NBSIR 79-1750(R)

Investigation of the Noise Generated by "Quiet" Design Bias-Ply and Radial Truck Tires With Cross-Bar Tread Patterns

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*
Jordan J. Baruch, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Conversion Table to SI Units

This publication uses customary English units for the convenience of engineers and others who use them habitually. The table below is for the reader interested in conversion to SI units. For additional information see:

(1) NBS LC1056, November, 1977, "NBS Guidelines for Use of the Metric System."

(2) NBS SP330, August, 1977 "The International System of Units (SI)."

Quantity	To convert from	To	Multiply by
Length	inch	m (meter)	2.540×10^{-2}
	foot	m	3.048×10^{-1}
	mile	m	1.609×10^{3}
Area	in^2	m^2	6.452×10^{-4}
	ft^2	m^2	9.290×10^{-2}
Volume	in^3	m^3	1.639×10^{-5}
	ft^3	m^3	2.832×10^{-2}
	gallon	m^3	3.785×10^{-3}
Temperature	° F	° C	$t_{°C} = (t_{°F} - 32)/1.8$
T. difference	$\Delta t_{°F}$	K	$\Delta T_K = \Delta t_{°F}/1.8$
Mass	pound	kg	4.536×10^{-1}
	ounce	kg	2.835×10^{-2}
Pressure	psi	Pa	6.895×10^{3}
	in H_2O	Pa	2.488×10^{2}
	in Hg	Pa	3.386×10^{3}
	mmHg	Pa	1.333×10^{2}
Energy	Btu	J	1.055×10^{3}
	MBtu	J	1.055×10^{9}
	kWh	J	3.600×10^{6}
	ft • lbf	J	1.356×10^{0}
	kilocalorie	J	4.187×10^{3}
Power	Btu/h	W	2.931×10^{-1}
	hp	W	7.457×10^{2}
Flow	gal/min	m^3/s	6.309×10^{-5}
	ft^3/min	m^3/s	4.719×10^{-4}
Density	lb/ft^3	kg/m^3	1.602×10^{1}
	lb/gal	kg/m^3	1.198×10^{2}
Heat Capacity	Btu/(lb • ° F)	J/(kg • K)	4.187×10^{3}
	Btu/(ft^3 • ° F)	J/(m^3 • K)	6.707×10^{4}

Abstract

Recent advances in the development of heavy duty truck tires has lead to the introduction of "quiet" design bias-ply cross-bar tires, as well as radial tires with cross-bar tread patterns. To adequately assess the noise/safety/economic tradeoffs, acoustic data on a representative sample of these newer tire designs are essential. This report presents acoustic data measured at 50 feet for one type of new "quiet" design bias-ply and seven types of radial cross-bar tires (both new and worn) for coastbys at 50 mph on three pavement surfaces--asphalt, concrete and Jennite. In general, the data show that these newer tire designs generate lower sound levels than conventional bias-ply cross-bar truck tires. The differences in sound level between these newer designs and conventional bias-ply cross-bars vary widely and are a function of the individual tire and state of tread wear. These data show that the sound level is dependent on pavement surface with a rank ordering of asphalt (the lowest sound levels), concrete and Jennite. Also, it is shown for the radial cross-bar tires that, depending upon the particular tire, the sound level increases with tread wear from 0.8 to 9.0 dB on the asphalt and concrete pavements.

1. INTRODUCTION

Operational noise emission standards are presently in effect for interstate motor carriers. Point-of-sale noise standards for medium and heavy duty trucks have been promulgated and became effective January 1, 1978. Although noise control technology has been developed and demonstrated to be feasible for most of the engine-related noise sources on trucks, control of tire noise, which is predominant at highway speeds, remains an unsolved problem. If community noise levels are to be reduced near highways, tire noise must also be reduced.

Although no more than a superficial understanding of the mechanisms of tire noise generation exists, truck tire noise reductions can be accomplished utilizing current tire technology. Existing data show that, from both a cost and safety point of view, the use of quieter bias-ply or radial rib tires (rather than bias-ply cross-bar tires) provides at least equal and, in general, more advantageous on-highway performance based on current tire use practices [1].[1/] However, "quiet" design bias-ply cross-bar tires, as well as radial tires with cross-bar tread patterns, are becoming commercially available. In order to develop the necessary information base to adequately assess the noise/safety/economic tradeoffs, there is a need to acquire acoustic data on a representative sample of these newer tire designs.

The objective of this program is to determine the characteristic noise levels generated by a sample of these newly designed bias-ply and radial cross-bar truck tires. This report presents the results of coastby noise measurements for one type of new "quiet" design bias-ply and seven types of radial cross-bar tires (both new and worn). Section 2 contains a description of the field test site, test equipment and measurement procedures. The results of these measurements are discussed in Section 3 and compared to data obtained previously for older design, conventional bias-ply cross-bar truck tires.

2. FIELD TEST PROGRAM

The operational procedures and measurement/analysis instrumentation utilized in this study were similar to that used in previous DOT/NBS truck tire noise studies [2, 3]. In the following sections detailed descriptions are provided for the field test site utilized for data acquisition, the test tires, vehicle configuration and the operational test procedures.

2.1 Field Test Site

The research runway of the Texas Transportation Institute (TTI) located at the Texas A&M Research Annex, Bryan, Texas, was selected as the test site

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

for the data acquisition phase of the program. The layout of this test site, located on property previously used as a jet-trainer airfield, is shown in Figure 1. The tests were conducted on specially constructed pads. These pads are located on runway B which is 150 feet wide and 7000 feet long. An overall view of runway B showing two of the test pads can be seen in Figure 2. The test pads consist of eight different pavements representing a broad range of surface textures. These test pads, originally designed for skid resistance research, are 24 feet wide and 600 feet long with a cross slope of about 1/8 inch per foot. A detailed layout of the eight test pads as constructed on runway B is shown in Figure 3.

Tests were conducted on three of the eight pavement surfaces -- Portland cement concrete, Jennite[2/] flush seal and the light-weight aggregate hot mix (asphalt). These are test pads 1, 2 and 8, respectively. The characteristics of each pad in terms of the materials used and the techniques of surface finish or coating are discussed in detail in reference [2] and summarized here in Tables 1, 2 and 3.

2.2 Test Tires

A total of 16 sets of tires were tested. These tires were loaned to the government for this project by Garrett Freight Lines, Inc. and the Kelly-Springfield Tire Company. These included one set of new "quiet" design bias-ply cross-bar tires, 14 sets of radial cross-bar tires (new and worn sets for seven different types) and one set of blank tires (full tread depth but no tread pattern). The characteristic tread patterns for these tires are shown in Figure 5 and the average tread depth[3/] and Shore hardness[4/] are given in Table 4.

2/ Jennite is a commercially available clay-filled tar emulsion manufactured by the Jennite Company, Houston, Texas. This material and all other commercial products mentioned in this report are identified in order to adequately describe the tests conducted in this program. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that these products were necessarily the best available for the purpose.

3/ Tread depth measurements were taken at four equally spaced locations around the tire circumference using a dial indicator. The operator positioned the displacement rod on a major groove (not over sipes or other small grooves), depressed the dial indicator until the base contacted the tread surface, and noted the tread depth directly from the instrument.

4/ The Shore hardness of the tread rubber was determined by ASTM test method D2240-68 [5]. 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.

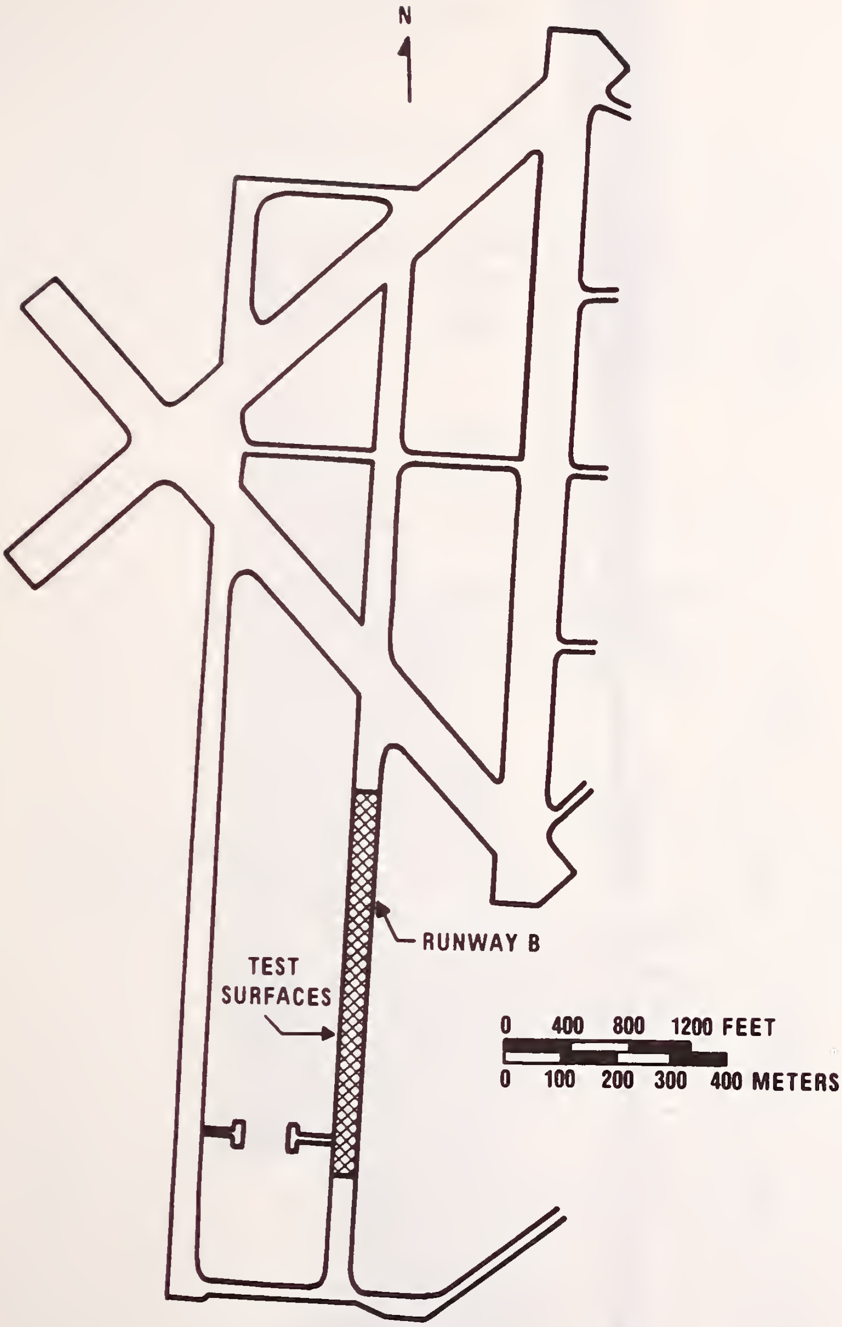


Figure 1. Plan of Texas A&M Research Annex, Bryan, Texas, showing the locations of the pavement test pads.

Figure 2. Overall view of runway B showing the Jennite and concrete test pads.

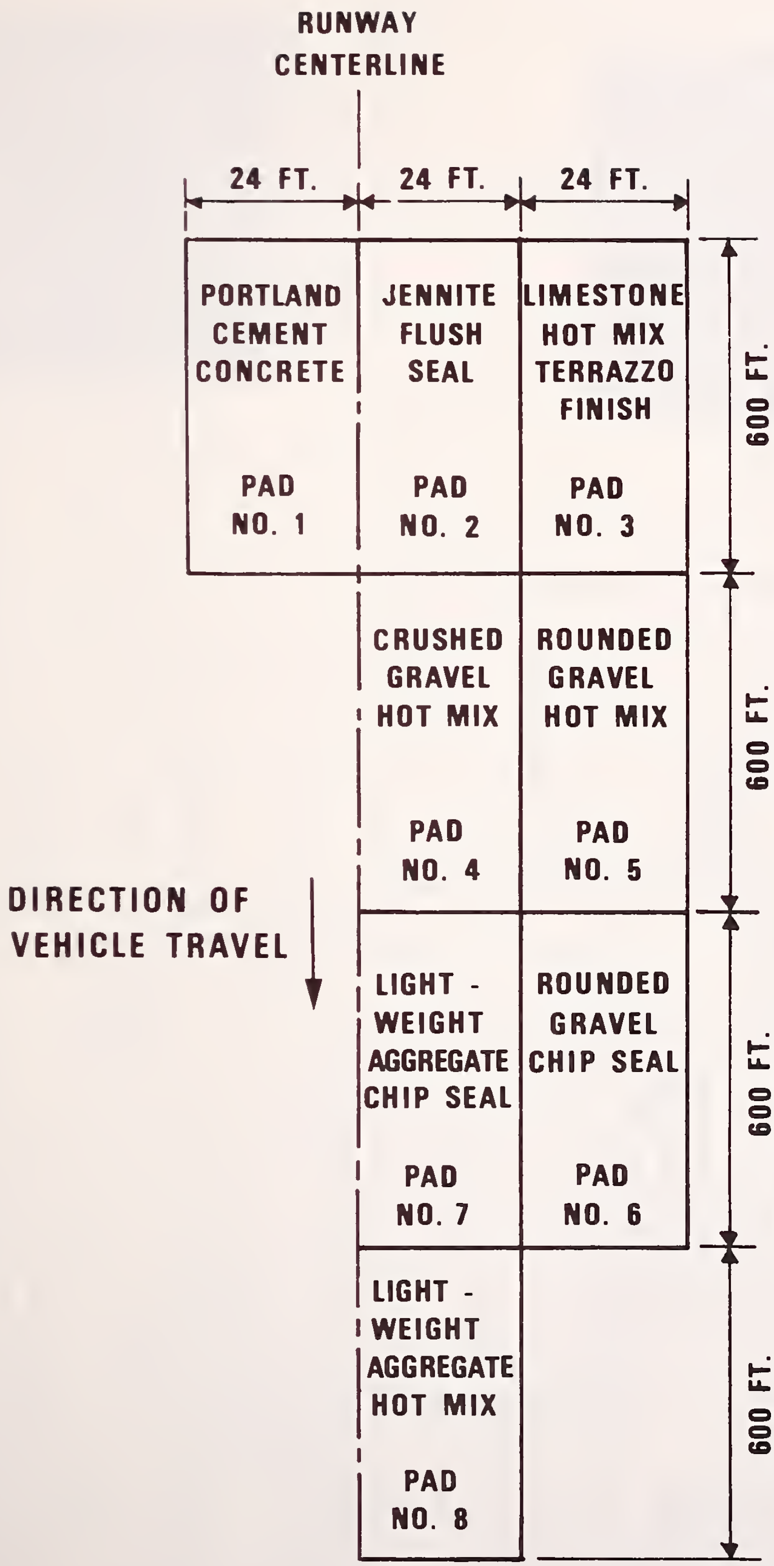


Figure 3. Plan of test pads on runway B.

Table 1. Summary description of Pad 1: Portland cement concrete

Surface Preparation		Aggregate				
Construction	Finish	Weight Percent	Type	Max. Size, in	Construction Date	Average Texture Depth,** in
Rounded siliceous gravel Portland cement concrete	Belt drag, cleaned with high pressure spray and rotary broom and water	67	Rounded siliceous gravel	1.5	1973	0.039
		33	Siliceous sand			

**Average texture depth was obtained by the putty impression method [4].

Surface Details of Pad 1. Scale 1:1.

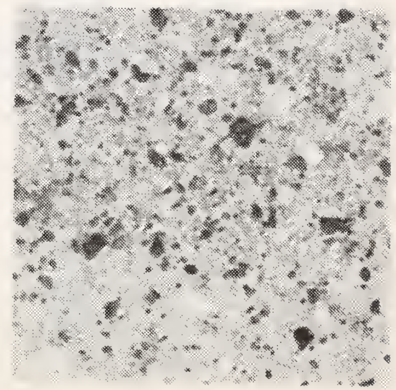


Table 2. Summary description of Pad 2: asphaltic concrete with Jennite flush seal.

Surface Preparation		Aggregate				
Construction	Finish	Weight Percent	Type	Max. Size, in	Construction Date	Average Texture Depth,** in
Asphaltic concrete (6.5% asphalt)	4 coats of clay filled tar emulsion (Jennite) flush seal		No aggregate †		1968	0.005

**Average texture depth was obtained by the putty impression method [4].

†A 3/16 inch maximum sieve size mix composed of slag and limestone screenings was used as a base for the seal (see Figure 4).

Surface Details of Pad 2. Scale 1:1.

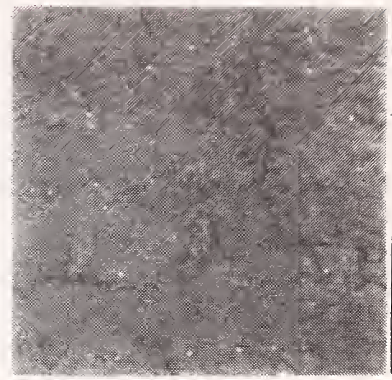


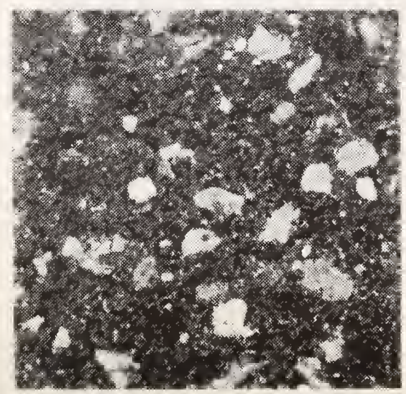
Table 3. Summary description of Pad 8: lightweight aggregate hot-mix asphaltic concrete.

Surface Preparation		Aggregate *				
Construction	Finish	Weight Percent	Type	Max. Size, in	Construction Date	Average Texture Depth,** in
Synthetic lightweight aggregate hot-mix asphalt concrete (8.5% asphalt)	Scrubbed with detergent, water and broom, followed by polishing using sponge rubber float with water and fine sand	40	Lightweight aggregate (fired clay)	0.5	1970	0.022
		40	Lignite boiler slag aggregate			
		20	Siliceous field sand			

*For the distribution of particle size of the aggregate used in this pad, see Figure 4.

**Average texture depth was obtained by the putty impression method [4].

Surface Details of Pad 8. Scale 1:1.



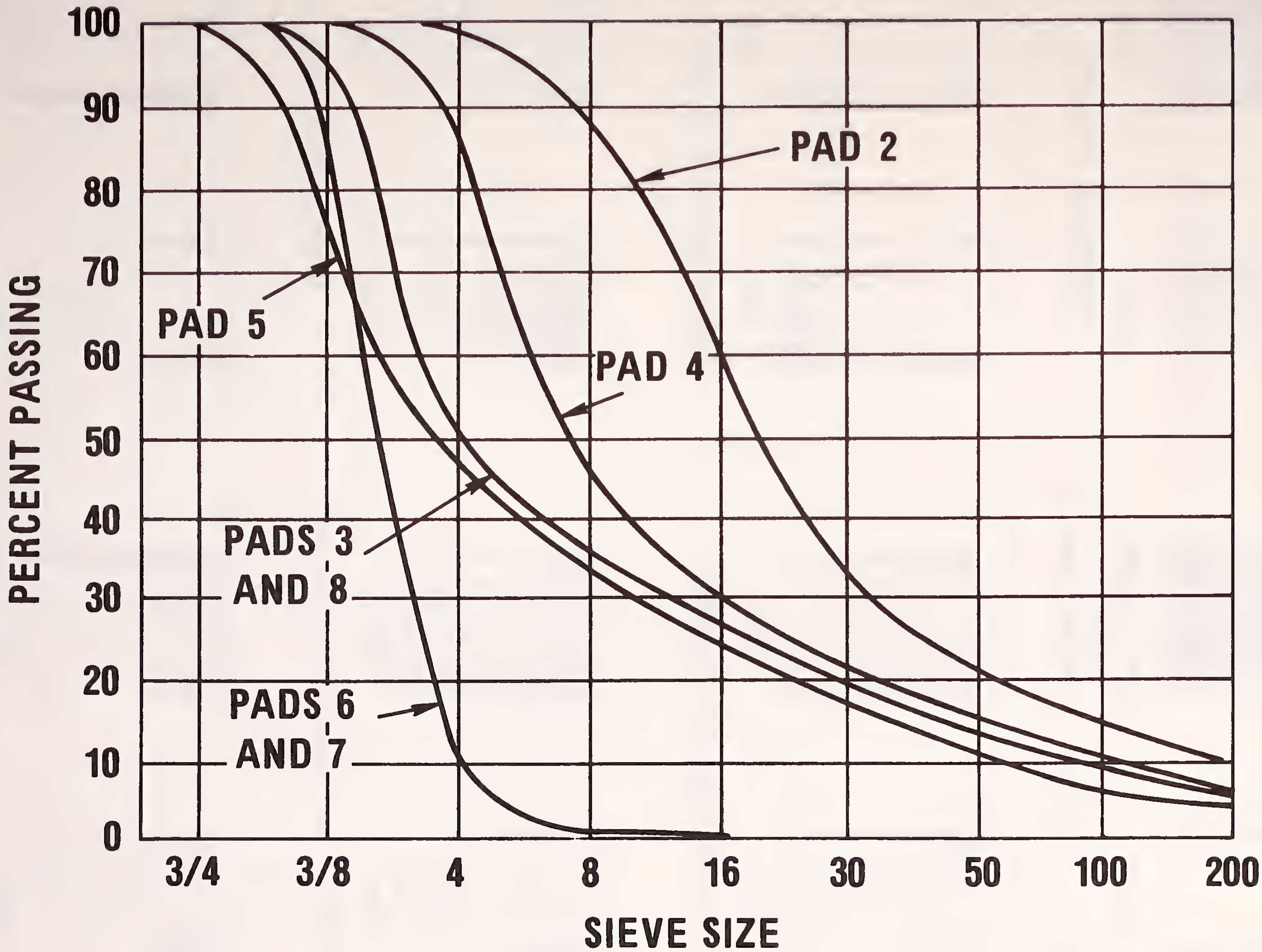


Figure 4. Aggregate grading for TTI skid pads.

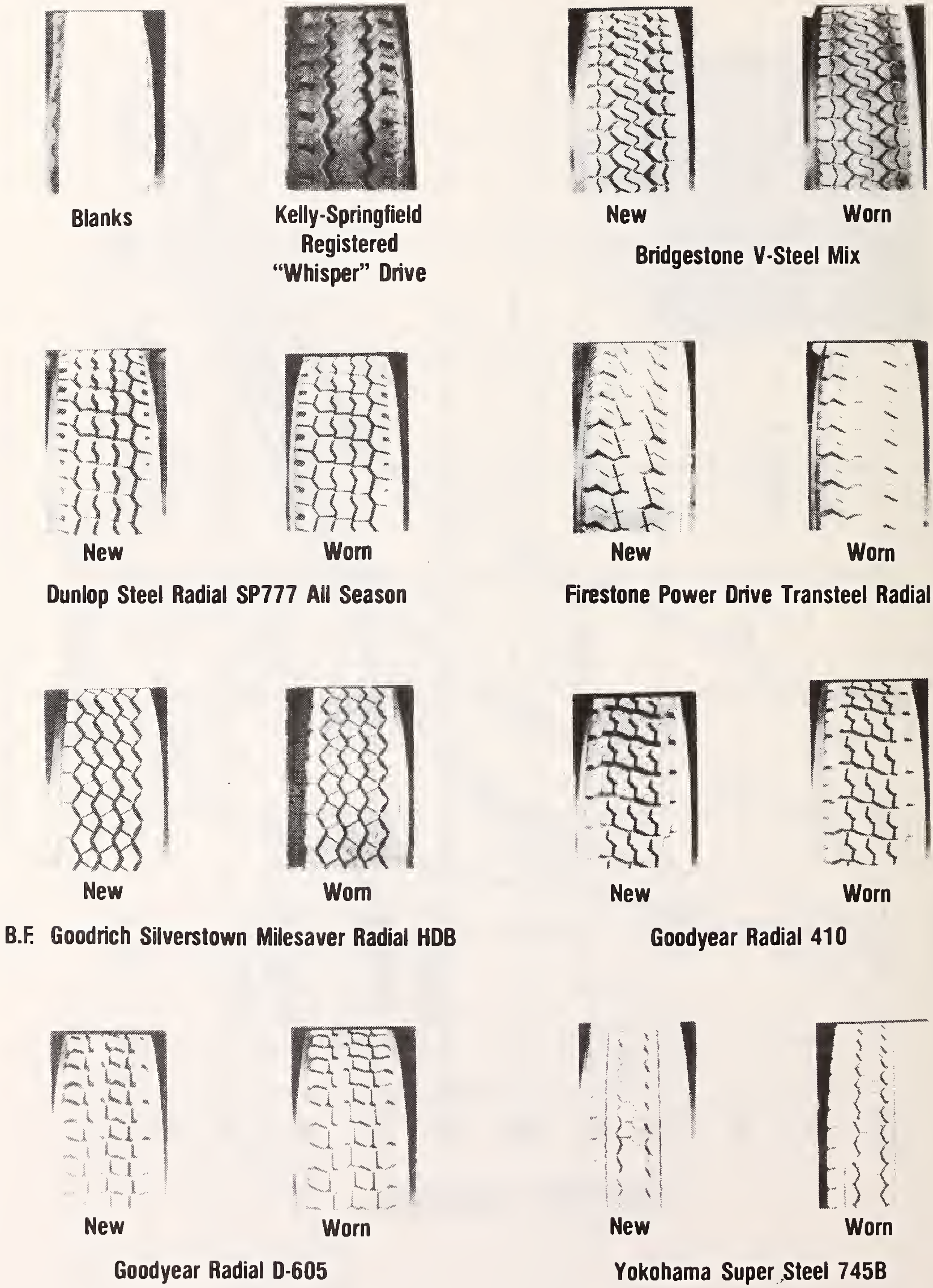


Figure 5. Characteristic tread element patterns for the 16 sets of test tires.

Table 4. Average tread depth, Shore hardness and load rating for the 16 sets of test tires.

TEST TIRE	CARCASS CONSTRUCTION	LOAD RATING	STATE OF WEAR	AVERAGE TREAD DEPTH, in	AVERAGE SHORE HARDNESS
Bridgestone V-Steel Mix	radial	G	new worn	0.642 0.294	66 65
Dunlop Steel Radial SP777 All Season	radial	H	new worn	0.628 0.365	65 66
Firestone Power Drive Transteel Radial	radial	G	new worn	0.685 0.256	62 65
B. F. Goodrich Silvertown Milesaver Radial HDB	radial	G	new worn	0.526 0.328	66 61
Goodyear Radial 410	radial	G	new worn	0.676 0.251	69 63
Goodyear Radial D-605	radial	G	new worn	0.675 0.339	65 65
Yokohama Super Steel 745B	radial	H	new worn	0.614 0.256	64 63
Kelly-Springfield Registered "Whisper" Drive	bias-ply	F	new	0.779	65
Blanks	bias-ply	F	new	---	67

The test tires were all size 11.00-24.5. The load ratings were "F" for the blanks and bias-ply tires and either "G" or "H" for the radial tires (see Table 4). All tests were conducted using the maximum inflation pressure and 75 percent of the maximum tire load recommended by the Tire and Rim Association for each load rating [6]. These inflation pressures and loads are listed in Table 5.

The test tires were always mounted on the drive axle of the test vehicle. Blank tires, which had a characteristic tire noise level that was as low as or lower than that of the test tires, were mounted on the steering axle. For each set of tires, the vehicle was run for a minimum of five miles to allow the tires to warm up. Immediately following this, the acoustic measurement test runs were made.

2.3 Test Vehicle

The test vehicle utilized in this study was a General Motors Corporation Model 6500 4 x 2 [5/] single-chassis flat-bed truck with a conventional cab. This vehicle was equipped with 10-hole Budd wheels, 366 CID gasoline engine, 5-speed transmission and 2-speed axle. All tests were run in a coastby mode (with the engine shut-off) at a nominal speed of 50 mph. The vehicle was loaded according to the particular tire being tested (see Table 5). An overall view of the vehicle is shown in Figure 6.

2.4 Test Procedures

The test procedures utilized were essentially identical to those specified in SAE J57a -- Sound Level of Highway Truck Tires [7] [6/]. The two exceptions were that the distance between the point of entrance and point of exit of the test section was 600 feet and that "fast" response was utilized for data analysis.

The components of the data acquisition and recording instrumentation, plus the automatic tape recorder control and elapsed time system utilized, are shown in Figure 7.

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.

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.

6/ The complete text of SAE J57a is reproduced in Appendix A.

Table 5. Load and inflation pressure conditions for the three tire load ratings.

TIRE LOAD RATING	LOAD, lb			Load Per Test Tire		COLD INFLATION PRESSURE, psi	
	Total Gross Vehicle Weight	Steering Axle	Drive Axle	Actual	75% of T&RA Recommendation	Bias-Ply	Radial
F	23,180	7,740	15,440	3,860	3,803	75	---
G	24,900	7,920	16,980	4,245	4,230	--	95
H	25,920	7,460	18,460	4,615	4,628	--	110

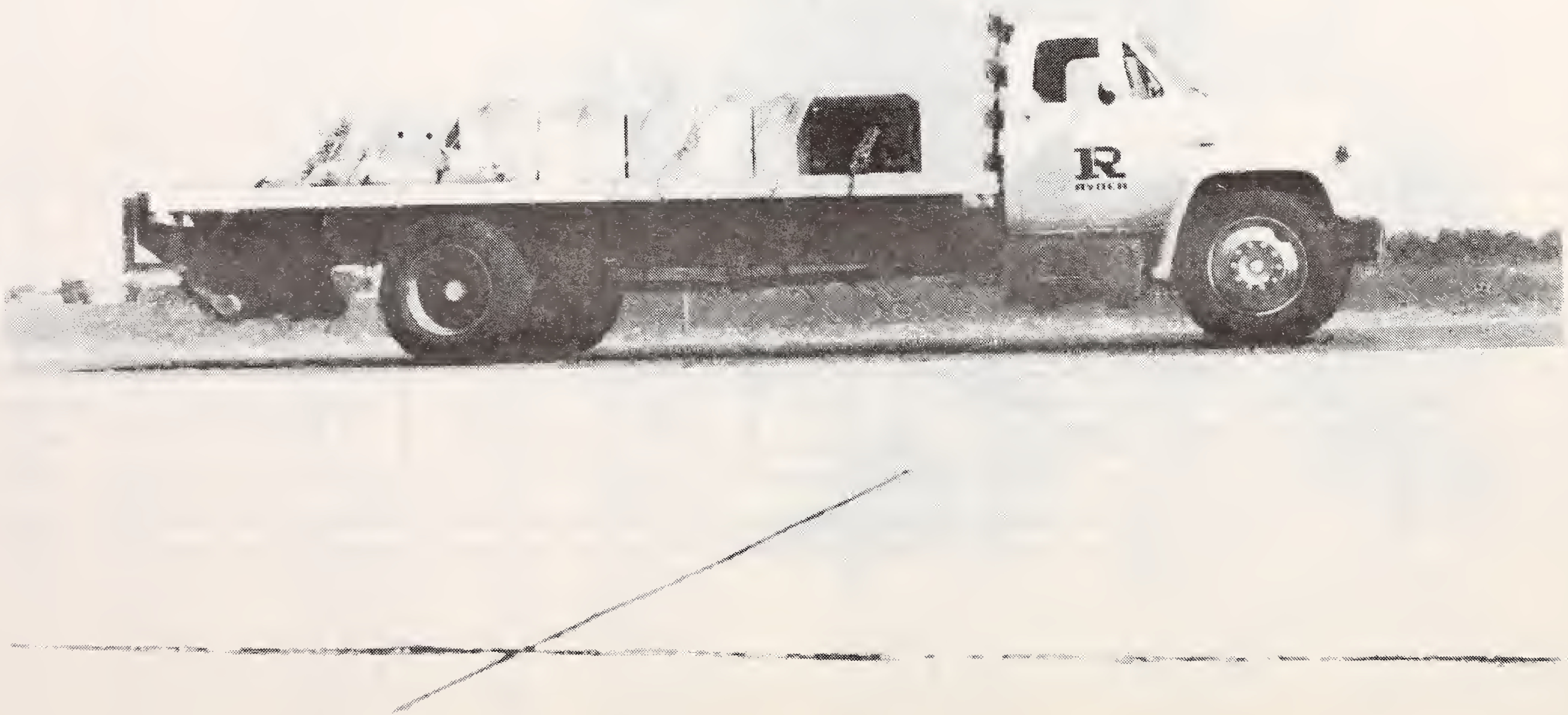


Figure 6. View of the 4x2 single-chassis flat-bed truck used as the test vehicle.

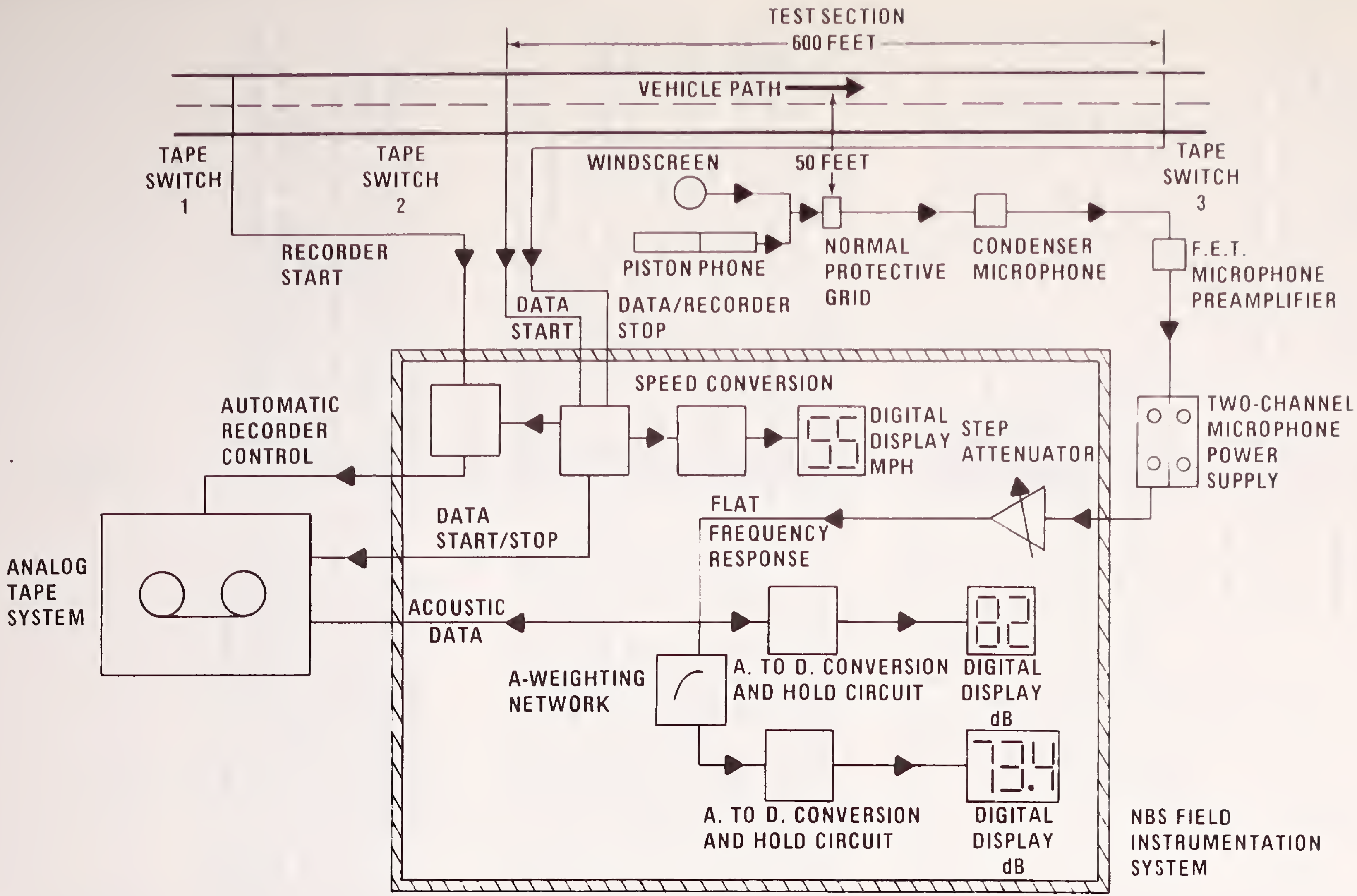


Figure 7. Data acquisition and recording instrumentation, plus automatic tape recorder control and elapsed time system.

The acoustic measurement system consisted of a 1/2-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 recorder 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 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 hand-held rotating vane anemometer was used to measure wind speed. No measurements were made for wind speeds greater than 12 mph. A single point calibration utilizing a pistonphone which produces a 124 dB sound pressure level (re 20 μPa) at a frequency of 250 Hz was used for system calibration in the field. Figure 8 shows the microphone location and associated instrumentation in the field at the TTI test site.

Once the data had been recorded, the analog tapes were returned to the National Bureau of Standards for reduction and analysis. Figure 9 identifies the equipment which was utilized for analysis purposes. Each tape was played back through the real-time analyzer. An interface-coupler was necessary to make the real-time analyzer compatible with a minicomputer. When a timing signal appeared on the analog tape, the computer was instructed to start sampling the digital data from the real-time analyzer at a rate of 20 times per second. A time constant of 120 msec, which corresponds to "fast" response [8], was used to obtain the A-weighted sound levels. 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. The results of these tests are discussed in the next section.

3. TEST RESULTS

For this study a minimum of two passbys were made for each test condition. Passbys were repeated until two test runs were obtained with the maximum A-weighted sound levels within 2 dB and the vehicle speeds within 2 mph. The results reported in this section consist of the maximum A-weighted sound levels for each of these coastbys and the arithmetic average of these values. These data, given in Tables 6, 7 and 8, are compared with existing data in Section 3.1. The effects of pavement surface and tread wear on the resultant sound levels are examined in Sections 3.2 and 3.3.

Figure 8. Overall view of the microphone location and 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.

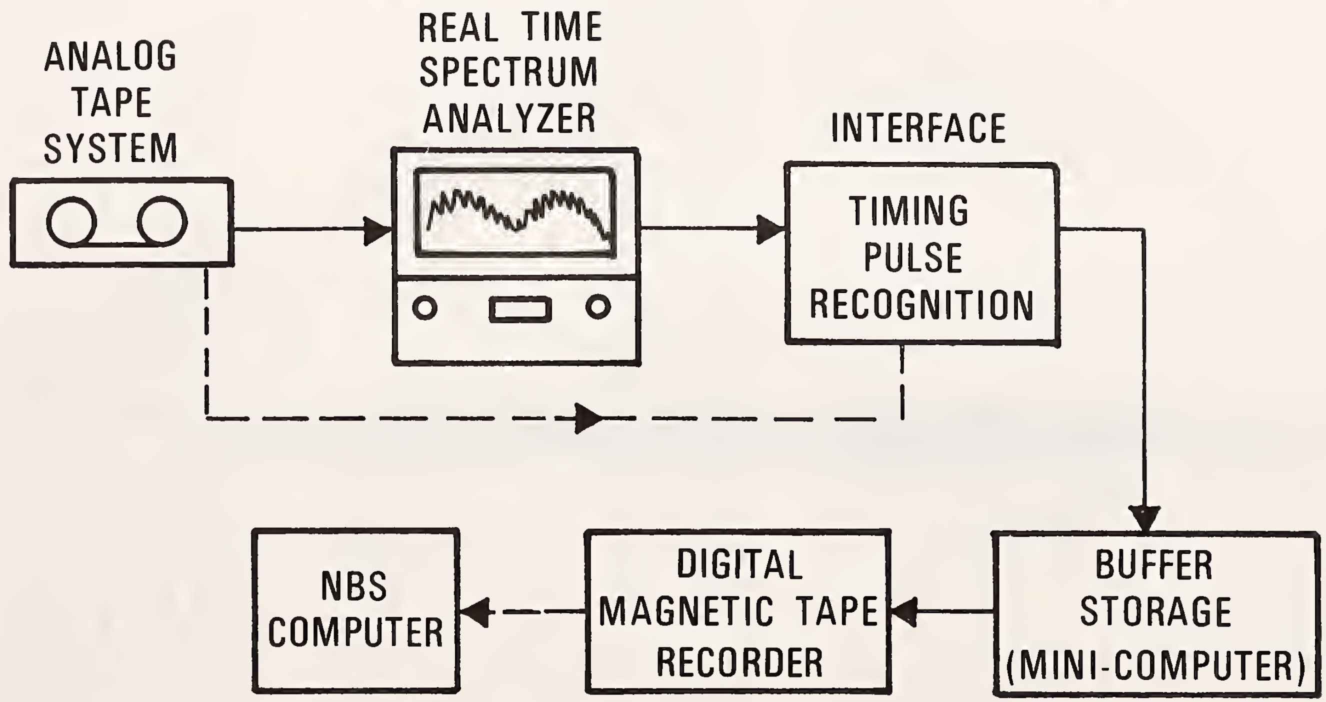


Figure 9. Data reduction and analysis system.

Table 6. Maximum A-weighted sound levels, as measured at 50 feet, for coastbys at a nominal speed of 50 mph over the asphalt test surface. "Fast" meter response was utilized.

TEST TIRE	TREAD DESIGN	STATE OF TREAD WEAR	SPEED, mph	A-WEIGHTED SOUND LEVEL, dB re 20 μPa: Maximum	A-WEIGHTED SOUND LEVEL, dB re 20 μPa: Average of the Two Maximum Values
Blanks	bias-ply	new	50.3 50.4	72.6 72.0	72.3
Kelly-Springfield Registered "Whisper" Drive	bias-ply	new	50.0 50.1	74.6 74.6	74.6
Bridgestone V-Steel Mix	radial	new	49.7 49.3	71.6 72.2	71.9
		worn	49.7 49.9	74.0 74.0	74.0
Dunlop Steel Radial SP777 All Season	radial	new	49.7 50.0	72.4 71.4	71.9
		worn	49.6 49.6	76.8 76.0	76.4
Firestone Power Drive Transteel Radial	radial	new	50.6 50.7	74.2 74.4	74.3
		worn	50.1 50.1	77.2 77.8	77.5
B. F. Goodrich Silvertown Milesaver Radial HDB	radial	new	50.4 50.5	72.4 72.2	72.3
		worn	50.5 50.5	80.2 80.0	80.1
Goodyear Radial 410	radial	new	50.5 50.3	74.0 73.0	73.5
		worn	50.1 50.5	76.6 76.4	76.5
Goodyear Radial D-605	radial	new	49.7 49.6	73.0 74.0	73.5
		worn	50.6 50.6	82.6 82.2	82.4
Yokahama Super Steel 745B	radial	new	50.3 50.6	72.0 72.8	72.4
		worn	50.0 50.1	72.8 73.6	73.2

Table 7. Maximum A-weighted sound levels, as measured at 50 feet, for coastbys at a nominal speed of 50 mph over the concrete test surface. "Fast" meter response was utilized.

TEST TIRE	TREAD DESIGN	STATE OF TREAD WEAR	SPEED, mph	A-WEIGHTED SOUND LEVEL, dB re 20 μPa	
				Maximum	Average of the Two Maximum Values
Blanks	bias-ply	new	50.8 50.4	74.4 74.8	74.6
Kelly-Springfield Registered "Whisper" Drive	bias-ply	new	50.2 50.4	76.4 76.8	76.6
Bridgestone V-Steel Mix	radial	new	50.3 50.2	74.0 74.8	74.4
		worn	50.0 50.1	76.8 76.2	76.5
Dunlop Steel Radial SP777 All Season	radial	new	50.3 50.5	74.0 73.8	73.9
		worn	49.7 50.6	78.8 78.6	78.7
Firestone Power Drive Transteel Radial	radial	new	51.2 50.1	76.2 76.6	76.4
		worn	50.4 50.4	79.0 78.8	78.9
B. F. Goodrich Silvertown Milesaver Radial HDB	radial	new	50.2 50.8	74.2 74.2	74.2
		worn	50.9 50.3	82.0 81.2	81.6
Goodyear Radial 410	radial	new	50.8 50.3	76.2 76.0	76.1
		worn	50.0 50.8	79.6 79.2	79.4
Goodyear Radial D-605	radial	new	50.0 50.5	74.6 74.6	74.6
		worn	50.6 50.3	83.6 83.6	83.6
Yokohama Super Steel 745B	radial	new	50.9 50.8	74.6 75.2	74.9
		worn	50.3 50.2	76.4 76.6	76.5

Table 8. Maximum A-weighted sound levels, as measured at 50 feet, for coastbys at a nominal speed of 50 mph over the Jennite test surface. "Fast" meter response was utilized.

TEST TIRE	TREAD DESIGN	STATE OF TREAD WEAR	SPEED, mph	A-WEIGHTED SOUND LEVEL, dB re 20 μPa	
				Maximum	Average of the Two Maximum Values
Blanks	bias-ply	new	50.4 50.7	75.6 74.8	75.2
Kelly-Springfield Registered "Whisper" Drive	bias-ply	new	51.5 50.6	77.8 77.8	77.8
Bridgestone V-Steel Mix	radial	new	50.6 50.5	75.6 74.8	75.2
		worn	49.8 49.6	80.6 80.2	80.4
Dunlop Steel Radial SP777 All Season	radial	new	50.0 50.6	75.0 75.0	75.0
		worn	49.9 50.1	81.0 80.8	80.9
Firestone Power Drive Transteel Radial	radial	new	49.5 50.3	76.8 77.0	76.9
		worn	49.6 50.5	80.8 80.8	80.8
B. F. Goodrich Silvertown Milesaver Radial HDB	radial	new	50.7 50.6	75.6 75.6	75.6
		worn	50.3 50.6	82.4 82.4	82.4
Goodyear Radial 410	radial	new	50.5 50.5	76.4 76.6	76.5
		worn	50.6 50.5	83.0 81.2	82.1
Goodyear Radial D-605	radial	new	50.7 50.4	75.8 74.8	75.3
		worn	49.9 50.8	86.4 86.4	86.4
Yokohama Super Steel 745B	radial	new	51.3 51.6	75.6 75.8	75.7
		worn	50.6 50.4	78.4 80.0	79.2

3.1 Comparison of Results with Existing Data for Bias-Ply Cross-Bar Tires

Because radial truck tires are relatively new on the U.S. commercial market, the majority of existing data is for bias-ply tires. A summary of the range of maximum A-weighted sound levels for various types of tire construction, taken from references [2, 3, 9-14], is shown in Figure 10. Also shown in Figure 10 are the results from the current study. In this figure, the unshaded portion of each bar represents the range between the upper and lower values of the maximum A-weighted sound level for that type of tire.

For the existing data shown in Figure 10, bias-ply cross-bar tires generate the highest sound levels of the four general types of tires grouped according to carcass construction and tread pattern. Radial ribs, on the other hand, generate the lowest sound levels, with bias-ply ribs and radial cross-bars being about equal and in-between these upper and lower values.

The data from the current study show a marked reduction of sound level (approximately 2-5 dB) for the "quiet" design bias-ply cross-bar when new. Unfortunately, worn tires of the same type were not available for testing. The data for the new radial cross-bars agrees with the existing data, but the interesting aspect is the effect of tread wear. Although the upper limit of the maximum A-weighted sound level is comparable to that for bias-ply cross-bars, the lower limit is substantially less. The bars in Figure 10 for the tires in the current study include data for all three types of pavement surface. If the data for the Jennite surface are excluded [7/], the upper limits drop to the dashed lines shown in each bar. This reduces the upper limit by approximately 3 dB for the worn radial cross-bars, which indicates that as a group they generate lower sound levels than bias-ply cross-bar tires.

As indicated by the large range between the upper and lower values of the maximum A-weighted sound levels, there are differences between the individual types of tires tested in this current study. These differences are shown in Figure 11. As in Figure 10, the unshaded portion of each bar represents the range between the upper and lower limits measured for that tire on the three pavement surfaces. The existing data for bias-ply cross-bars are shown for reference purposes on the extreme right of this figure.

When new, the seven types of radial cross-bar tires generate approximately the same range of sound levels on the three pavement surfaces

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7/ The Jennite test surface was chosen for testing because it is similar to an asphalt surface which has an excessive amount of sealer on it. As will be shown in Section 3.2, the sound levels were the highest on the Jennite surface for all tires tested. Since the existing data shown in Figures 10 and 11 are for coastbys on concrete and asphalt pavements, a more accurate comparison can be made if the data for the Jennite surface are excluded.

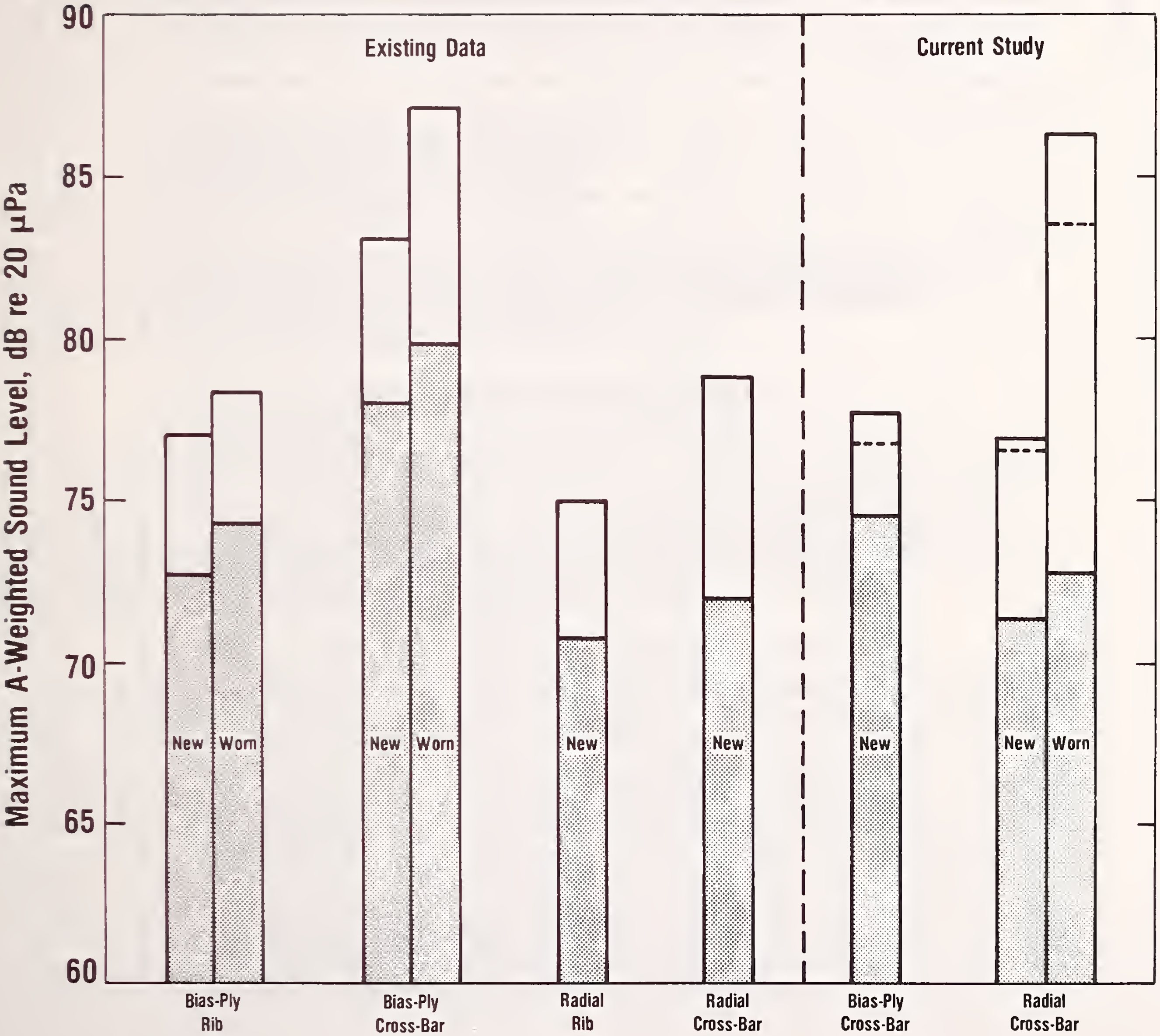

Figure 10. Comparison of the maximum A-weighted sound levels for tires with various types of construction. The unshaded portion of each bar represents the range between the upper and lower values for that type of tire. The dashed line represents the upper limit excluding the data for the Jennite surface.

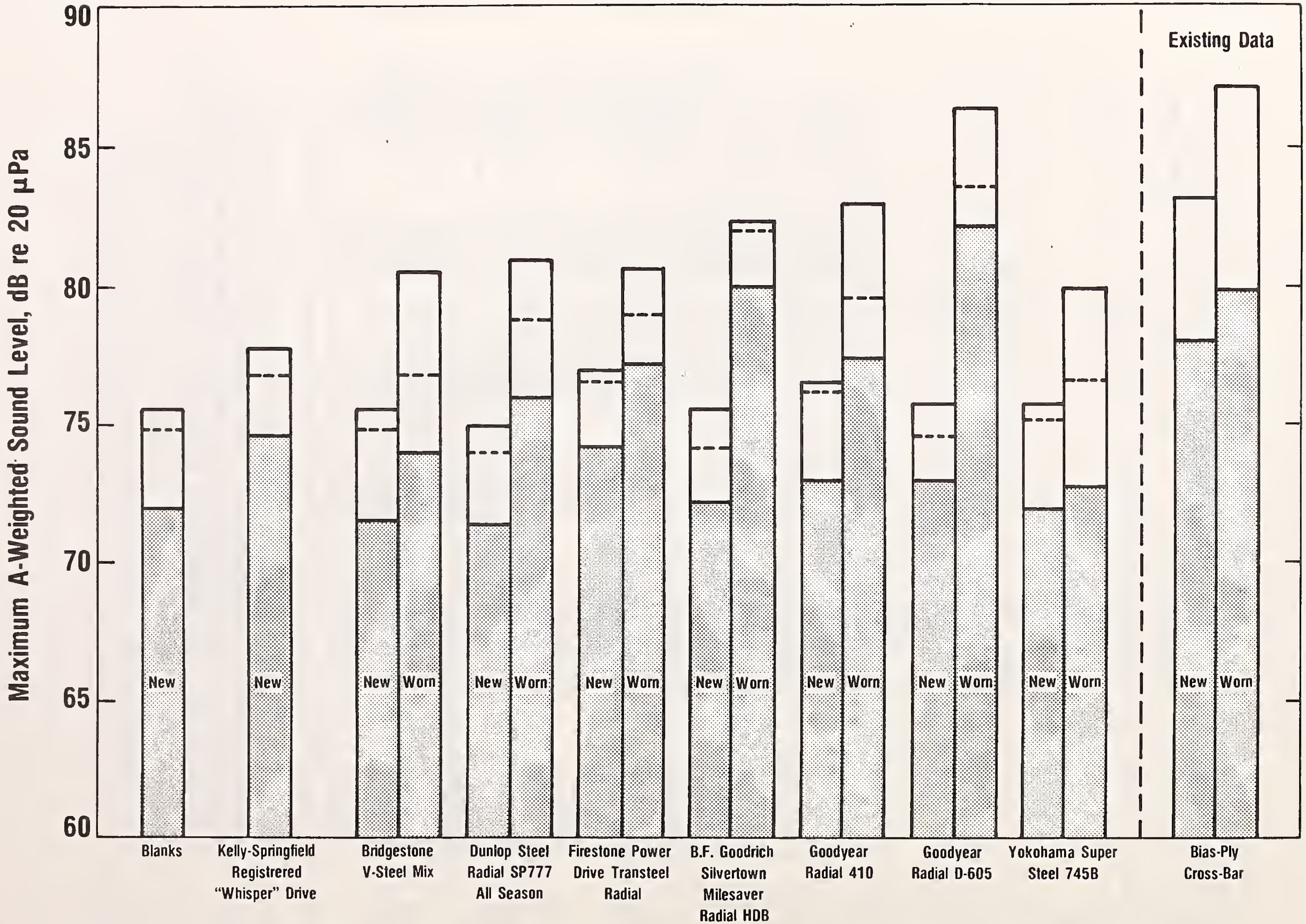

Figure 11. Comparison of the maximum A-weighted sound levels for the 16 sets of test tires. The unshaded portion of each bar represents the range between the upper and lower values measured for that tire on the three pavement surfaces. The dashed line represents the upper limit excluding the data for the Jennite surface. Existing data for conventional bias-ply cross-bar tires are shown for reference purposes.

(71.4 to 74.2 dB for the lower values and 75.0 to 77.0 dB for the upper values). The variation is more apparent for these tires when they are worn (the lower values vary from 74.0 to 82.2 dB and the upper values 80.0 to 86.4 dB). If the data for the Jennite surface are again excluded (shown by the dashed line in each bar), the upper values are reduced, but the range between these values remains about the same. Although the upper limit for the Goodyear Radial D-605 is reduced by excluding the data for the Jennite surface, the upper limits for the Bridgestone V-Steel Mix and Yokohama Super Steel 745B are also reduced. In this case, the upper limits for these latter two types of tires are below the lower limits for the existing data on conventional bias-ply cross-bars, even when new. Thus, based solely on noise considerations, radial cross-bar tires would be preferable to bias-ply cross-bar tires. Realistically though, noise considerations play only a small role in the overall evaluation of a tire. Other factors such as traction and handling, tread wear, fuel economy and costs must also be considered.

3.2 Effect of Pavement Surface

As shown in the previous section in Figures 10 and 11, pavement surface can have a significant effect on tire noise. This effect is dependent upon a complex interrelationship between tire construction, tread design and state of wear, and pavement surface characteristics. The exact nature of this relationship is not known and previous attempts to relate tire noise with any type of quantitative measure of the pavement surface characteristics have had limited success [2].

The effect of pavement surface is shown for the three pavements tested in this study in Figure 12. In this figure each bar represents one of the three pavements. The upper limit of the shaded portion of each bar corresponds to the maximum A-weighted sound level (average of the two test runs) for the new tire and the unshaded portion for the worn tire. As seen in Figure 12, the rank ordering of the pavements based on sound level is the same for all 16 sets of test tires--asphalt (the lowest), concrete and Jennite. The increase of maximum A-weighted sound level for the concrete surface relative to the asphalt surface is relatively consistent for all test tires and averages 2.1 dB (standard deviation of 0.6 dB). The increase in going from the concrete surface to the Jennite is dependent upon tire tread wear. For the new radial tires the average increase is 0.8 dB (standard deviation of 0.3 dB) and for the worn radial tires 2.4 dB (standard deviation of 0.9 dB).

One of the empirical techniques that has been applied as a means for characterizing pavement surface involves using a particular tire to rank order or "calibrate" the surfaces. In reference [2], a pocket tread tire (tread design consists of pockets that are <u>not</u> vented to the outside shoulder of the tire) was used as a pavement calibrator, but the results were inconclusive. However, data from a study of passenger car tire noise

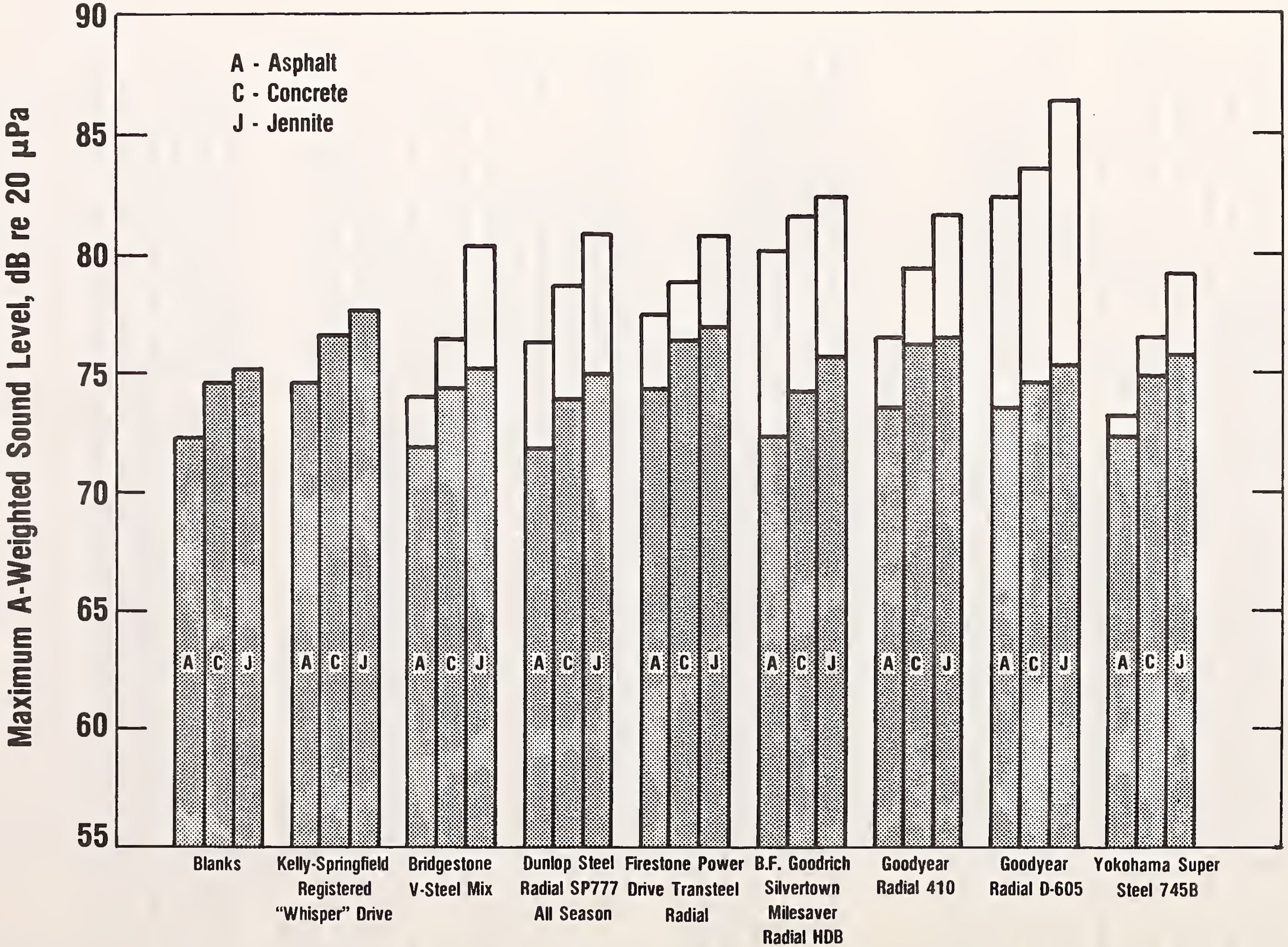

Figure 12. Illustration of the effect of pavement surface and tread wear for the 16 sets of test tires. The upper limit of the shaded portion of each bar corresponds to the average maximum A-weighted sound level when the tire is new and the unshaded portion for the tire when worn.

[15], also examined in reference [2], showed that blank tires might be useful as a pavement calibrator. Data for the 16 sets of tires are plotted in Figure 13 using the blank tire as a calibrator. This is done by arbitrarily chosing the end points for the asphalt and Jennite surfaces and adjusting the location of the concrete surface along the horizontal axis to get the best fit to a straight line. If the surfaces are assigned the numbers 1 for asphalt and 9 for Jennite, the value giving the best fit for concrete is 7.35. As seen in Figure 13, the fit with the linear regression line is quite good for all of the new tires. However, the fit is not as good for the worn radial tires. Averaging the values for the seven sets of worn radial tires, the optimum surface number for concrete is 4.82. The data for the worn radial tires are replotted in Figure 14 using this average value for concrete. As expected, the fit to the linear regression line is much improved.

Although the data fit for the worn tires was not as good as desired, it does appear that blank tires could be used as a pavement calibrator for the new tires. This conclusion is somewhat tentative because tests were conducted on only three pavement surfaces. Data obtained at the same test site show that these three pavements do not encompass the total range of pavement surface characteristics that exist [2] (although they do encompass the vast majority found on today's roads). Thus, before any final conclusions can be made, data for other types of surfaces are required.

3.3 Effect of Tread Wear

In the two previous sections, a distinction was made between new and worn tires when comparing the results of this study with existing data and when examining the effects of pavement surface. In both cases tread wear was shown to have an effect on the resultant sound level.

As seen in Figure 10, existing data on tread wear are limited to bias-ply rib and cross-bar tires. Because very little information is available, no data are presented on the effect of tread wear for radial truck tires. The data for bias-ply tires are limited to two or three different states of wear between new and fully worn [10]. These data show that in general the sound level increases with tread wear. In some cases the sound level increases uniformly with tread wear, while in others it reaches a maximum then decreases slightly when fully worn. The magnitude of the increase in sound level with tread wear is dependent upon the particular tire and pavement surface. Based on existing data the maximum increase is on the order of 2-3 dB for bias-ply rib tires and 4-6 dB for bias-ply cross-bar tires.

The effect of tread wear for the seven sets of radial cross-bar tires (these tires were worn in fleet service) examined in this study is also illustrated in Figure 12. As seen in this figure, the sound level increases

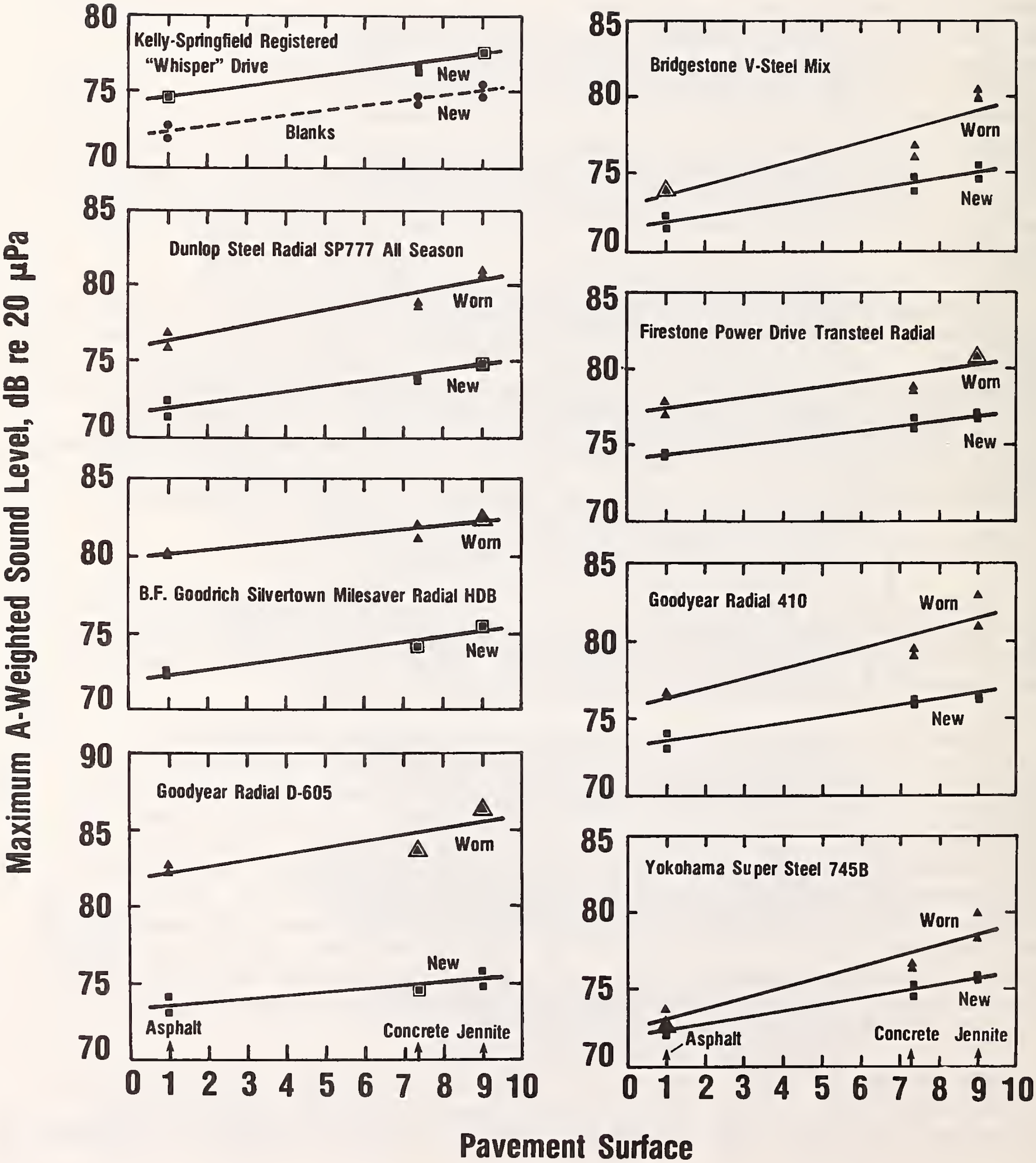

Figure 13. Maximum A-weighted sound level versus pavement surface for the 16 sets of test tires using the blank tire as a pavement calibrator. The solid line corresponds to the linear regression line using a value of 7.35 for the concrete surface.

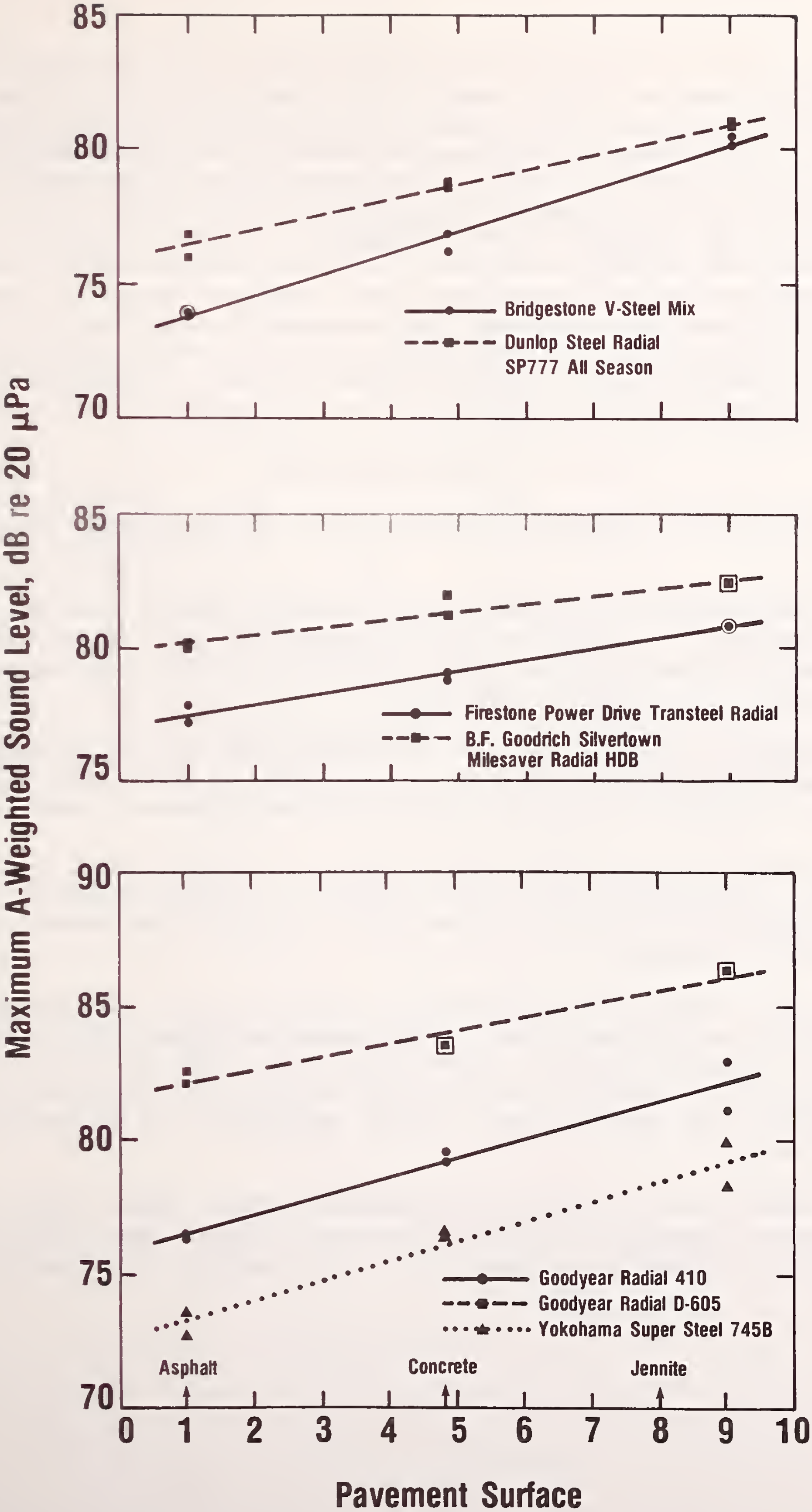

Figure 14. Maximum A-weighted sound level versus pavement surface for the seven sets of worn radial tires. The solid line corresponds to the linear regression line using the average value of 4.82 for the concrete surface.

with tread wear as it did for the bias-ply tires. The magnitude of the increase, represented by the length of the unshaded portion of each bar, varies widely and is dependent upon the particular tire and pavement surface. These increases of A-weighted sound level are listed in Table 9. As shown in this table the range of increases is about the same for the asphalt and concrete pavements (0.8 to 9.0 dB) and slightly higher (3.5 to 11.1 dB) for the Jennite surface. Because of the high degree of variability of the magnitude of this increase for the seven sets of tires, no general conclusions can be made except that sound level increases with tread wear. It should be noted that although the increases of sound level with tread wear are greater than for conventional bias-ply cross-bar tires, the sound levels for the worn radial cross-bar tires are still comparable to, and in most cases less than, that for worn bias-ply cross-bars.

3.4 Conclusions

Based upon the data presented in this report, the following conclusions can be made:

- The sound level for the new "quiet" design bias-ply cross-bar tires is approximately 2-5 dB lower than existing data for conventional bias-ply cross-bar tires when new. Data for this tire when worn are needed to determine the effect of tread wear.

- Considering only the data for the asphalt and concrete pavements, the radial cross-bar tires tested in this study generate lower sound levels than conventional bias-ply cross-bar tires, especially when worn.

- The sound level increases with tread wear for the radial cross-bar tires. The magnitude of this increase is strongly dependent on the individual tire and varies from 0.8 to 9.0 dB on the asphalt and concrete pavements.

- Pavement surface has a significant effect on the sound generated by "quiet" design bias-ply and radial cross-bar tires. The rank ordering of the pavements based on sound level is the same for all 16 sets of test tires -- asphalt (the lowest), concrete (2.1 dB higher than asphalt), and Jennite (new - 0.8 dB, and worn - 2.4 dB, higher than concrete).

- It appears that for the three pavements tested, blank tires might be a reasonable pavement calibrator for new cross-bar tires. Data for other types of pavements are required to fully validate this hypothesis.

Table 9. Increase of sound level with tread wear for the seven sets of radial cross-bar tires on the three pavement surfaces.

TEST TIRE	INCREASE OF SOUND LEVEL WITH TREAD WEAR, dB		
	Asphalt	Concrete	Jennite
Bridgestone V-Steel Mix	2.1	2.1	5.2
Dunlop Steel Radial SP777 All Season	4.5	4.8	5.9
Firestone Power Drive Transteel Radial	3.2	2.5	3.9
B.F. Goodrich Silvertown Milesaver Radial HDB	7.8	7.4	6.8
Goodyear Radial 410	3.0	3.3	5.1
Goodyear Radial D-605	8.9	9.0	11.1
Yokohama Super Steel 745B	0.8	1.6	3.5

4. APPENDIX A. SAE RECOMMENDED PRACTICE FOR MEASUREMENT OF TRUCK TIRE NOISE[8]

SOUND LEVEL OF HIGHWAY TRUCK TIRES—SAE J57a

SAE Recommended Practice

Report of Vehicle Sound Level Committee approved July 1973 and last revised June 1976. Approved by American National Standards Institute November 1976. Rationale Statement available.

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 80 km/h (50 mph) 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 sound levels.

Factors influencing sound level measurement and reference to sound levels are 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 American National Standard Specification for Sound Level Meters, S1.4-1971.

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 other indicating instrument, providing the system meets the requirements of SAE J184, Qualifying a Sound Data Acquisition System, with slow response specified in place of fast response as applicable to paragraph 3.6 therein.

ϕ 2.2 An acoustical calibrator, having an accuracy of ± 0.5 dB, for establishing the calibration of the sound level meter and associated instrumentation.

ϕ 2.3 An anemometer having an accuracy of $\pm 10\%$ at 19 km/h (12 mph).

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 30 m (100 ft) of the measurement area.

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

3.3 The microphone shall be located 15 m (50 ft) from the centerline of the vehicle path at a height of 1.2 m (4 ft) 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 15 m (50 ft) 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 snow, grass, 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 19 km/h (12 mph).

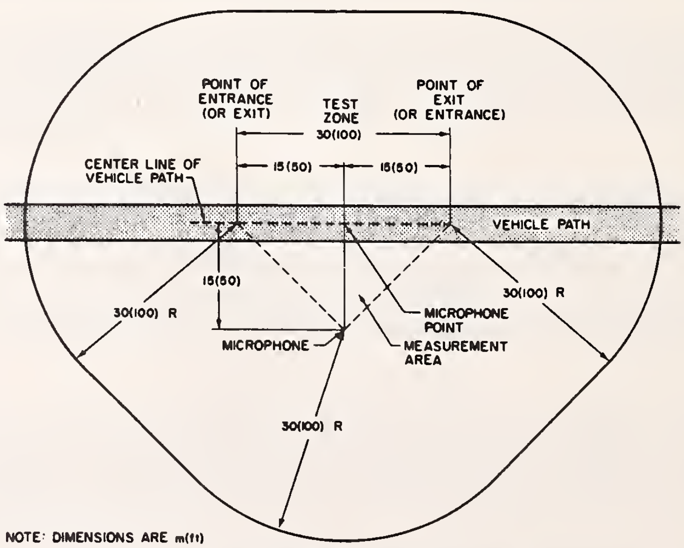

FIG. 1—TEST SITE (SEE PARAGRAPH 3). (VEHICLE MAY BE RUN IN EITHER DIRECTION)

[8] Reprinted with permission from 1978 SAE Handbook © 1978 Society of Automotive Engineers, Inc.

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 230 ± 100 mm (9 ± 4 in) clearance with the tire fully loaded. This body shall be nominally 2440 mm (96 in) in width and extend a minimum of 910 mm (36 in) 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 80 km/h (50 mph).

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 [illegible] 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 shall not be reported 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 sources is minimized throughout the test zone. The vehicle speed at the microphone point shall be 80 km/h (50 mph).

6.2 The sound level meter shall be set for slow dynamic 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 15 m (50 ft) 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 (R1971), Acoustical Terminology

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

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

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

8.5 Tire and Rim Association Yearbook

8.6 SAE Publication SP-373, Truck Tire Noise

8.7 G. R. Thurman, "Effect of Road Surface and Bed Clearance on Truck Tire Noise." Paper 740607 presented at SAE West Coast Meeting, Anaheim, California, August 1974.

The ANSI documents are available from the American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

APPENDIX

A1. An A-weighted sound level not exceeding 85 dB, determined in accordance with this recommended practice, is 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 levels generated by highway truck tires. Rib type tires generally produce lower sound levels on smooth surfaces than on surfaces having a textured finish such as that brushed in during construction. Differences as great as 5 dB have been observed between sound levels obtained on very smooth and coarse concrete surfaces for tires producing relatively low levels of sound. For cross-ribbed tires, however, generated sound levels have been found to not differ by more than approximately 1 dB for given tire types on a variety of Portland cement concrete surfaces judged to be relatively smooth. For these reasons, the vehicle path description in paragraph 3.2 is sufficient to provide for reproducible sound levels for cross-ribbed tires, within the expected accuracy of such measurements (±1 dB), and to provide surface-dependent relative sound levels for rib type tires.

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.

5. REFERENCES

[1] Leasure, Jr., W. A., Tire Noise Regulations - Technical and Economic Implications, SAE Paper 762033, published in SAE Publication P-70: SAE Highway Tire Noise Symposium Proceedings, San Francisco, California, November 10-12, 1976.

[2] Kilmer, R. D., Leasure, Jr., W. A., and Mathews, D. E., Truck Noise 1-C Pavement Surface Effects on the Generation of Truck Tire Noise, U. S. Department of Transportation Report No. DOT-TST-76-49 (National Bureau of Standards, Washington, D. C., October 1975).

[3] Kilmer, R. D., Cadoff, M. A., Mathews, D. E., and Shoemaker, Jr., C. O., Effects of Load, Inflation Pressure and Tire Deflection on Truck Tire Noise Levels, U. S. Department of Transportation Report No. DOT HS-803 874 (National Bureau of Standards, Washington, D. C., December 1978).

[4] Gallaway, B. M., and Rose, J. G., Macrotexture, Friction, Cross Slope, and Wheeltrack Depression Measurements on 41 Typical Texas Highway Pavements, Research Report 138-2 (Texas Transportation Institute, Texas A&M University, Bryan, Texas, 1970).

[5] American Society for Testing and Materials, D 2240-75, Standard Methods of Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer, in Part 37, Book of ASTM Standards, 1978 (ASTM, Philadelphia, Pa.).

[6] Anon., The 1978 Yearbook (Tire and Rim Association, Inc., Akron, Ohio, 1978).

[7] SAE Recommended Practice J57a, Sound Level of Highway Truck Tires (Society of Automotive Engineers, Inc., Warrendale, Pa., 1978).

[8] American National Standard S1.4-1971, Specification for Sound Level Meters (American National Standards Institute, Inc., New York, N.Y., 1971).

[9] Anon., Truck Noise-1, Peak A-Weighted Sound Levels Due to Truck Tires, U. S. Department of Transportation Report No. OST-ONA-71-9 (National Bureau of Standards, Washington, D. C., September 1970).

[10] Leasure, Jr., W. A., Corley, D. M., Flynn, D. R., and Forrer, J. S., Addendum to Truck Noise-1, Peak A-Weighted Sound Levels Due to Truck Tires, U. S. Department of Transportation Report No. OST/TST-72-1 (National Bureau of Standards, Washington, D. C., July 1972).

[11] 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 No. DOT-TST-74-21 (National Bureau of Standards, Washington, D. C., February 1974).

[12] Kilmer, R. D., Leasure, Jr., W. A., Corley, D. M., Mathews, D. E., and Shoemaker, Jr., C. O., Truck Noise 1-D, Empirical Model for Predicting In-Service Truck Tire Noise Levels, U. S. Department of Transportation Report DOT-TST-76T-5 (National Bureau of Standards, Washington, D.C. July 1976).

[13] Kilmer, R. D., Test Procedures for Future Tire Noise Regulations, SAE Paper 762034, published in SAE Publication P-70: SAE Highway Tire Noise Symposium Proceedings, San Francisco, California, November 10-12, 1976.

[14] Thruman, G. R., and Leasure, Jr., W. A. (editors), Noise and Traction Characteristics of Bias-Ply and Radial Tires for Heavy Duty Trucks, DOT Report No. DOT-TST-78-2 (U. S. Department of Transportation, Washington, D. C., October 1977).

[15] Hillquist, R. K., and Carpenter, P. C., A Basic Study of Automobile Tire Noise, presented at the 85th meeting of the Acoustical Society of America, Boston, Mass., April 1973.

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Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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

Recent advances in the development of heavy duty truck tires has lead to the introduction of "quiet" design bias-ply cross-bar tires, as well as radial tires with cross-bar tread patterns. To adequately assess the noise/safety/economic tradeoffs, acoustic data on a representative sample of these newer tire designs are essential. This report presents acoustic data measured at 50 feet for one type of new "quiet" design bias-ply and seven types of radial cross-bar tires (both new and worn) for coastbys at 50 mph on three pavement surfaces--asphalt, concrete and Jennite. In general, the data show that these newer tire designs generate lower sound levels than conventional bias-ply cross-bar truck tires. The differences in sound level between these newer designs and conventional bias-ply cross-bars vary widely and are a function of the individual tire and state of tread wear. These data show that the sound level is dependent on pavement surface with a rank ordering of asphalt (the lowest sound levels), concrete and Jennite. Also, it is shown for the radial cross-bar tires that, depending upon the particular tire, the sound level increases with tread wear from 0.8 to 9.0 dB on the asphalt and concrete pavements.

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

Acoustics; noise measurement; noise (sound); tire noise; transportation noise; truck.

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