)	73.6	75.6	2.0
2	26.6 (42.8)	76.2	74.4	-1.8
	35.3 (56.8)	80.4	79.2	-1.2
	43.1 (69.4)	82.8	81.1	-1.7
3	26.8 (43.1)	74.6	72.8	-1.8
	36.0 (57.9)	80.0	79.0	-1.0
	44.5 (71.6)	85.2	84.8	-0.4
5	33.3 (53.6)	74.2	73.0	-1.2
	42.8 (68.9)	79.2	76.6	-2.6
	48.5 (78.1)	80.2	78.4	-1.8
6	33.5 (53.9)	77.2	76.9	-0.3
	43.8 (70.5)	83.8	83.6	-0.2
7	33.2 (53.4)	75.4	76.4	1.0
	41.5 (66.8)	80.1	81.3	1.2
	46.8 (75.3)	81.0	84.3	3.3
10	26.2 (42.2)	83.4	80.0	-3.4
	31.8 (51.2)	86.8	83.8	-3.0
	42.9 (69.0)	91.4	88.4	-3.0
14	26.0 (41.8)	80.6	76.8	-3.8
	35.3 (56.8)	85.2	82.8	-2.4
	43.7 (70.3)	88.4	85.8	-2.6
17	26.4 (42.5)	82.2	76.8	-5.4
	36.7 (59.1)	88.2	83.7	-4.5
	44.8 (72.1)	92.0	86.7	-5.3
18	31.1 (50.0)	81.4	78.5	-2.9
	36.0 (57.9)	88.0	85.3	-2.7
	44.4 (71.5)	93.2	89.2	-4.0
19	32.6 (52.5)	74.2	73.6	-0.6
	44.7 (71.9)	81.6	80.9	-0.7
	50.0 (80.5)	84.6	81.6	-3.0
20	31.9 (51.3)	74.8	73.2	-1.6
	41.8 (67.3)	81.8	79.2	-2.6
	47.2 (76.0)	81.6	81.0	-0.6
21	31.9 (51.3)	73.2	71.8	-1.4
	40.6 (65.3)	78.2	76.0	-2.2
	43.3 (69.7)	76.3	77.2	0.9
21	50.7 (81.6)	80.2	80.9	0.7
	57.6 (92.7)	85.2	83.1	-2.1
22	31.5 (50.7)	74.0	70.5	-3.5
	33.5 (53.9)	70.1	71.8	1.7
	39.8 (64.1)	79.4	75.0	-4.4
	43.7 (70.3)	73.9	76.5	2.6
	49.7 (80.0)	77.1	78.8	1.7
	50.6 (81.4)	80.4	79.2	-1.2
	57.1 (91.9)	85.4	81.0	-4.4
23	33.5 (53.9)	70.2	71.9	1.7
	44.1 (71.0)	77.2	76.5	-0.7
	50.7 (81.6)	78.0	79.2	1.2
24	31.4 (50.5)	73.2	73.6	0.4
	41.5 (66.8)	78.4	78.4	0
	50.1 (80.6)	80.0	82.5	2.5
	55.0 (88.5)	81.4	87.8	6.4
25	32.7 (52.6)	75.4	74.7	-0.7
	40.8 (65.7)	78.4	80.4	2.0
	49.7 (80.0)	83.4	83.8	0.4
	56.8 (91.4)	85.6	86.7	1.1
26	31.9 (51.3)	73.0	72.5	-0.5
	33.0 (53.1)	70.6	73.2	2.6
	39.2 (63.1)	77.4	77.8	0.4
	42.3 (68.1)	74.9	78.7	3.8
	48.1 (77.4)	81.4	80.8	-0.6
	49.2 (79.2)	77.9	81.3	3.4
	55.9 (90.0)	83.4	84.1	0.7
27	36.4 (58.6)	72.6	75.7	3.1
	42.1 (67.8)	75.1	78.7	3.6
	49.6 (79.8)	78.5	81.4	2.9
28	30.4 (48.9)	76.8	74.9	-1.9
	40.0 (64.4)	83.0	80.8	-2.2
	48.5 (78.1)	88.4	84.0	-4.4
	55.6 (89.5)	92.2	88.6	-3.6
29	30.7 (49.4)	78.8	76.4	-2.4
	40.0 (64.4)	86.2	82.6	-3.6
	49.7 (80.0)	87.4	86.0	-1.4
	55.4 (89.2)	89.6	89.3	-0.3

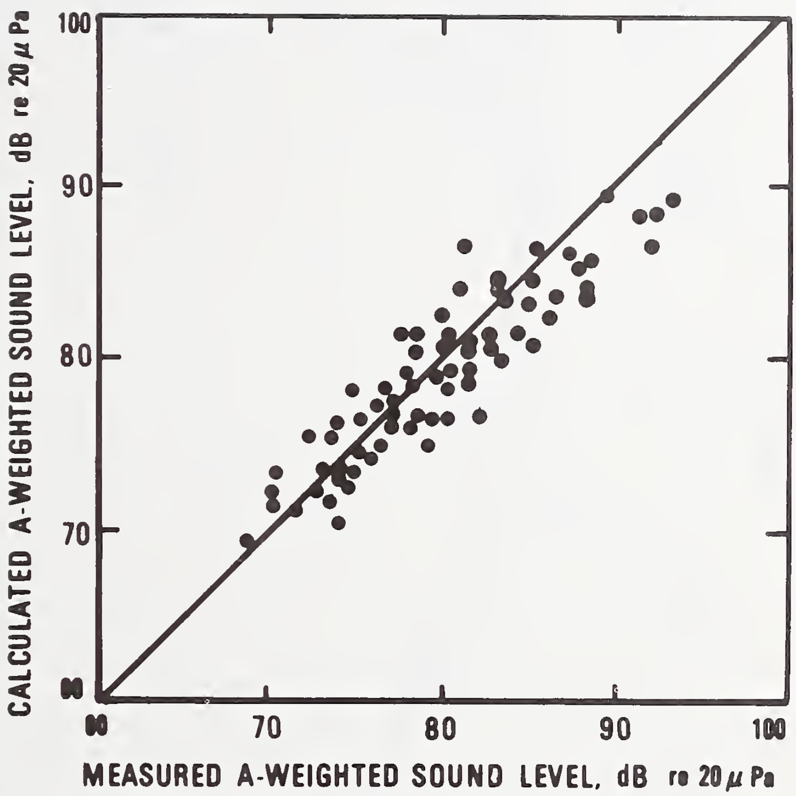


Figure 1. Comparison of the calculated and measured maximum A-weighted sound levels at 50 feet (15.2 m) for the seventy-six test conditions corresponding to runs of a 6 x 4 tractor with double-axle trailer. These data were obtained in a previous DOT/NBS truck tire noise study[5,6].

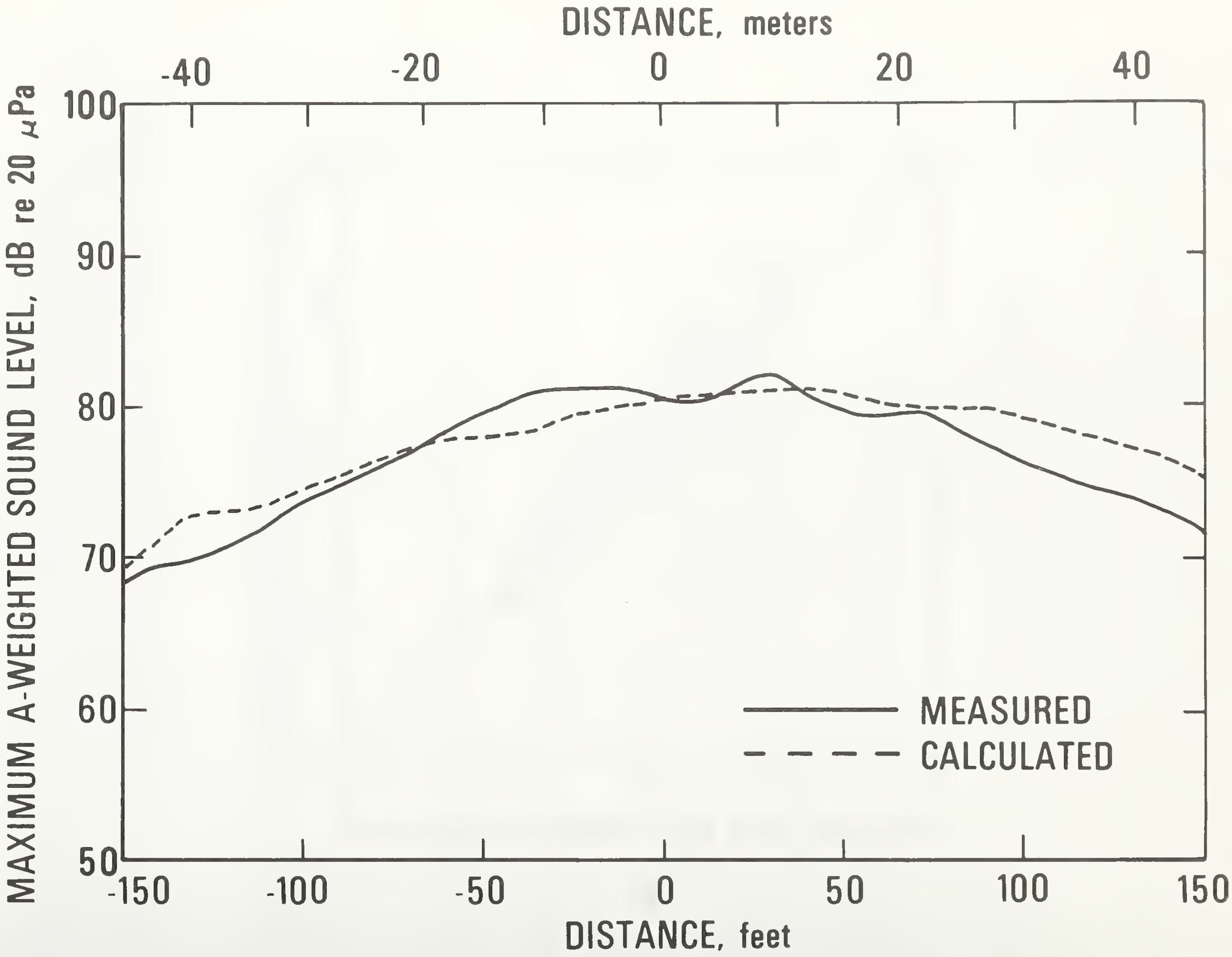


Figure 2. Comparison of the calculated and measured A-weighted sound levels versus distance. Data correspond to 50 foot (15.2 m) measurement for trial number 20 at 47.2 mph (76.0 km/hr) on concrete pavement. These data were obtained in a previous DOT/NBS truck tire noise study[5,6] .

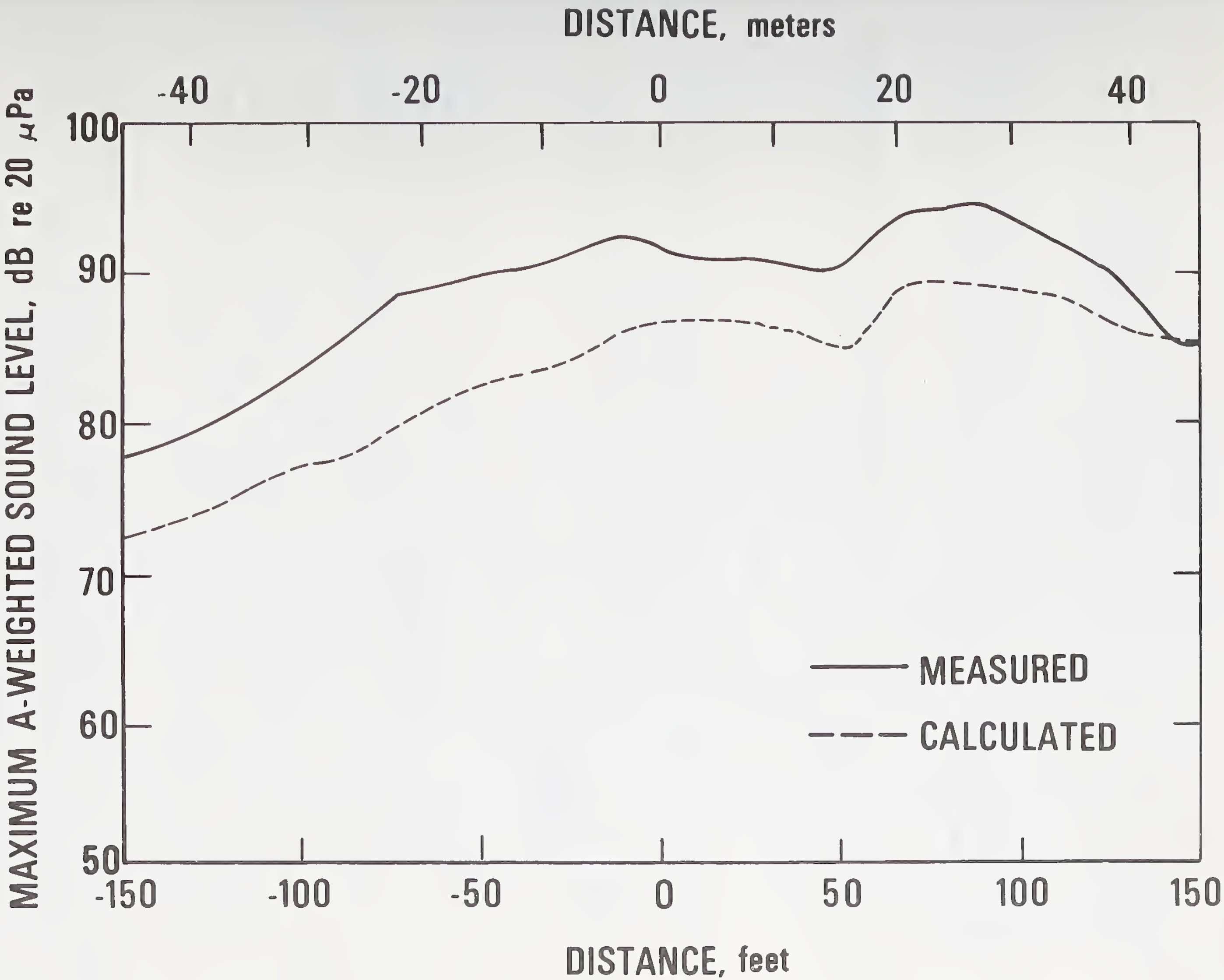


Figure 3. Comparison of the calculated and measured A-weighted sound levels versus distance. Data correspond to 50 foot (15.2 m) measurement for trial number 17 at 44.8 mph (72.1 km/hr) on concrete pavement. These data were obtained in a previous DOT/NBS truck tire noise study[5,6].

The results of this feasibility study were very encouraging considering the *a priori* known deficiencies associated with the model and/or input data available; namely:

- The comparisons are based on a single test run.
- The load corrections to be applied to the data are based on the assumption that noise level increases linearly with load and that all rib and cross-bar tires behave like the particular rib and cross-bar tire for which load data exist.
- The input data obtained from the noise certification test includes a contribution from the steering tires. This noise contribution which gets added in every time an additional axle is added is not accounted for in the model.

On the basis of the results of this feasibility study, the decision was made to carry out a full scale test of the predictive model to serve as the basis for validation and refinement.

3. Model Validation Program

The operational procedures and measurement/analysis instrumentation utilized in this model validation program were similar to that used in previous DOT/NBS truck tire noise studies. In the following sections detailed descriptions are provided of the vehicle configurations, test tires, field test site utilized for data acquisition and the operational test procedure.

3.1. Field Test Site

The dynamometer course at the U. S. Army Proving Ground located in Yuma, Arizona was selected as the test site for the data acquisition phase of the program. This facility provided an adequate stretch of pavement necessary for safe operation of the test vehicles, a flat terrain providing a well-defined reflecting surface without any unusual reflection or attenuation effects, a remote location where interference from other noise sources could easily be avoided and normal climatic conditions –– low relative humidity and very infrequent rainfall –– ideal for the efficient conduct of outdoor testing. Utilization of this site was arranged through agreement with the U. S. Army Test and Evaluation Command, Aberdeen Proving Ground, Aberdeen, Maryland.

The dynamometer course is approximately 2 miles (3219 m) long with 500 foot (152.4 m) radius turn-arounds at each end. The roadway is 30 feet (9.1 m) wide, near-level (0.8 percent grade) and is surfaced with a high strength asphalt. A 600 foot (182.9 m) test section was established at the southwest end of the course. A maintenance shelter and storage building located adjacent to the dynamometer course were used to store test tires and as the area where the tires were mounted on the test vehicles. Figure 4 shows an overall view of the test site with the location of the test section and maintenance facilities noted.

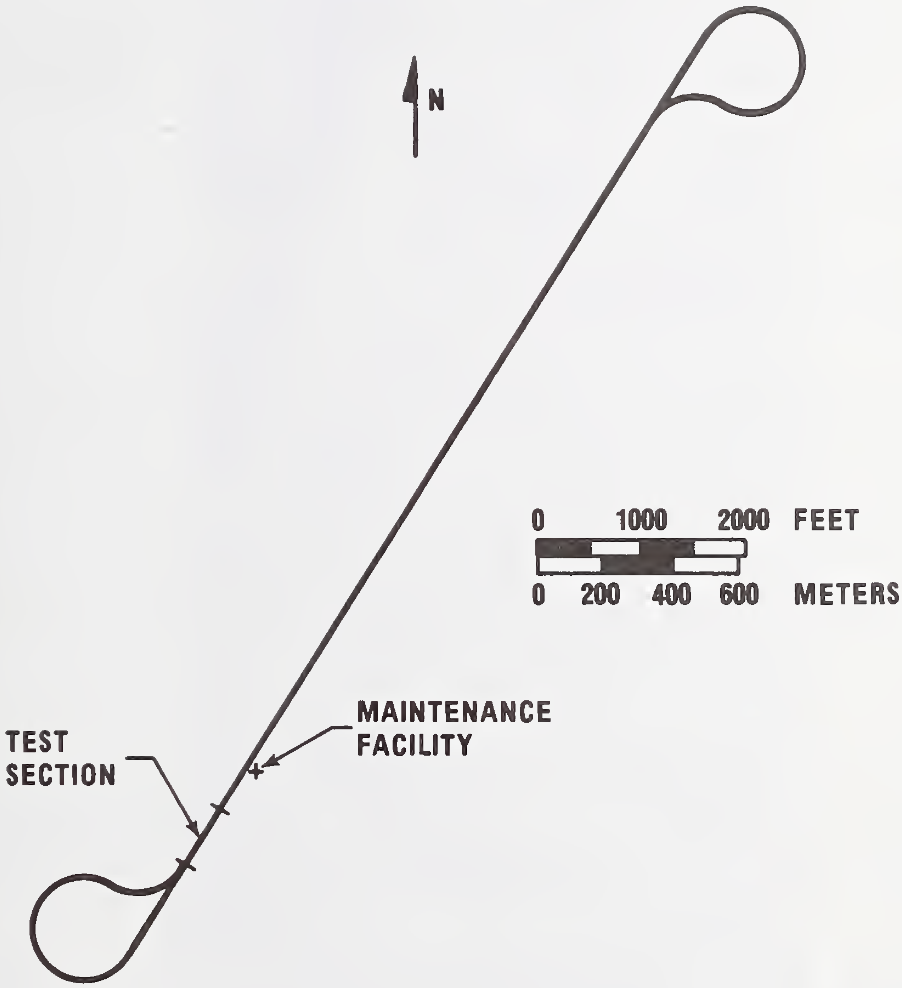


Figure 4. Plan of dynamometer course at the U. S. Army Yuma Proving Ground, Yuma, Arizona, showing the location of the test section and maintenance facility.

To comply with the measurement area requirements of SAE J57 (see Appendix B), an asphalt pad was constructed adjacent to the dynamometer course roadway. This triangular-shaped pad consisted of three rectangular sections of asphalt each 3 inches (7.6 cm) thick, 10 feet (3.0 m) wide and 600, 400, and 200 feet (182.9, 121.9, and 61.0 m) long, respectively. The pad was allowed to cure for two weeks after construction and then was sealed using a commercial driveway sealer. Figure 5 is a photograph showing the test section on the dynamometer course roadway and the measurement area pad.

3.2. Test Tires

For this study a sample of five tire types were selected for evaluation. The tires were all size 11.00-24.5 and were of the following construction, state of wear and tread design:

Tire A	New	bias ply	rib
Tire B	New	bias ply	rib
Tire C	New	steel belted radial ply	rib
Tire D	Half-worn	bias ply	cross-bar
Tire E	Half-worn	bias ply	cross-bar

The test tires were always mounted on the drive axle(s) of the tractors. Rib tires (tire C) whose characteristic tire noise level was known to be low were mounted on the steering axle. The trailer tires utilized during testing were those which were on the trailer when it was rented. These tires were bias ply rib type tires with three different tread designs (designated R1, R2 and R3).

The characteristic tread patterns for the steering, test and trailer tires are shown in Figure 6. The nominal tread depth[7/] and average Shore hardness[8/] for these tires are also indicated.

[7/] Tread depth measurements were taken at four equally spaced locations around the tire circumference. The device utilized for this measurement was simply a depth gage with 1/32 inch graduations. The operator located the depth gage over a major groove (not over sipes or other small grooves), depressed the probe into the groove, and noted the tread depth directly from the instrument.

[8/] The Shore hardness of the tread rubber was determined by ASTM test method D2240-68[8]. A type A durometer (for soft materials) was utilized in the following manner: the durometer was held in a vertical position with the point of the indentor at the center of the tread face. The presser foot was applied to the specimen as rapidly as possible without shock, keeping the foot parallel to the specimen surface. The scale was read five seconds after the presser foot was in firm contact with the specimen. The reported values represent the average for readings taken at approximately the same four locations as the tread depth measurements.

Figure 5. A view of the test section established on the dynamometer course roadway and the measurement area pad.

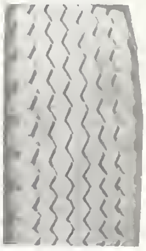
TIRE A

New Bias Ply Rib

Nominal Tread Depth - $\frac{19}{32}$ inch

Average Shore Hardness - 60

TIRE B



New Bias Ply Rib

Nominal Tread Depth - $\frac{16}{32}$ inch

Average Shore Hardness - 54

TIRE C

New Steel Belted Radial Ply Rib

Nominal Tread Depth - $\frac{17}{32}$ inch

Average Shore Hardness - 60

TIRE D

Half-Worn Bias Ply Cross-Bar

Nominal Tread Depth - $\frac{16}{32}$ inch

Average Shore Hardness - 64

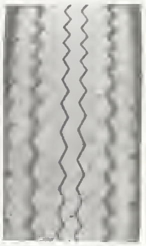
TIRE E

Half-Worn Bias Ply Cross-Bar

Nominal Tread Depth - $\frac{11}{32}$ inch

Average Shore Hardness - 64

TIRE R1



Half-Worn Bias Ply Rib

Nominal Tread Depth - $\frac{13}{32}$ inch

Average Shore Hardness - 63

TIRE R2

Half-Worn Bias Ply Rib

Nominal Tread Depth - $\frac{8}{32}$ inch

Average Shore Hardness - 70

TIRE R3

Half-Worn Bias Ply Rib Retread

Nominal Tread Depth - $\frac{10}{32}$ inch

Average Shore Hardness - 58

Figure 6. Characteristic tread element pattern, nominal tread depth and average Shore hardness for the steering, test and trailer tires.

In accordance with standard operating procedure for bias-ply tire use the tires utilized during this test program were not balanced. When new tires are installed on a truck, balancing is not performed unless there is a definite handling problem or severe vibration reported which might jeopardize the safety of the vehicle. When such a problem arises, the entire front end assembly, not just the tires, is checked. Unlike the normal practice with automobile tires, only front (steering) tires are ever balanced on trucks.

A tire was not considered acceptable as a test specimen for the tire noise investigation until it had undergone a break-in period of sufficient mileage under actual driving conditions to ensure the removal of all mold marks and manufacturing irregularities. Immediately prior to the actual noise testing of a given set of tires, a warm-up procedure was followed which normally required a minimum trip of approximately 10 miles (16.1 km).

3.3. Test Vehicles

Six different single-chassis and tractor-trailer combinations were utilized throughout this program. Two tractors -- a 4 x 2 and a 6 x 4 -- served as the basic single-chassis (or straight truck) test vehicles, hereafter noted as 4 x 2 STR and 6 x 4 STR, respectively. The 4 x 2 tractor was also tested in combination with a single-axle trailer (4 x 2 SAT), a double-axle trailer (4 x 2 DAT), and a double bottom (4 x 2 DB). The 6 x 4 tractor was tested in combination with a double-axle trailer (6 x 4 DAT). Overall views of these test vehicles and the loading arrangements are shown in Figures 7 through 9.

The 4 x 2 and 6 x 4 test vehicles were International[9/] Model CO-4070A single drive axle tractor and International Model COF-4070A dual drive axle tractor, respectively. Both tractors were equipped with 10 hole Budd wheels, 11.00-24.5 tires, a 350 CID Cummins diesel engine and a 10-speed transmission.

Three trailers -- two single-axle trailers and one double-axle trailer -- were used in this study. The single-axle trailer was the front trailer of the double bottom combination which consisted of two 27 foot (8.2 m) flat bed trailers interconnected by a dolly. These trailers were equipped with 10 hole Budd wheels and 11.00-24.5 type R1 and R2 tires. The mounting locations of these tires are shown in Figure 10. The double-axle trailer was a 40 foot (12.2 m) flat bed trailer equipped with 10 hole Budd wheels. Size 11.00-24.5 type R3 tires were mounted at all axle positions.

9/ The commercial vehicles utilized are identified in this report in order to adequately describe the vehicles on which the test tires were mounted throughout this program. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that these vehicles were necessarily the best available for the purpose.

4 x 2 Straight (4 x 2 STR)

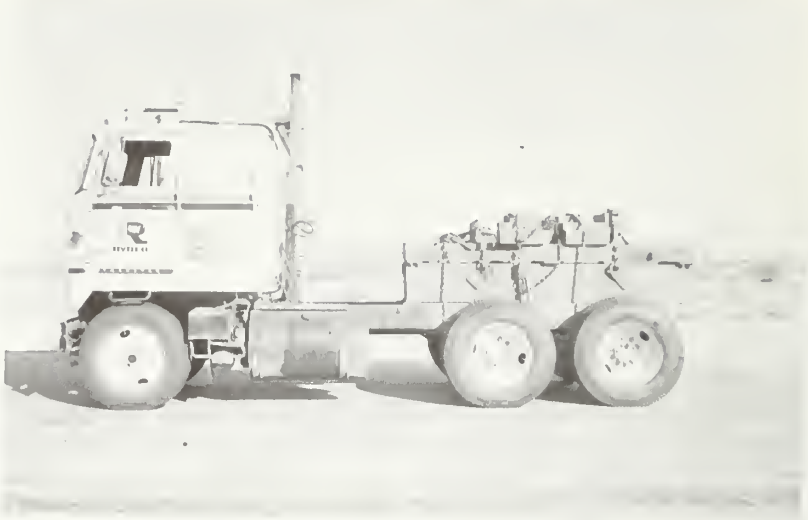
4 x 2 Tractor with Single-Axle
Trailer (4 x 2 SAT)

Figure 7. View of test vehicles used in model validation study.

4 x 2 Tractor with Double-Axle Trailer (4 x 2 DAT)

4 x 2 Tractor with Double Bottom Trailer (4 x 2 DB)

Figure 8. View of test vehicles used in model validation study.



6 x 4 Straight (6 x 4 STR)

6 x 4 Tractor with Double-Axle Trailer (6 x 4 DAT)

Figure 9. View of test vehicles used in model validation study.

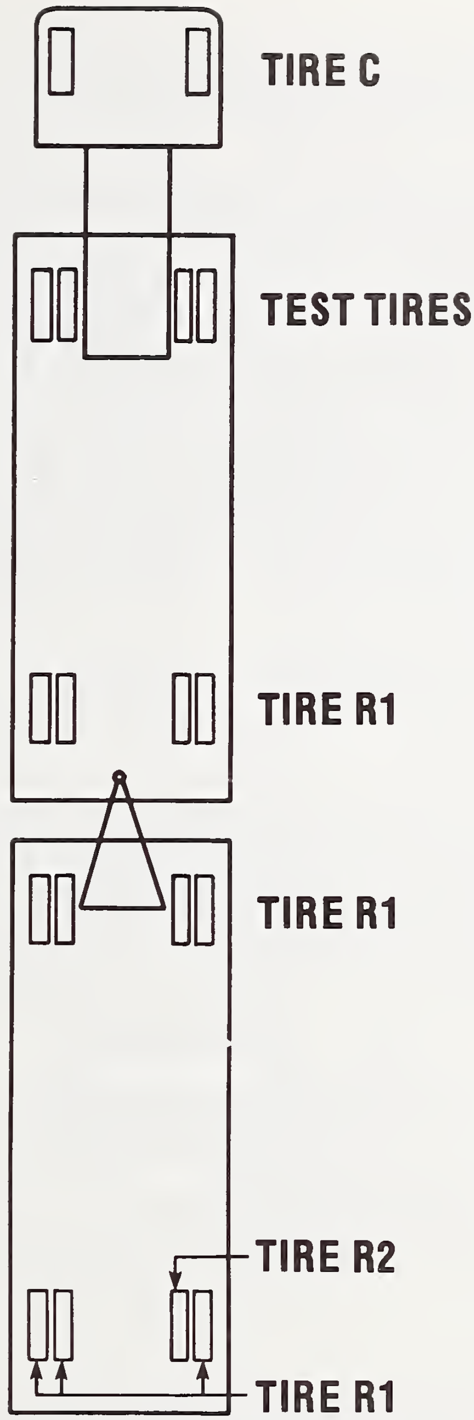


Figure 10. Mounting location of tires on the 4 x 2 tractor with double bottom trailer.

The lineal dimensions between axles of the various vehicle configurations are given in Table 2. These dimensions, required as input data for the predictive model, establish the spatial location of the respective axles.

The vehicles were operated in a loaded condition for all test runs. The loading was provided by either a series of steel plates or concrete blocks as shown in Figures 7 through 9. The resulting weight distribution on each axle and the gross vehicle weight or gross combination weight for each test configuration are given in Table 3. These loading values, which were representative of the allowable weight limits regulated by Federal law prior to 1974 for vehicles in interstate transit, were: 18,000 pounds (8,165 kg) on a single axle, 32,000 pounds (14,515 kg) on tandem axles and 73,280 pounds (33,240 kg) total gross combination weight. The only exception to these weight limits in the model validation study is in the case of the 4 x 2 double bottom with a total gross combination weight of 71,597 pounds (32,476 kg). This lighter loading was used because of the load limit specified by the manufacturer of the double bottom.

The bias ply tires were inflated to 75 psi (5.2×10^5 Pa) and the radial ply tires to 80 psi (5.5×10^5 Pa). These inflation pressure/load values were equivalent to 75-90 percent of the rated tire load per Tire and Rim Association recommendations.

In view of the newly adopted allowable weight limits[10/], a limited investigation was carried out with increased vehicle loading. Table 4 lists the vehicles and loadings studied. Only tire E was utilized and to differentiate the two loading conditions the increased loading is denoted as E*. The increased loading was equivalent to 90-100 percent of the rated tire load at 75 psi (5.2×10^5 Pa) per Tire and Rim Association recommendations.

3.4. Test Procedure

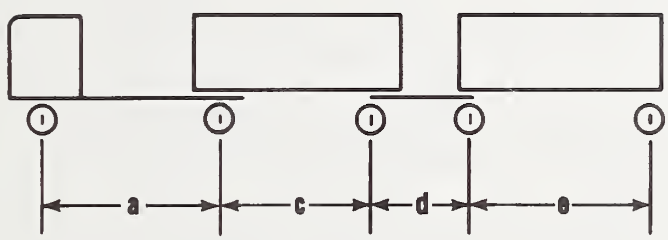
The test procedure utilized was essentially identical to that specified in SAE J57; however, the following exceptions should be noted:

- "Fast" meter response was utilized.
- The hard surface (vehicle path and measurement area) was sealed asphalt.

10/ The Federal-Aid Highway Act of 1974 revised Section 127 of Title 23 of the United States Code to permit commercial vehicles to carry a maximum of 20,000 pounds (9,072 kg) on a single axle, 34,000 pounds (15,422 kg) on tandem axles and 80,000 pounds (36,288 kg) total gross combination weight. These limits affect the interstate highway system but provide that any state which allowed higher limits previous to July 1956 may continue those limits in effect on the interstate system.

Table 2. Lineal dimensions in inches (meters) of the six single-chassis and tractor-trailer combinations used as test vehicles in this study. The dimensions a through e are defined in the sketches below the table.

Test Vehicle	Vehicle Dimensions, inches (m)				
	a	b	c	d	e
4 x 2 STR	118 (3.0)				
4 x 2 SAT	118 (3.0)		233 (5.9)		
4 x 2 DAT	118 (3.0)		370 (9.4)	52 (1.3)	
4 x 2 DB	118 (3.0)		233 (5.9)	115 (2.9)	235 (6.0)
6 x 4 STR	144 (3.7)	50 (1.3)			
6 x 4 DAT	144 (3.7)	50 (1.3)	346 (8.8)	52 (1.3)	



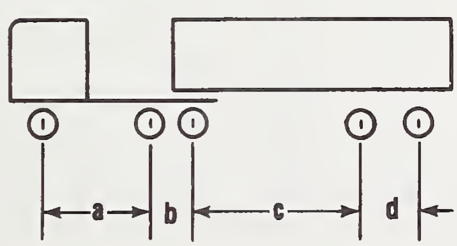


Table 3. Weight distributions on each axle and gross vehicle and/or combination weights for the six test vehicles.

Test Vehicle	Load Per Axle, pounds (kg)							Gross Vehicle and/or Combination Weight, Pounds (kg)
	Steering	First Drive	Second Drive	Front Axle First Trailer	Rear Axle First Trailer	Dolly	Second Trailer	
4 x 2 STR	8900 (4037)	18080 (8201)						26980 (12238)
4 x 2 SAT	9040 (4101)	17800 (8074)		18060 (8192)				44900 (20367)
4 x 2 DAT	8400 (3810)	18200 (8255)		15200 (6895)	17160 (7784)			58960 (26744)
4 x 2 DB	8134 (3690)	15296 (6938)		15987 (7252)		15800 (7167)	16380 (7430)	71597 (32476)
6 x 4 STR	9060 (4110)	18180 (8246)	18040 (8183)					45280 (20539)
6 x 4 DAT	9080 (4119)	15320 (6949)	16550 (7507)	15400 (6985)	17360 (7874)			73710 (33435)

Table 4. Weight distributions on each axle and gross vehicle and/or combination weights for alternate loadings of the 4 x 2 STR, 4 x 2 DAT, 6 x 4 STR and 6 x 4 DAT test vehicles. Measurements were made of only tire E (denoted E*) using these loadings.

Test Vehicle	Load Per Axle, pounds (kg)							Gross Vehicle and/or Combination Weight, Pounds (kg)
	Steering	First Drive	Second Drive	Front Axle First Trailer	Rear Axle First Trailer	Dolly	Second Trailer	
4 x 2 STR	9015 (4089)	19985 (9065)						29000 (13154)
4 x 2 SAT								
4 x 2 DAT	7200 (3266)	20840 (9453)		17520 (7947)	18100 (8210)			63660 (28876)
4 x 2 DB								
6 x 4 STR	9060 (4110)	19880 (9018)	19740 (8954)					48680 (22081)
6 x 4 DAT	8780 (3983)	17100 (7757)	18660 (8464)	17460 (7920)	18520 (8401)			80520 (36524)

- The distance between the point of entrance and point of exit of the test section was 600 feet (182.9 m).

- Measurements were made of both coast and powered passbys. A constant speed was maintained during powered passby test runs.

The components of the data acquisition and recording instrumentation, plus the automatic tape recorder control and elapsed time system utilized are shown in Figure 11.

Three tape switches -- one immediately before the test section and one each at the beginning and end of the test section -- were used to start and stop the recorder and to mark the data tapes to designate the start and end of data. The tape switches at the beginning and end of the test section were also used to control an elapsed time system which provided a direct readout of average vehicle speed in miles per hour.

The acoustic measurement system consisted of a one-inch condenser microphone, a battery-operated microphone power supply (to supply the polarization voltage to the microphone), a step attenuator which provided the capability for selection of gain over a range of 60 dB in 10 dB steps, and a tape recorder with two direct record analog data channels and one "FM" timing channel. The system included both a flat frequency response hold capability -- which provided an indication as to whether or not a tape channel had saturated (saturated runs were repeated) -- and an A-weighting hold capability -- which provided a direct reading, in the field, of the maximum A-weighted sound level observed during a passby without having to return to the laboratory for the analysis of the tapes. The measurements were performed out-of-doors; therefore, a windscreen was placed over the microphone to reduce the noise produced by wind passing over the microphone grid. A single point calibration utilizing a pistonphone which produced a 124 dB sound pressure level (re 20 μPa)[11/] at a frequency of 250 Hz was used for system calibration in the field. Calibration tones were recorded on the data tape once each hour as well as at the beginning and end of each data tape. Figure 12 shows the microphone location and associated instrumentation in the field at the Yuma Proving Ground test site.

Once the data had been recorded, the analog tapes were returned to the National Bureau of Standards for reduction and analysis. Figure 13 identifies the equipment which was utilized for analysis purposes. Each tape was played back a channel at a time through the real-time analyzer. An interface-coupler was necessary to make the real-time analyzer compatible with a mini-computer. When a timing signal appeared on the analog tape, the computer was instructed

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11/ A pistonphone generates a reference sound pressure level of 124 dB (re 20 μPa) only at the standard atmospheric pressure of 760 mm Hg. For ambient pressure conditions other than standard the actual level will vary from the reference value of 124 dB (e.g., 760 ± 10 mm Hg corresponds to 124 ± 0.1 dB). Because the magnitude of this departure from the reference level is small for the range of ambient pressure conditions at the Yuma test site, no corrections were made to the data.

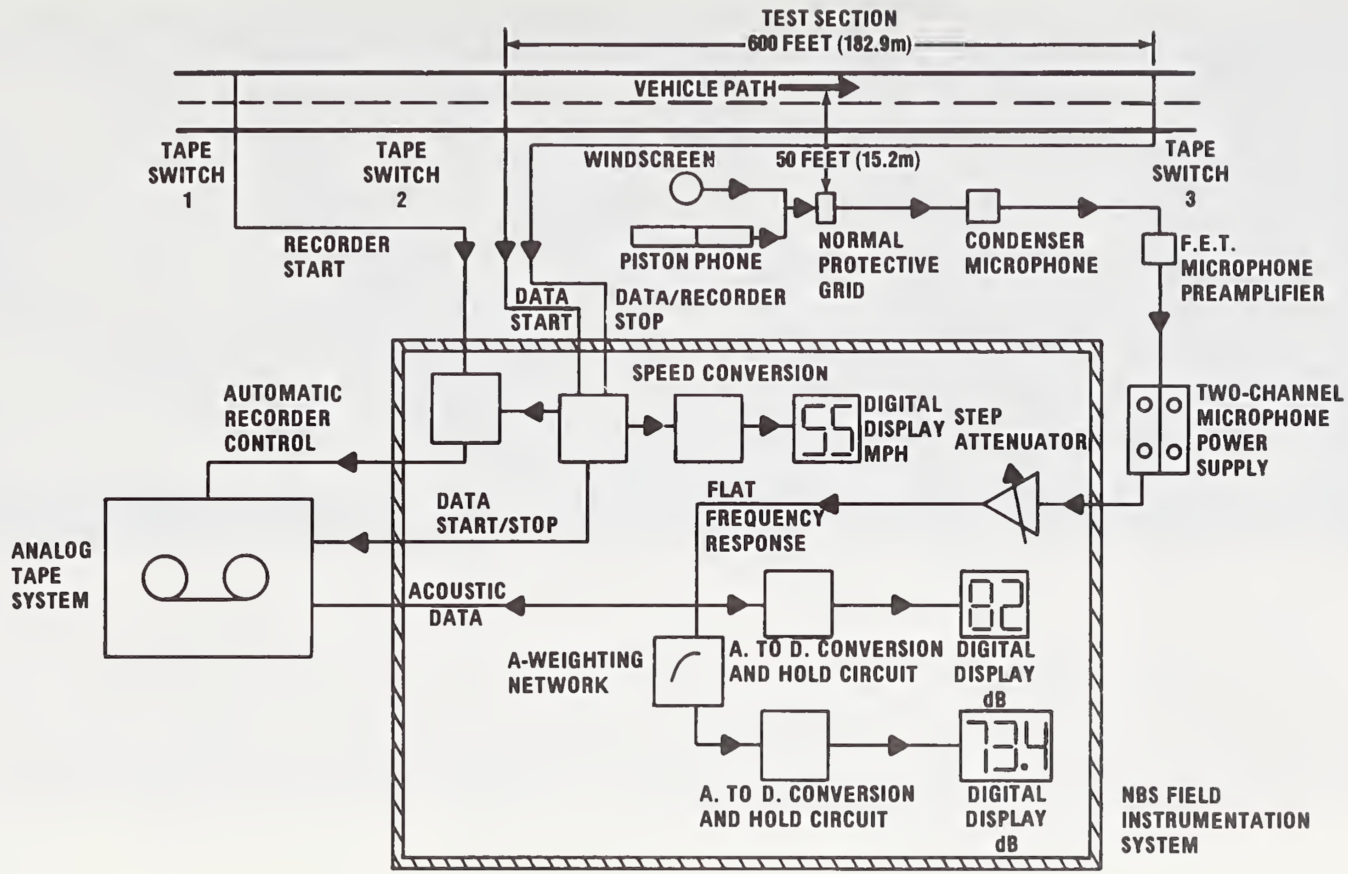


Figure 11. Data acquisition and recording instrumentation plus automatic tape recorder control and elapsed time system.

Figure 12. Overall view of the microphone location with the test vehicle. The tripod mounted microphone was located 50 feet (15.2 m) from the centerline of vehicle travel along a line perpendicular to the vehicle path.

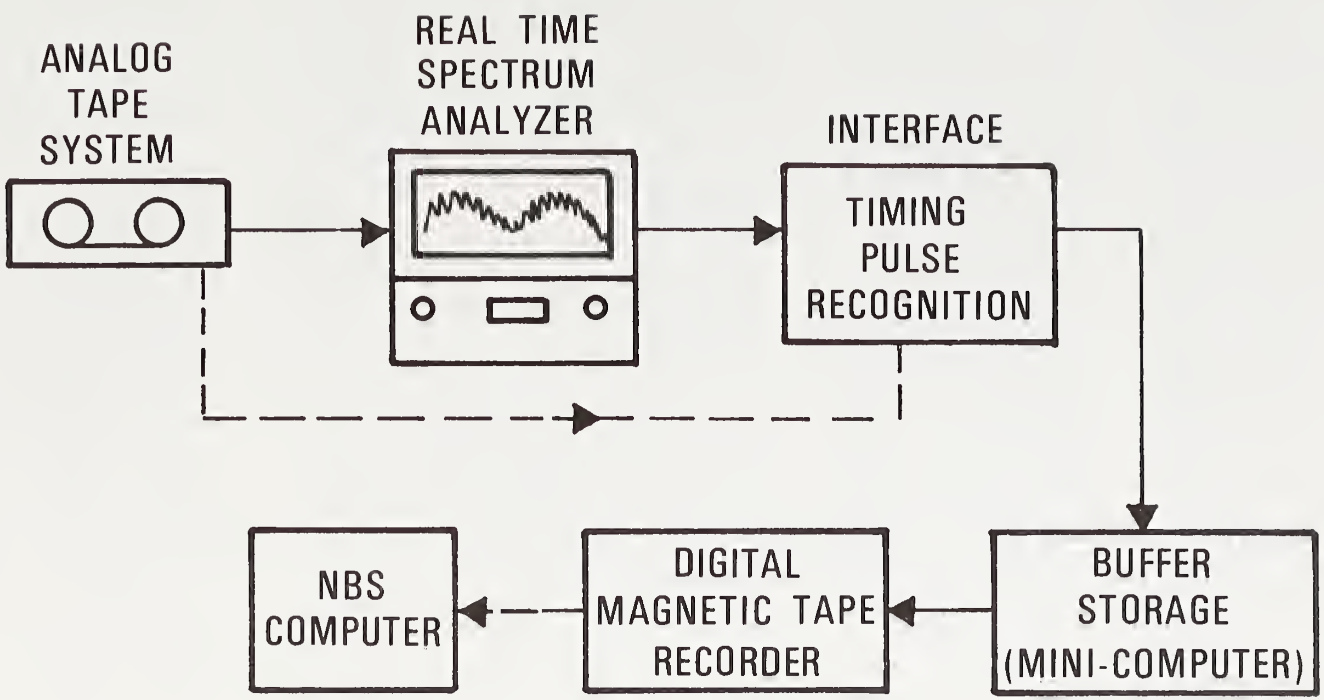


Figure 13. Data reduction and analysis system.

to start sampling the digital data from the real-time analyzer. A real-time analyzer time constant of 0.2 second above 200 Hz and one which below 200 Hz increased linearly to 3.15 seconds at 12.5 Hz was utilized to obtain the root-mean-square (rms) value of the level. Once all data had been analyzed, the computer stored the data and dumped it onto digital magnetic tape. This tape was formated to be acceptable to the large NBS computer which was utilized for further analysis.

4. Results of Full-Scale Model Validation Study

In order to develop the data base necessary to evaluate the DOT/NBS tire noise predictive model, the test matrix shown in Table 5 was established. The data acquisition portion of the full-scale validation study followed this pre-defined test plan.

The objective of the test program was to obtain two sets of data: (1) 50 mph (80.5 km/hr) coastby A-weighted sound level versus time data for the 4 x 2 single-chassis vehicle (certification data)[12/] to serve as input for the predictive model, and (2) 55 mph (88.5 km/hr) coastby and powered passby A-weighted sound level versus time data for all of the single-chassis and tractor-trailer combinations in the test to be used for comparison with the model predictions. The maximum A-weighted sound levels for all test vehicle and tire combinations measured during the test are presented in Tables 6 through 12.

Before the certification data could be used as input to the model, load corrections[13/] -- to account for load differences between the 4 x 2 STR and the other vehicle configurations -- were applied to these A-weighted sound level versus time data. A speed correction was also applied to these data using a 40 log V relationship between sound level and vehicle speed. Utilizing these adjusted data, the maximum A-weighted sound levels and A-weighted sound levels versus distance were calculated for all test conditions using the empirical model. [See Appendix A for an example of the step by step computational procedures of the model.] To account for engine noise when predicting in-service total truck noise, the engine was approximated by an omnidirectional point source located on the center line of the vehicle directly over the steering axle. The A-weighted sound pressure level of the engine was assumed to be 80 dB at 50 feet (15.2 m). The value of 80 dB was selected on the basis of a comparison of the calculated and measured powered passby noise levels to determine the best "empirical fit" for the data.

[12/] To obtain the necessary certification data for the trailer tires, these tires were mounted on the 4 x 2 straight test vehicle in the same arrangement as on the trailers. The certification levels are given in Table 6 for tire R1 on the first trailer and dolly of the double bottom, the combination of tires R1 and R2 (denoted R1,2) on the last trailer of the double bottom, and tire R3 on the double-axle trailer.

[13/] See footnote 6. The load corrections applied to these data were determined from Figure A-1.

Table 5. Test matrix for DOT/NBS empirical truck tire noise model validation study. O's correspond to input data to the model and X's to data to be compared with the model predictions. A minimum of two test runs were made for each operational condition.

Test Vehicle		4 x 2 STR		4 x 2 STR		4 x 2 SAT		4 x 2 DAT		4 x 2 DB		6 x 4 STR		6 x 4 DAT	
Speed, mph (km/hr)		50 (80.5)		55 (88.5)		55 (88.5)		55 (88.5)		55 (88.5)		55 (88.5)		55 (88.5)	
Operational Mode†		C	P	C	P	C	P	C	P	C	P	C	P	C	P
TEST TIRE CODE	A	O		X	X	X	X	X	X	X	X	X	X	X	X
	B	O		X	X	X	X	X	X	X	X	X	X	X	X
	C	O		X	X	X	X	X	X	X	X	X	X	X	X
	D	O		X	X	X	X	X	X	X	X	X	X	X	X
	E	O		X	X	X	X	X	X	X	X	X	X	X	X
	E*	O		X	X			X	X			X	X	X	X
	R1	O													
	R1,2	O													
	R3	O													

† C - Passby in coast mode

P - Passby in power mode

Table 6. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for the 4 x 2 straight test vehicle operated in the coast mode at a nominal speed of 50 mph (80.5 km/hr) [certification test runs]. These data are adjusted to 50 mph (80.5 km/hr) using a 40 log V relationship between sound level and vehicle speed.

Test Tire Code	Test Run Number	Actual Speed mph (km/hr)	Maximum A-Weighted Sound Level, dB re 20 μPa	
			Measured	Adjusted to 50 mph (80.5 km/hr)
A	1	49.7 (80.0)	73.4	73.5
	2	51.0 (82.1)	73.5	73.2
B	1	51.3 (82.6)	72.6	72.2
	2	51.0 (82.1)	73.2	72.9
C	1	51.3 (82.6)	71.0	70.6
	2	52.4 (84.3)	71.8	71.0
D	1	50.7 (81.6)	85.8	85.6
	2	52.0 (83.7)	85.8	85.1
E	1	52.2 (84.0)	84.0	83.3
	2	50.9 (81.9)	83.8	83.5
E*	1	52.4 (84.3)	82.8	82.0
	2	51.9 (83.5)	84.4	83.8
R1	1	50.9 (81.9)	75.0	74.7
	2	50.0 (80.5)	76.0	76.0
R1,2	1	50.0 (80.5)	77.2	77.2
	2	49.5 (79.7)	78.4	78.6
R3	1	49.1 (79.0)	72.4	72.7
	2	50.4 (81.1)	72.8	72.7

Table 7. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for the 4 x 2 straight test vehicle operated in the coast and power passby modes at a nominal speed of 55 mph (88.5 km/hr). These data are adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed and then are averaged for the two test runs.

Mode	Test Tire Code	Test Run Number	Actual Speed mph (km/hr)	Maximum A-weighted Sound Level, dB re 20 μPa Measured	Adjusted To 55 mph (88.5 km/hr)	Average of Two Runs
COAST	A	1 2	54.3 (87.4) 54.6 (87.9)	75.0 75.0	75.2 75.1	75.2
COAST	B	1 2	54.8 (88.2) 55.7 (89.6)	74.0 74.8	74.1 74.6	74.4
COAST	C	1 2	56.3 (90.6) 56.2 (90.4)	73.0 73.4	72.6 73.0	72.8
COAST	D	1 2	55.6 (89.5) 54.1 (87.1)	87.6 87.4	87.4 87.7	87.6
COAST	E	1 2	55.8 (89.8) 56.1 (90.3)	84.6 85.2	84.3 84.9	84.6
COAST	E*	1 2	56.3 (90.6) 56.1 (90.3)	86.0 85.6	85.6 85.3	85.5
POWER	A	1 2	57.1 (91.9) 57.3 (92.2)	80.6 79.6	79.9 78.9	79.4
POWER	B	1 2	56.3 (90.6) 56.0 (90.1)	80.2 80.0	79.8 79.7	79.8
POWER	C	1 2	56.3 (90.6) 55.4 (89.2)	80.4 80.8	80.0 80.7	80.4
POWER	D	1 2	57.7 (92.9) 57.2 (92.1)	88.0 88.4	87.2 87.7	87.5
POWER	E	1 2	57.0 (91.7) 56.1 (90.3)	87.4 86.6	86.8 86.3	86.6
POWER	E*	1 2	55.7 (89.6) 55.4 (89.2)	86.6 86.4	86.4 86.3	86.4

Table 8. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for the 4 x 2 tractor with single-axle trailer test vehicle operated in the coast and power passby modes at a nominal speed of 55 mph (88.5 km/hr). These data are adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed and then are averaged for the two test runs.

Mode	Test Tire Code	Test Run Number	Actual Speed mph (km/hr)	Maximum A-weighted Sound Level, dB re 20 μPa		
				Measured	Adjusted To 55 mph (88.5 km/hr)	Average of Two Runs
COAST	A	1	54.3 (87.4)	79.6	79.8	79.8
		2	54.5 (87.7)	79.6	79.8	
	B	1	53.0 (85.3)	79.0	79.6	79.2
		2	54.6 (87.9)	78.6	78.7	
	C	1	53.3 (85.8)	77.6	78.1	78.6
		2	54.6 (87.9)	79.0	79.1	
	D	1	52.2 (84.0)	86.6	87.5	87.9
		2	53.5 (86.1)	87.8	88.3	
	E	1	53.3 (85.8)	85.0	85.5	85.9
		2	55.5 (89.3)	86.4	86.2	
POWER	A	1	56.9 (91.6)	82.4	81.8	81.8
		2	56.6 (91.1)	82.2	81.7	
	B	1	57.5 (92.5)	83.4	82.6	82.5
		2	56.3 (90.6)	82.8	82.4	
	C	1	55.4 (89.2)	82.8	82.7	82.7
		2	56.3 (90.6)	83.0	82.6	
	D	1	55.9 (90.0)	89.4	89.1	89.2
		2	55.5 (89.3)	89.4	89.2	
	E	1	53.6 (86.3)	87.2	87.6	88.0
		2	54.1 (87.1)	88.0	88.3	

Table 9. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for the 4 x 2 tractor with double-axle trailer test vehicle operated in the coast and power passby modes at a nominal speed of 55 mph (88.5 km/hr). These data are adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed and then are averaged for the two test runs.

	Test Tire Code	Test Run Number	Actual Speed mph (km/hr)	Maximum A-weighted Sound Level, dB re 20 μPa		
				Measured	Adjusted To 55 mph (88.5 km/hr)	Average of Two Runs
COAST	A	1 2	55.5 (89.3) 55.4 (89.2)	78.6 79.6	78.4 79.5	79.0
	B	1 2	55.1 (88.7) 56.0 (90.1)	78.8 78.5	78.8 78.2	78.5
	C	1 2	54.8 (88.2) 56.7 (91.2)	77.4 79.0	77.5 78.5	78.0
	D	1 2	55.5 (89.3) 57.1 (91.9)	87.8 88.6	87.6 87.9	87.8
	E	1 2	56.0 (90.1) 56.3 (90.6)	85.8 87.0	85.5 86.6	86.1
	E*	1 2	56.0 (90.1) 55.1 (88.7)	87.0 86.0	86.7 86.0	86.4
POWER	A	1 2	56.4 (90.8) 56.3 (90.6)	82.8 82.0	82.4 81.6	82.0
	B	1 2	55.4 (89.2) 55.1 (88.7)	81.6 81.6	81.5 81.6	81.6
	C	1 2	56.1 (90.3) 55.5 (89.3)	82.2 81.8	81.9 81.6	81.8
	D	1 2	56.9 (91.6) 56.0 (90.1)	89.4 88.5	88.8 88.2	88.5
	E	1 2	55.1 (88.7) 54.7 (88.0)	86.6 86.8	86.6 86.9	86.8
	E*	1 2	55.1 (88.7) 54.4 (87.5)	87.4 87.0	87.4 87.2	87.3

Table 10. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for the 4 x 2 tractor with double bottom trailer test vehicle operated in the coast and power passby modes at a nominal speed of 55 mph (88.5 km/hr). These data are adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed and then are averaged for the two test runs.

Mode	Test Tire Code	Test Run Number	Actual Speed mph (km/hr)	Maximum A-weighted Sound Level, dB re 20 μPa		
				Measured	Adjusted To 55 mph (88.5 km/hr)	Average of Two Runs
COAST	A	1 2	54.4 (87.5) 55.5 (89.3)	84.0 84.0	84.2 83.8	84.0
	B	1 2	54.0 (86.9) 54.8 (88.2)	82.8 84.0	83.1 84.1	83.6
	C	1 2	55.0 (88.5) 54.3 (87.4)	83.8 83.8	83.8 84.0	83.9
	D	1 2	56.3 (90.6) 53.1 (85.5)	89.8 89.4	89.4 90.0	89.7
	E	1 2	55.9 (90.0) 53.7 (86.4)	88.2 87.2	87.9 87.6	87.8
POWER	A	1 2	56.3 (90.6) 56.6 (91.1)	86.0 85.2	85.6 84.7	85.2
	B	1 2	56.1 (90.3) 56.5 (90.9)	85.8 85.4	85.5 84.9	85.2
	C	1 2	55.7 (89.6) 55.7 (89.6)	85.0 84.8	84.8 84.6	84.7
	D	1 2	55.6 (89.5) 55.8 (89.8)	90.0 90.4	89.8 90.1	90.0
	E	1 2	55.5 (89.3) 57.5 (92.5)	88.4 89.8	88.2 89.0	88.6

Table 11. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for the 6 x 4 straight test vehicle operated in the coast and power passby modes at a nominal speed of 55 mph (88.5 km/hr). These data are adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed and then are averaged for the two test runs.

Mode	Test Tire Code	Test Run Number	Actual Speed mph (km/hr)	Maximum A-weighted Sound Level, dB re 20 μPa: Measured	Adjusted To 55 mph (88.5 km/hr)	Average of Two Runs
COAST	A	1 2	53.4 (85.9) 53.3 (85.8)	81.0 81.2	81.5 81.7	81.6
COAST	B	1 2	56.3 (90.6) 55.8 (89.8)	77.2 78.2	76.8 77.9	77.4
COAST	C	1 2	56.7 (91.2) 55.8 (89.8)	76.2 76.6	75.7 76.3	76.0
COAST	D	1 2	54.8 (88.2) 54.0 (86.9)	90.2 90.6	90.3 90.9	90.6
COAST	E	1 2	54.0 (86.9) 54.5 (87.7)	88.5 89.0	88.8 89.2	89.0
COAST	E*	1 2	53.9 (86.7) 53.0 (85.3)	87.6 87.0	88.0 87.6	87.8
POWER	A	1 2	55.4 (89.2) 54.8 (88.2)	84.0 83.2	83.9 83.3	83.6
POWER	B	1 2	56.2 (90.4) 55.4 (89.2)	82.8 82.8	82.4 82.7	82.6
POWER	C	1 2	56.3 (90.6) 55.9 (90.0)	81.8 82.6	81.4 82.3	81.9
POWER	D	1 2	56.5 (90.9) 55.1 (88.7)	91.4 90.6	90.9 90.6	90.8
POWER	E	1 2	55.4 (89.2) 55.7 (89.6)	89.4 89.4	89.3 89.2	89.3
POWER	E*	1 2	54.3 (87.4) 55.4 (89.2)	89.2 88.4	89.4 88.3	88.9

Table 12. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for the 6 x 4 tractor with double-axle trailer test vehicle operated in the coast and power passby modes at a nominal speed of 55 mph (88.5 km/hr). These data are adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed and then are averaged for the two test runs.

Mode	Test Tire Code	Test Run Number	Actual Speed mph (km/hr)	Maximum A-weighted Sound Level, dB re 20 μPa: Measured	Adjusted To 55 mph (88.5 km/hr)	Average of Two Runs
COAST	A	1	54.8 (88.2)	80.8	80.9	81.1
		2	55.9 (90.0)	81.6	81.3	
	B	1	56.8 (91.4)	81.0	80.4	80.0
		2	57.1 (91.9)	80.2	79.5	
	C	1	54.0 (86.9)	78.4	78.7	78.5
		2	54.0 (86.9)	78.0	78.3	
	D	1	56.3 (90.6)	90.0	89.6	90.1
		2	56.5 (90.9)	91.0	90.5	
	E	1	56.1 (90.3)	88.2	87.9	88.2
		2	55.4 (89.2)	88.6	88.5	
	E*	1	53.4 (85.9)	86.8	87.3	87.6
		2	54.3 (87.4)	87.6	87.8	
POWER	A	1	56.3 (90.6)	83.8	83.4	83.3
		2	56.6 (91.1)	83.6	83.1	
	B	1	56.0 (90.1)	83.6	83.3	83.3
		2	56.3 (90.6)	83.7	83.3	
	C	1	56.7 (91.2)	83.0	82.5	82.6
		2	56.2 (90.4)	83.0	82.6	
	D	1	56.1 (90.3)	91.8	91.5	90.7
		2	56.1 (90.3)	91.2	89.9	
	E	1	54.8 (88.2)	88.6	88.7	88.7
		2	55.7 (89.6)	88.8	88.6	
	E*	1	54.8 (88.2)	89.4	89.5	89.2
		2	54.7 (88.0)	88.8	88.9	

The results of the model predictions of the maximum A-weighted sound levels are compared with the measured values [average of the two test runs adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed] in Tables 13 and 14. For comparison purposes these data are plotted as calculated versus measured values in Figures 14 and 15.

In general the agreement between the measured and predicted results is quite encouraging -- the average (absolute) difference being 0.86 dB for test runs in the coast mode and 0.94 dB for test runs in the power mode. As shown by the dashed lines in Figure 14, a band of ± 1.5 dB encompasses 88 percent of the data points. In Figure 15 a similar band of ± 1.5 dB encompasses 76 percent of the data points, and if the band is expanded to ± 2.0 dB this is increased to 88 percent.

The largest discrepancy between the measured and calculated data occurs for the 6 x 4 straight test vehicle equipped with tire A. In this case the measured maximum A-weighted sound levels appear to be too high. In the ideal case of the combination of two identical incoherent sources (i.e., two axles) an increase of 3 dB would be expected. Data published in the literature[4] indicate that doubling the number of axles with loud tires increases the maximum A-weighted sound level approximately 2 dB. A comparison of the 4 x 2 straight and 6 x 4 straight data show the following increases for the addition of another axle:

tire A - 6.4 dB
tire B - 3.0 dB
tire C - 3.2 dB
tire D - 3.0 dB
tire E - 4.4 dB
tire E* - 2.3 dB

These values all seem reasonable except for tires A and E. The 4.4 dB for tire E is slightly high, but 6.4 dB for tire A would appear to be incorrect resulting from some undetected problem in data acquisition or analysis. The original data tapes were rechecked but no obvious anomalies were discovered for the 6 x 4 straight coastbys. One speculation concerns the possibility of two different tread designs for tire A. As shown in Figure 6, the center rib of tire A is diamond shaped, but in a previous study[9], this identical brand of tire had a zig-zag shaped center rib which has been shown to be quieter[5,6]. Thus, if the 4 x 2 straight was equipped with a zig-zag shape tread pattern and the 6 x 4 straight with a diamond shape tread pattern, the increase in sound level would be greater than 3 to 4 dB for the additional axle as seen for the other test tires. This explanation cannot be verified because the tires were borrowed to perform these tests and since then have been returned.

A recheck of Tables 13 and 14 shows that the larger variations between the measured and calculated data occur primarily for tires D and E which are cross-bar type tires. These large discrepancies are believed to be due to

Table 13. Comparison of calculated and measured maximum A-weighted sound levels for test runs at 55 mph (88.5 km/hr) in the coast mode.

Test Vehicle	Test Tire Code	Maximum A-Weighted Sound Level, dB re 20 μPa		
		Measured†	Calculated	Difference (Calculated-Measured)
4 x 2 STR	A	75.2	75.2	0
	B	74.4	74.5	0.1
	C	72.8	72.2	-0.6
	D	87.6	87.2	-0.4
	E	84.6	85.1	0.5
	E*	85.5	85.4	-0.1
4 x 2 SAT	A	79.8	79.9	0.1
	B	79.2	79.3	0.1
	C	78.6	79.1	0.5
	D	87.9	86.7	-1.2
	E	85.9	85.3	-0.6
4 x 2 DAT	A	79.0	79.6	0.6
	B	78.5	79.1	0.6
	C	78.0	78.9	0.9
	D	87.8	86.9	-0.9
	E	86.1	85.5	-0.6
	E*	86.4	85.8	-0.6
4 x 2 DB	A	84.0	83.8	-0.2
	B	83.6	83.8	0.2
	C	83.9	83.7	-0.2
	D	89.7	86.7	-3.0
	E	87.8	85.5	-2.3
6 x 4 STR	A	81.6	77.9	-3.7
	B	77.4	76.8	-0.6
	C	76.0	75.1	-0.9
	D	90.6	89.3	-1.3
	E	89.0	87.8	-1.2
	E*	87.8	87.1	-0.7
6 x 4 DAT	A	81.1	80.6	-0.5
	B	80.0	79.7	-0.3
	C	78.5	79.4	0.9
	D	90.1	88.0	-2.1
	E	88.2	86.7	-1.5
	E*	87.6	86.4	-1.2

† The measured values represent the average of data from two test runs adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed (Tables 7 through 12).

Table 14. Comparison of calculated and measured maximum A-weighted sound levels for test runs at 55 mph (88.5 km/hr) in the power mode.

Test Vehicle	Test Tire Code	Maximum A-Weighted Sound Level, dB re 20 μPa		
		Measured†	Calculated	Difference (Calculated-Measured)
4 x 2 STR	A	79.4	81.1	1.7
	B	79.8	80.9	1.1
	C	80.4	80.6	0.2
	D	87.5	87.3	-0.2
	E	86.6	86.2	-0.4
	E*	86.4	85.7	-0.7
4 x 2 SAT	A	81.8	82.4	0.6
	B	82.5	82.2	-0.3
	C	82.7	81.9	-0.8
	D	89.2	87.4	-1.8
	E	88.0	86.4	-1.6
4 x 2 DAT	A	82.0	82.3	0.3
	B	81.6	82.3	0.7
	C	81.8	81.9	0.1
	D	88.5	87.6	-0.9
	E	86.8	86.6	-0.2
	E*	87.3	86.7	-0.6
4 x 2 DB	A	85.2	84.9	-0.3
	B	85.2	84.8	-0.4
	C	84.7	84.8	0.1
	D	90.0	87.3	-2.7
	E	88.6	86.2	-2.4
6 x 4 STR	A	83.6	81.9	-1.7
	B	82.6	81.7	-0.9
	C	81.9	81.2	-0.7
	D	90.8	89.7	-1.1
	E	89.3	88.5	-0.8
	E*	88.9	87.8	-1.1
6 x 4 DAT	A	83.3	82.7	-0.6
	B	83.3	82.6	-0.7
	C	82.6	82.2	-0.4
	D	91.2	88.6	-2.6
	E	88.7	87.5	-1.2
	E*	89.2	87.2	-2.0

† The measured values represent the average of data from two test runs adjusted to 55 mph (88.5 km/hr) using a 40 log V relationship between sound level and vehicle speed (Tables 7 through 12).

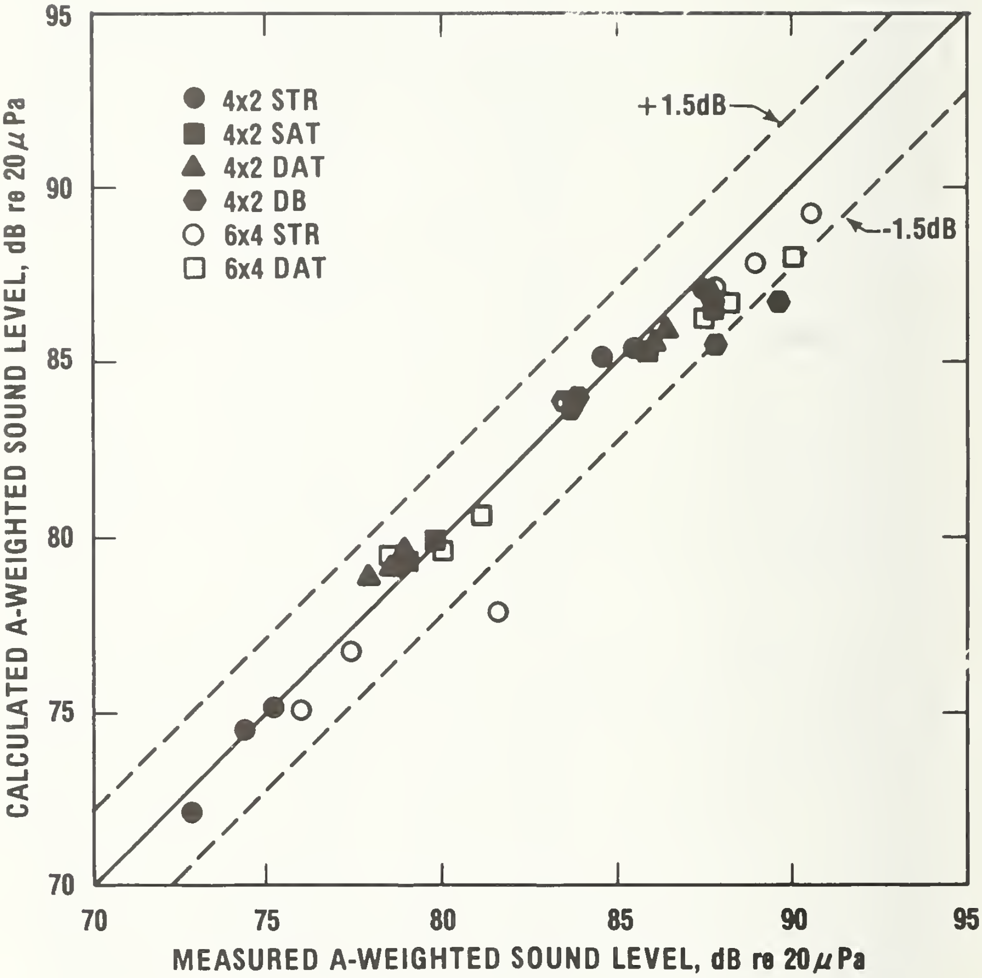


Figure 14. Comparison of the calculated and measured maximum A-weighted sound levels for runs at 55 mph (88.5 km/hr) in the coast mode.

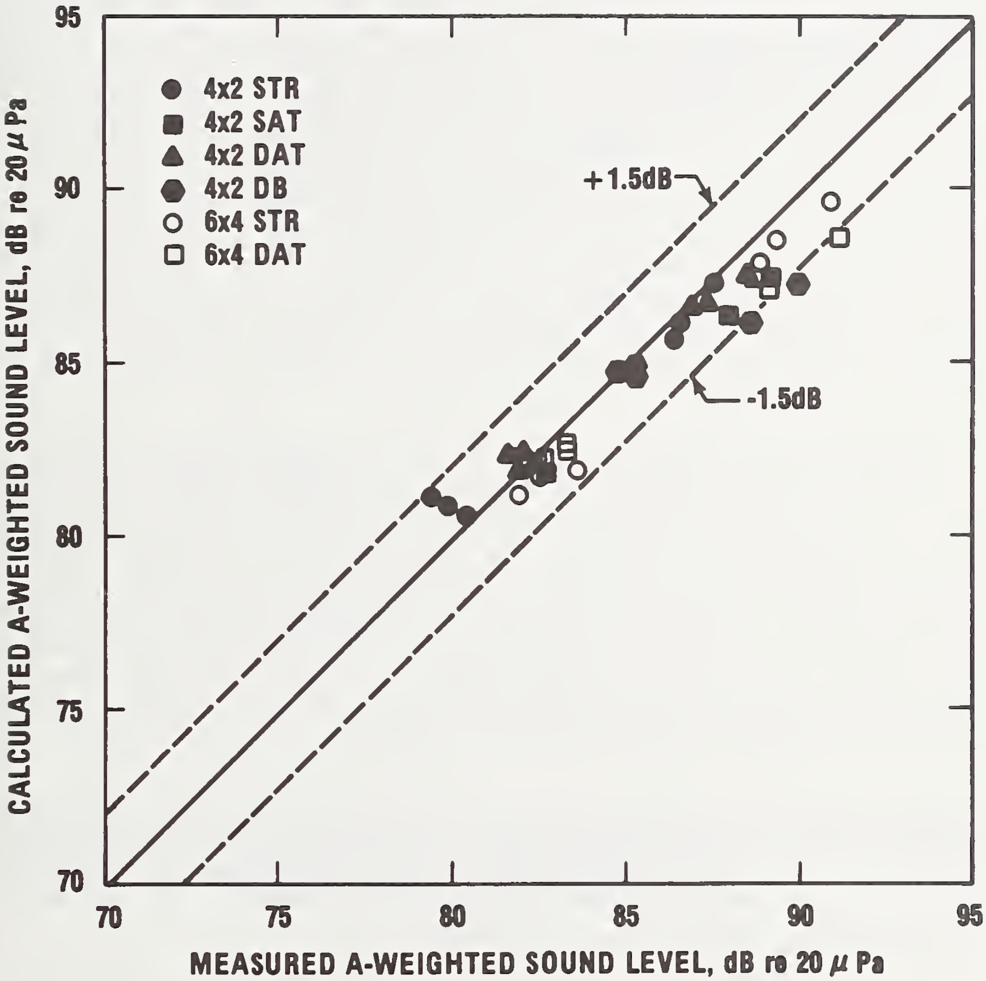


Figure 15. Comparison of calculated and measured maximum A-weighted sound levels for runs at 55 mph (88.5 km/hr) in the power mode.

the load corrections applied to the input data. As pointed out in footnote 6 and discussed in more detail in Appendix A, at the time of this study only a limited amount of data existed showing the influence of load on the generated sounds levels. During a recent field test program conducted at the U. S. Army Yuma Proving Ground, Yuma, Arizona in March 1976, additional data on the influence of load on the generated sound levels were obtained. Data were measured for coastbys at 50 mph (80.5 km/hr) of a 4 x 2 single-chassis vehicle equipped with 11.00-24.5 cross-bar tires (new tire D) mounted on the drive axle and blank tires (full tread depth but no tread pattern) on the steering axle. Measurements were taken for vehicle loadings of 23 (corresponding to empty vehicle weight), 50, 60, 70, 80, 90 and 100 percent of maximum rated tire load at 75 psi (5.2×10^5 Pa) as recommended by the Tire and Rim Association. These results (solid curve) and the corresponding data used to apply the load corrections in the model validation study (dashed curve) are shown in Figure 16. As seen from this plot, the relationship between load and generated sound level varies significantly from the linear dependency assumed in this study. For example, if the certification tests were performed with a tire loading of 100 percent, but the in-service operating conditions were 70 percent, the load corrections would be 3.9 dB using the dashed curve (linear relationship) and 0.9 dB based on the solid curve. This variation explains why the model underestimates the maximum A-weighted sound levels for cross-bar tires. Referring to Figures 14 and 15, the roll-off at large sound levels (i.e., data points corresponding to cross-bar tires) is due to the assumed load corrections and is not a trend of the model to underpredict high noise levels.

Re-examining the results of the model computations treating rib and cross-bar tires separately, the percentage of data points falling within bands of ± 1.5 and ± 2.0 dB on Figures 14 (coastbys) and 15 (powered passbys) are given in Table 15. As shown by these values, the model more accurately predicts the maximum A-weighted sound level for rib tires than cross-bar tires. In fact if the 6 x 4 straight equipped with tire A is disregarded, for coastby operations 100 percent of the data points fall within a band of ± 1.0 dB. The accuracy of prediction for the powered passbys is less, but considering the simple point source model used to represent the engine noise source the results are quite good.

Based on these results, it can be concluded that the model as presently postulated gives a reliable estimate of the maximum A-weighted sound level generated by a variety of vehicle and tire combinations. Before further refinements can be made on the model more information on the effect of load on the generated sound levels is needed.

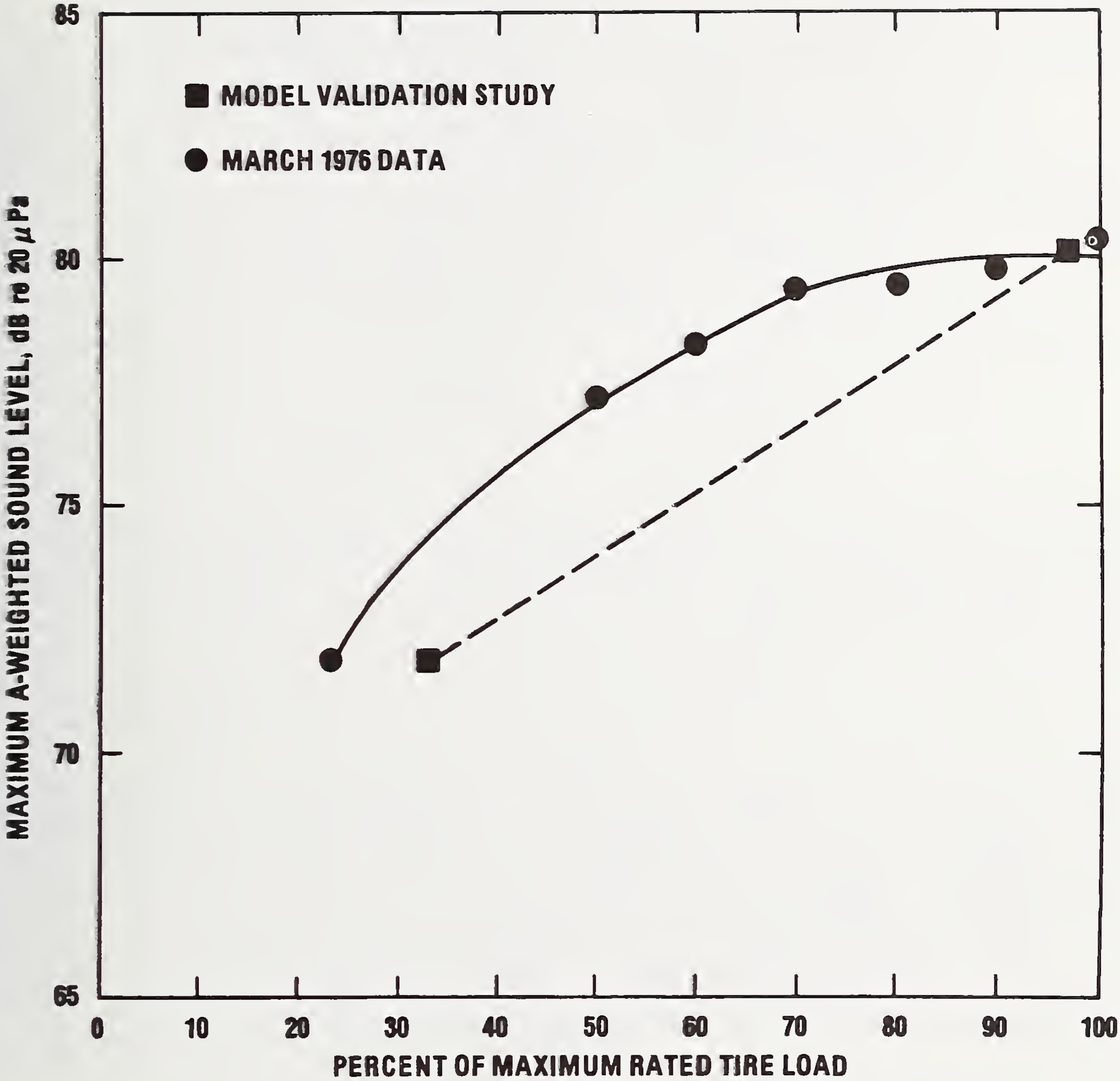


Figure 16. Comparison of load data obtained during a March 1976 field test program with the linear relationship used in the model validation study. These data are for coastbys of a 4 x 2 single-chassis vehicle with cross-bar tires mounted on the drive axle operated at 50 mph (80.5 km/hr) over an asphalt surface.

Table 15. Statistical comparison of the accuracy of the predictive model for rib and cross-bar tires.

Test Vehicle Operational Mode	Tire Type	Percentage of data points falling within the specified bands	
		± 1.5 dB	± 2.0 dB
Coast	Rib	94	94
	Cross-Bar	81	81
Power	Rib	89	100
	Cross-Bar	63	81

5. Application of Predictive Model

One practical application of the DOT/NBS empirical truck tire noise predictive model is the estimation of the range of noise levels generated by tires with different certification levels mounted on various single-chassis vehicles and tractor-trailer combinations[10]. This information is useful in determining what combination of tires can be used on a vehicle such that the generated noise level meets the appropriate regulatory limit.

To illustrate this application a series of tire noise certification levels were selected which are representative of a broad cross-section of tires on the road today. These certification levels are: 78 and 80 dB -- characteristic of rib truck tires, 82 dB -- characteristic of noisy rib and quiet cross-bar truck tires, 84 and 86 dB -- characteristic of cross-bar truck tires, and 90 and 95 dB -- characteristic of pocket tread truck tires[14/] [10]. The necessary A-weighted sound level versus time data to be used as input to the predictive model were chosen from actual passby time histories obtained in the DOT/NBS truck tire noise study at Wallops Island, Virginia[5,6]. The data were chosen such that the maximum A-weighted sound levels of the passby time histories corresponded approximately to the 78, 80, 82, 84, 86, 90 and 95 dB certification levels. Prior to performing the calculations, the A-weighted sound level time histories were uniformly adjusted such that the maximum A-weighted sound levels were exactly 78 dB, 80 dB, etc.

14/ These tires are included only for illustrative purposes and represent an upper limit of the sound levels generated by truck tires. The pocket tread tire is no longer in use on the highway today because it does not conform to the requirements of the U. S. Environmental Protection Agency Motor Carrier Noise Emission Standard 40 CFR 202.23 which states that: "No motor vehicle should be operated on any tire having a tread pattern composed primarily of cavities in the tread (excluding sipes and local chunking or irregularities of wear) which are not vented by grooves to the tire shoulder or circumferentially to each other around the tire".

For this example seven different single-chassis and tractor-trailer combinations were examined. These vehicles are the same as described in the previous section with the addition of a 4 x 2 triple bottom (4 x 2 TB) which is a 4 x 2 double bottom with another dolly and single-axle trailer attached to the second trailer. Typical lineal dimensions of these vehicles are given in Table 16 and the assumed axle loadings in Table 17. These loads are based on a maximum legal limit permitted by the Federal-Aid Highway Act of 1974 [See footnote 10] of 20,000 pounds (9,072 kg) on a single axle, 34,000 pounds (15,422 kg) on tandem axles and 80,000 pounds (36,288 kg) total gross combination weight for all vehicles except the 4 x 2 triple bottom which is permitted a total gross combination weight of 105,000 pounds (47,628 kg). It is assumed that the tires for which the certification noise level applies are mounted on the drive axle(s), that rib tires whose characteristic noise level is known to be low are mounted on the steering axle, and that half-worn rib tires are mounted on all trailer axles. The engine is approximated by an omnidirectional point source located on the centerline of the vehicle directly over the steering axle. For this example the A-weighted sound pressure level of the engine is assumed to be 83 dB at 50 feet (15.2 m). This level corresponds to the EPA standard for medium and heavy duty trucks which goes into effect January 1, 1978.

The predicted in-service total truck noise levels at 50 feet (15.2 m) and 55 mph (88.5 km/hr) are listed in the truck tire noise criteria chart shown in Table 18. As an example of the use of this table, a 4 x 2 tractor with double-axle trailer should be equipped with tires on the drive axle whose certification level is 84 dB or less in order to meet the 90 dB total vehicle noise limit of the Federal Interstate Motor Carrier Regulations for high speed operations.

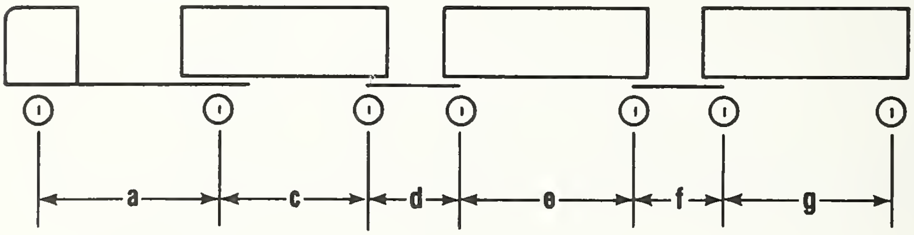
Special caution should be taken in using this table for several reasons. First, the sound level generated by truck tires is dependent on the state of tread wear and in general increases with wear, in certain cases as much as 4-5 dB[5,6]. Ideally, the maximum noise as a function of tread wear measured according to the certification test procedures should be known if such a table is to be used to estimate the maximum in-service noise levels. If this information is not available, the in-service noise levels predicted using the certification levels for new tires must be adjusted to account for the observed increases in tire noise as the tire wears in order to adequately estimate the maximum in-service noise levels.

Another important point is that the values given in Table 18 are dependent upon the engine noise level. For example, if the engine noise level was greater than 83 dB, the in-service noise levels would increase and as a result the allowable tire certification level which would meet the regulatory limit would decrease.

A final point to note is that in typical fleet operations, cross-bar type tires run on the tractor drive axle(s) are removed after a certain state of tread wear and mounted on the trailer to be worn down until they are ready to be recapped. This can significantly increase the in-service noise level and further reduce the allowable certification noise level for the drive axle(s) tires.

Table 16. Assumed lineal dimensions in inches (meters) of the seven vehicle configurations examined in the example application of the predictive model. The dimensions a through g are defined in the sketches below the table.

Vehicle Configuration	Vehicle Dimensions, inches (m)						
	a	b	c	d	e	f	g
4 x 2 STR	145 (3.7)						
4 x 2 SAT	115 (2.9)		240 (6.1)				
4 x 2 DAT	115 (2.9)		351 (8.9)	52 (1.3)			
4 x 2 DB	115 (2.9)		240 (6.1)	73 (1.9)	242 (6.1)		
4 x 2 TB	115 (2.9)		240 (6.1)	73 (1.9)	242 (6.1)	73 (1.9)	242 (6.1)
6 x 4 STR	145 (3.7)	49 (1.2)					
6 x 4 DAT	115 (2.9)	52 (1.3)	325 (8.3)	52 (1.3)			



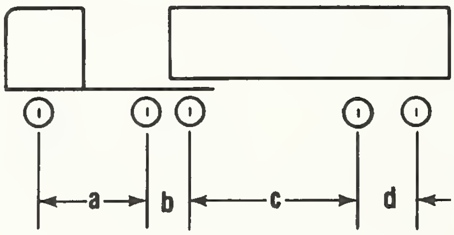


Table 17. Assumed weight distributions on each axle and total gross vehicle and/or combination weights used in the example application of the predictive model.

Vehicle Configuration	Load Per Axle, Pounds (kg)									Gross Vehicle and/or Combination Weight, pounds (kg)
	Steering	First Drive	Second Drive	Front Axle First Trailer	Rear Axle First Trailer	First Dolly	Second Trailer	Second Dolly	Third Trailer	
4 x 2 STR	9000 (4082)	18000 (8165)								27000 (12247)
6 x 4 STR	9000 (4082)	17000 (7711)	17000 (7711)							43000 (19505)
4 x 2 SAT	9000 (4082)	19000 (8618)		19000 (8618)						47000 (21319)
4 x 2 DAT	9000 (4082)	19000 (8618)		17000 (7711)	17000 (7711)					62000 (28123)
4 x 2 DB	10000 (4536)	17500 (7938)		17500 (7938)		17500 (7938)	17500 (7938)			80000 (36288)
6 x 4 DAT	12000 (5443)	17000 (7711)	17000 (7711)	17000 (7711)	17000 (7711)					80000 (36288)
4 x 2 TB	9000 (4082)	16000 (7258)		16000 (7258)		16000 (7258)	16000 (7258)	16000 (7258)	16000 (7258)	105000 (47628)

Table 18. Truck tire noise criteria chart for predicting in-service noise levels at 50 feet (15.2 m) and 55 mph (88.5 km/hr) from tire certification noise levels. The tires for which the certification level applies are mounted on the drive axle(s), quiet rib tires on the steering axle and half-worn rib tires on the trailer axles. The engine noise level is assumed to be 83 dB at 50 feet (15.2 m).

Vehicle Configuration	4 x 2 STR	6 x 4 STR	4 x 2 SAT	4 x 2 DAT	4 x 2 DB	6 x 4 DAT	4 x 2 TB
Total Gross Vehicle Weight, pounds (kg)	27000 (12247)	43000 (19505)	47000 (21319)	62000 (28123)	80000 (36288)	80000 (36288)	105000 (47628)
A-weighted Certification Noise Level, Measured At 50 feet (15.2 m) and 50 mph (80.5 km/hr), dB re 20 μPa	In-Service Maximum A-Weighted Sound Level at 50 feet (15.2 m) and 55 mph (88.5 km/hr), dB re 20 μPa						
78	85	86	85	86	86	86	86
80	85	86	86	86	87	87	87
82	86	88	87	88	87	88	88
84	88	89	88	89	88	90	88
86	89	91	90	90	90	91	89
90	92	95	92	93	92	95	92
95	97	99	97	98	97	99	96

6. Appendix A

Model Computational Procedures

This appendix contains a general discussion of the basic concepts underlying the DOT/NBS empirical truck tire noise predictive model. To illustrate these basic concepts and the application of the model, an example computation is presented.

6.1. General Assumptions of the Model

As previously stated in the Introduction, the basic hypotheses of the predictive model are: (a) that for any given single-chassis truck or tractor-trailer, each axle (actually the two or four tires mounted on the axle) can be treated as a single independent sound source, unaffected by other axles of the vehicle; and (b) that with a knowledge of the noise characteristics of each axle for any particular set of operating conditions, the in-service tire noise level for vehicles with numerous axles and axle locations can be estimated by combining the contributions from each axle on an energy basis.

In the empirical model the axles (tires) of the vehicle are represented as an array of sources spatially located according to the geometric arrangement of the axles of the particular vehicle of interest. A primary assumption of the model is that the sound generation characteristics of each axle can be represented by tire noise certification data (A-weighted sound level versus time data) if the number of tires mounted on the axle, the tread design, and the state of tread wear of the tires are comparable.

A second assumption is that the certification data representative of each axle can be adjusted to account for speed and load variations between the certification test and in-service operating conditions. The tire noise certification data are measured according to prescribed procedures recommended in SAE J57[7][15/]. This standard specifies that the data be measured for coastbys at 50 mph (80.5 km/hr) of a 4 x 2 single-chassis vehicle equipped with "quiet" rib tires on the steering axle and the tires to be certified on the drive axle. The vehicle is operated in the loaded condition with tire loading defined by the size and inflation pressure as recommended by the Tire and Rim Association. To adjust the certification data to the in-service operating conditions, speed and load corrections are applied.

Based on the data presented in the literature, it is assumed that the generated tire noise levels increase with the fourth power of vehicle speed. This relationship, given in terms of the change of A-weighted sound level, ΔL_A, due to a variation in vehicle speed, V expressed in mph, from the reference speed of 55 mph (88.5 km/hr), is

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[15/] In this current study data were obtained utilizing "fast" meter response while SAE J57 specifies use of "slow" meter response.

$$\Delta L_A = 40 \log \frac{55}{V} \qquad (1)$$

This correction is uniformly applied to the certification data for all types of tire constructions and tread designs.

Only a limited amount of data investigating the effect of load on the generated tire noise levels is available in the literature. These data exist for only one type of rib and cross-bar tire, three states of tread wear -- new, half-worn and fully worn -- and for only two loading conditions -- loaded, 17,720 pounds per axle (8038 kg per axle); and unloaded, 6120 pounds per axle (2776 kg per axle)[5,6]. In this current study it is assumed that the noise level changes linearly with load and that any rib or cross-bar tire behaves with load changes exactly like the typical rib and cross-bar tires for which data exist. The corrections for variations in tire loading between the certification test and in-service conditions are given in Figure A-1. These corrections, given in terms of load difference (certification loading minus in-service loading) for new, half-worn and fully worn rib and cross-bar tires, are uniformly applied to the certification data according to tread design and state of tread wear.

To account for engine noise when predicting total in-service truck noise, the engine was approximated by an omnidirectional point source located on the centerline of the vehicle directly over the steering axle. The A-weighted sound level [at 50 feet (15.2 m) from the centerline of travel] versus distance data for the passby of a point source is presented in Figure A-2. For this study a level of 80 dB at 50 feet (15.2 m) was selected because of good agreement with the measured data, but this curve can be used for any engine noise level by vertically shifting the curve to the appropriate value. These data are combined with the certification data to estimate the total in-service truck noise.

Using these basic concepts and assumptions, the computational procedure for predicting the in-service noise levels is:

(a) Obtain the A-weighted sound level versus time certification data for each axle of the vehicle of interest.

(b) Convert these data to A-weighted sound level versus distance data.

(c) Determine the speed and load corrections from Equation 1 and Figure A-1, respectively, for each axle.

(d) Uniformly apply these corrections to the certification data and replot the speed/load adjusted A-weighted sound level versus distance data for each axle.

(e) Combine the adjusted A-weighted sound level versus distance data for each axle (also the engine if predicting total in-service truck noise) after shifting the data by an appropriate distance corresponding to the spatial separation of the axle(s) (or engine) relative to a reference point such as the centerline of the front drive axle.

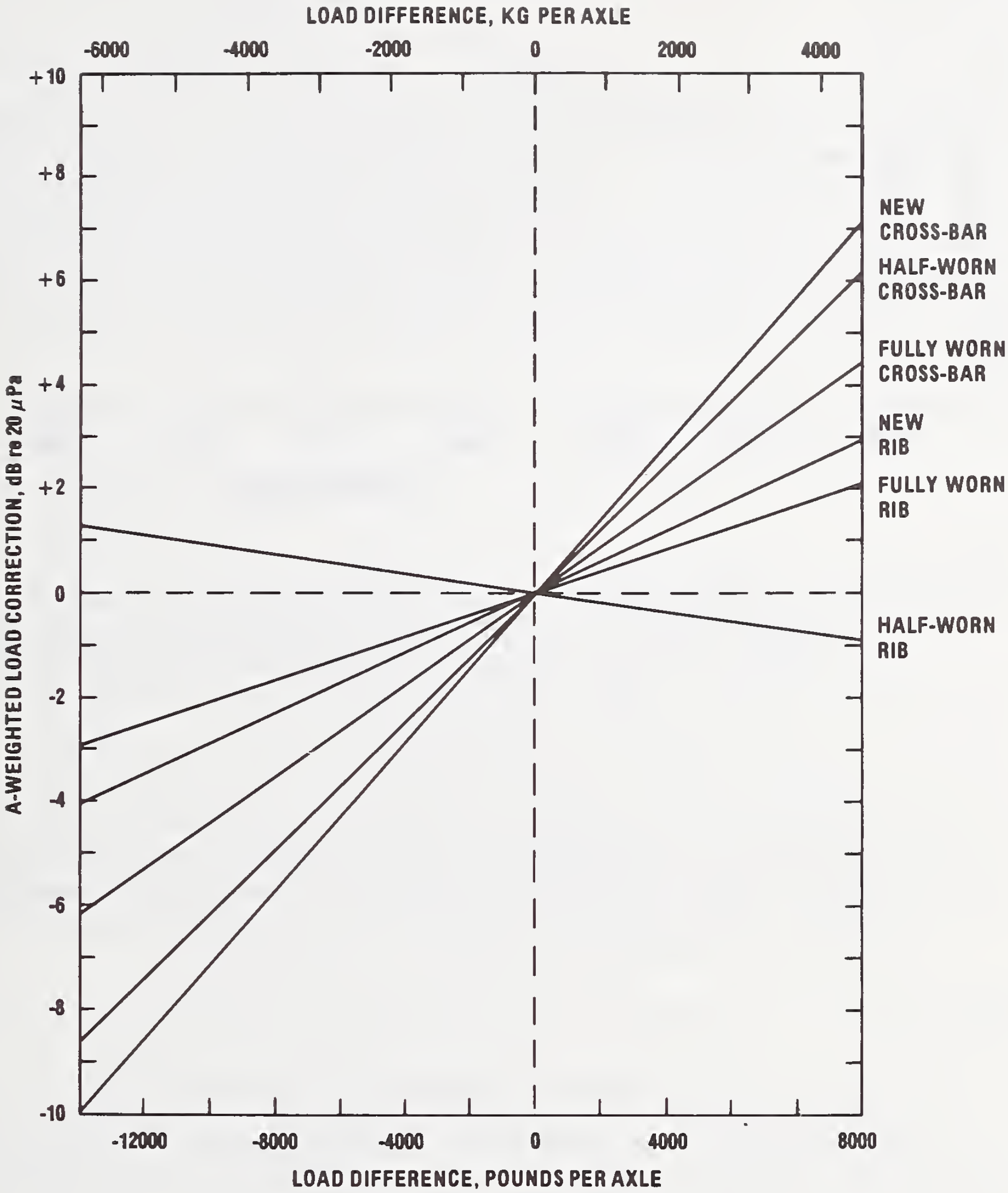


Figure A-1. A-weighted sound level corrections for variations in loading between the certification test and in-service operating conditions. Load difference = [certification loading - in-service loading]. Data were obtained from coastbys at 50 mph (80.5 km/hr) over an asphalt surface with loadings of 17,720 and 6120 pounds per axle (8038 and 2776 kg per axle) [5,6].

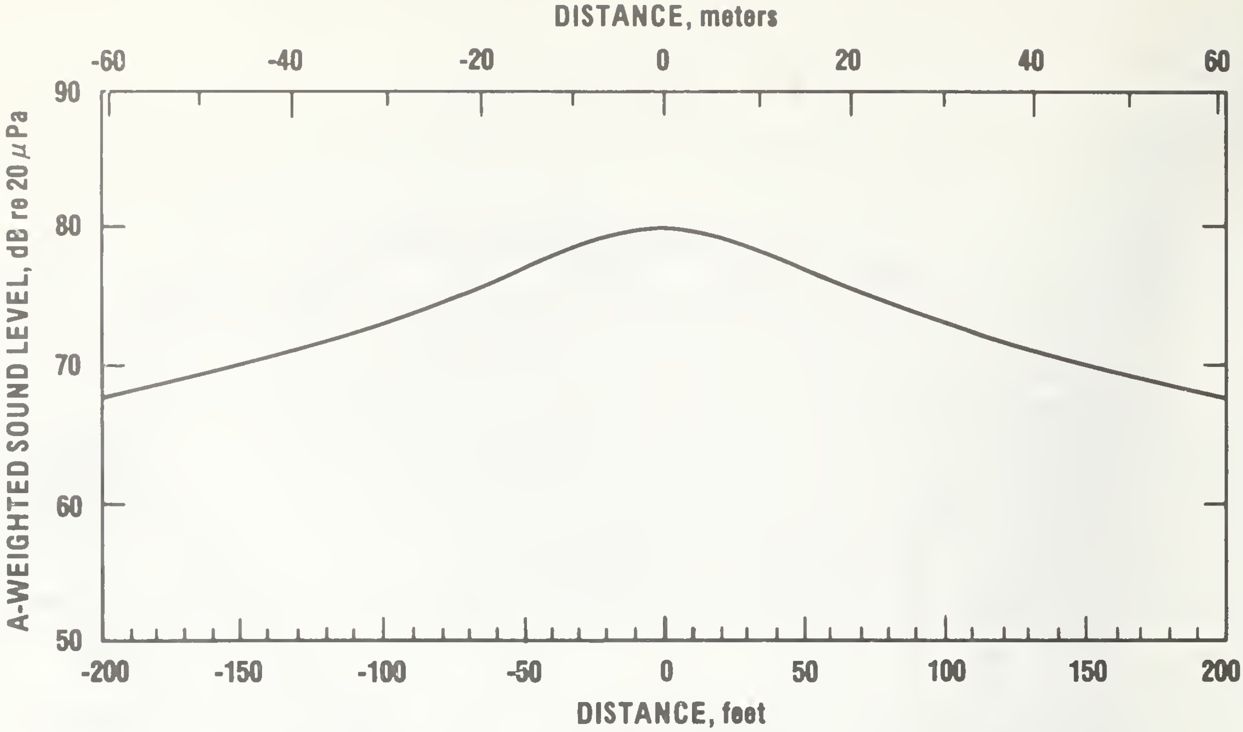


Figure A-2. A-weighted sound level [at 50 feet (15.2 m) from the centerline of travel] versus distance for the passby of an omnidirectional point source with an A-weighted sound level of 80 dB at 50 feet (15.2 m).

(f) Logarithmically add the A-weighted sound levels for all axles (and the engine if predicting total in-service truck noise) at various points along the passby to obtain the predicted A-weighted sound level versus distance data (also the maximum A-weighted sound level) for the in-service operation of this vehicle.

These steps are illustrated in the following example.

6.2. Example Computation Using the Model

As an example of the application of the predictive model, the in-service noise levels for the 6 x 4 tractor with double-axle trailer used in the model validation study are predicted. The tractor is equipped with rib tires whose characteristic noise level is known to be low on the steering axle (the tire noise contribution from the steering axle is neglected) and tire E -- half-worn bias ply cross-bar tires -- on the drive axles. The double-axle trailer is equipped with tire R3 -- half-worn bias ply rib tires -- on both axles. The in-service noise levels are predicted for both coastbys and powered passbys at 55 mph (88.5 km/hr) with the vehicle loading given in Table 3. The computational steps are performed as shown below.

a. Tire noise certification data

For the purposes of this example, the certification test data were plotted by replaying the original data tapes through a graphic level recorder. These A-weighted sound level versus time data are given in Figures A-3 and A-4 for tires E and R3, respectively[16/].

b. Convert time data to distance data

The time data are converted to distance data by using the points on the time history plot corresponding to the start and end of the test section, or as an alternative, the point corresponding to the start of the test section and the average vehicle speed through the test section. In either case, the distance conversion is an approximation because the speed is decreasing as the vehicle coasts through the test section. In this example, the start point and average vehicle speed are used to convert to distance using the simple relationship,

$$x = 1.47\ Vt\ , \tag{2}$$

where x = distance, feet
V = vehicle speed, mph
t = time, seconds.

The A-weighted sound level versus distance data for tires E and R3 are given in Figures A-5 and A-6, respectively. These curves have been replotted limiting the abscissa to ±200 feet (± 61 m) using a sign convention of plus for positions before the drive axle reaches the microphone and minus for positions after it passes. The zero point -- point corresponding to the passage of the drive axle of the 4 x 2 single-chassis vehicle by the microphone -- is located 309.8 feet (94.4 m) from the point corresponding to the start of the test section. This distance is equal to one-half the length of the test section [300 feet (91.4 m)] plus the distance between the steering and drive axle of the 4 x 2 single-chassis vehicle [9.8 feet (3.0 m)] which is necessary because the data start signal recorded on tape is activated by the steering axle.

c. Speed and load corrections

The vehicle speeds for the two certification test runs are 50.9 mph (81.9 km/hr) for tire E and 50.4 mph (81.1 km/hr) for tire R3. Using Equation 1, the speed corrections are calculated to be 1.4 dB for tire E and 1.5 dB for tire R3.

[16/] Because of the transient response characteristics of a graphic level recorder, the maximum A-weighted sound levels shown in Figures A-3 and A-4 are less than the values reported in Table 6 which were obtained using a real time analyzer as shown in Figure 13.

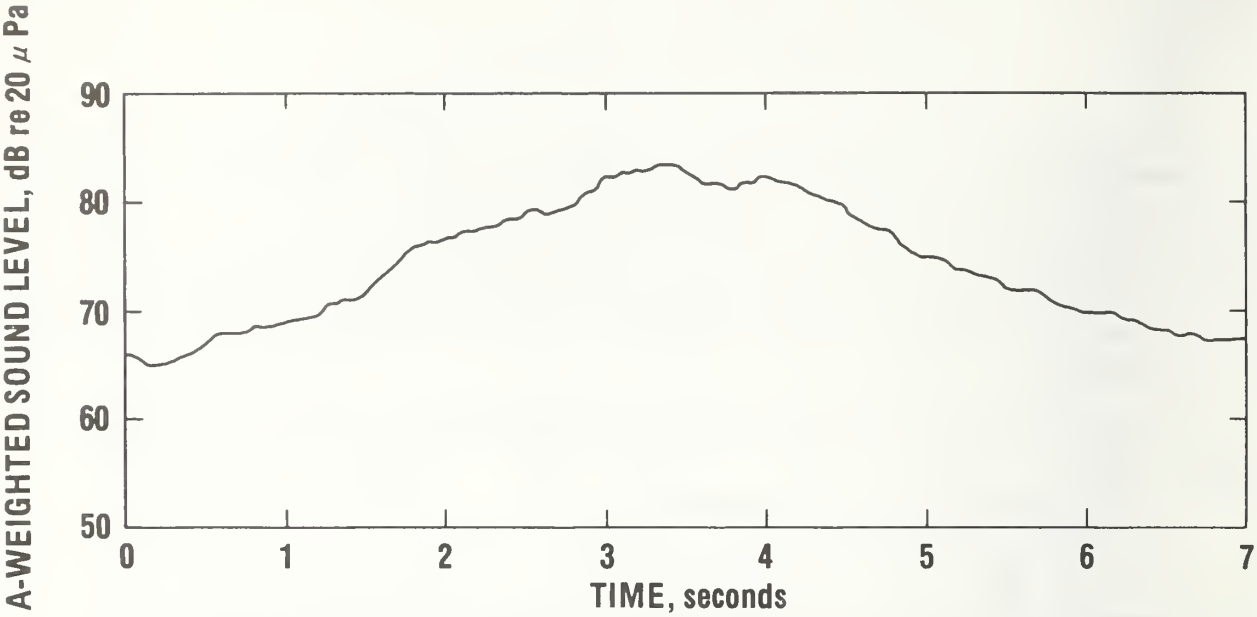


Figure A-3. A-weighted sound level versus time certification data for tire E. Vehicle speed is 50.9 mph (81.9 km/hr) and loading is 18,080 pounds per axle (8201 kg per axle).

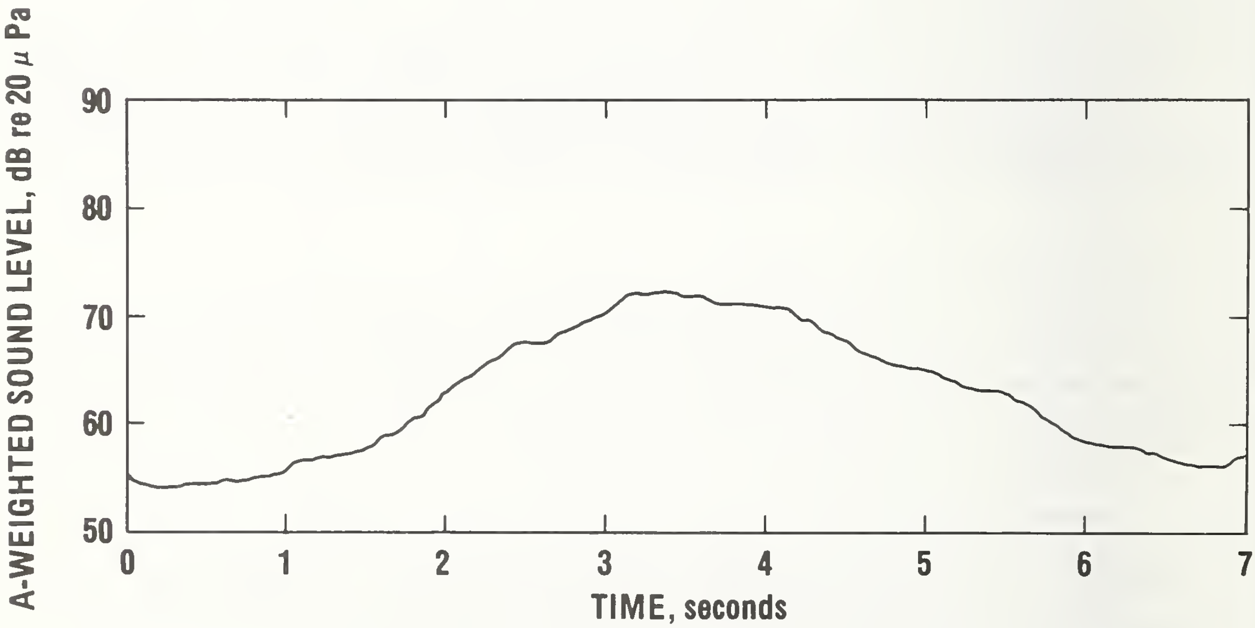


Figure A-4. A-weighted sound level versus time certification data for tire R3. Vehicle speed is 50.4 mph (81.1 km/hr) and loading is 18,080 pounds per axle (8201 kg per axle).

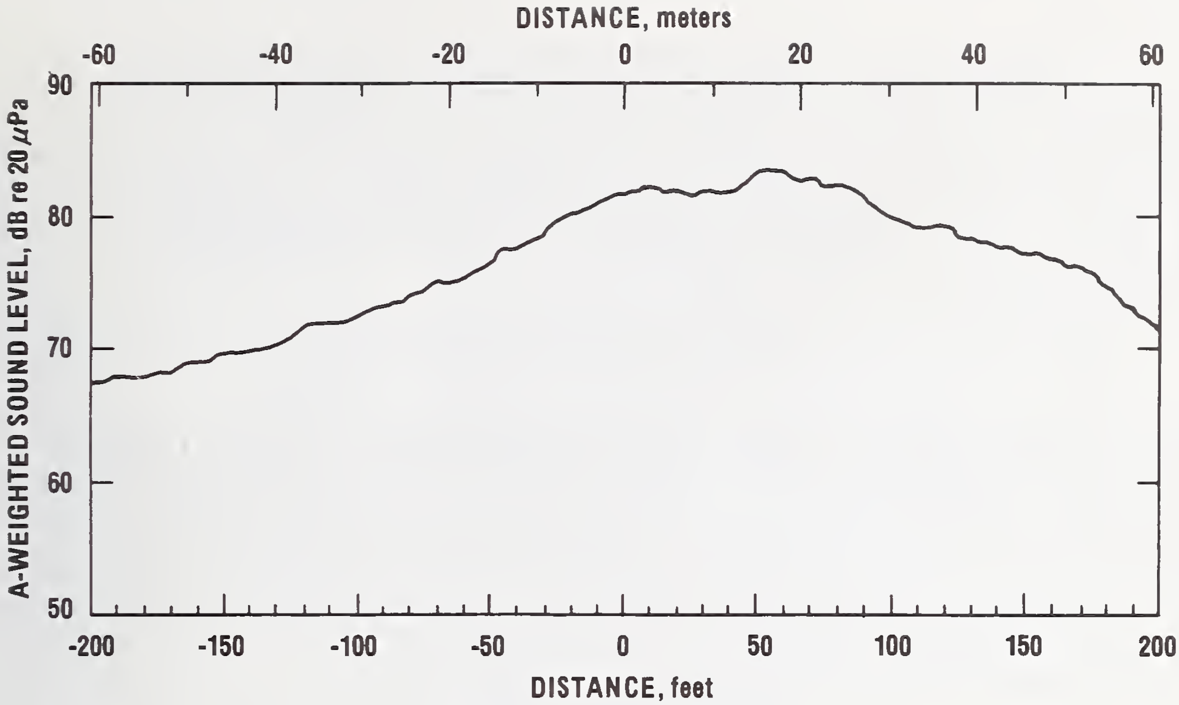


Figure A-5. A-weighted sound level versus distance certification data for tire E. The zero point corresponds to the passage of the drive axle of the 4 x 2 single-chassis vehicle by the microphone.

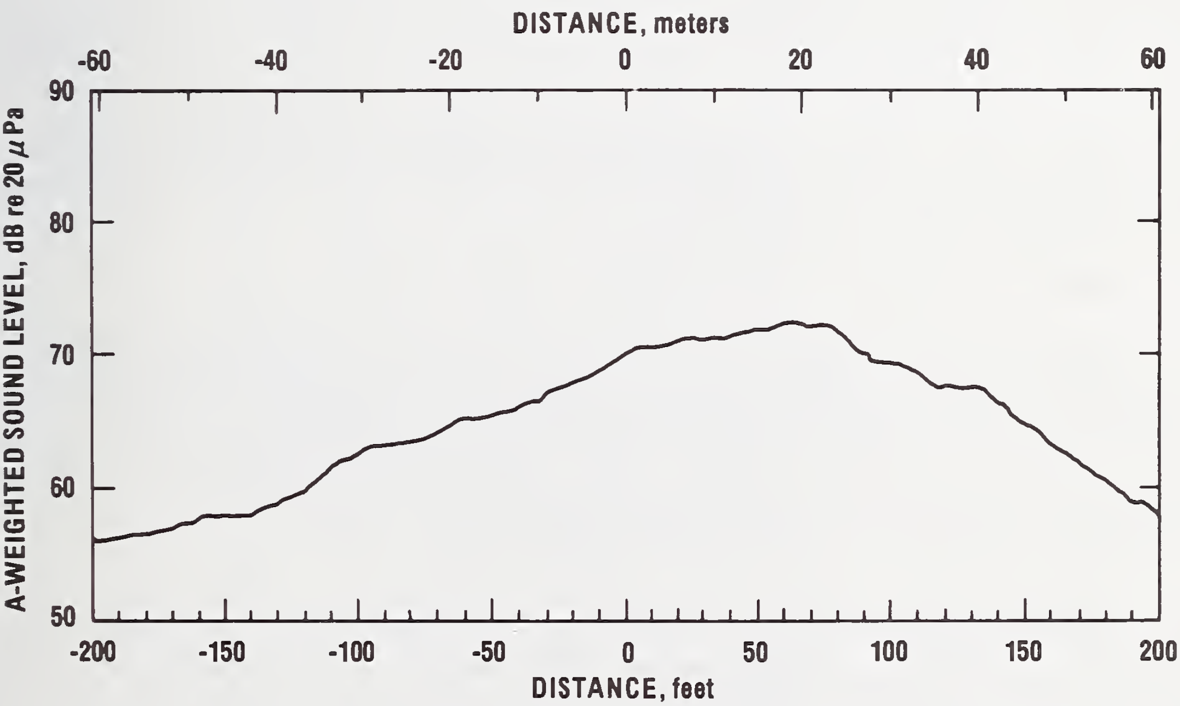


Figure A-6. A-weighted sound level versus distance certification data for tire R3. The zero point corresponds to the passage of the drive axle of the 4 x 2 single-chassis vehicle by the microphone.

The loading for the 6 x 4 tractor with double-axle trailer is given in Table 3. Since the axle loadings are different, a separate load correction is calculated for each axle. The axle loadings, load difference [certification loading of 18,080 pounds per axle (8201 kg per axle) minus the in-service load per axle] and load corrections determined from Figure A-1 are summarized in Table A-1. Also presented in Table A-1 are the total corrections [combination of speed and load corrections] which are applied to the tire noise certification data for each axle.

d. Adjusted A-weighted sound level versus distance certification data

The speed and load corrections are uniformly applied to the certification data for each axle by shifting the entire A-weighted sound level versus distance curve vertically up or down by an amount corresponding to the total correction. The adjusted certification data for each axle are then replotted using the same scale for distance on the abscissa of each plot so that the data can be easily combined as described in the next step. These four plots are not shown here because the distance scales -- determined by vehicle speed -- are approximately the same for tire E and tire R3 certification data as shown in Figures A-5 and A-6.

e. Combination of certification data for all axles

The certification data for the four axles are combined by plotting the A-weighted sound level versus distance data on the same graph with the appropriate shifts to account for the spatial separations of the axles. Using the front drive axle centerline as the reference or zero point, the shifts for the other axles are: -4.2 feet (-1.3 m) for the rear drive axle; -33.0 feet (-10.1 m) for the front axle of the trailer; and -37.3 feet (-11.4 m) for the rear axle of the trailer. For the powered passby case, the engine shift is +12 feet (+3.7 m). The combinations of the adjusted certification data using the appropriate shifts are shown in Figures A-7 and A-8 for the coastby and powered passby cases, respectively.

f. Predicted A-weighted sound levels

The predicted A-weighted sound levels are determined by combining the A-weighted levels for each of the four axles (and the engine for powered passbys) at various points along the passby. For example, in Figure A-7 the levels at +50 feet (15.2 m) are 84.0 and 82.7 dB for the drive axles and 72.4 and 71.6 dB for the trailer axles. These levels combine to give a predicted A-weighted sound level of 86.7 dB. The predicted A-weighted sound level versus distance data are plotted in Figures A-7 and A-8.

The data measured for an actual passby of the 6 x 4 tractor with double-axle trailer were also plotted using a graphic level recorder. These data [adjusted to 55 mph (88.5 km/hr) using Equation 1] are compared with the predicted A-weighted sound levels in Figure A-9. These predicted levels agree well with the measured data especially considering the graphical technique used.

Table A-1. Speed and load corrections to be applied to tire noise certification data.

Axle Position	Tire	Axle Load, pounds (kg)	Load Difference, pounds (kg)	A-weighted Load Correction, dB re 20 μPa	Certification Test Vehicle Speed mph (km/hr)	A-weighted Speed Correction to 55 mph (88.5 km/hr), dB re 20 μPa	Total A-weighted Correction (Speed + Load), dB re 20 μPa
Front Drive Axle	E	15320 (6949)	2760 (1252)	-1.7	50.9 (81.9)	+1.4	-0.3
Rear Drive Axle	E	16550 (7507)	1530 (694)	-0.9	50.9 (81.9)	+1.4	+0.5
Front Axle of Trailer	R3	15400 (6985)	2680 (1216)	+0.2	50.4 (81.1)	+1.5	+1.7
Rear Axle of Trailer	R3	17360 (7874)	720 (327)	+0.1	50.4 (81.1)	+1.5	+1.6

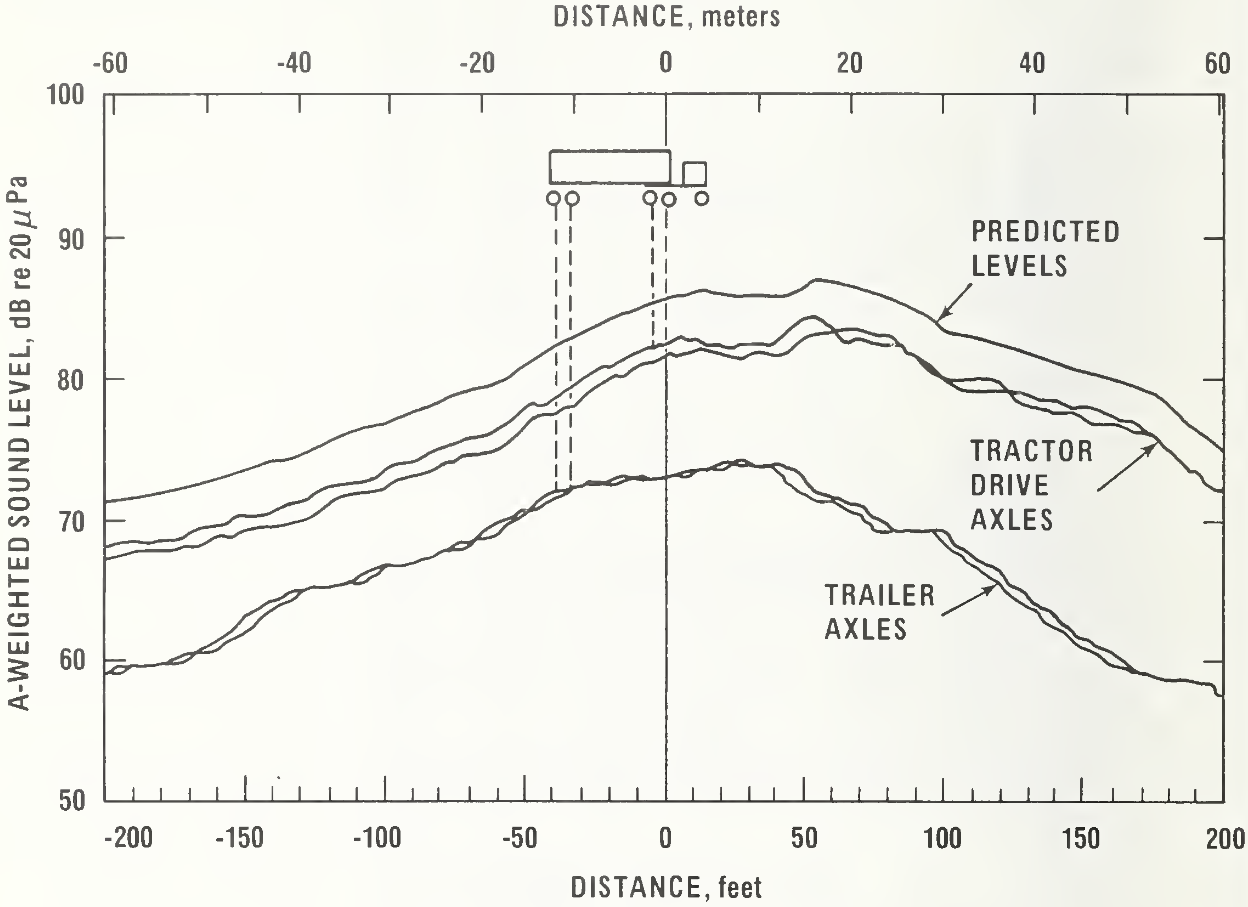


Figure A-7. Predicted A-weighted sound level versus distance data at 50 feet (15.2 m) for the passby of the 6 x 4 tractor with double-axle trailer at 55 mph (88.5 km/hr) in the coast mode.

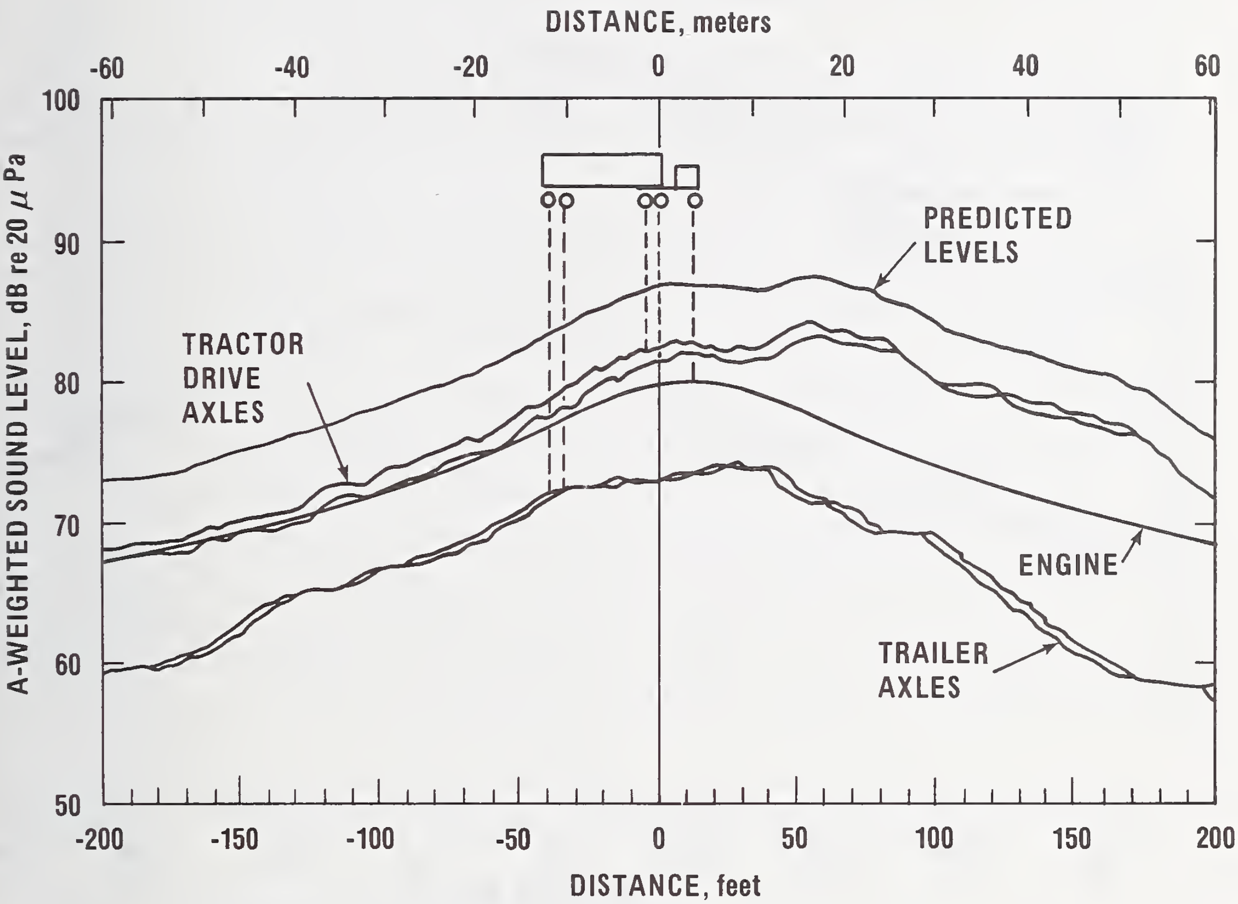


Figure A-8. Predicted A-weighted sound level versus distance data at 50 feet (15.2 m) for the passby of the 6 x 4 tractor with double-axle trailer at 55 mph (88.5 km/hr) in the power mode.

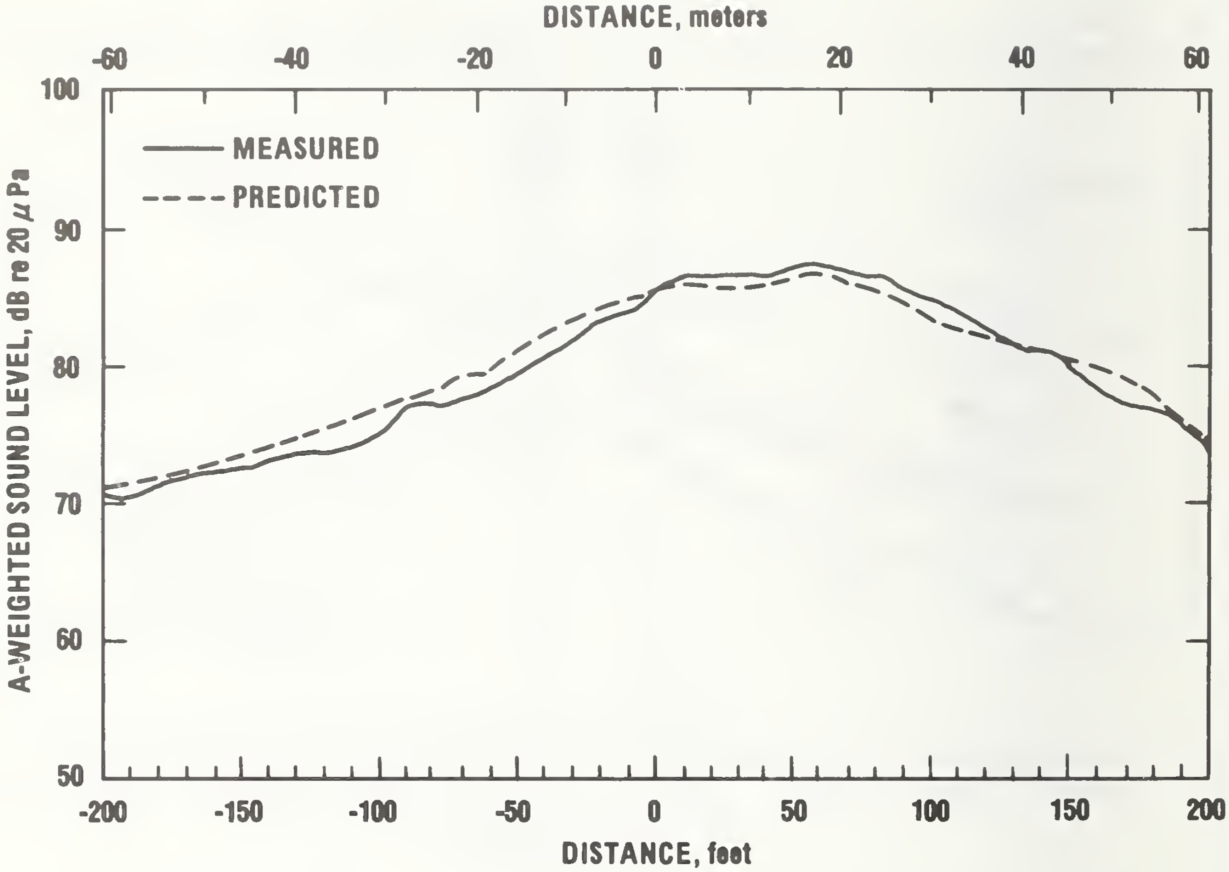


Figure A-9. Comparison of predicted and measured A-weighted sound level versus distance data at 50 feet (15.2 m) for the passby of the 6 x 4 tractor with double-axle trailer at 55 mph (88.5 km/hr) in the coast mode. Measured data were corrected to 55 mph (88.5 km/hr) using Equation 1.

7. Appendix B. SAE Standard for Measurement of Truck Tire Noise[17/]

SOUND LEVEL OF HIGHWAY TRUCK TIRES—SAE J57

SAE Recommended Practice

Report of Vehicle Sound Level Committee approved July 1973.

1. Introduction—This SAE Recommended Practice establishes a test procedure for measuring the sound level produced by tires intended primarily for highway use on motor trucks, truck tractors, trailers and semitrailers, and buses. The procedure provides for the measurement of the sound generated by a set of test tires, mounted on the rear axle operated at 50 mph (80 km/h) and at maximum rated tire load.

Specifications for the instrumentation, the test site, and the operation of the test vehicle are set forth to minimize the effects of extraneous sound sources and to define the basis of reported levels.

Reference to sound levels is given in the Appendix.

2. Instrumentation—The following instrumentation shall be used for the measurements as required:

2.1 A sound level meter which satisfies the Type 1 requirements of ANSI S1.4-1971, Specification for Sound Level Meters.

2.1.1 As an alternative to making direct measurements using a sound level meter, a microphone or sound level meter may be used with a magnetic tape recorder and/or a graphic level recorder or indicating meter, providing the system meets the requirements of SAE J184, with "slow" response specified in place of "fast" as applicable in paragraph 3.6 therein.

2.2 An acoustical calibrator for establishing the calibration of the sound level meter and associated instrumentation.

2.3 An anemometer.

3. Test Site

3.1 The test site shall be located on a flat area which is free of reflecting surfaces (other than the ground), such as parked vehicles, trees, or buildings within 100 ft (30 m) of the measurement area.

3.2 The vehicle path shall be relatively smooth, semipolished, dry, Portland concrete which is free of extraneous surface material.

3.3 The microphone shall be located 50 ft (15 m) from the centerline of the vehicle path at a height of 4 ft (1.2 m) above the ground plane. The normal to the vehicle path from the microphone shall establish the microphone point on the vehicle path. See Fig. 1.

3.4 The test zone extends 50 ft (15 m) on either side of the microphone point along the vehicle path. The measurement area is the triangular area formed by the point of entrance into the test zone, point of exit from the test zone, and the microphone.

3.5 The measurement area should be surfaced with concrete, asphalt, or similar hard material and, in any event, shall be free of powdery snow, grass, loose soil, ashes, or other sound-absorbing materials.

3.6 The ambient sound level (including wind effects) at the test site shall be at least 10 dB below the level of the test vehicle operated in accordance with the test procedure.

3.7 The wind speed in the measurement area shall be less than 12 mph (19 km/h).

4. Test Vehicle

4.1 The vehicle shall be a motor truck equipped with two axles (a nonpowered steering axle and a powered axle).

4.2 The vehicle shall have a platform, rack, or van body capable of retaining the loading or ballast. This body shall have an essentially flat and horizontal undersurface, and be mounted such that this surface has a 5 ±1 in (127 ±25 mm) minimum clearance with the tire fully loaded. This body shall be nominally 96 in (2440 mm) in width and extend a minimum of 36 in (910 mm) rearward of the rear (powered) axle centerline.

4.3 Mud flaps should be removed at the test site, if permissible.

5. Tires

5.1 Tires used for dual installations shall be dual mounted (four tires) on the rear axle for testing. Tires used in single installations (wide base) shall be mounted singly. A tire used as both duals and singles may require test at both dual and single mounting. The sound level reported must be identified as to type of mounting.

5.2 The tires shall be inflated to the maximum pressure and loaded to the maximum load specified by the Tire and Rim Association for continuous operation at highway speeds exceeding 50 mph (80 km/h).

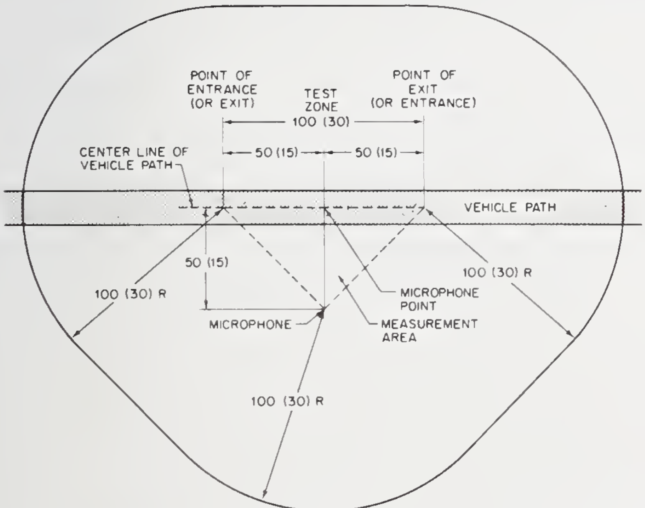
5.2.1 If local load limits will not permit full rated load, the test may be conducted at the local load limit with inflation pressure reduced to provide a tire deflection equal to the maximum load and inflation pressure, provided the load is not less than 75% of the maximum rated load.

As an alternative, the pressure in the tires can be adjusted to correspond to the actual load following the appropriate load/pressure tables in the Tire and Rim Association Yearbook. Because the choice of procedure may cause small differences in level, such levels may not be reported as absolute unless they are identified with the percent load used.

5.3 Quiet tires are recommended for use on the front axle.

6. Procedure

6.1 The test vehicle shall be operated in such a manner (such as coasting) that the sound level due to the engine and other mechanical



NOTE DIMENSIONS ARE FT (m)

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

sources is minimized throughout the test zone. The vehicle speed at the microphone point shall be 50 mph (80 km/h).

6.2 The sound level meter shall be set for "slow" response and the A-weighting network. The observer shall record the highest level attained during each pass of the test vehicle, excluding readings where known acoustical interferences have occurred.

6.2.1 Alternatively, each pass of the test vehicle may be recorded on magnetic tape and subsequently analyzed with a sound level meter and/or graphic level recorder.

6.3 There shall be at least three measurements. The number of measurements shall equal or exceed the range in decibels of the levels obtained.

6.4 The sound level reported shall be the average of the two highest readings which are within 2 dB of each other.

7. General Comments

7.1 It is recommended that technically competent personnel select the equipment to be used for the test measurements and that these tests be conducted only by persons familiar with the current techniques of sound measurement.

7.2 All instrumentation should be operated according to the practices recommended in the operating manuals or other literature provided by the manufacturer. All stated precautions should be observed Some specific items for consideration are:

7.2.1 Specifications for orientation of the microphone relative to the ground plane and the source of sound should be adhered to. (Assume that the sound source is located at the microphone point.)

7.2.2 Proper signal levels, terminating impedances, and cable lengths should be maintained on all multi-instrument measurement systems.

7.2.3 The effect of extension cables and other components should be taken into account in the calibration procedure.

7.2.4 The position of the observer relative to the microphone should be as recommended.

7.3 Instrument manufacturer's recommended calibration procedure and schedule for individual instruments should be employed. Field calibrations should be made immediately before and after testing each set of tires.

7.4 Not more than one person, other than the observer reading the meter, shall be within 50 ft (15 m) of the vehicle path or the microphone, and that person shall be directly behind the observer reading the meter, on a line through the microphone and the observer.

7.5 The sound level of the tires being tested is valid only when the sound level of the vehicle equipped with quiet tires is at least 10 dB below that of the vehicle equipped with test tires. The sound levels obtained with this procedure may be used for a relative ranking of the test tires, if the sound level of the vehicle equipped with the quietest tires available is 3-10 dB lower than when equipped with the tires being tested.

8. Reference Material—Suggested reference material is as follows:

8.1 ANSI S1.1-1960, Acoustical Terminology

8.2 ANSI S1.2-1962, Physical Measurement of Sound

8.3 ANSI S1-4-1971, Specification for Sound Level Meters

8.4 SAE J184, Qualifying a Sound Data Acquisition System

8.5 Tire and Rim Association Yearbook

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

APPENDIX

A1. An A-weighted sound level exceeding 85 dB, determined in accordance with this recommended practice, is not consistent with present best current practice for cross ribbed tires in normal states of wear. It is general experience that the sound level of unworn tires is significantly less than that of worn tires.

A2. Road surfaces are known to significantly affect the sound level exhibited by truck tires. The vehicle path surface specified herein is not sufficiently defined to eliminate variations in sound level due to surface (see paragraph 3.2).

A3. Persistence of tire sounds after the passage of the vehicle and the tonal components of these sounds are properties of certain types of tires which tend to occur concurrently. Both are factors that direct attention to the sound, and are important determinants of the acceptability of the sound.

Insufficient data are available concerning the measurement of the sound from distant truck tires and the significance of these sounds compared to the sound levels measured with this procedure.

8. References

[1] Kibbee, L. C., The Noise Trucks Make - Report of Tests (American Trucking Associations, Inc., Washington, D. C., 1964).

[2] Anon., Truck Tire Noise, Presentation by the Rubber Manufacturers Association to the Office of Noise Abatement and Control, U. S. Environmental Protection Agency, Washington, D. C., November 12, 1971.

[3] Lippmann, S. A., Establishing a Testing Standard for Truck Tire Sounds, published in SAE Report SP-373: Truck Tire Noise (Society of Automotive Engineers, Inc., Warrendale, PA, 1972).

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[5] Anon., Truck Noise-I, Peak A-Weighted Sound Levels Due to Truck Tires, U. S. Department of Transportation Report OST-ONA-71-9 (National Bureau of Standards, Washington, D. C., 1970).

[6] Leasure, Jr., W. A., Corley, D. M., Flynn, D. R., and Forrer, J. S., Addendum to Truck Noise-I, Peak A-Weighted Sound Levels Due to Truck Tires, U. S. Department of Transportation Report OST/TST-72-1 (National Bureau of Standards, Washington, D. C., 1974).

[7] Society of Automotive Engineers, Inc., J57 - Sound Level of Highway Truck Tires, SAE Recommended Practice (Society of Automotive Engineers, Inc., Warrendale, PA, 1973).

[8] American Society for Testing and Materials, D 2240-75, Standard Method of Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer in Part 37, Book of ASTM Standards, 1975 (ASTM, Philadelphia, PA).

[9] Leasure, Jr., W. A., Mathews, D. E., and Rinkinen, W. J., Truck Noise 1-A: Noise Evaluation Tests of Military Truck Tires, U. S. Department of Transportation Report DOT-TST-74-21 (National Bureau of Standards, Washington, D. C., 1974).

[10] Close, W. H., Should There Be Truck Tire Noise Regulations?, S)V Sound and Vibration 9 (2), 24-27 (1975).

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