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AUTOMOBILE TIRE NOISE: RESULTS OF A PILOT STUDY AND REVIEW OF THE OPEN LITERATURE

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Abstract

Automobiles, the primary mode of transportation in the United States, contribute significantly to the noise environment due to the large number in operation. In this report, one aspect of automobile noise is discussed; namely, the contribution to overall vehicle noise resulting from the interaction of the tires with the road surface. The results of this pilot study, which investigated the influence of selected parameters on automobile tire noise levels, in conjunction with a review of the open literature, serve as the basis for comparison of parametric trends between truck (for which an extensive noise data base exists) and automobile tires. As was the case with trucks, vehicle speed, road surface characteristics and tread design are major factors affecting automobile tire noise. The effect of pavement surface is more significant for automobile tires than for trucks since the texture within the tire-road interaction zone is on the same scale as the tread element spacing typical of passenger car tires. Load and wear, significant factors for truck tires, do not affect automobile tires as much due to the fact that the majority of automobile tires utilize rib tread designs. On the basis of the limited data available in the literature, factors such as inflation pressure, number of plies, tire dimensions, tire cord material, etc., do not appear to be significant factors affecting automobile tire noise.

1. Introduction

Automobiles are the primary mode of transportation in the United States. Even though they are not usually as noisy as trucks, buses and motorcycles, the total contribution of automobiles to the noise environment is significant due to the large number in operation -- over 90 million.

The basic noise sources for automobiles and trucks are essentially the same -- engine exhaust, cooling fan, engine casing radiation, and tires -- but they do not necessarily have the same relative importance for these two vehicles under the same driving conditions.

Tire noise for automobiles may become a significant contributor to overall vehicle noise levels at speeds as low as 35-40 mph (56.3-64.6 km/hr). For both passenger cars and trucks, the exact speed at which the tire-roadway noise starts to predominate is highly dependent upon tire characteristics, road surface, vehicle condition, engine-exhaust characteristics, etc.

Since trucks are generally considered to present a more serious tire noise problem than passenger cars, the majority of the data available in the open literature have resulted from measurements of truck tire noise[1-6] 1/.

Rather than conduct a large scale study of automobile tire noise, it was decided by DOT and NBS, that a pilot program should be carried out to investigate the influence of selected parameters which affect automobile tire noise levels. This program was intended to serve as the basis for determining whether parametric trends for truck and automobile tires were similar (therefore defining the extent of additional noise testing of automobile tires needed in the future) to supplement the rather limited data on automobile tire noise 2/.

The National Bureau of Standards conducted this pilot noise evaluation program on passenger car tires in the summer of 1973 for the Office of Noise Abatement, U. S. Department of Transportation. The test design was based on that utilized by NBS in previous studies of truck tire noise[1,3,4,5]. Tread design, wear, speed and pavement surface were the parameters studied. Briefly, the testing included the following:

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

2/ At the onset of this pilot program some limited data were available in the public domain on automobile tire noise; however, the majority of the information was relative to passenger car interior noise[7].

- Noise measurements were made at 25 and 50 feet (7.6 and 15.2 metres) as measured from the centerline of vehicle travel. These distances correspond to the typical European and American measurement locations.

- A full-size 1973 automobile loaded to a gross vehicle weight of 5000 pounds (2268 kg) -- 1250 pounds/tire -- was operated at nominal speeds of 50, 60 and 70 mph (80.5, 96.5 and 112.6 km/hr) over three pavement surfaces -- jointed concrete, continuous poured reinforced concrete and asphalt.

- Bias-ply and bias-belted tires with six different tread patterns -- three rib-tread and three snow tread -- were tested in the new and nominally half-worn states of wear. In addition, a radial-ply and a bias-ply set of tires with identical tread patterns were tested in the new condition only.

- A minimum of two test runs were made at each operational condition.

The results of the pilot program are presented and discussed in this report. Additional data that have been reported since the onset of this pilot program are also discussed[7-10].

2. Field Test Program

2.1. Field Test Sites

Two test sites were utilized in this study. One was the research runway at the Wallops Station, Virginia facility of the National Aeronautics and Space Administration. The other was an unopened section of Interstate 81 near Carlisle, Pennsylvania. Agreements were reached with NASA and the State of Pennsylvania for utilization of the respective sites for the data acquisition phase of the program.

Research runway 4-22 (bearing 040° and 220°) provided an adequate stretch of pavement [8750 feet (2667 m)] and a flat terrain providing a well-defined reflecting surface without any unusual reflection or attenuation effects. Two test sections, each 1000 feet (304.8 m) in length, were established on the runway. One test area was designated as the concrete test section while the other was the asphalt test section. The nominal runway width was 150 feet (45.7 m) with a center section [50 feet (15.2 m) wide located at the center of the runway] of specially constructed substrates including some grooved sections. Although no lanes, such as one thinks of as being present on highways, were marked on the runway, the concrete on either side of the special pavement area was laid in sections 12 feet (3.7 m) wide and 20 feet (6.1 m) long. For this test program, the car ran in one of these 12 foot (3.7 m) lanes. Due to the deteriorated condition of the pavement surface near the edge of the runway, the car ran one lane in from the edge. On the asphalt surface, a lane was marked which corresponded to the location of the concrete lane. Figure 1 shows an overall view of the research runway with the locations of both test sections noted.

The concrete test section began 2650 feet (807.7 m) from the northeast end of runway 4-22 and extended to 3650 feet (1112.5 m). It consisted of a substrate of reinforced, air-entrained Portland Cement concrete with two types of finishes. They were "C" finish or smooth concrete and "D" finish or textured concrete. The only difference between the two surface finishes was the method of final finishing. To the untrained eye, there appears to be no difference between the two sections. The "C" finish section of pavement was smoothed with a belt of canvas composition while the "D" finish section utilized a finishing belt of burlap. Figure 2 is a detailed layout of the concrete test area while Figure 3 is a photograph of the smooth concrete surface. Three grooved pavement sections existed on this portion of the runway. One grooved section extended 75 feet (22.9 m) into the test area but did not interfere with the line-of-sight from the truck to the two microphones. However, the other grooved sections (grooved smooth concrete and grooved textured concrete) did lie between the car and the 50 foot (15.2 m) microphone location.

The effect of the grooves on reflection of sound was not established during this study; however, the width and spacing of the grooves [1/4 inch (0.6 cm) and 1 inch (2.5 cm) respectively] appear to be such that only high frequencies would be affected. It is felt that the grooves would have little or no effect at those frequencies (160-2000 Hz) where most of the tire noise is concentrated.

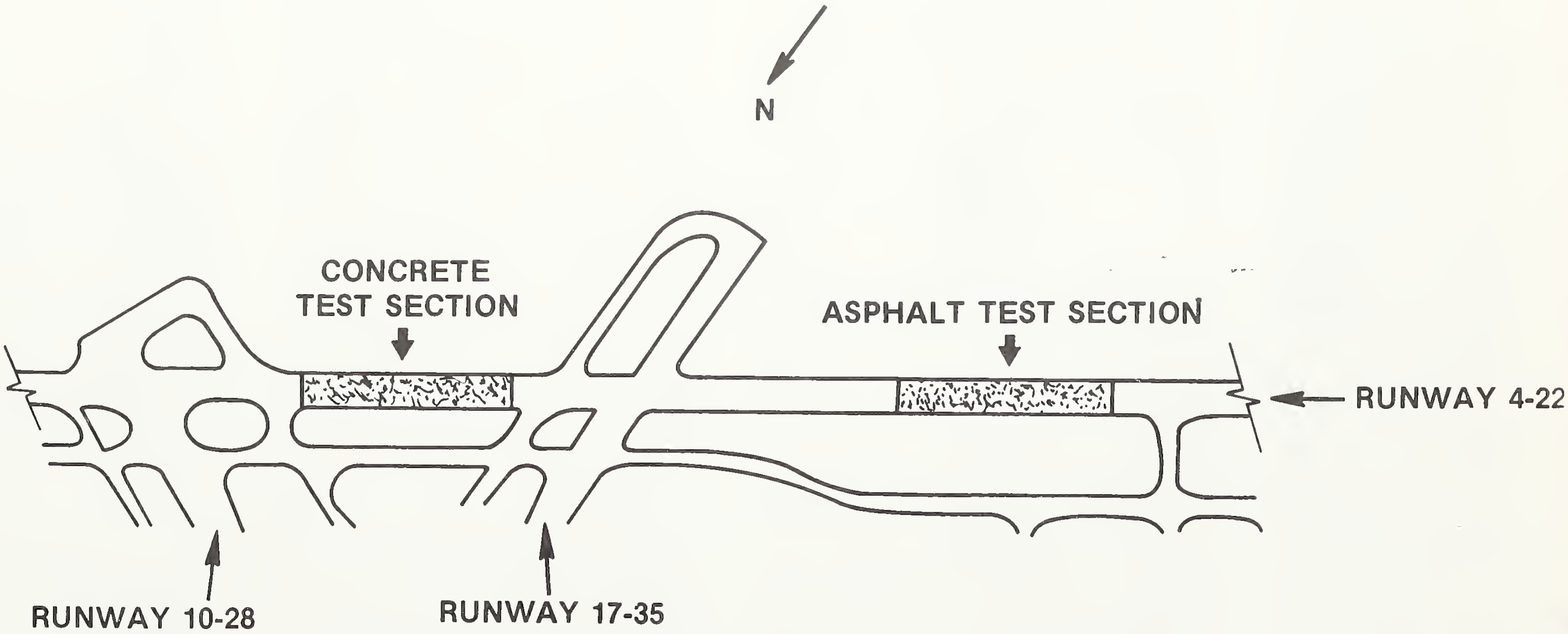

Figure 1. Plan of research runway 4-22 Wallops Station, Virginia, showing the locations of the concrete and asphalt test sections.

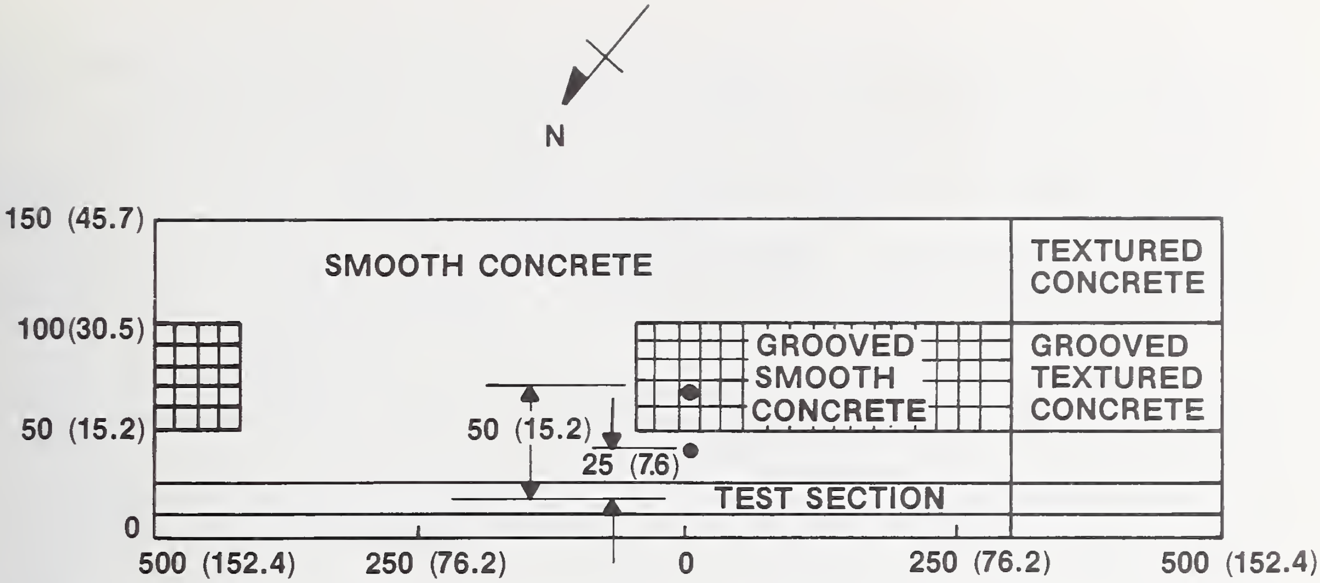

Figure 2. Plan of concrete test area on runway 4-22. Distances are in feet (metres). Solid circles designate the two microphone locations.

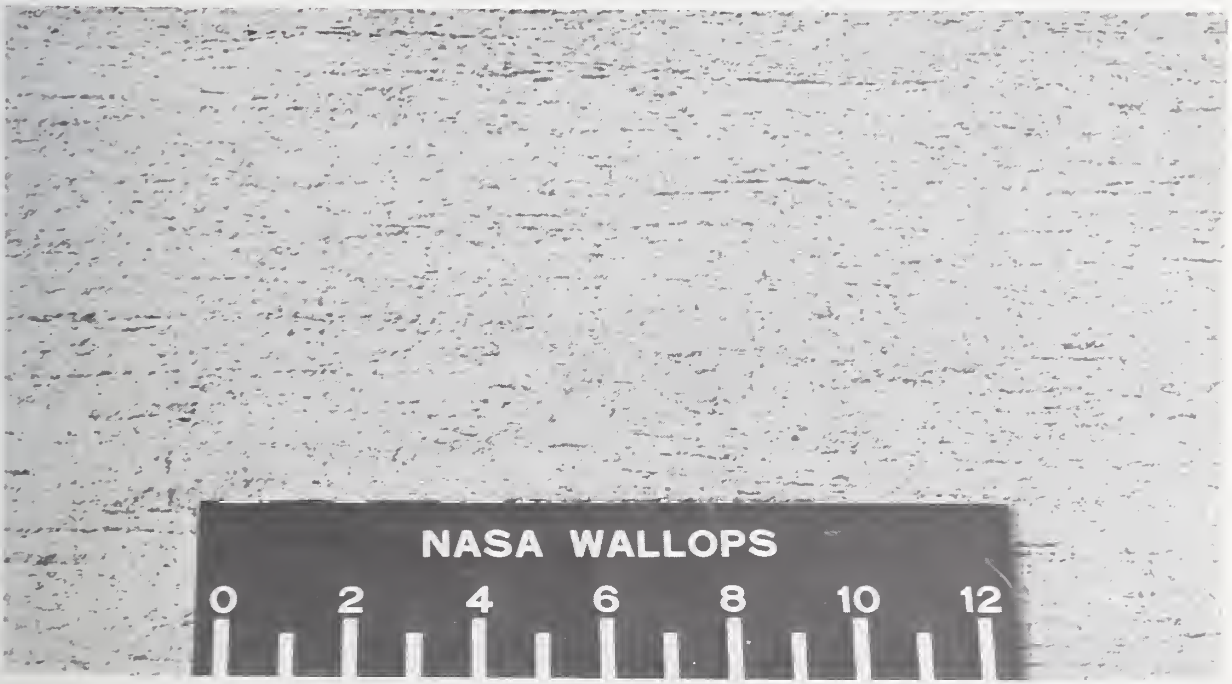

Figure 3. Smooth concrete surface on runway 4-22. Scale is in inches.

The asphalt test section began 5700 feet (1737.4 m) from the northeast end of runway 4-22 and extended to 6700 feet (2042.2 m). It consisted of a substrate of "B" surface course bituminous concrete -- also referred to as "textured asphalt". Reference to Figure 4 shows that the test section was a continuous surface of textured asphalt with the exception of a grooved textured asphalt section 150 feet (45.7 m) long and 50 feet (15.2 m) wide along the centerline of the runway. Only a small corner of this grooved section was in the line-of-sight path from the test vehicle to the microphones. Figure 5 shows the texture of the asphalt test section.

In addition to the concrete and asphalt surfaces at Wallops Station, a third surface -- continuous poured reinforced concrete -- was investigated. This surface (roadway of an unopened section of I-81 near Carlisle, Pennsylvania) was selected since it is typical of Interstate Highway System construction. However, the surface had not undergone the polishing effect that could be expected once the roadway is opened to traffic. The roadway consisted of two 12 foot (3.7 m) wide lanes with 6 foot (1.8 m) paved shoulders on either side of a grass covered median strip (see Figure 6). At this site it was not possible to provide a well-defined reflecting surface. The microphone at the 25 foot (7.6 m) location was at the edge of the shoulder; however, the 50 foot (15.2 m) microphone was located in the median strip. The land to either side of the roadway was contoured away from the road surface for drainage purposes; therefore, the microphone height for the 50 foot (15.2 m) measurement position was adjusted so that the two microphones were at the same height relative to the road surface (see section A-A of Figure 6). The test vehicle ran in the outside southbound lane. Figure 7 shows a view of the test site looking in a northeast direction. The surface finish of the continuous poured reinforced concrete pavement (see Figure 8) was very rough and possessed a characteristic "grain" which ran perpendicular to the direction of traffic flow.

2.2. Test Tires

A total of eight tire types were investigated during the conduct of this study. The sample of test tires included three rib-tread tires, three snow-tread tires and two rib retreads. A photograph showing the tread designs of each of the test tires is given in Appendix A. Additional details of carcass construction and materials are shown in Table 1. All test tires were size H 78-15, load range B (with the exception of the two retreads which were size G 78-15 and GR 78-15).

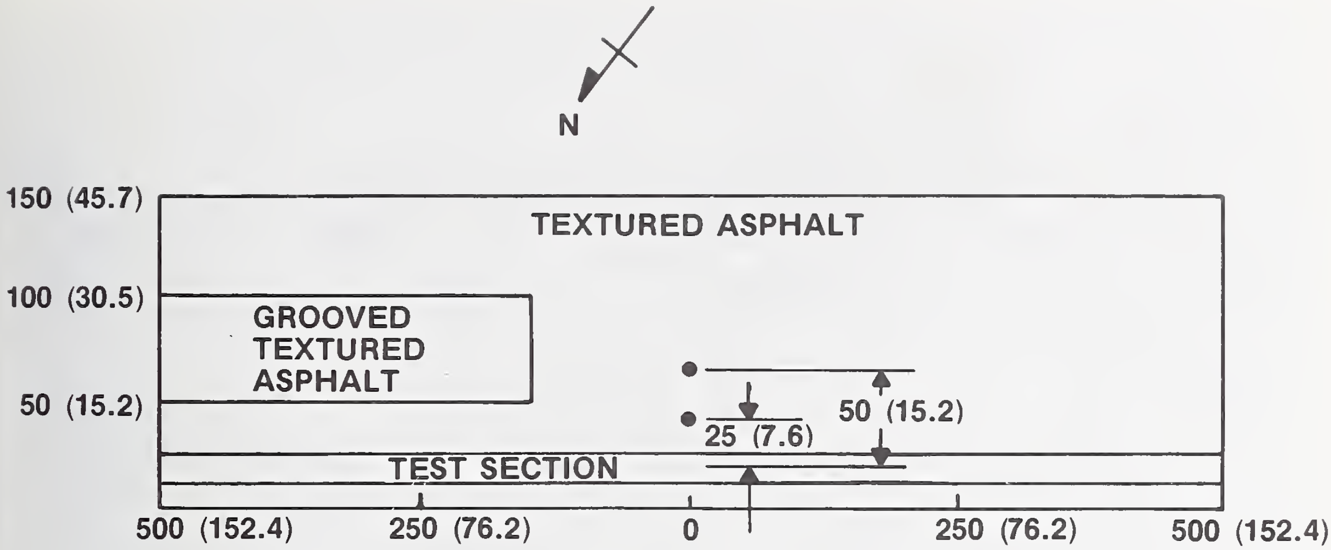

Figure 4. Plan of asphalt test area on runway 4-22. Distances are in feet (metres). Solid circles designate the two microphone locations.

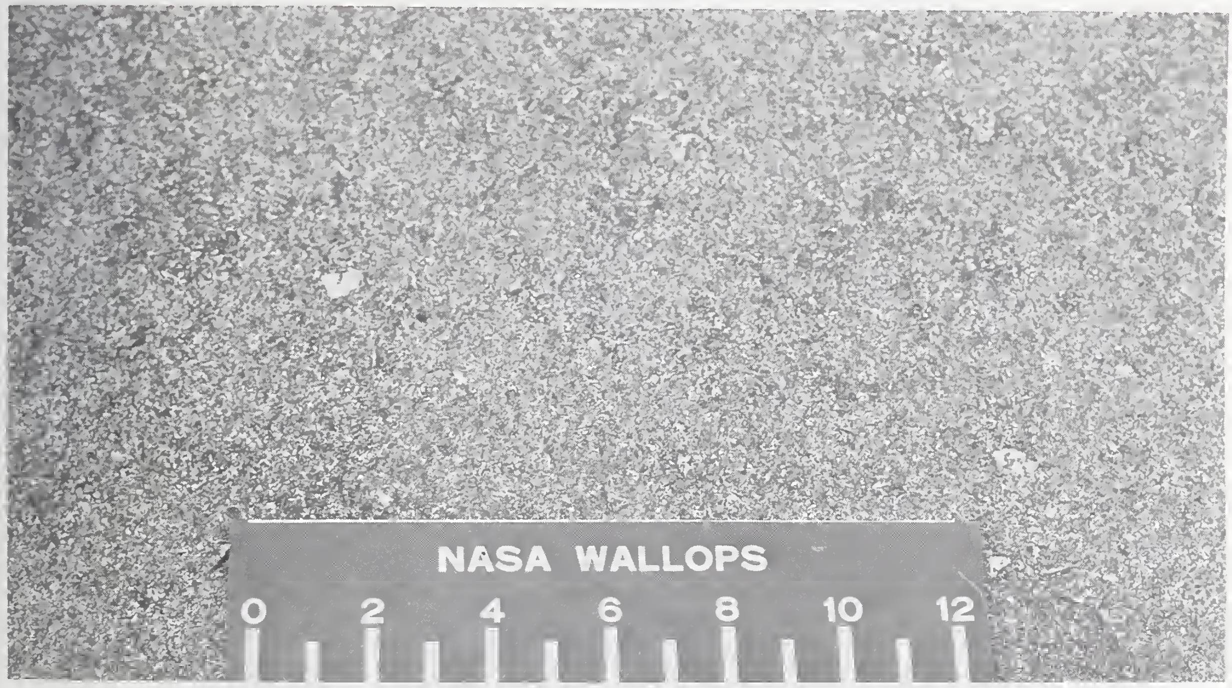

Figure 5. Textured asphalt surface on runway 4-22. Scale is in inches.

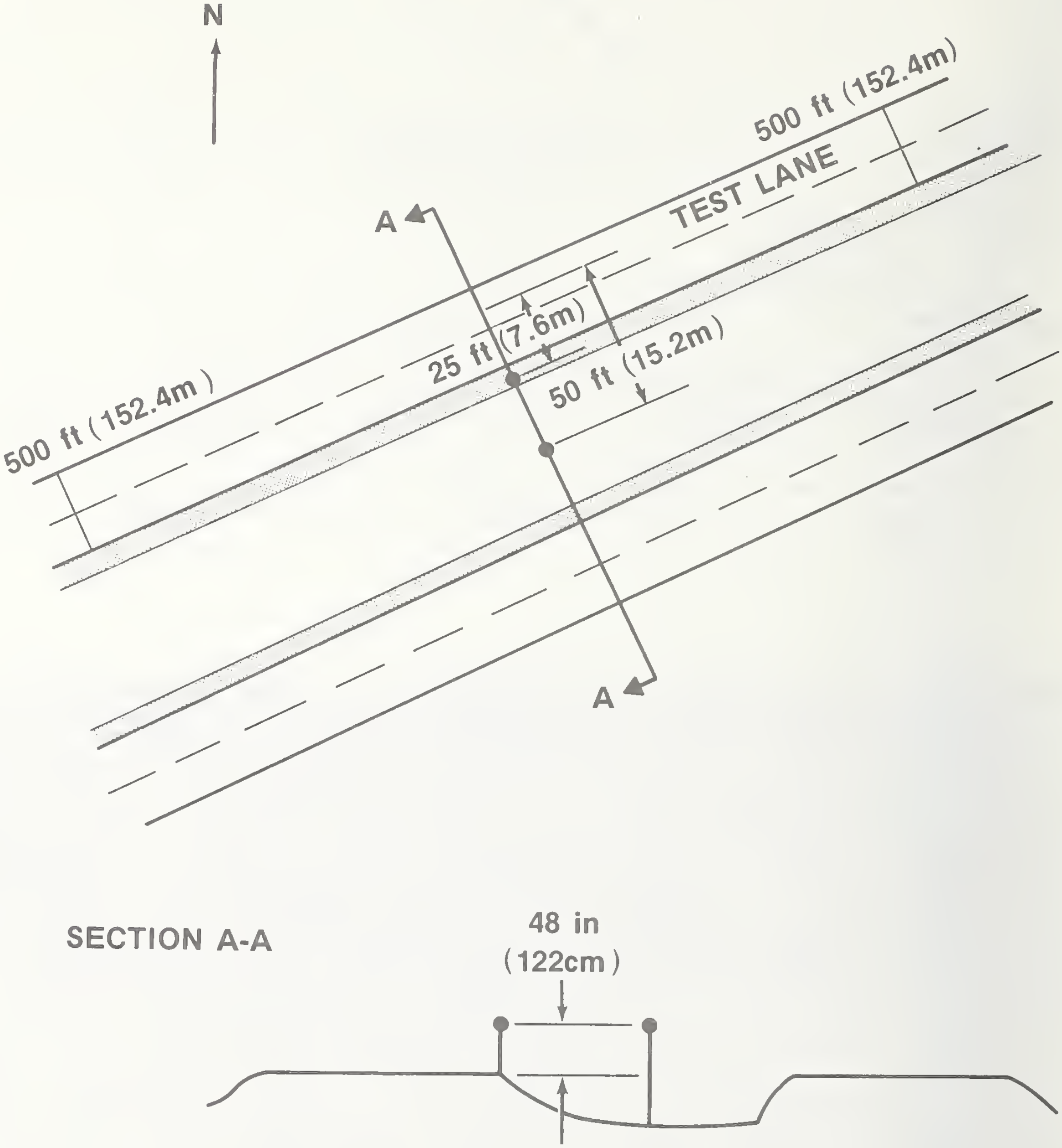

Figure 6. Plan of continuous poured reinforced concrete test area on Interstate-81 plus sectional view through the microphone locations. Solid circles designate the two microphone locations.

Figure 7. View of continuous poured reinforced concrete test section looking northeast.

Figure 8. Continuous poured reinforced concrete surface on Interstate-81 near Carlisle, Pennsylvania. Traffic flow would be from left to right.

Table 1. Tread design and carcass construction characteristics of the test tires.

TEST TIRE	TREAD TYPE	CARCASS TYPE
B	Rib	Polyester, Bias-Ply
C	Rib	Fiberglass, Bias-Belted
D	Rib	Rayon-Belted, Radial-Ply
E	Snow	Rayon-Belted, Radial Ply
F	Snow	Polyester, Bias-Ply
G	Studded Snow	Polyester, Bias-Ply
BR	Rib	Polyester, Bias-Ply
RR	Rib	Rayon-Belted, Radial Ply

A special note should be made about the retread test tires. The question had been raised as to whether radial-ply tires were noisier than tires of bias-ply or bias-belted carcass construction. In order to address this question, an attempt was made to locate bias-ply (or bias-belted) and radial-ply tires which utilized identical tread patterns. It was felt that noise tests on such tires would allow one to determine whether differences in observed noise levels were due to differences in carcass construction or simply due to the fact that the tread patterns typically found on radial-ply tires were more "aggressive" (tend toward a snow- tread type pattern) than conventional rib-tread patterns typically utilized on tires of bias-ply and bias-belted carcass construction. The attempt, however, was not successful. For this reason, a set of radial-ply and bias-ply tires were purchased, the tread was buffed off and the tires were retreaded with identical rib-tread patterns. The results of the experiment conducted utilizing these tires are discussed later in the report.

Both new and nominally half-worn tires were tested (retread tires were tested in the new condition only). The half-worn tires were worn through actual in-service usage on NBS vehicles utilized for shuttle service between downtown Washington, D. C. and the NBS Gaithersburg, Maryland campus. These vehicles averaged 2600 miles (4183.4 km) per month. The tires were closely monitored and no uneven wear patterns were observed.

The tires were statically balanced prior to mounting on the vehicles. This is standard operating procedure for automobile tires. A new tire was not considered acceptable as a test specimen 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).

Two characteristic measurements were made for each test tire -- tread depth and shore hardness. The resultant data are tabulated in Appendix A.

Tread depth measurements were taken at four equally spaced locations around the tire circumference. The device utilized for these measurements was a depth gage with 1/32 inch (0.8 mm) 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.

The Shore hardness of the tread rubber was determined by ASTM test method D-2240-68[11]. 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.

2.3. Test Vehicle

The test vehicle utilized throughout this program was a 1973 Plymouth Fury II[3/] which was rented from the General Services Administration. The vehicle was equipped with a V-8 engine (318 CID), automatic transmission and H 78-15 tires.

The car was operated in a loaded condition. The test loads represented 100 percent of gross vehicle weight and 75 percent of rated tire load at 26 psi (179×10^3 Pa) per Tire and Rim Association recommendations. The vehicle was ballasted with 80 pound (36 kg) sand bags such that all tires were loaded equally. Figures 9a-c show the placement of the sand bags within the car: two bags in the front -- one on the passenger seat and one on the floor (Figure 9a); five sand bags in the rear -- four on the floor and one on the seat (Figure 9b); and one or two sand bags in the trunk (Figure 9c). When the fuel tank was full only one sand bag was placed in the trunk. When the fuel level reached 50 percent, a second sand bag was added in order to maintain comparable loading. The weight distribution was:

[3/] The vehicle utilized is identified in this report in order to adequately describe the vehicle 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 this vehicle was necessarily the best available for the purpose.

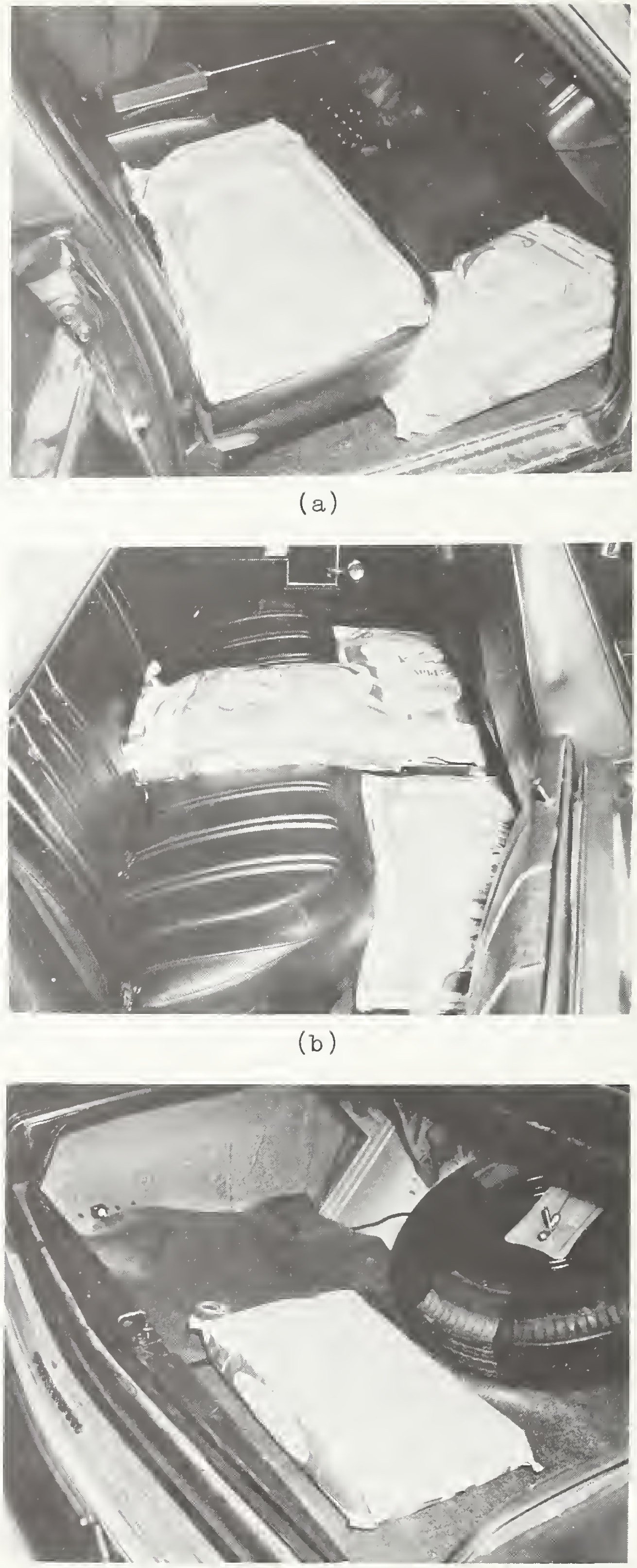

Figure 9. A view of the test vehicle showing placement of the sand bags used to provide the necessary tire loading -- (a) front seat, (b) rear seat and (c) trunk.

front axle	2500 pounds (1134 kg)
rear axle	2500 pounds (1134 kg)
	5000 pounds (2268 kg)

Throughout the program the test tires were always mounted on the rear axle and rib tires whose characteristic tire noise level was known to be low were always mounted on the front axle. The tires were inflated to an air pressure of 26 psi (179×10^3 Pa).

2.4. Test Procedure

Prior to a discussion of the test procedure, a few words of description are necessary to establish the placement of all instrumentation within the test section. Figure 10 shows the placement of the microphones, radio transmitters, and the path of the test vehicle.

The two microphones were located at 25 and 50 feet (7.6 and 15.2 m) from the centerline of the lane in which the vehicle travelled along a line perpendicular to the path of travel of the test vehicle. Radio transmitters, activated by the car running over a tape switch, were located along the test lane parallel to the path of the vehicle. Coaxial cables connected the microphones with the tape recording and monitoring equipment.

For a nominal 50 mph (80.5 km/hr) run (the vehicle should be travelling 50 mph (80.5 km/hr) as it passed the microphone array) the driver of the test vehicle accelerated the car to slightly more than the desired speed to compensate for the deceleration characteristics of the vehicle (during coast-bys with the engine off).

As the car passed over the initial tape switch, the tape recorder was remotely commanded to turn on via the signal from the radio transmitters. The initial tape switch/radio transmitter system was located such that the tape recorder was up to speed by the time that the test vehicle entered the test section. (The location of the initial tape switch was selected based on the maximum test speed of the vehicle during the program.) Following a time delay a signal was recorded on the FM channel of the tape recorder which designated the start of data. As the car left the test section, a second tape switch was activated, the radio transmitter sent a signal to the tape recorder identifying the end of data and then the tape recorder was remotely turned off. The data-start and data-end signals were transmitted to the receiver at different frequencies. An elapsed time clock indicated the time it took for the vehicle to cover the known distance between the tape switches from which the average speed of the vehicle was calculated.

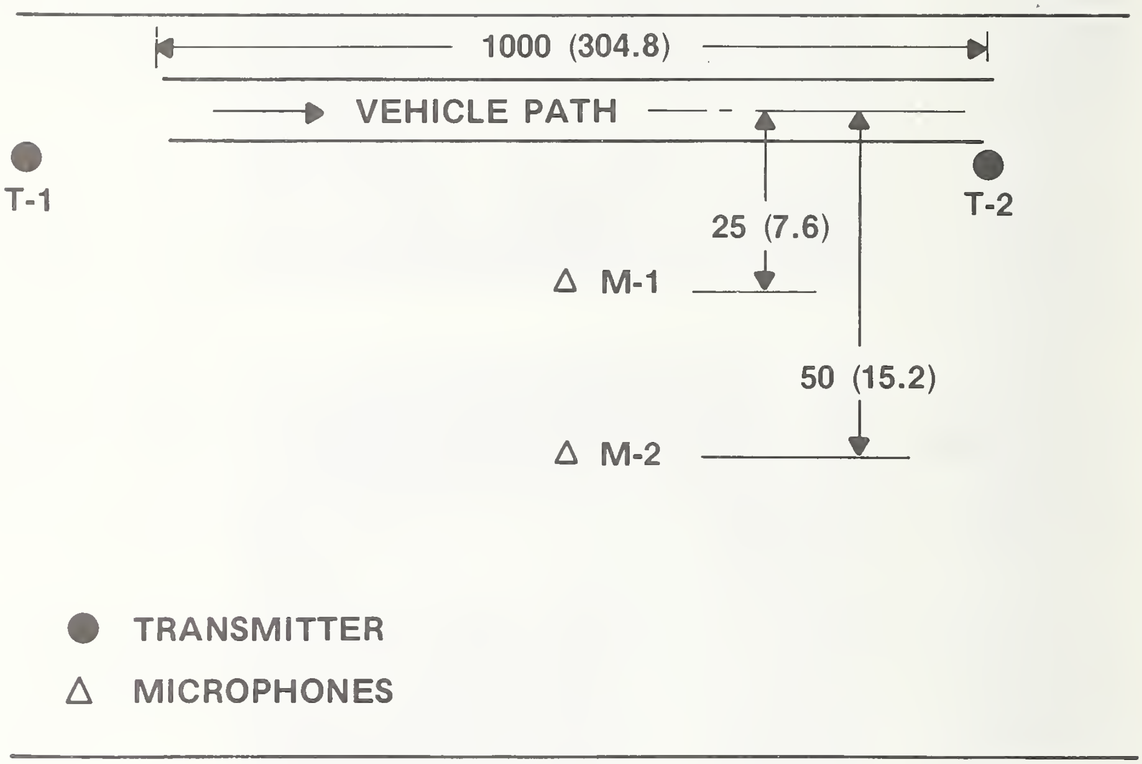

Figure 10. View of test section showing instrumentation placement plus vehicle path (not to scale). Distances are in feet (metres). Microphones were placed 25 and 50 feet (7.6 and 15.2 metres) from the centerline of the lane in which the vehicle travelled and along a line perpendicular to the path of travel. Radio transmitters (activated by tape switches) remotely controlled the on/off sequence of the tape recorder.

Figure 11 identifies the components that constituted the data acquisition system -- 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 attenuation over a range of 60 dB in 10 dB steps, and a three-channel analog tape recorder. The system included both a linear 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, windscreens were placed over the microphones to minimize the noise produced by wind passing over the microphone. A single point calibration utilizing a pistonphone which produced a 124 dB sound pressure level (re 20 μPa) 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 array and associated instrumentation in the field at the Wallops Station 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 real-time analyzer was commanded to begin analysis. A time constant of .2 second above 2 kHz and one which below 2 kHz followed a straight line to 3.15 seconds at 12.5 Hz was utilized to obtain the root-mean-square (rms) value of the level in each one-third octave band at the output of the analyzer. Once all data had been analyzed in one-third octave bands, the computer stored the data and dumped it onto digital magnetic tape. This tape was formatted to be acceptable to the large NBS computer which was utilized for further analysis. This instrumentation system provided for efficient data acquisition and data handling for the thousands of data points generated for each passby.

Appendix B contains a brief description of the instruments utilized for data acquisition, reduction and analysis.

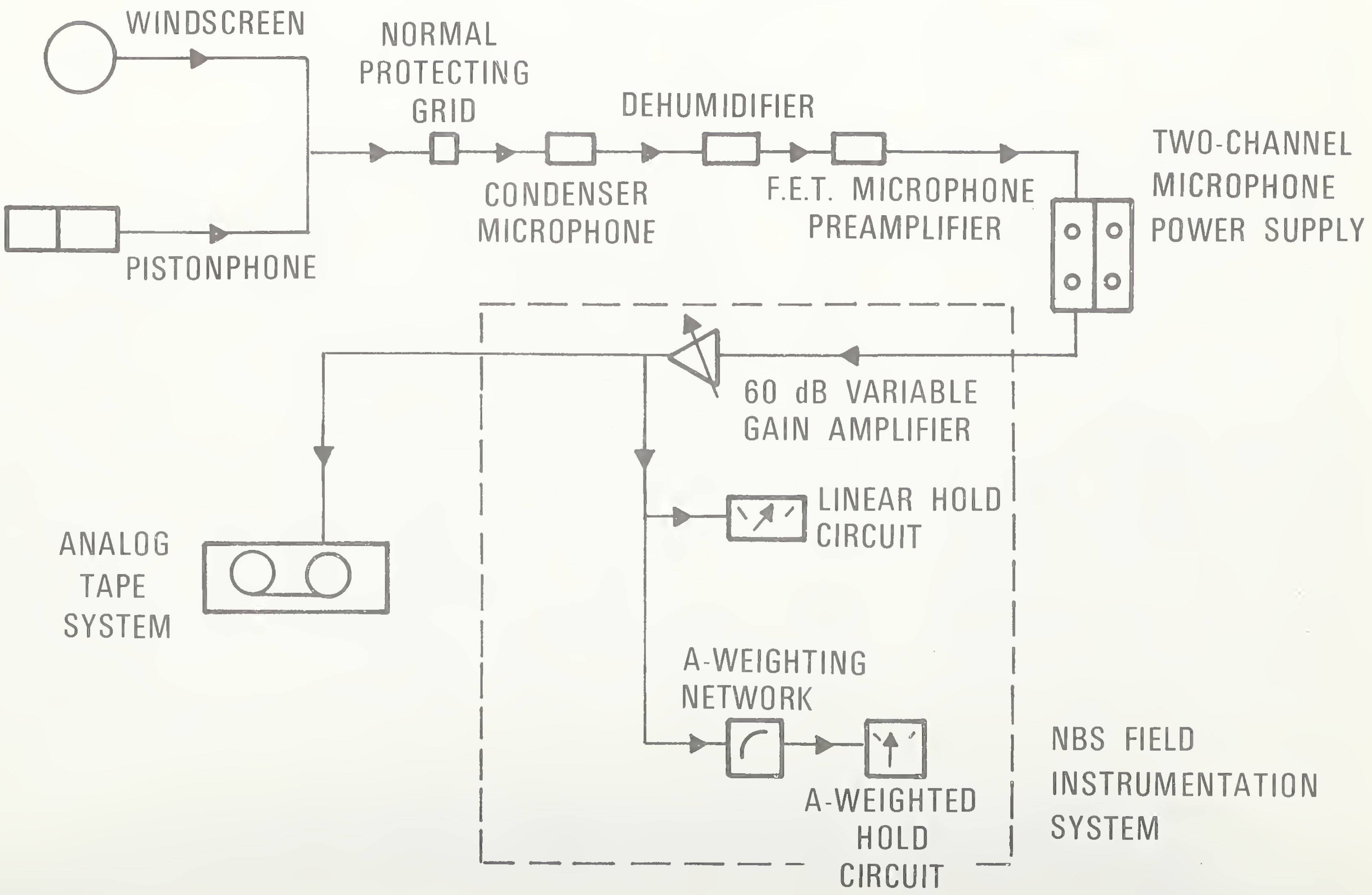

Figure 11. Data acquisition and recording system. Note that only one of the two microphone systems are shown.

Figure 12. Overall view of the microphone array with the test vehicle (concrete test section, Wallops Station site). The array consisted of two tripod-mounted microphones located at 25 and 50 feet (7.6 and 15.2 m) from the centerline of vehicle travel along a line perpendicular to the vehicle path.

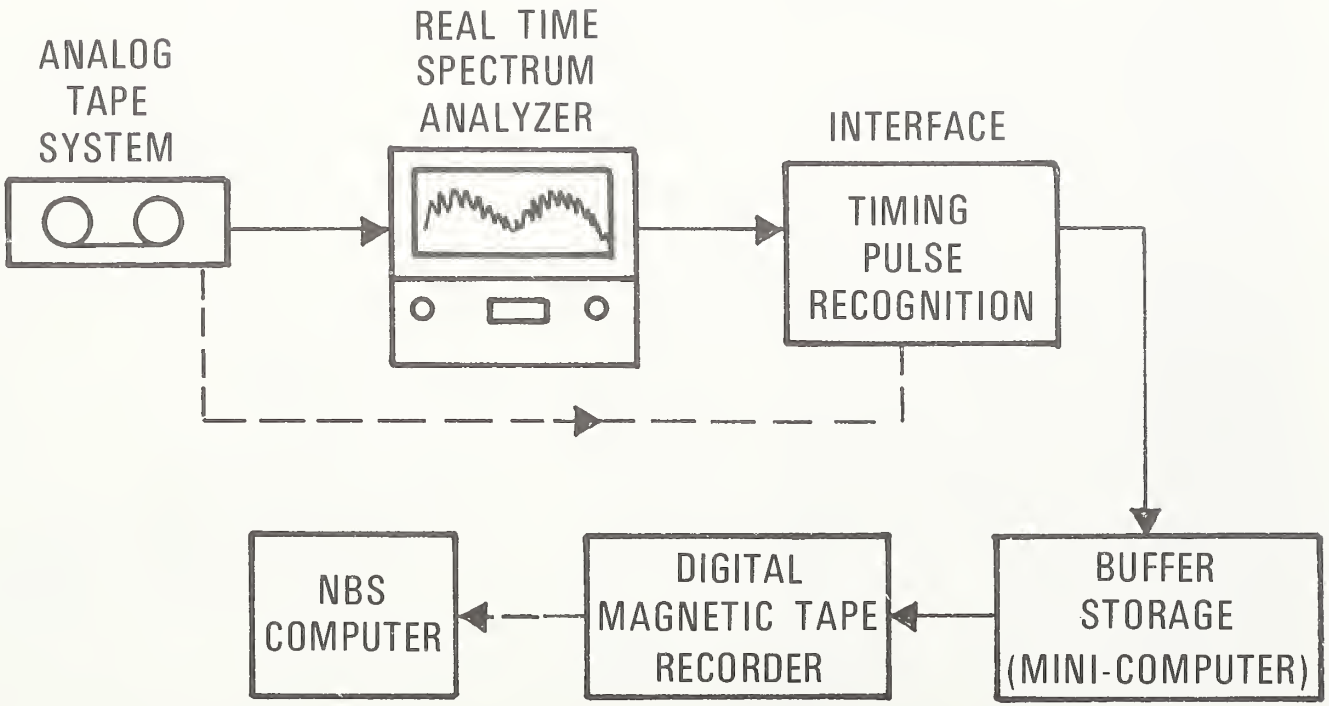

Figure 13. Data reduction and analysis system.

3. Parametric Study: Discussion and Conclusions

The data acquisition phase of this program was designed to address the following questions:

> What is the effect of parameters such as tread design, speed, wear and pavement surface on the noise level of automobile tires?
>
> Are parametric trends for automobile and truck tires similar?
>
> What are the noise generation characteristics of these tires?

In order to develop the data base necessary to answer these questions, the test matrix shown in Table 2 was established. The data acquisition program followed this pre-defined test plan.

For each operational mode, a minimum of two runs was made. The maximum A-weighted sound level data for all test runs are tabulated in Appendix A. Also included are photographs showing characteristic tread design patterns of the test tires and the associated tread depth and rubber hardness. In this section, the data for the 50 foot (15.2 m) microphone location are the basis for summary plots which are presented to show the effect of tread design, speed, wear and pavement surface on the noise levels generated by this sample of automobile tires. Also presented are selected spectral data which provide additional insight into passenger car tire noise as well as a comparison of 25 and 50 foot (7.6 and 15.2 m) measurements with respect to recommending a microphone location for future standards. At present, SAE J57 specifies a 50 foot (15.2 m) distance for truck tires; however, experimenters have found that for passenger car tires under certain combinations of road surface, vehicle speed, and tire tread design, coastby sound levels using a 50 foot (15.2 m) microphone distance (from vehicle path centerline) approach the ambient levels at many test sites. Therefore, in order to improve the signal to noise ratio, some studies have utilized a microphone placed 25 feet (7.6 m) from the centerline of vehicle travel[8].

3.1. Tire Inflation Pressure and Load Effects

For this program the inflation pressure and tire loads were held constant. In the case of truck tires, changes in load were found[1,2,3] to significantly affect the noise level generated by tires with cross-bar (snow tread) tread patterns while noise from tires with rib type tread patterns were relatively unaffected by load changes. However, data reported by Hillquist and Carpenter[8] showed variations of only about 1 dB in A-weighted sound level for bias-belted and radial- belted passenger car tires with continuous rib and discrete block tread patterns over a vehicle weight range of 4700 to 6370 pounds (2132-2889 kg). These weights represented 85-115 percent gross vehicle weight and 75-100 percent of tire load ratings. Later work by Veres[10] also showed changes in sound level

Table 2. Test matrix for the noise evaluation tests of passenger car tires. All conditions marked with an X were measured. A minimum of two test runs were made for each operational condition. The speeds 50, 60 and 70 mph correspond to 80.5, 96.5 and 112.6 km/hr, respectively.

		WALLOPS STATION						CARLISLE		
		CONCRETE			ASPHALT			CONTINUOUS POURED REINFORCED CONCRETE		
TREAD DESIGN	DEGREE OF WEAR	50 MPH	60 MPH	70 MPH	50 MPH	60 MPH	70 MPH	50 MPH	60 MPH	70 MPH
Tire-B (Bias-Ply Rib)	New	X	X	X	X	X	X	X	X	X
	Worn	X	X	X	X	X	X	X	X	X
Tire-C (Bias-Belted Rib)	New	X	X	X	X	X	X	X	X	X
	Worn	X	X	X	X	X	X	X	X	X
Tire-D (Radial Rib)	New	X	X	X	X	X	X	X	X	X
	Worn	X	X	X	X	X	X	X	X	X
Tire-E (Radial Snow)	New	X	X	X	X	X	X	X	X	X
	Worn	X	X	X	X	X	X	X	X	X
Tire-F (Bias-Ply Snow)	New	X	X	X	X	X		X	X	X
	Worn	X	X	X	X	X		X	X	X
Tire-G (Bias-Ply Studded Snow)	New	X	X	X	X	X	X	X	X	X
	Worn	X	X	X	X	X	X	X	X	X
Tire-BR (Bias-Ply Rib Retread)	New	X	X	X	X	X	X	X	X	X
	Worn									
Tire-RR (Radial-Ply Rib Retread)	New	X	X	X	X	X	X	X	X	X
	Worn									

to be on the order of 1 dB between minimum (curb weight of the car plus the driver) and maximum (maximum design load as recommended by the Tire and Rim Association) loads -- 4540-6040 pounds (2059-2680 kg).

Another factor that could have an influence on tire noise is tire inflation pressure. A change in tire pressure can be intentionally made or it can occur unintentionally in service as a result of poor maintenance or temperature. Temperature increases, which result in increases in tire pressure, principally occur through heat buildup in the tire caused by flexing and friction during extended driving. Hillquist and Carpenter[8] studied the effect of inflation pressure on A-weighted sound levels by making measurements while the tire inflation pressure was varied over the range 12 to 36 psi (82.7×10^3 - 248.0×10^3 Pa) ($\pm$12 psi around a control pressure of 24 psi) in increments of 4 psi. This was felt to be representative of the range of inflation pressures one is likely to encounter in "normal" driving conditions. The results showed that the noise levels tend to increase with increasing pressure and decrease with decreasing pressure; however, the changes were not found to be significant. Until a change of $\pm$8 psi from the control pressure was achieved, differences between the passby noise levels at the control pressure and the test pressure were less than 1 dB. Further pressure changes resulted in little or no additional changes in passby noise levels.

3.2. Speed, Tread Design and Road Surface Effects

It is difficult to distinguish clearly among the effects of speed, tread design and road surface. Data are typically presented as maximum A-weighted sound level versus speed, with tread design and road surface as parameters.

Hillquist and Carpenter[8] and Veres[10] report increases in A-weighted sound level on the order of 8-18 dB for passenger car tires as the speed increases from 40-70 mph (64.4-112.6 km/hr). This corresponds to sound level increasing as the third to fourth power of speed. The data from this study shows similar trends with increases on the order of 5-7 dB for speed changes from 50-70 mph (80.5-112.6 km/hr); with the range of data being 3-8 dB (see Figures 14-16). Richards[9] compared the A-weighted sound level versus speed for a coastby with the microphone located 25 feet (7.6 m) from the centerline of vehicle travel and for the identical tire with one wheel of the automobile on a smooth, highly damped dynamometer roll in a semi-anechoic room. As can be seen in Figure 17, the 40 log velocity relationship provides a reasonable fit to both sets of data.

Tread design is not as significant a factor in passenger car noise as it is for trucks since most passenger car tires utilize rib-type tread patterns -- either continuous rib or discrete blocks. Hillquist and Carpenter[8] report that discrete block tread patterns, typical with radial-ply carcasses, tend to be slightly noisier than continuous rib tread

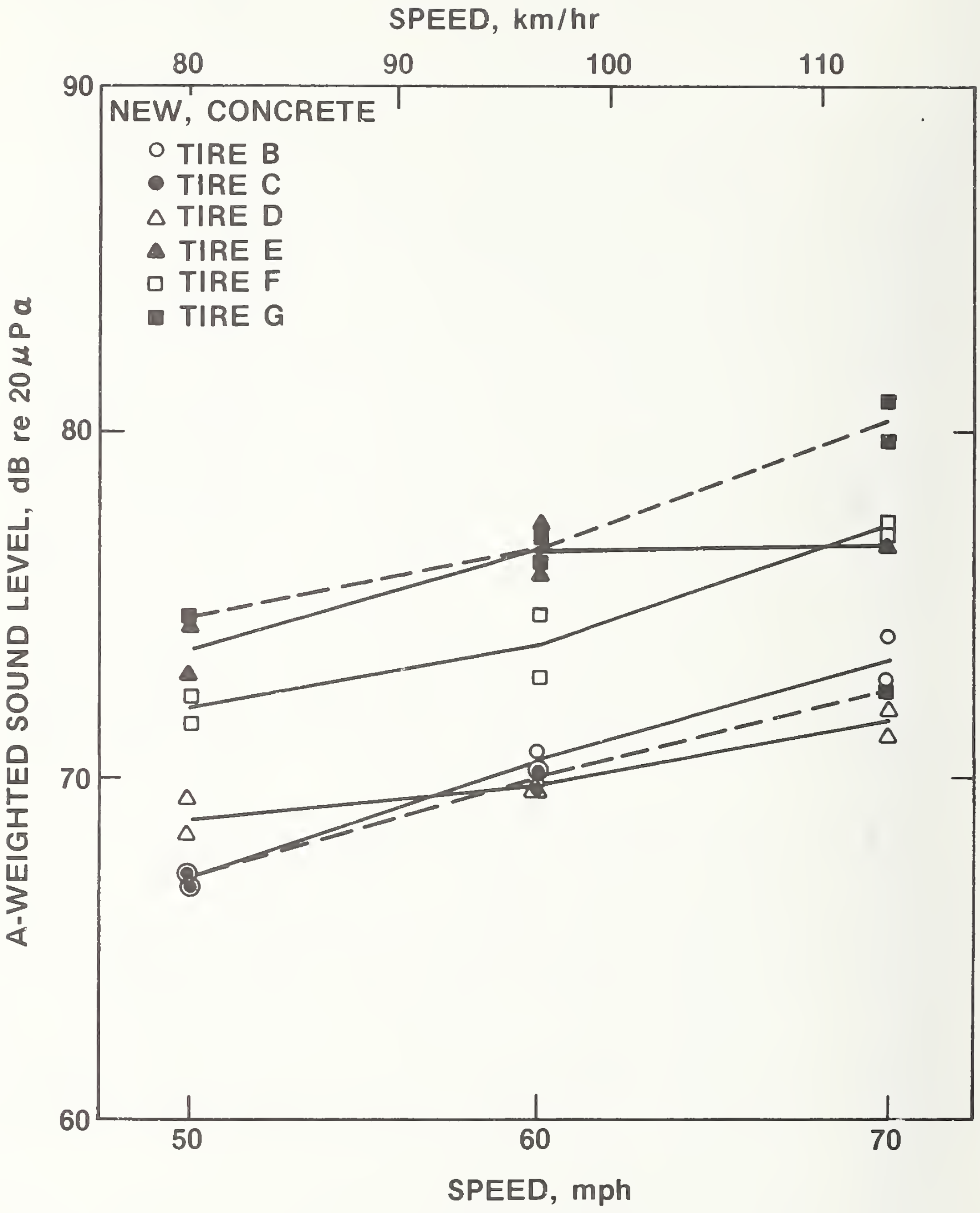

Figure 14. Maximum A-weighted sound level, as measured at 50 feet (15.2 m), versus speed for a loaded vehicle coast-by on a concrete surface. Various types of new tires were mounted on the rear axle of the automobile.

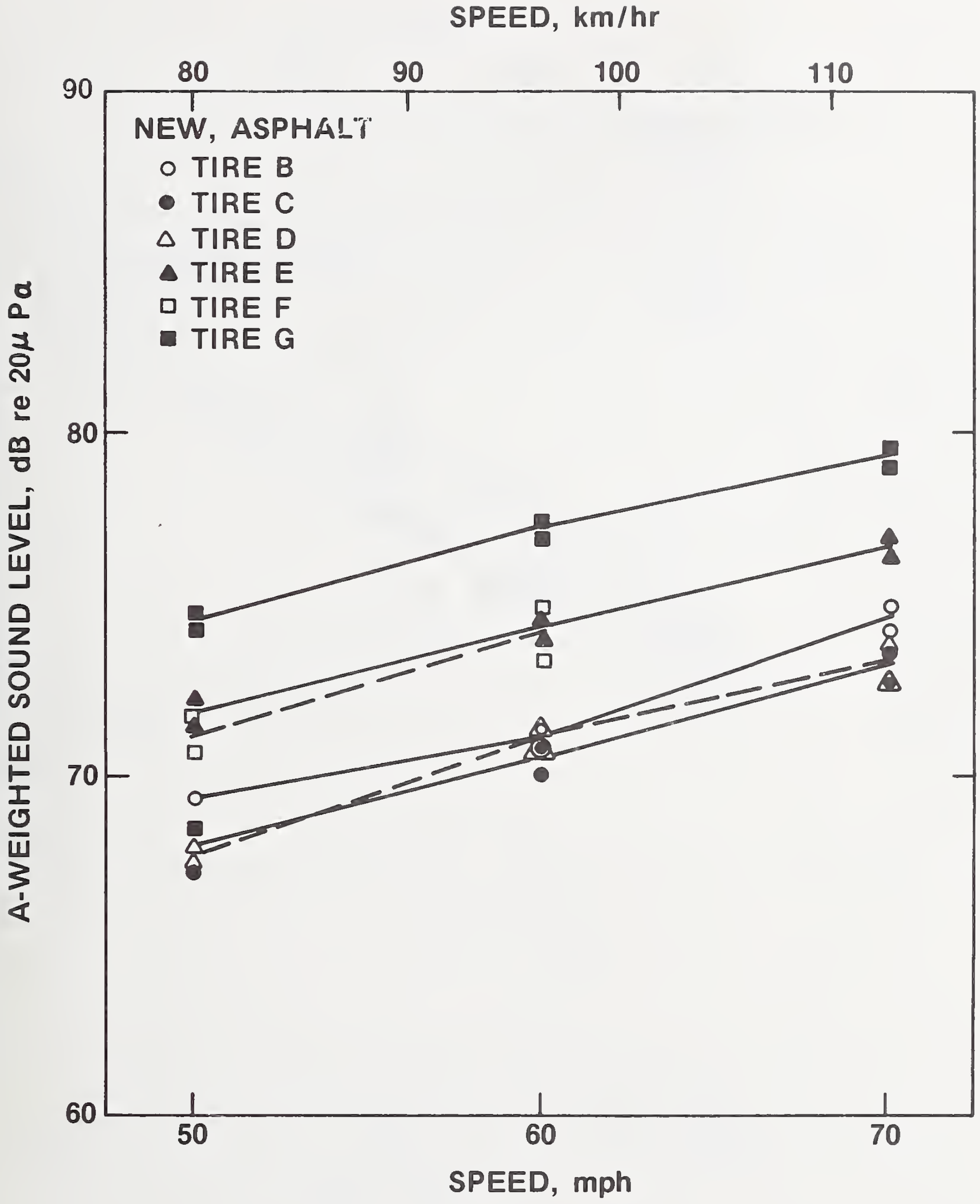

Figure 15. Maximum A-weighted sound level, as measured at 50 feet (15.2 m) versus speed for a loaded vehicle coast-by on an asphalt surface. Various types of new tires were mounted on the rear axle of the automobile.

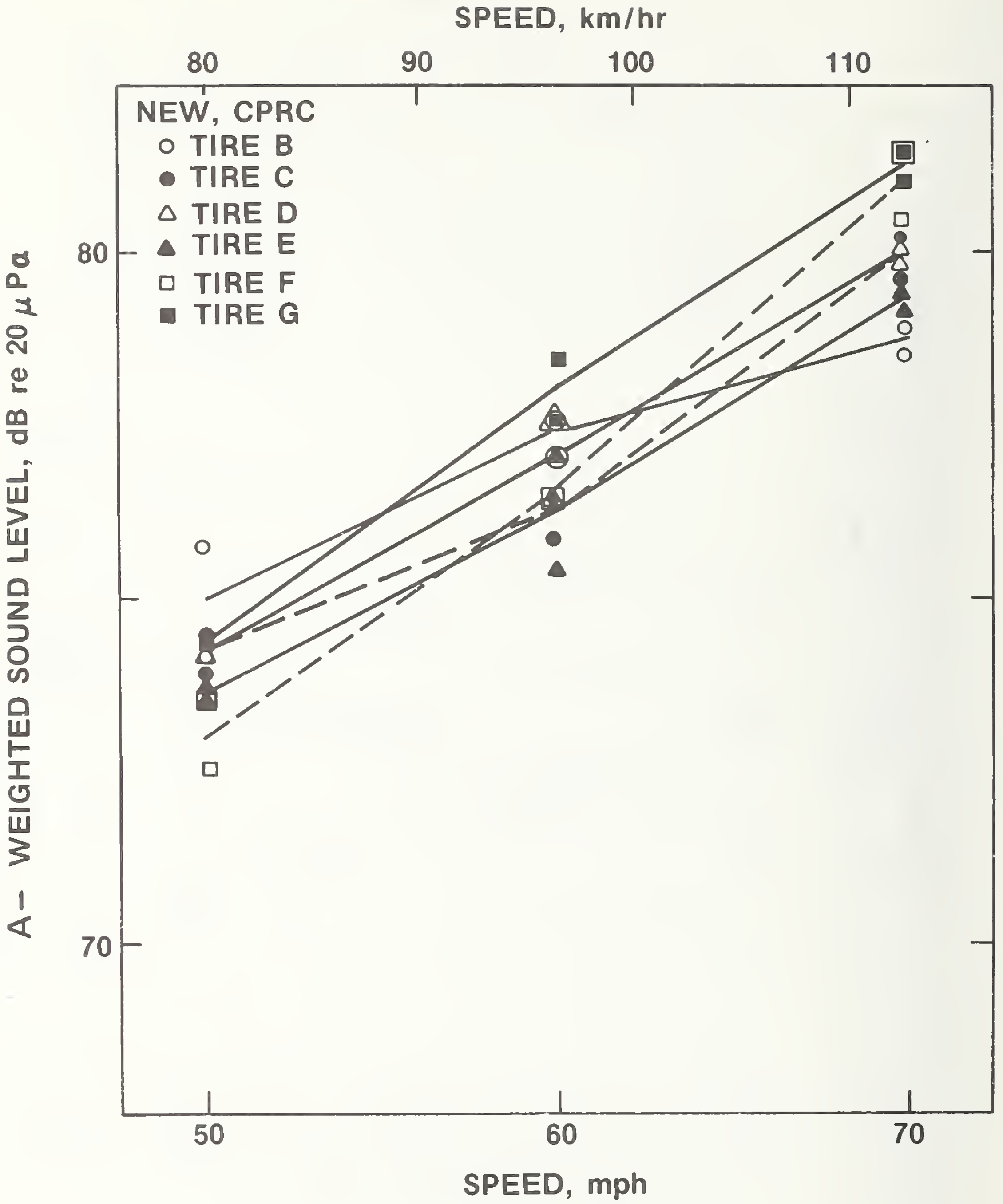

Figure 16. Maximum A-weighted sound level, as measured at 50 feet (15.2 m), versus speed for a loaded vehicle coast-by on a continuous poured reinforced concrete surface. Various types of new tires were mounted on the rear axle of the automobile.

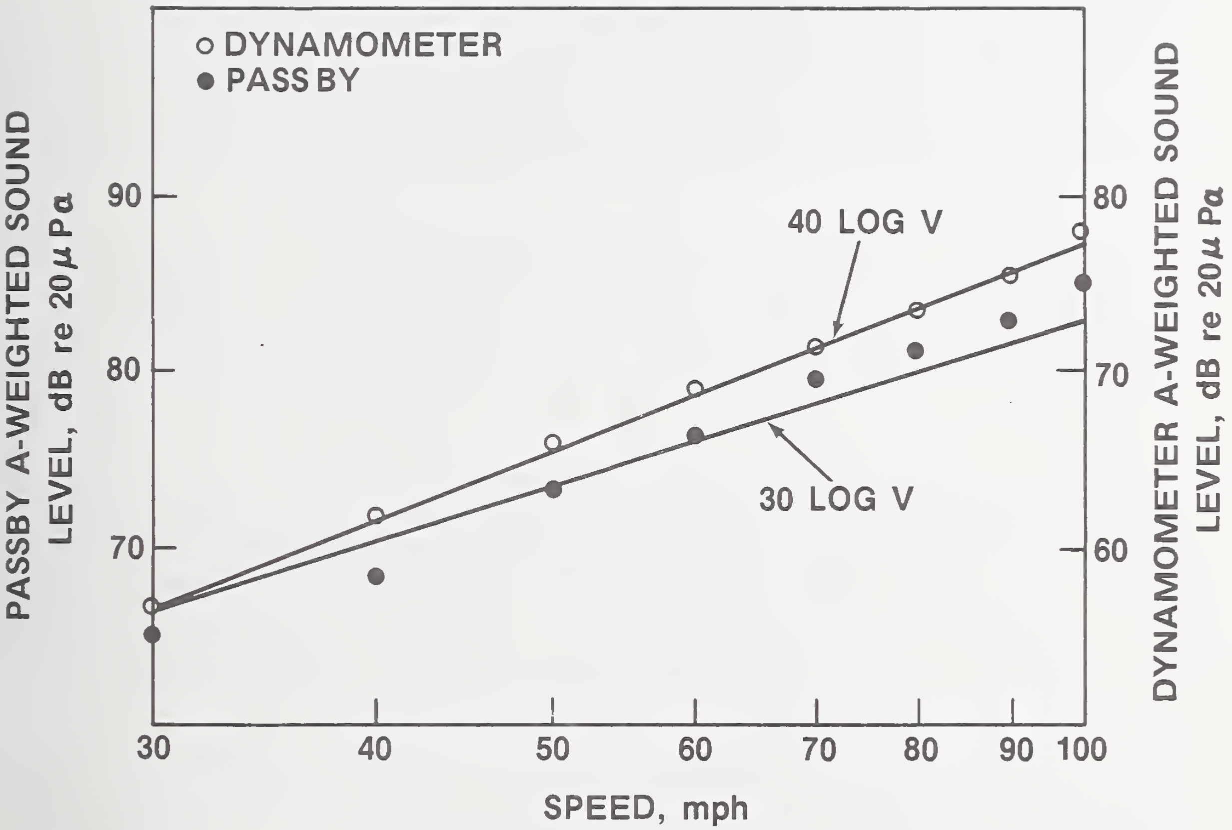

Figure 17. A comparison of the A-weighted sound level versus speed for a coast-by with the microphone located 25 feet (7.6 m) from the centerline of vehicle travel and for the identical tire with one wheel of the automobile on a smooth, highly damped dynamometer roll in a semi-anechoic room[9].

patterns. As could be predicted on the basis of truck tire noise data, the highest noise levels are produced by snow tires, which possess cross-bar type tread patterns. In general, the data from this study show the following trends: (1) on the concrete and asphalt surfaces, the tread designs clustered into two groups -- tires-E, -F and -G (radial and bias snow and studded snow tires) were the noisiest with Tires-B, -C and -D (radial, bias and bias-belted rib tires) being quieter, and (2) on the continuous poured reinforced concrete surface, the surface effects appear to completely dominate the effect of tread design. In this case, all the tread designs cluster closely together with little more than 2 dB difference between the tire types over the entire speed range. The plotted data are for new tires; however, the data indicate that there is little difference between the new and worn state for the tires tested (see Figures 19-21, Section 3.3).

It is obvious that road surface conditions can have a strong influence on tire noise levels; however, the road surface does not influence the noise from various tire types in the same way. Normally continuous-rib tread tires tend to produce higher noise levels on rougher road surfaces while cross-bar tread tires tend to produce similar noise levels regardless of the surface. The results of this study also exhibit these trends.

It does appear, however, that road surface can have a much greater effect on the noise of passenger car tires than on truck tires. This is due to the fact that the texture within the tire-road interaction area is on the same scale as the tread element spacing typical of passenger car tires. The scale of interest, which is thought to be important in at least some tire noise source mechanisms, is pavement macrotexture. The macrotexture scale is that appropriate to the overall dimensions of individual stones in the pavement aggregate -- generally of the order of one or two centimeters and less. This phenomena is evidenced by the apparent dominance of road surface as the influencing parameter in the case of the continuous poured reinforced concrete surface -- a lateral drag finished surface which is common on the older sections of the interstate highway system.

3.3. Tread Wear Effects

Tread wear occurs both through natural abrasion under normal operating conditions and through faulty wheel alignment. For truck tires, tread wear was found to be a variable that can greatly affect the sound level generated by tires[1,2,3]. In general, the noise was found to increase and then decrease with increasing tire wear. The actual tread depth at which the maximum noise is generated for any given tread design is not known; however, this maximum usually occurs at or near the half-worn state of tread wear. The physical phenomenon responsible for this behavior is unclear; but, work by Tetlow[2] indicates that change in tread curvature is a significant parameter. Tetlow found that when a new tire is ground down artificially to simulate the tread depth of a worn tire but the tread radius kept the same as for a new tire, there is much less increase in sound level than would be expected under conditions of normal wear. In fact, the sound level is scarcely changed at all from that when new (Figure 18). When both the worn tread depth and tread radius have been simulated artificially, the data obtained have varied, with the sound levels measured for these tires sometimes being very close to those measured for normally worn tires. The difficulty is finding a tire worn in actual over-the-road service that can serve as a model for the grinding of the tire to be artificially worn.

These trends, however, do not appear to hold in the case of passenger car tires. Data from the present study -- Figures 19, 20 and 21 -- show that automobile tire noise either slightly increased or slightly decreased as the tires wore, but the changes were not significant. With the exception of the studded snow tire on a concrete surface (an increase of 4 dB was observed in the noise level between the new and half-worn states of tread depth), the noise levels for the sample of tires tested in the half-worn state of tread depth were within 2 dB of the levels measured when the tires were new. The maximum sound level increases were observed for tires running on the concrete surface. It should be noted that these test tires were worn in actual service. Therefore, it appears that tread wear is not as significant a parameter for automobile tires as it is for truck tires.

This conclusion is further substantiated by the data of Hillquist and Carpenter[8]. They utilized both service worn tires and mechanically worn tires which were run in for about 100 miles prior to testing. They report -- for continuous- rib, discrete block and blank (full tread depth but no tread pattern) tread designs -- that for both naturally and artificially worn tires, passby noise levels increased on the order of 2 dB between the new (full tread depth) and half-worn state of tread wear. As wear increased, no further increase in sound level was noted.

It should be pointed out that this appears to be the first citation in the literature of any success with simulation of tire wear through artificial buffing techniques. No details were provided as to how this was achieved; that is, how the appropriate tread depth and tread radius were selected. The influence of tread curvature appears to be more important for cross-bar type tread designs which were not investigated in the Hillquist and Carpenter study. This could explain the success of the buffing technique in this case.

The relationship between tread depth and tread wear and the effect on generated tire noise should be further investigated so that the data necessary to allow the prediction of tire noise levels at various stages of wear based on measurements made utilizing artificially worn tires can be provided. This is an extremely important factor if tire noise regulations are promulgated. From a certification standpoint, one is primarily interested in that state of tire wear that results in the maximum noise level for that particular tire type. Without the aid of a predictive model, it would be necessary to develop a curve of noise level versus tread depth so that the maximum noise level that could be expected for a given tread design, or a class of tread patterns, could be identified -- a costly and time-consuming process.

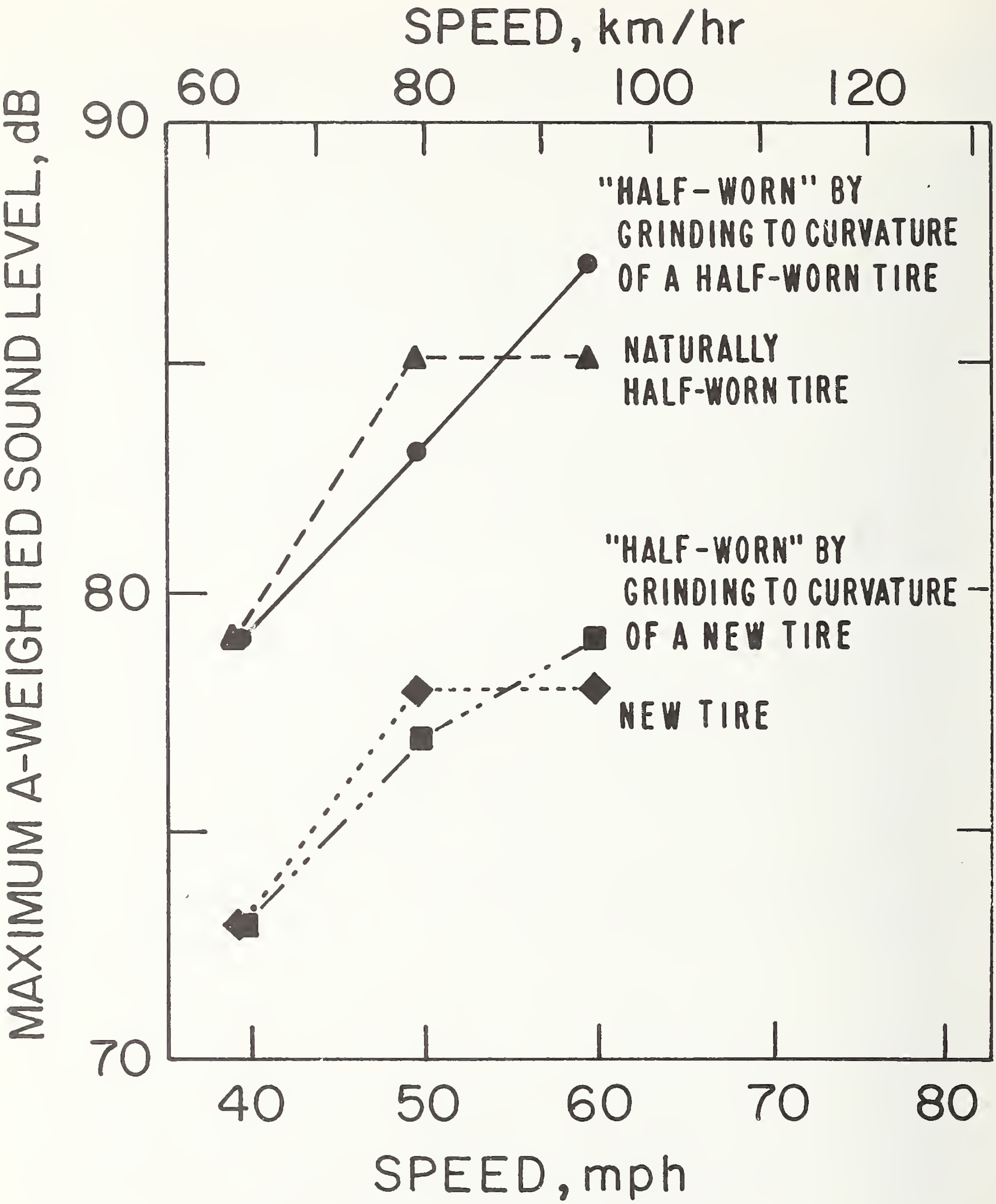

Figure 18. The effect of tread curvature on tire noise for a typical cross-bar tire when (1) new, (2) "half-worn" by grinding to curvature of a half-worn tire, (3) "half-worn" by grinding to curvature of a new tire, and (4) naturally half-worn tire[2].

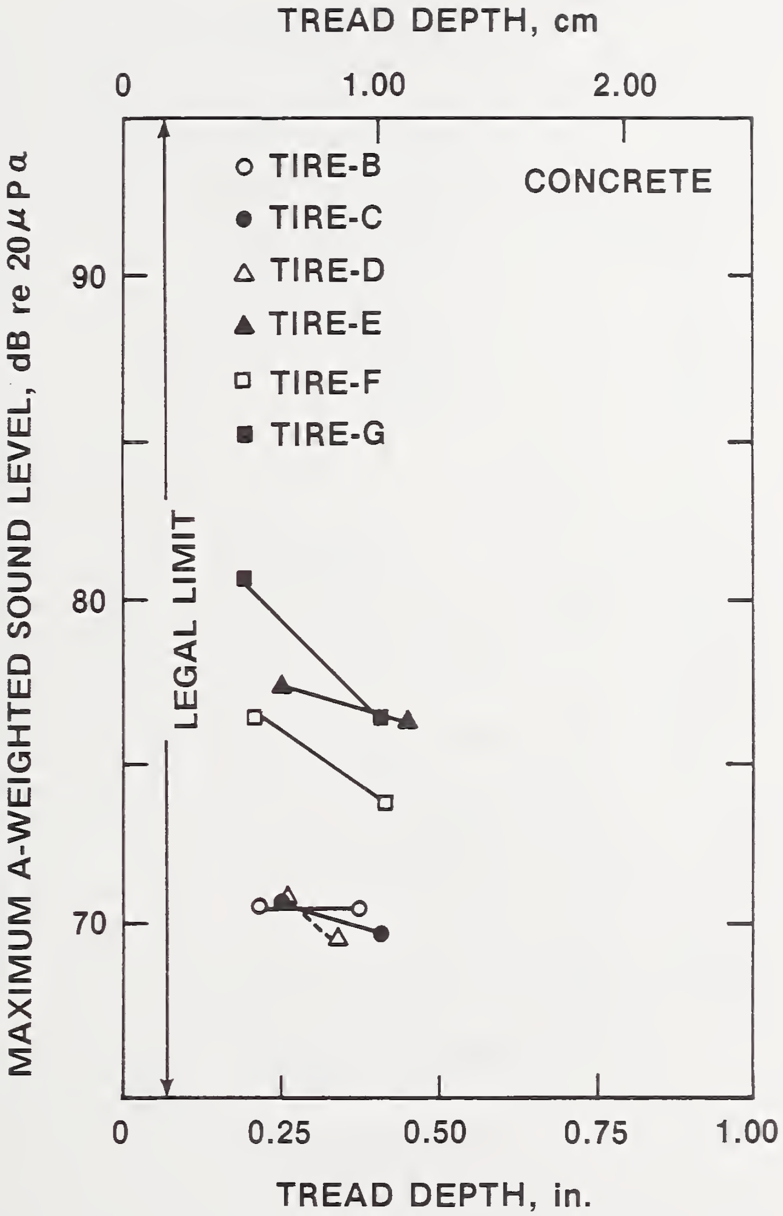

Figure 19. Maximum A-weighted sound level, as measured at 50 feet (15.2 m) versus wear for a loaded vehicle coast-by on a concrete surface. Various types of tires were mounted on the rear axle. Vehicle speed was 60 mph (96.5 km/hr).

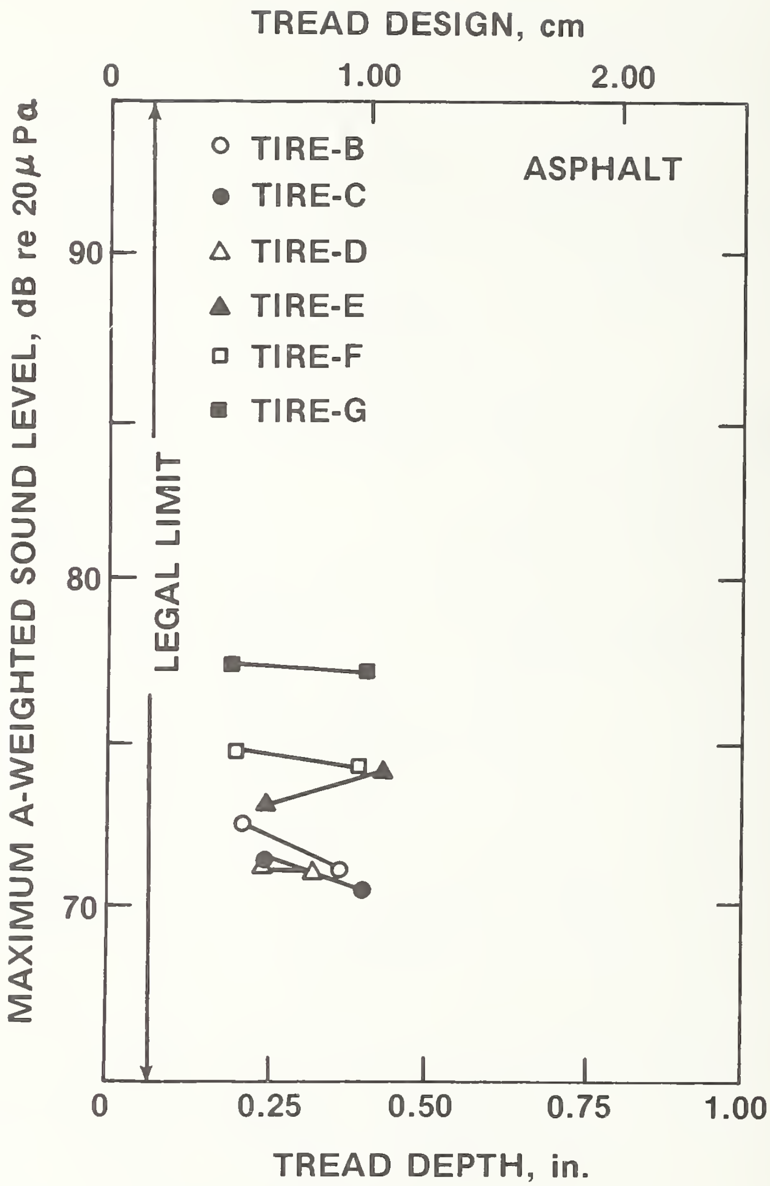

Figure 20. Maximum A-weighted sound level, as measured at 50 feet (15.2 m) versus wear for a loaded vehicle coast-by on an asphalt surface. Various types of tires were mounted on the rear axle. Vehicle speed was 60 mph (96.5 km/hr).

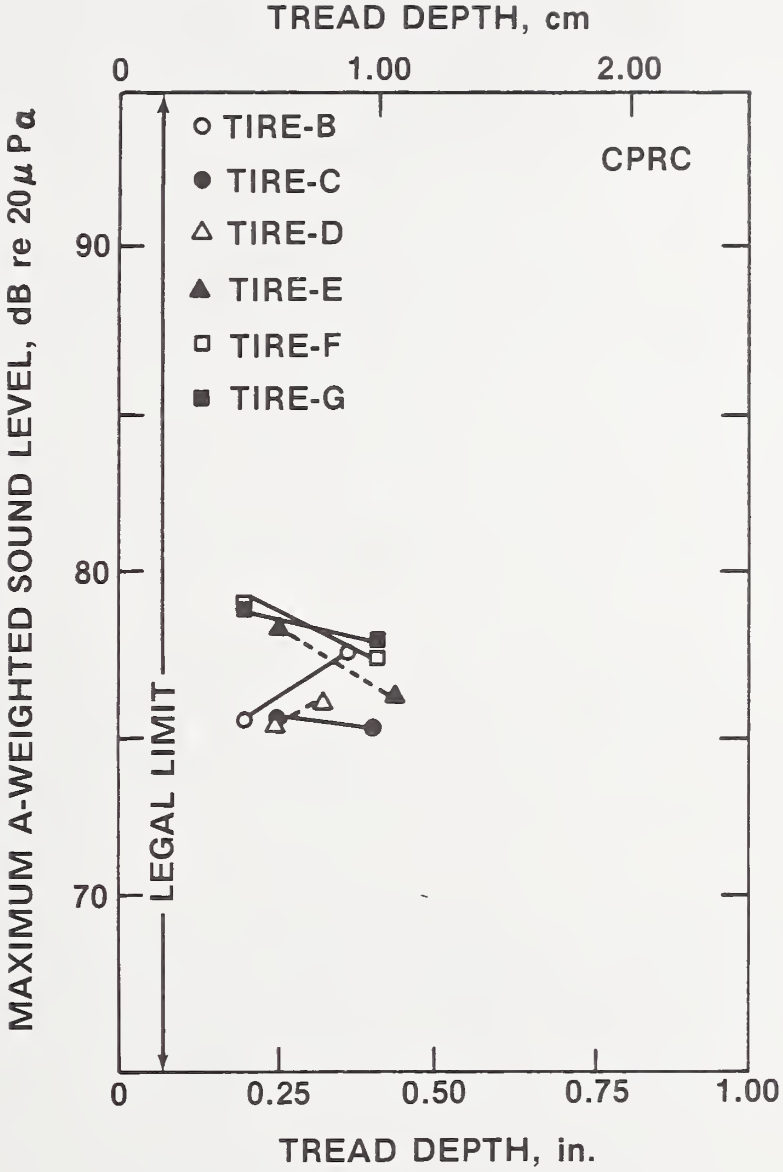

Figure 21. Maximum A-weighted sound level, as measured at 50 feet (15.2 m) versus wear for a loaded vehicle coast-by on a continuous poured reinforced concrete surface. Various types of tires were mounted on the rear axle. Vehicle speed was 60 mph (96.5 km/hr).

Although a break-in period has been utilized by tire researchers prior to making noise measurements, the length of the break-in period has varied. Veres[10] investigated this problem and his results are shown in Figure 22. He made tire noise measurements when the tires were new and at mileage intervals of 50, 100, 150, 200, 300, 400, 500, 750 and 1000 miles (80.5, 160.9, 241.4, 321.8, 482.7, 643.6, 804.5, 1206.8 and 1609 km). The data show that after approximately 200 miles (321.8 km), the noise level stabilized and did not vary significantly up to 1000 miles (1609 km). No other data of this nature has been found in the literature.

3.4. Effect of Carcass Construction

As discussed in Section 2.2., the question had been raised as to whether radial-ply tires were noisier than tires of bias-ply or bias-belted construction. In order to isolate the effect of carcass construction from the effect of tread design, an attempt was made to locate tires with identical tread patterns of each of the three carcass types. Such tires could not be located; therefore, NBS purchased a set of new bias-ply (G78-15) and radial-ply (GR78-15) tires, had the existing tread buffed off and had the tires retreaded with identical rib tread patterns (see Appendix A for a photograph of tread pattern). These experimental test tires are identified as tire-BR (bias-ply retread) and tire-RR (radial-ply retread) in the test matrix (see Table 2).

The A-weighted sound level data for these tires are shown in Table 3. The data are as measured at the 50 foot (15.2 m) microphone location for a vehicle speed of 60 mph (96.5 km/hr). One-third octave band spectral data for the identical test conditions are shown in Figures 23, 24 and 25 corresponding to tests on the concrete, asphalt and continuous poured reinforced concrete surfaces, respectively.

On the basis of this limited experiment, the data indicate that, in general, the bias-ply tires exhibit the higher noise levels. This was the case in all but three of the eighteen test runs. The differences in maximum A-weighted sound level were always less than 3 dB and in one-half of the cases, 1 dB or less. The fact that many people consider radial-ply tires to be noisier is probably attributable to the following two reasons. First, the tread patterns typically found on radial-ply tires are more "aggressive" -- more like a snow tire than a summer tire -- than conventional rib tread patterns typically utilized on tires of bias- ply or bias-belted construction. Second, the rubber grommets in an automobile suspension tend to attenuate vibrations above 100 Hz. As reported by Potts[12] for H78-15 tires, all the resonances of bias-ply and bias-belted tires lie above this cutoff frequency, therefore, minimal transmission into the automobile of road disturbances occurs. However, in the case of a radial tire, the first three modes are below 100 Hz. The radial tire demonstrates a proliferation of radial resonant frequencies and strong low level resonances which promote direct passage of sharp disturbances into the automobile chassis.

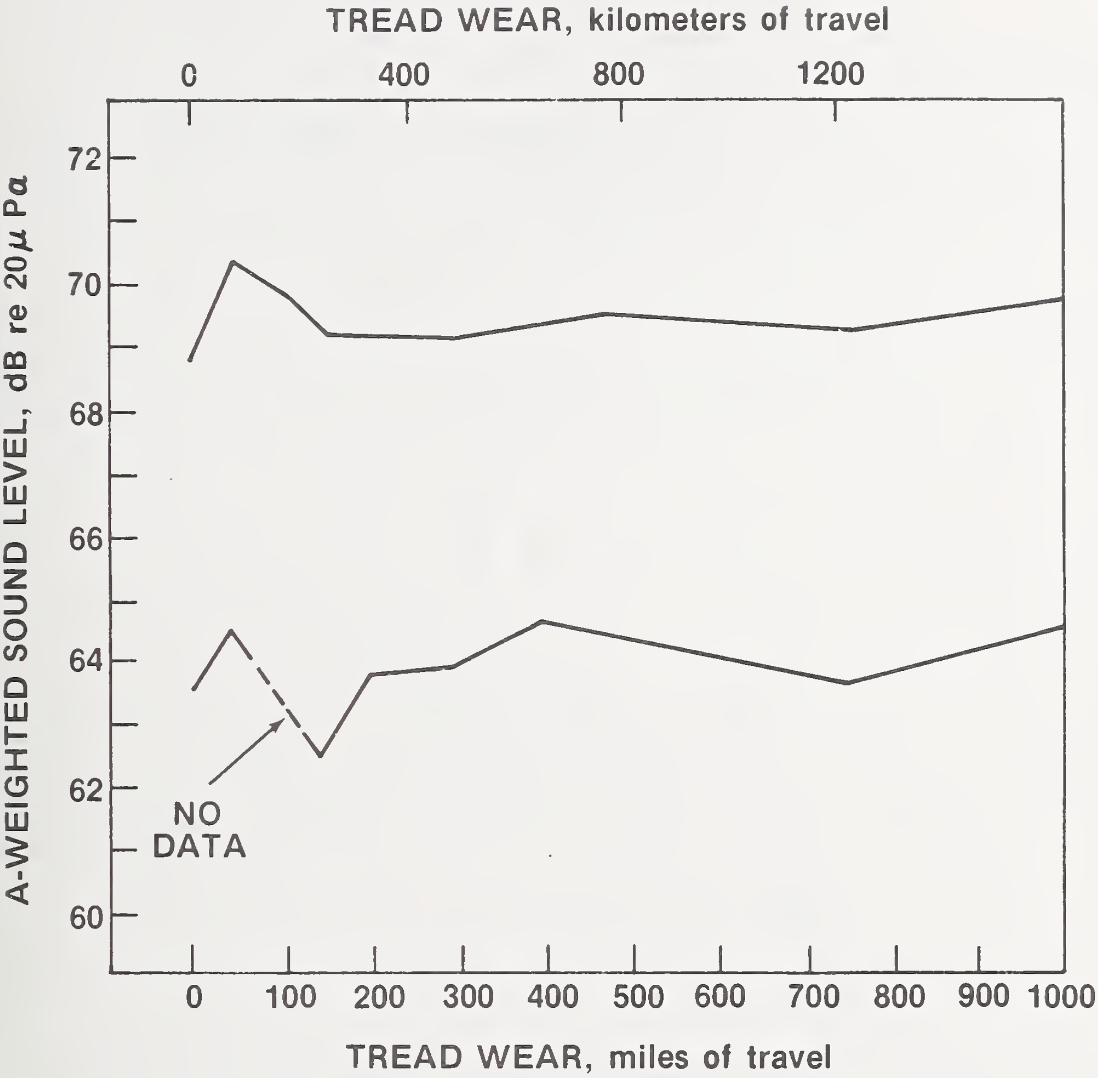

Figure 22. Results of an investigation of the effect of tread wear on the A-weighted sound level during the initial 1000 miles (1690 km) of travel. Vehicle speed was 40 mph (64.4 km/hr). Surface was concrete[10].

Table 3. Maximum A-weighted sound level (in dB re 20 μPa) as measured at 50 feet (15.2 m) for test runs at 60 mph (96.5 km/hr) on a concrete, asphalt and continuous poured reinforced concrete (CPRC) surface. The test tires had bias-ply and radial-ply carcass constructions with identical rib tread patterns.

TIRE TYPE	SPEED MPH (km/hr)	PAVEMENT SURFACE					
		CONCRETE		ASPHALT		CPRC	
Bias-Ply	50 (80.5)	65.8	67.0	68.4	68.2	73.4	73.4
	60 (96.5)	71.0	70.4	72.8	70.0	76.6	77.0
	70 (112.6)	71.6	72.4	73.2	73.4	79.8	78.8
Radial-Ply	50 (80.5)	67.6	67.2	66.4	66.4	72.6	72.2
	60 (96.5)	69.8	70.0	70.6	69.2	76.2	75.8
	70 (112.6)	72.0	71.8	72.6	72.4	77.2	76.2

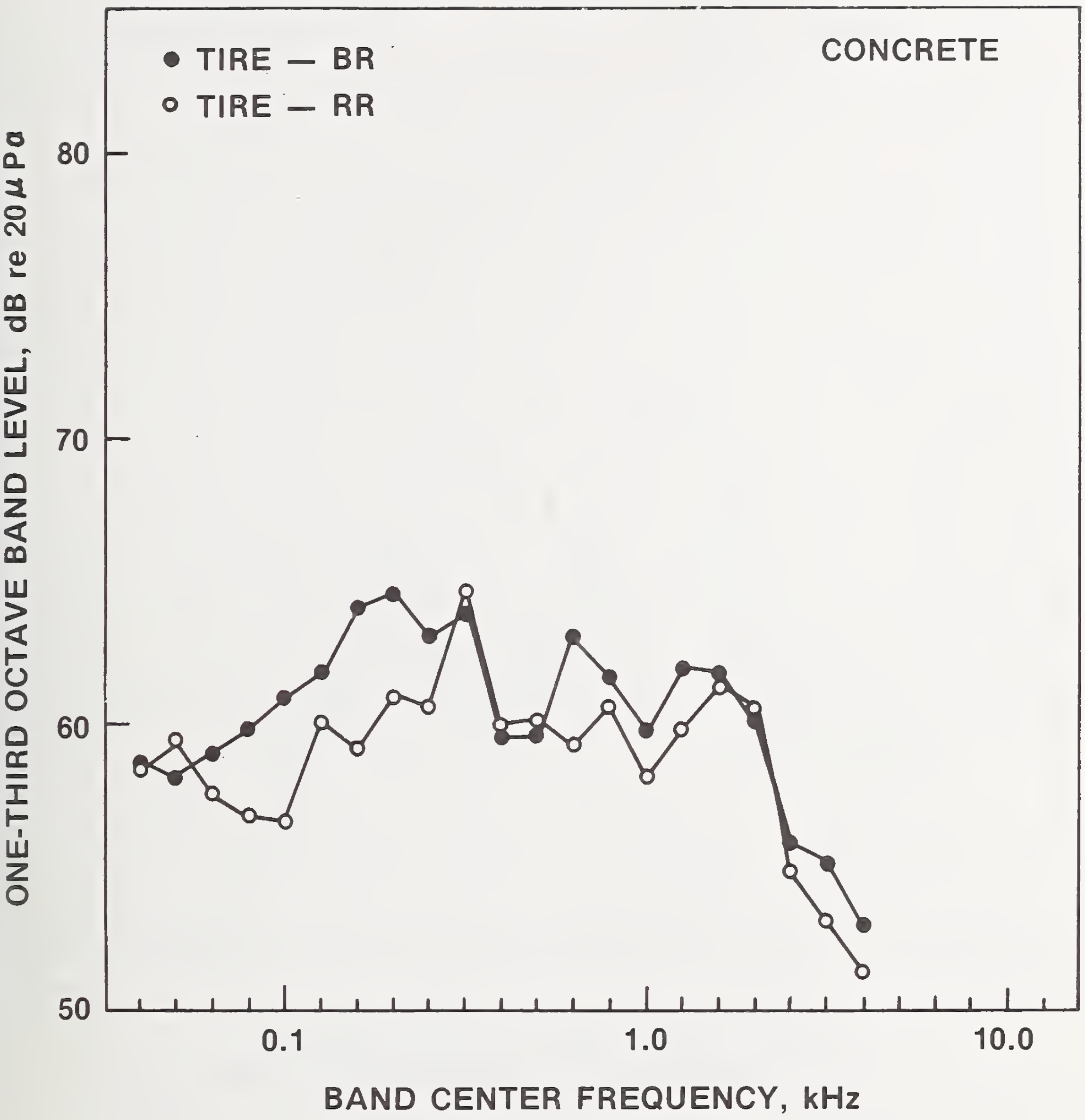

Figure 23. One-third octave band frequency spectra for tires BR and RR as measured at 50 feet (15.2 m). The vehicle was loaded and operated in a coast-by mode at a speed of 60 mph (96.5 km/hr) while running on a concrete surface. [A-weighted sound levels: tire-BR, 71.0 dB; tire-RR, 69.8 dB.]

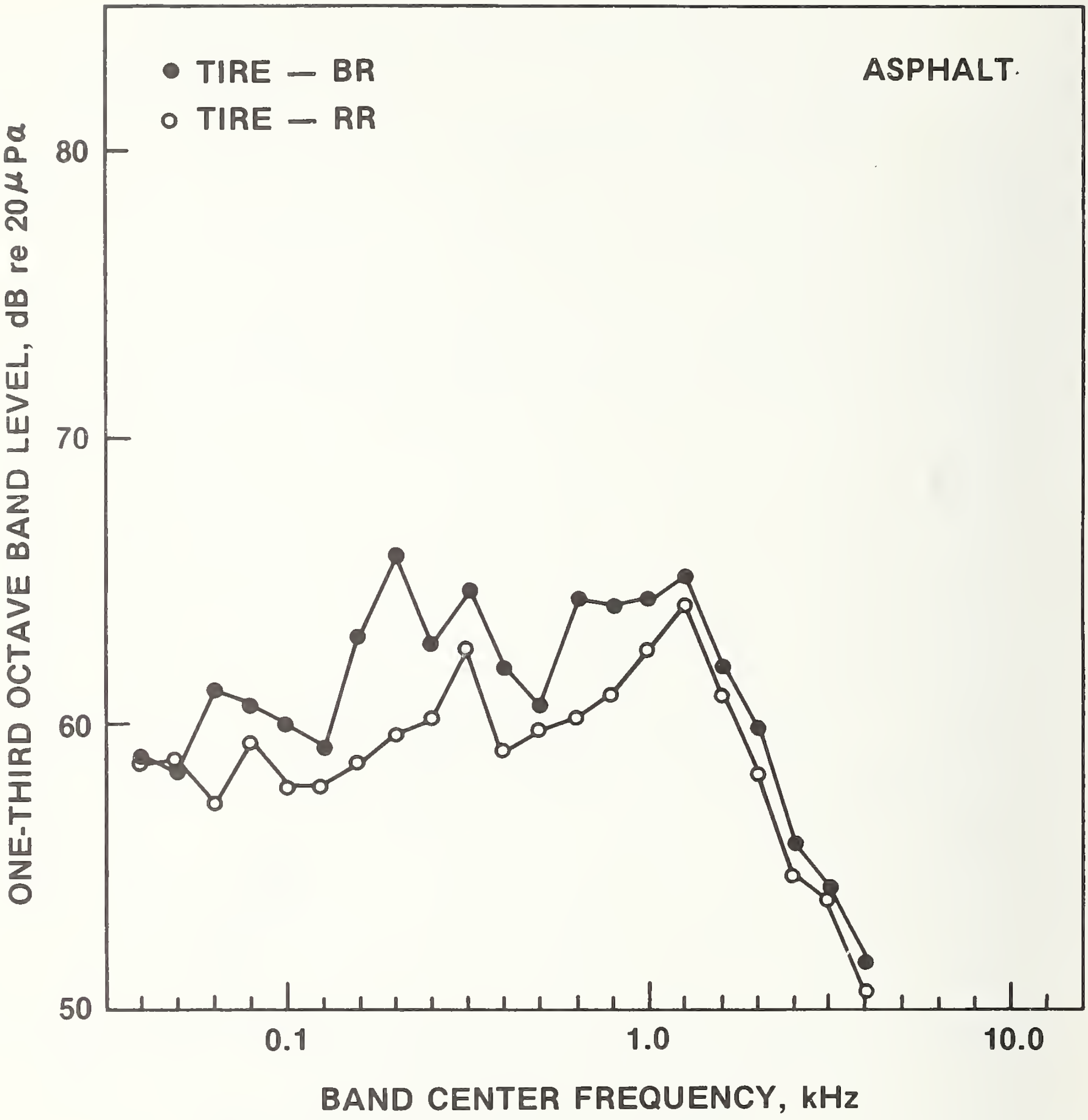

Figure 24. One-third octave band frequency spectra for tires BR and RR as measured at 50 feet (15.2 m). The vehicle was loaded and operated in a coast-by mode at a speed of 60 mph (96.5 km/hr) while running on an asphalt surface. [A-weighted sound levels: tire BR, 72.8 dB; tire-RR, 70.6 dB.]

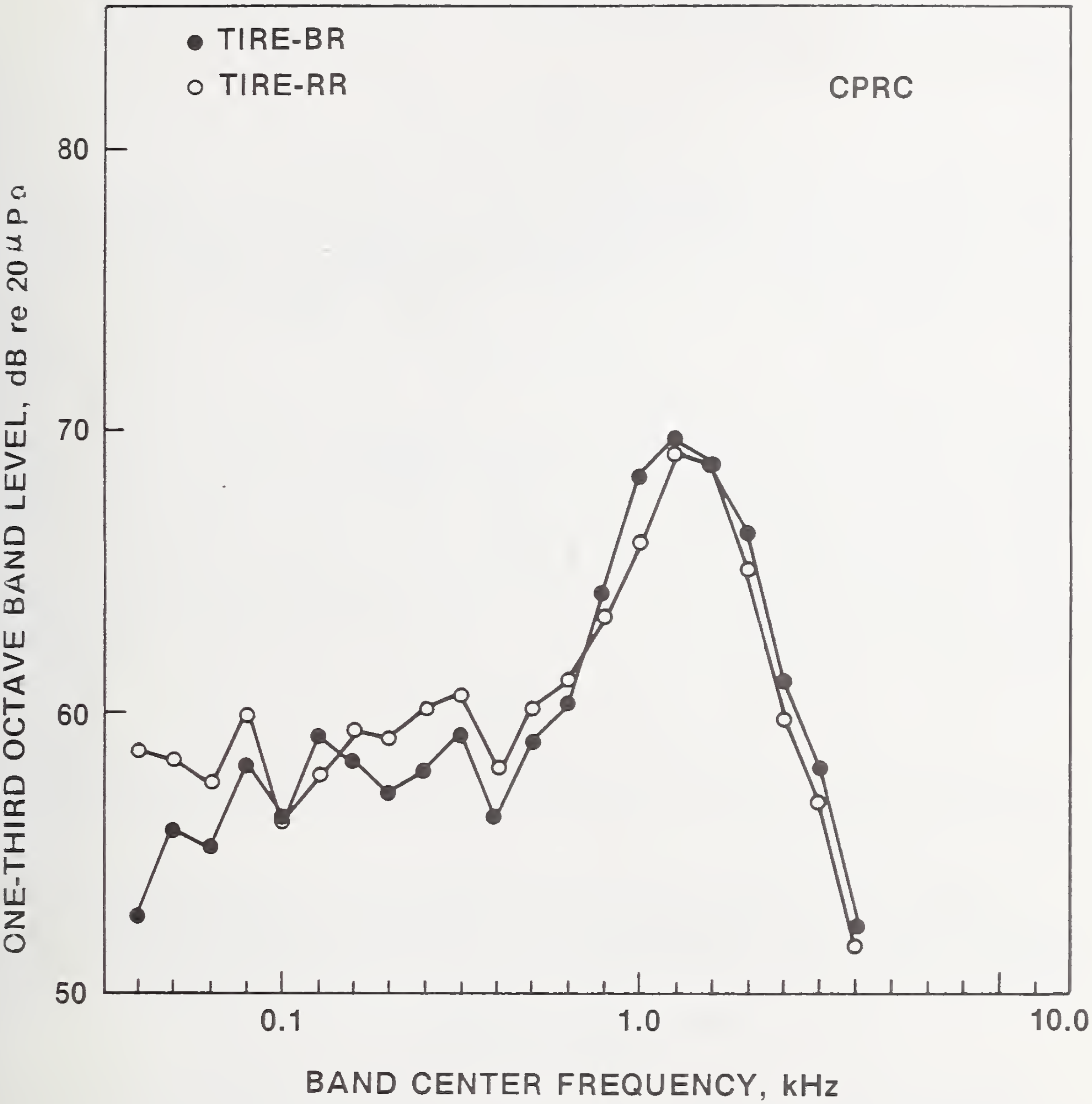

Figure 25. One-third octave band frequency spectra for tires BR and RR as measured at 50 feet (15.2 m). The vehicle was loaded and operated in a coast-by mode at a speed of 60 mph (96.5 km/hr) while running on a continuous poured reinforced concrete (CPRC) surface. [A-weighted sound levels: tire-BR, 7616 dB; tire-RR, 76.2 dB.]

3.5. Miscellaneous Effects

The parameters discussed in this subsection were not investigated in the present study; however, for completeness, the findings of other researchers are discussed.

a. Number of Plies

Yurkovski, et al[13] report that using two plies rather than four slightly increases the noise level. They speculated that this is due to lower hysteresis losses in the tires as a result of the lower rubber content, and consequently the high-frequency vibrations caused by obstacles in the road are damped by the tires to a lesser extent.

b. Tire Reinforcing Fabric

Wiener[14] tested tires of various construction and observed a remarkable constancy of the tire noise spectrum and level with respect to changes in the fiber material of the tire reinforcing fabric, e.g., nylon, rayon, etc., for a given set of operating conditions. Figure 26 shows two spectra obtained on a rough road at 50 mph (80.5 km/hr) for tires containing two different synthetic fibers in their reinforcing fabric. The differences in the noise levels shown may be significant, especially those in the frequency region around 500 Hz. Figure 27 shows similar results obtained on a smooth road.

c. Tire Dimensions

Hillquist and Carpenter[8] investigated two aspects of tire dimensions; namely, overall size and aspect ratio (tire sectional height/sectional width).

No significant differences in A-weighted sound levels were observed for tests utilizing 14 and 15 inch tires with the same tread pattern. However, coastby noise levels increased approximately 2 dB when low aspect ratio (e.g., "wide oval") tires were compared with more conventional tires.

d. Wet Road Surface

When it rains, a layer of water is present in the contact area between the tire and the road which affects noise generation. Engler[15] reports that higher A-weighted sound levels and different frequency spectra occur on a wet road and are chiefly due to the additional splash noise. Other European work[16,17] show typical increases in the A-weighted sound level for passenger cars equipped with "summer tires" on the order of 6-10 dB between data for wet roads as compared to dry road surfaces. Spectral data on truck tires[3] show considerable increases in sound pressure level at frequencies above 1000 Hz but little or no increase (0-3 dB) in the A-weighted sound level. No comparable spectral data have been cited in the literature for passenger car tires. It should be noted that evaluation of the quantitative descriptions of the surfaces used for the European studies indicate they are, in general, not typical of those found in the United States.

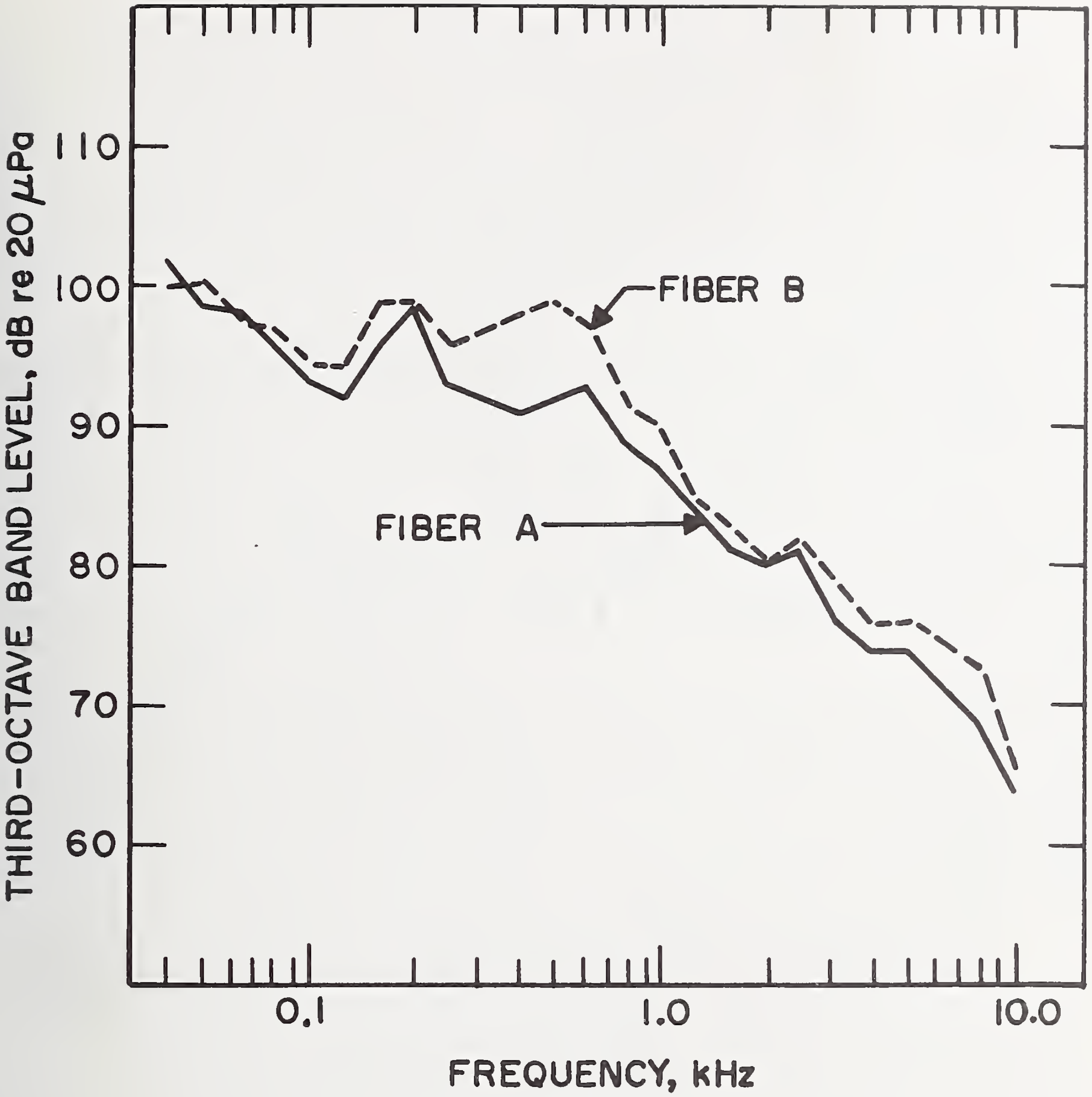

Figure 26. Tire noise spectra at constant speed (50 mph, 80.5 km/hr) on a rough road for two different tire types. The microphone was mounted on the outside of the rear fender of a fully-loaded, full size passenger car[13].

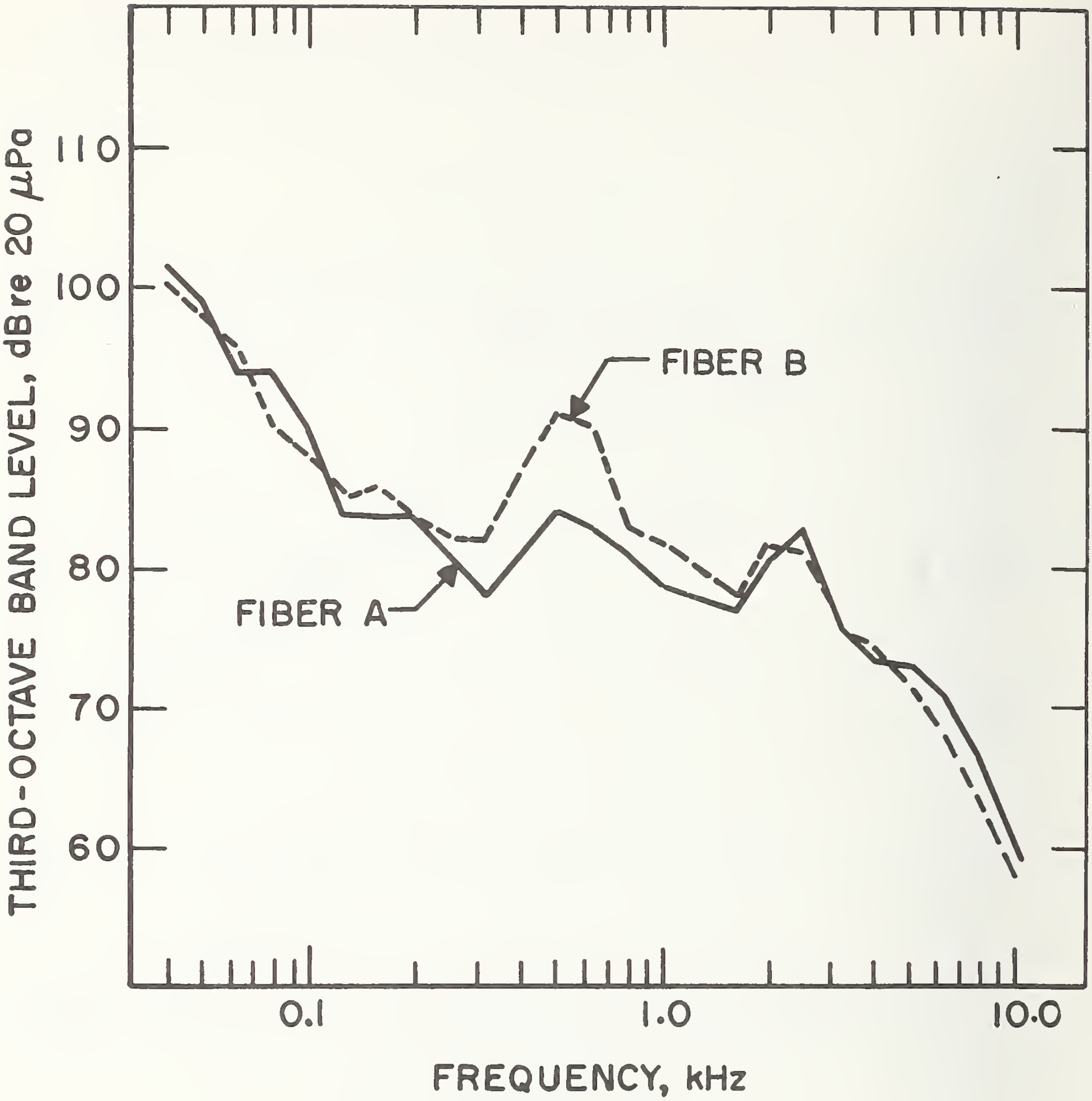

Figure 27. Tire noise spectra at constant speed (50 mph, 80.5 km/hr) on a smooth road for two different tire types. The microphone was mounted on the outside of the rear fender of a fully-loaded, full size passenger car[13].

3.6. Effect of Microphone Location

As noted earlier in Section 3, some researchers have found that under certain combinations of tread design, vehicle speed, and road surface, the sound levels for passenger car tires at 50 feet (15.2 m) were approaching the ambient at many test sites. In order to improve the signal to noise ratio and to take advantage of the fact that the closer to the source the microphone is located, the less influence environmental effects (such as thermal gradients rising from the road surface) can have on the propagation of the sound from source to receiver, some studies have utilized a microphone placed 25 feet (7.6 m) from the centerline of vehicle travel.

Veres[10] investigated the effect of microphone location by making simultaneous measurements at 25 and 50 feet (7.6 and 15.2 m). He observed that the decreases in A-weighted sound level from 25 to 50 feet (7.6 to 15.2 m) averaged 5.8 dB; however, the magnitude of the decrease varied with the tire type and surface texture on which the tires ran. He noted that other researchers have reported a 5.5 dB average decrease in A-weighted sound level between these distances and on the basis of his data, Veres feels that this is probably a good estimate. However, due to the significant standard deviations and the dependency of the decrease on tire type and surface texture, he recommends that if the actual sound level at 50 feet (15.2 m) is desired, it should be measured.

Simultaneous measurements were also made during the present study at microphone distances of 25 and 50 feet (7.6 and 15.2 m) from the centerline of vehicle travel. The decreases in A-weighted sound level from 25 to 50 feet (7.6 to 15.2 m) observed during this study are tabulated in Table 4 (new tires) and Table 5 (half- worn tires). It should be noted that the concrete and asphalt test sites were "hard sites"; that is, a well-defined reflecting surface existed between the automobile and measuring microphones. The continuous poured reinforced concrete test site was a "soft site" -- a combination of hard surface (on which the vehicle operated) and grass between source and receiver. This is the reason that the average differences for the continuous poured reinforced concrete surface are higher than those observed for the concrete and asphalt surfaces. The average decrease (for the hard surface sites only) was approximately 4.9 dB with a range from 4.5-5.2 dB, lower than the average observed by Veres. In general, the rank ordering of the tires according to noise level would be the same at either 25 or 50 feet (7.6 or 15.2 m) even though the prediction from 25 to 50 feet (7.6 to 15.2 m) or vice versa cannot be accurately predicted for any given set of tires for a particular set of operating conditions.

Table 4. Decrease in A-weighted sound level (in decibels re 20 μPa) from 25 to 50 feet (7.6 to 15.2 m) observed for new test tires running over a concrete, asphalt and continuous poured reinforced concrete surface. The speeds 50, 60, and 70 mph correspond to 80.5, 96.5, and 112.6 km/hr, respectively.

TIRE TYPE (NEW)	CONCRETE						ASPHALT						CONTINUOUS POURED REINFORCED CONCRETE					
	50 MPH		60 MPH		70 MPH		50 MPH		60 MPH		70 MPH		50 MPH		60 MPH		70 MPH	
	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2
B	5.4	4.0	4.0	3.8	5.2	4.2	4.6	4.8	4.0	6.0	4.8	4.8	5.6	7.6	6.4	6.0	6.6	7.8
C	4.2	4.6	4.6	5.2	3.8	6.0	5.6	4.0	3.8	6.0	4.8	4.4	5.6	7.0	6.4	7.4	7.2	6.2
D	4.2	4.6	5.0	6.0	4.6	5.0	4.8	6.0	4.6	4.4	5.4	4.8	5.4	7.4	7.8	5.8	6.6	7.2
E	3.8	5.8	2.8	3.8	4.6	4.6	4.6	5.6	5.2	5.4	7.4	4.8	5.8	5.4	5.2	7.6	6.8	6.6
F	4.0	4.8	6.2	3.6	5.0	4.0	4.6	5.6	4.6	4.0	---	---	7.2	6.2	5.0	5.6	5.8	5.8
G	4.8	4.4	5.8	4.8	3.2	5.6	5.2	4.4	4.0	5.2	4.8	5.8	5.1	5.6	4.4	5.6	6.2	5.2
RR	5.0	4.2	3.8	4.8	5.0	4.4	6.0	5.6	5.4	5.6	3.6	6.2	6.0	5.6	4.4	6.2	5.8	7.4
BR	5.0	5.6	3.8	3.8	5.4	5.2	5.4	6.4	4.4	6.4	5.4	5.6	6.4	6.6	6.4	6.8	6.0	7.6
AVG.	4.7		4.5		4.7		5.2		4.9		5.2		6.2		6.1		6.6	

Table 5. Decrease in A-weighted sound level (in decibels re 20 μPa) from 25 to 50 feet (7.6 to 15.2 m) observed for half-worn test tires running on a concrete, asphalt and continuous reinforced concrete surface. The speeds 50, 60, and 70 mph correspond to 80.5, 96.5, and 112.6 km/hr, respectively.

TIRE TYPE (HALF-WORN)	CONCRETE						ASPHALT						CONTINUOUS POURED REINFORCED CONCRETE					
	50 MPH		60 MPH		70 MPH		50 MPH		60 MPH		70 MPH		50 MPH		60 MPH		70 MPH	
	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2
B	5.4	5.6	6.0	4.8	4.8	4.6	4.6	4.6	5.2	4.8	5.2	5.2	5.8	6.4	6.8	7.0	4.8	5.2
C	4.8	4.2	4.8	5.4	5.4	5.2	5.6	5.4	3.4	3.4	6.2	5.2	7.2	7.8	6.0	7.8	7.6	6.4
D	5.6	5.4	5.0	4.8	5.0	3.8	5.0	5.0	5.4	4.4	4.6	4.6	6.8	5.6	5.2	6.2	5.6	4.6
E	5.2	3.8	5.4	5.2	5.8	5.4	4.0	5.4	5.2	4.2	5.6	4.8	6.2	6.4	5.8	5.6	6.2	5.4
F	4.0	4.6	5.0	6.4	5.4	4.4	4.4	4.4	5.0	6.6	---	---	4.2	8.2	5.6	6.8	5.2	6.4
G	3.6	5.8	5.6	5.4	4.2	4.0	5.0	4.2	4.2	4.0	3.0	4.4	7.2	7.0	6.2	6.4	4.4	4.4
AVG.	4.8		5.3		4.8		4.8		4.7		4.9		6.6		6.3		5.5	

3.7 Spectral Data

In order to gain an understanding of the mechanisms by which tire-road interaction noise is generated[4/], one cannot simply look at only single number descriptors such as the A-weighted sound level, but must analyze the noise in finer detail through spectral analysis. The data for all test runs in this study have been analyzed in one-third octave bands. Figures 28-33 show characteristic frequency spectra for each of the six automobile tires tested. Each figure contains three plots corresponding to coast-by tests with new tires at 60 mph (96.5 km/hr) on a concrete, asphalt and continuous poured reinforced concrete surface.

The tire noise spectrum is composed of two parts: a periodic variation due to the tread pattern and tire nonuniformities and an aperiodic variation due to road surface cavities. The periodic component exhibits spectral peaks at discrete frequencies and the aperiodic component exhibits a more continuous spectrum. The frequencies of the spectral peaks associated with the tire design can be predicted by calculating the number of tread elements which pass through the footprint per second. If the distance between consecutive tread elements is uniform, the sound produced is nearly a pure tone. Most automobile tire manufacturers, however, do not utilize a uniform element spacing. The pitch lengths are usually varied in some manner so as to produce a less intrusive sound than a pure tone.

In the case of truck tires[5,6] it appeared that the observed spectral peaks were attributable to tread design alone. However, the author did caution the reader not to be misled into thinking that the tire noise mechanism question is simply one associated with tread design alone, especially since the apparent attainable "limit" with present structural design -- a blank tire (full tread depth but no tread pattern) on a smooth surface -- is only a few decibels lower than current original equipment rib tires of quiet design. For the automobile tires tested in this study the major tread element spacings ranged from 0.66 - 1.32 in. (1.68 - 3.35 cm) which result in predicted fundamental frequencies in the range 800 - 1600 Hz. A review of the data shows that these frequencies are apparent; however, many times the spectra are dominated by peaks at much lower frequencies.

Potts[12] studied tire vibrations by applying an oscillatory load to bias-ply, bias-belted and radial-ply tires in the radial, lateral and circumferential directions. Resonant frequencies were noted for each type of tire and the corresponding mode shapes observed. The radial direction

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[4/] At present, three generic types of tire noise source mechanisms have been postulated -- aerodynamic, air pumping and vibration. Reference 6 provides a discussion of the existing knowledge pertinent to tire noise source mechanisms and additional literature references.

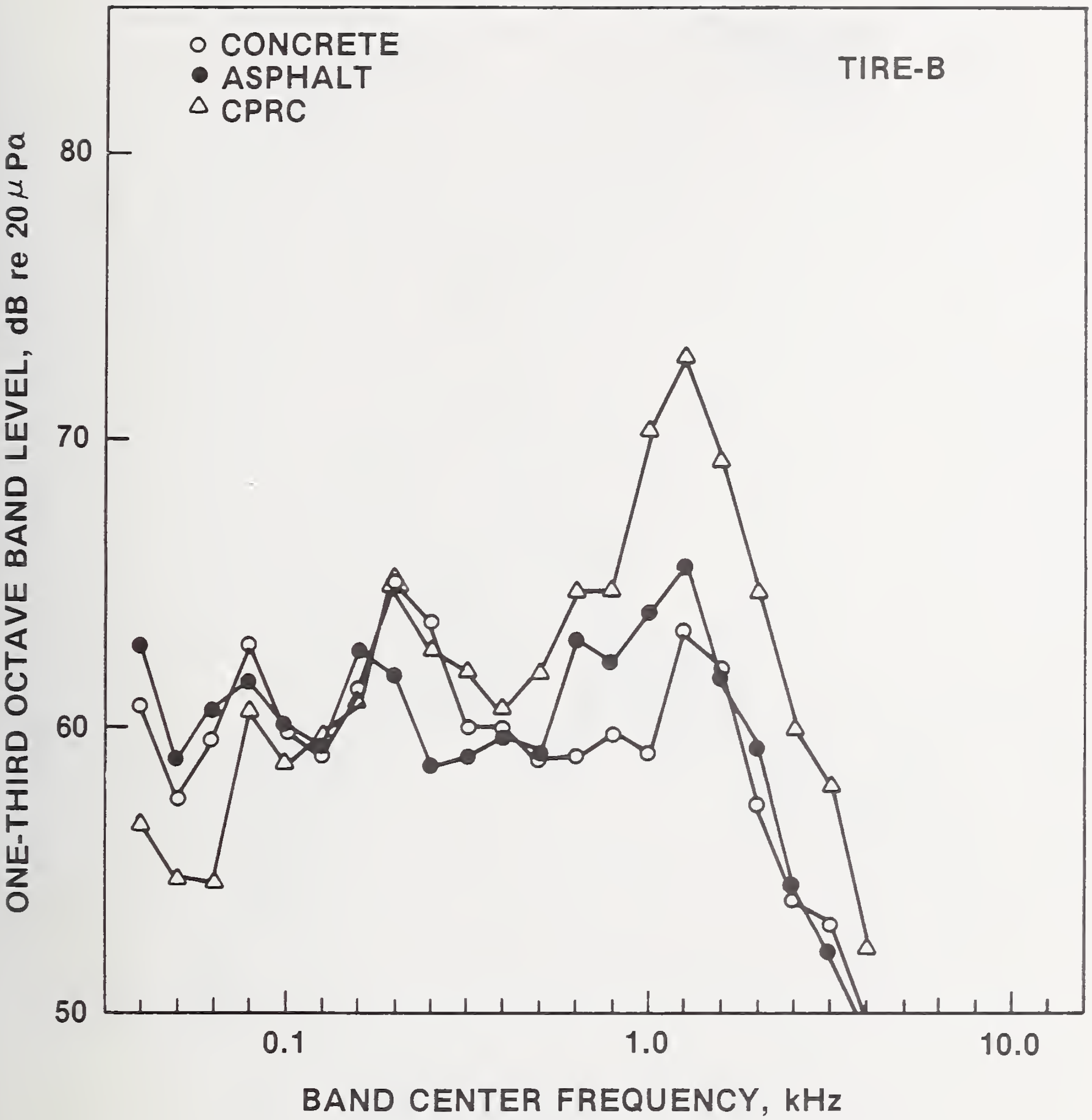

Figure 28. One-third octave band frequency spectra for tire-B as measured at 50 feet (15.2 m) corresponding to operation of the car in a coast-by mode over concrete, asphalt, and continuous poured reinforced concrete. The vehicle was loaded and operated at a speed of 60 mph (96.5 km/hr). The test tires were new (full tread depth).

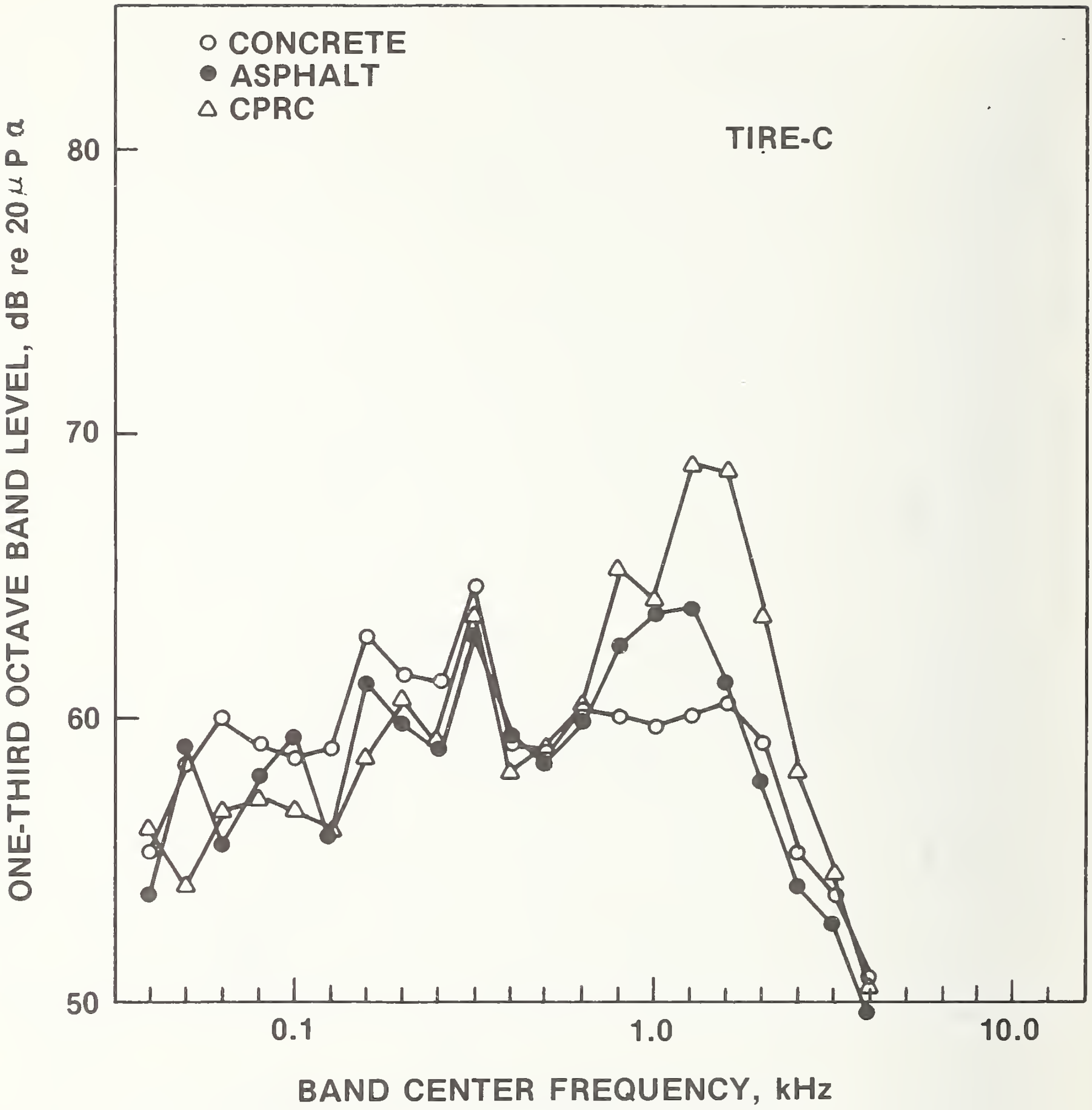

Figure 29. One-third octave band frequency spectra for tire-C as measured at 50 feet (15.2 m) corresponding to operation of the car in a coast-by mode over concrete, asphalt, and continuous poured reinforced concrete. The vehicle was loaded and operated at a speed of 60 mph (96.5 km/hr). The test tires were new (full tread depth).

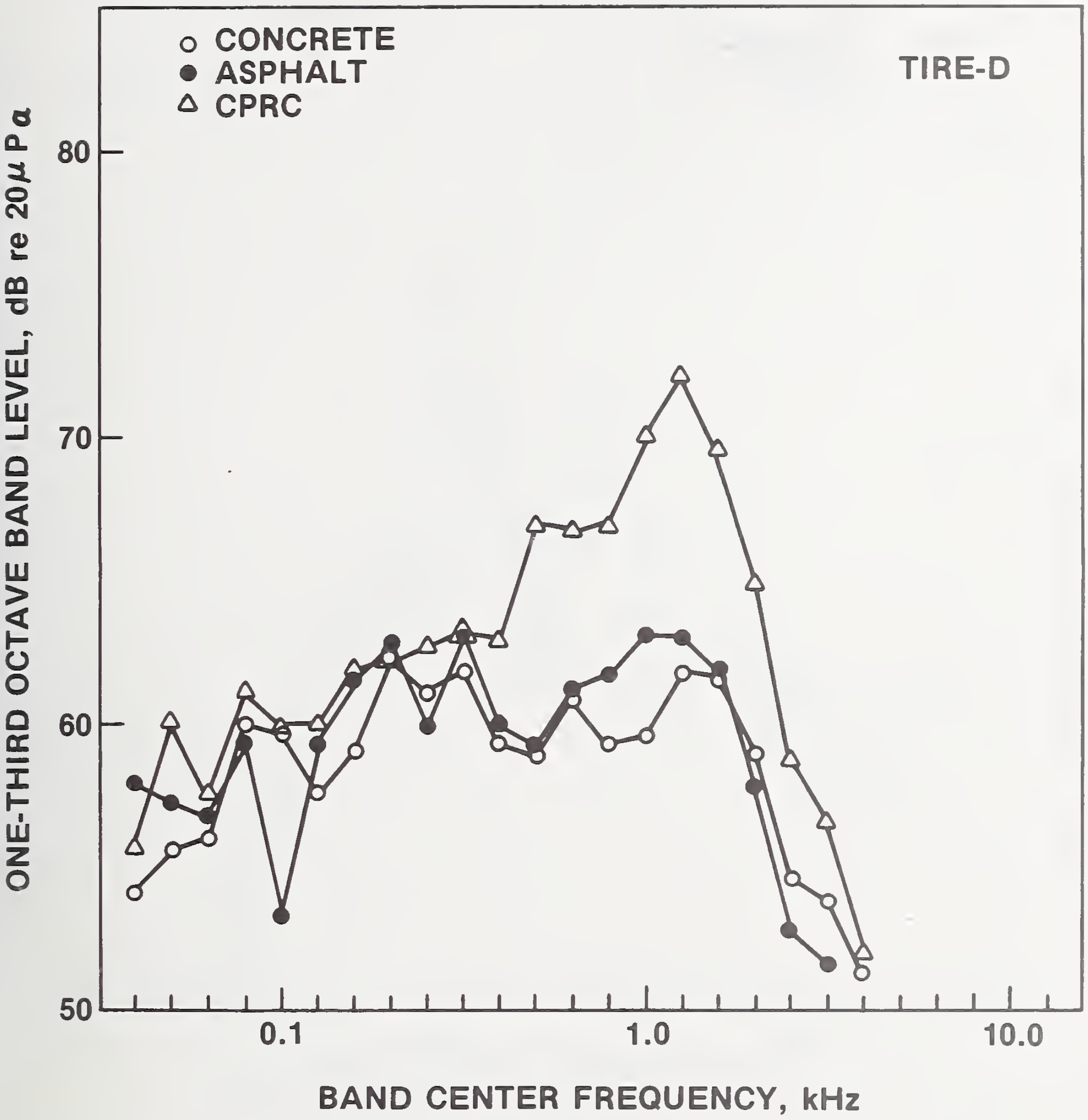

Figure 30. One-third octave band frequency spectra for tire-D as measured at 50 feet (15.2 m) corresponding to operation of the car in a coast-by mode over concrete, asphalt, and continuous poured reinforced concrete. The vehicle was loaded and operated at a speed of 60 mph (96.5 km/hr). The test tires were new (full tread depth).

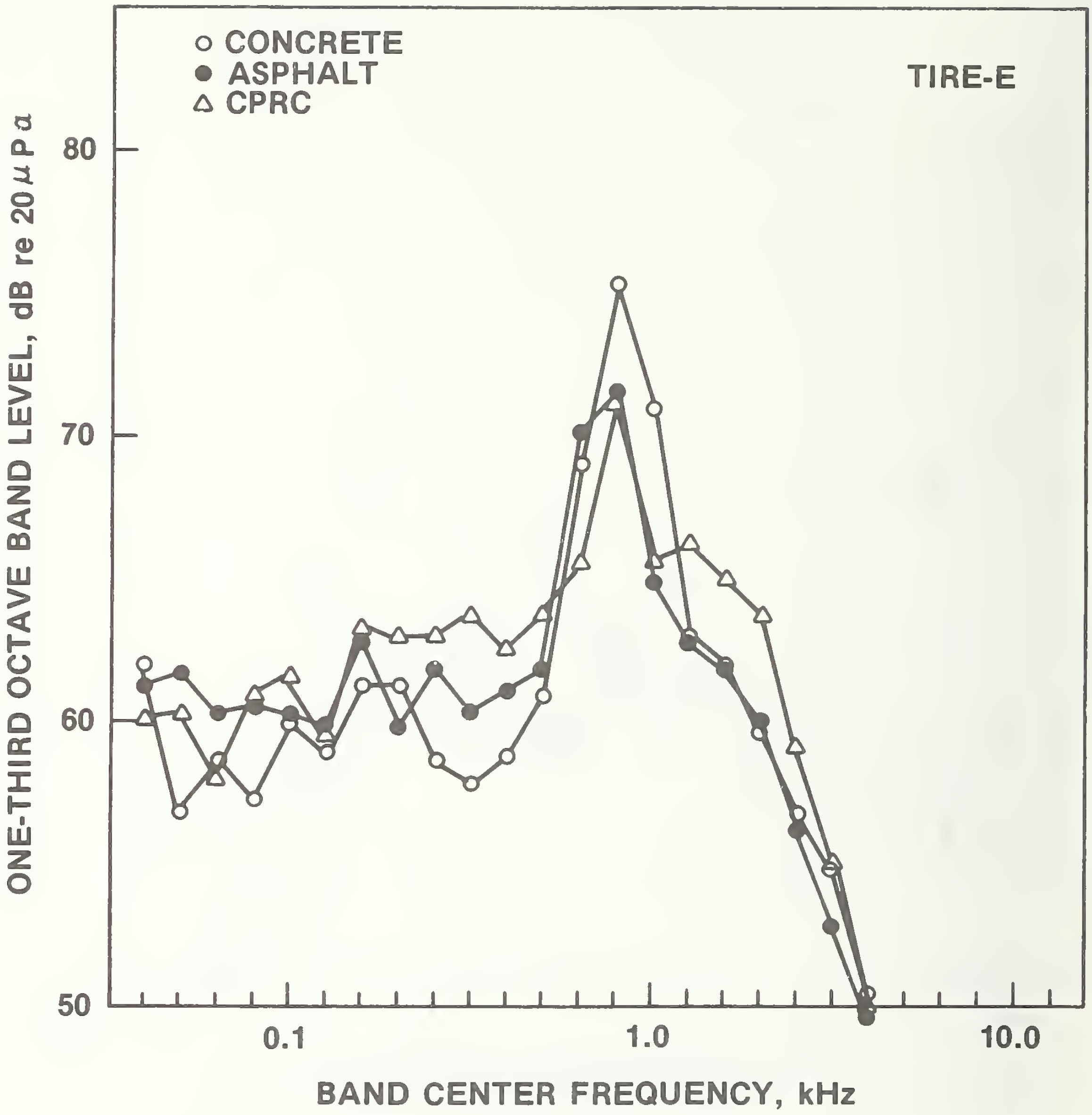

Figure 31. One-third octave band frequency spectra for tire-E as measured at 50 feet (15.2 m) corresponding to operation of the car in a coast-by mode over concrete, asphalt, and continuous poured reinforced concrete. The vehicle was loaded and operated at a speed of 60 mph (96.5 km/hr). The test tires were new (full tread depth).

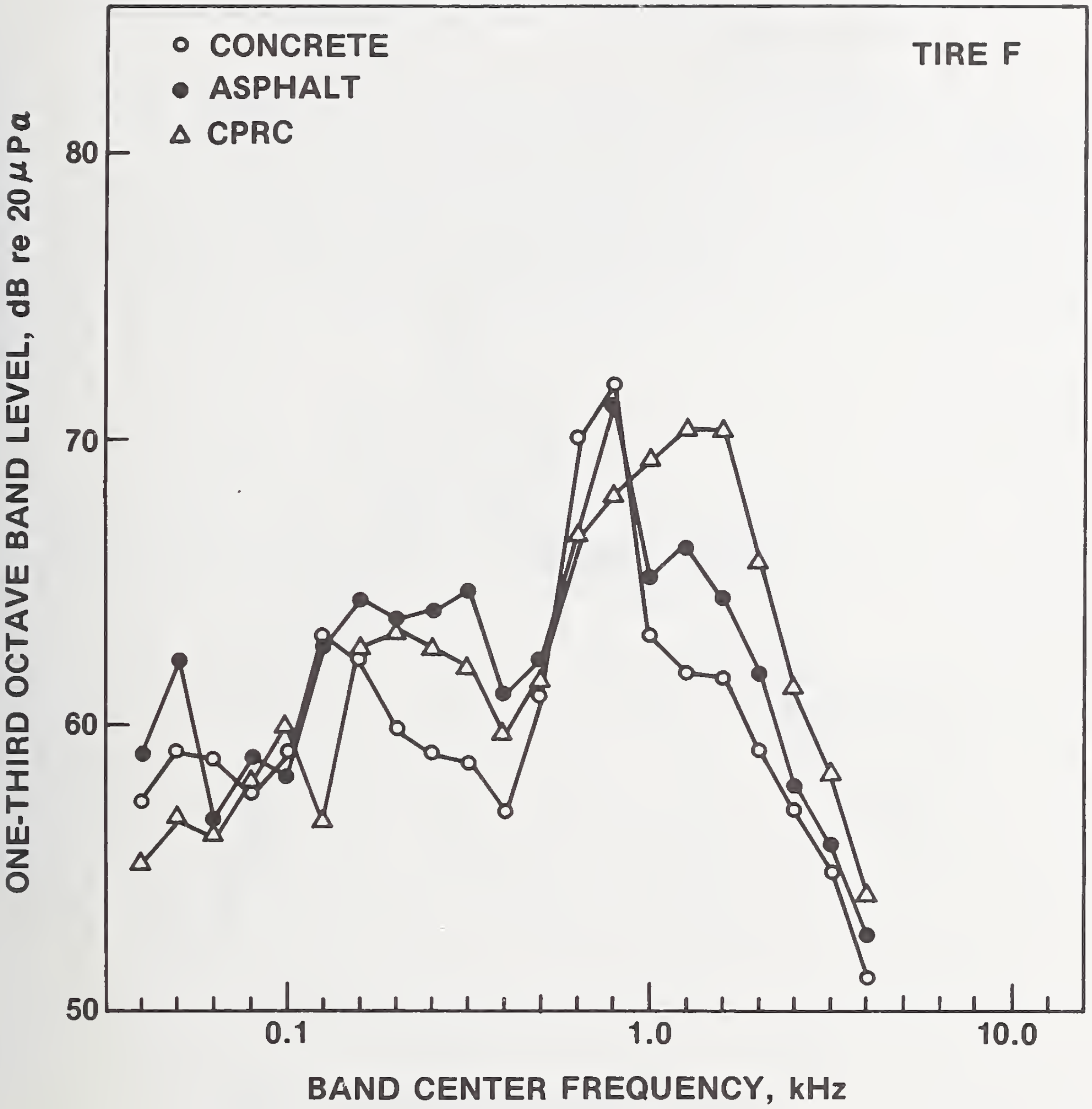

Figure 32. One-third octave band frequency spectra for tire-F as measured at 50 feet (15.2 m) corresponding to operation of the car in a coast-by mode over concrete, asphalt, and continuous poured reinforced concrete. The vehicle was loaded and operated at a speed of 60 mph (96.5 km/hr). The test tires were new (full tread depth).

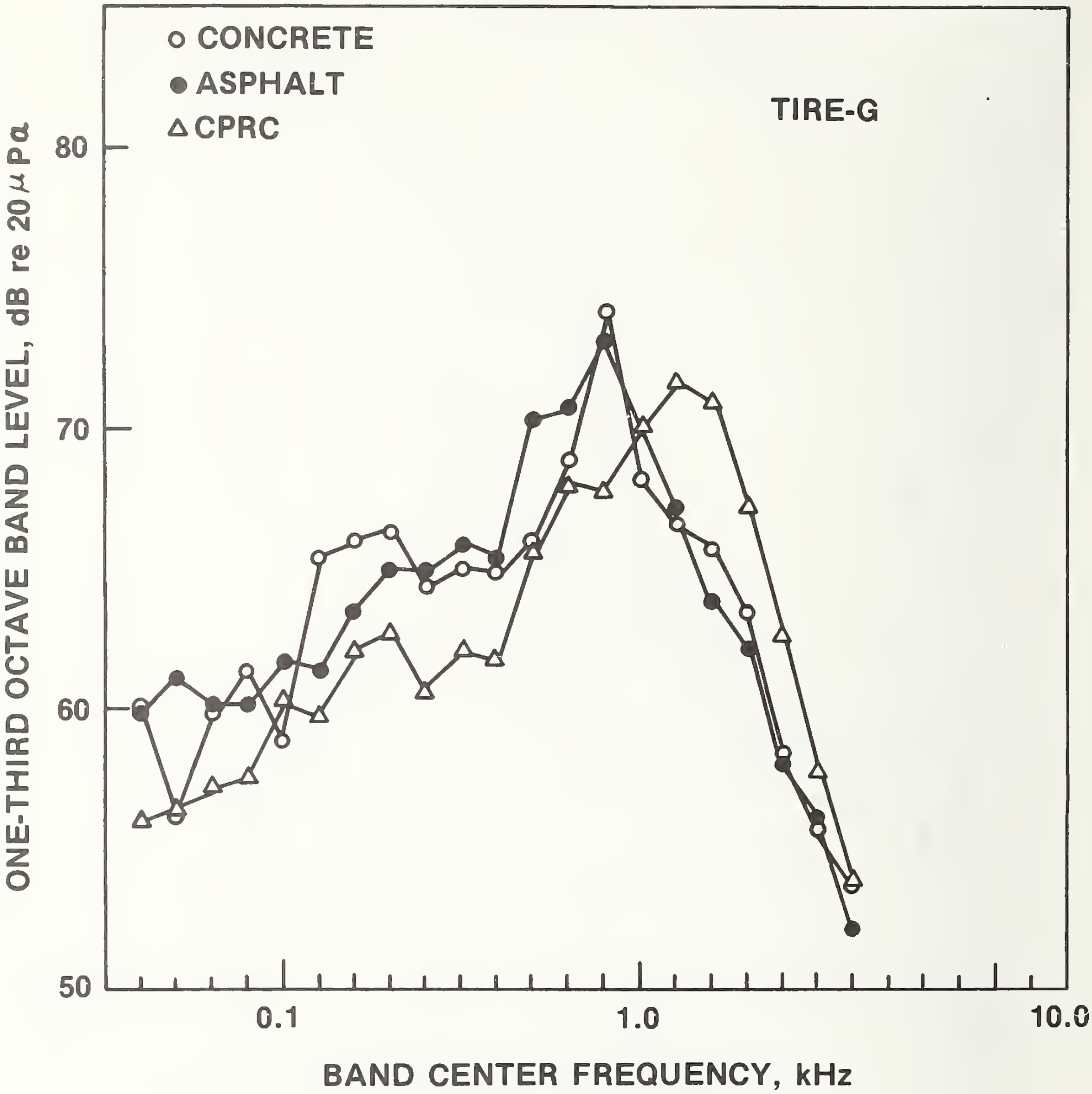

Figure 33. One-third octave band frequency spectra for tire-G as measured at 50 feet (15.2 m) corresponding to operation of the car in a coast-by mode over concrete, asphalt, and continuous poured reinforced concrete. The vehicle was loaded and operated at a speed of 60 mph (96.5 km/hr). The test tires were new (full tread depth).

resonant frequencies for H78-15 tires are shown in Table 6. The radial resonant frequencies result from road induced vibrations caused by road discontinuities such as pavement expansion joints and road asperities and tire induced vibrations caused by circumferential variations in tire uniformity.

It appears probable that the lower frequency peaks observed in the sound spectra are associated with vibration induced noise source mechanisms. It is difficult to correlate passby spectral peaks with the resonant frequencies shown in Table 6 on a one-to-one basis since the sound spectra at a stationary observation point along a roadway are complicated by the motion of the source of sound -- the spectra change with time as the relative positions of the tire and the observer change. The Doppler effect contributes an additional shift in frequencies which also changes as the relative position of the tire and observer change.

Table 6. Radial direction resonant frequencies, in hertz, of H78-15 automobile tires[12].

MODE NUMBER	BIAS-PLY	BIAS-BELTED	RADIAL-PLY
1	140	164	59
2	168	215	80
3			96
4			112
5			130
6			151
7	278		175
8	312		188
9			420
10			570

3.8. Conclusions

Based on the data obtained during the conduct of this test program and a review of the open literature, the following conclusions can be drawn:

- Vehicle speed, road surface characteristics, tread design and carcass construction appear to be the major factors affecting automobile tire noise.

- The effect of pavement surface appears to be more significant for automobile tires than for truck tires due to the fact that the texture within the tire-road interaction area is on the same scale as the tread element spacing typical of passenger car tires.

- The spectral peaks observed for automobile tires are not predictable from considerations of tread element spacing and tire rotational rate alone. Carcass resonant vibration also appears to be a significant influencing parameter.

- Load and wear, significant factors for truck tires, do not affect automobile tires as much due to the fact that the majority of the automobile tires utilize rib tread designs. However, automobile snow tires -- as is the case with truck cross-bar tires -- are noisier than rib tires when new and exhibit more of an increase in noise level with wear than rib tires.

- When tires of both radial-ply and bias-ply construction were equipped with identical rib-tread patterns, limited tests showed the radial-ply tire to be the quieter of the two. However, radial-ply tires are typically manufactured with more "aggressive" tread patterns than conventional rib tread patterns typically utilized on tires of bias-ply and bias-belted construction. Also the radial resonant frequencies for the bias-ply and bias-belted tires are above the lower cutoff frequency of the rubber grommets in an automobile suspension system while the first three modes for a radial-ply tire are below this frequency. The aggressive tread and lower reasonant frequencies contribute to the conception that radial tires are noisier than bias-ply or bias-belted tires.

- On the basis of the limited data available in the literature, factors such as inflation pressure, number of plies, tire dimensions, tire cord material, etc., do not appear to be significant parameters affecting tire noise.

- A comparison of automobile tire noise levels measured at 25 and 50 feet (7.6 and 15.2 m) from the centerline of vehicle travel indicate that the rank ordering of the tires according to noise level would be the same at either measurement distance even though the relative levels between 25 and 50 feet (7.6 to 15.2 m) or vice versa cannot be accurately predicted for any given set of tires for a particular set of operating conditions.

4. Appendix A

Parametric Study Results

The tabulated values of A-weighted sound level (maximum rms value of the A-weighted sound level during a passby) as measured at the two microphone locations are reported. The data are assembled according to tread design and stated wear of the test tires, the speed of the test vehicle, and the surface over which the tests were conducted. A photograph showing the characteristic tread element pattern is presented for each of the tire types tested. Also included are the average tread depth and Shore hardness values characteristic of these tires.

Figure A-1. Characteristic tread element pattern of tire-B (bias-ply rib). The nominal new tread depth for this tire was 12/32 inch. Shore hardness values ranging from 58-61 were observed with the average being 60. The nominal worn tread depth for this tire was 7/32 inch and the Shore hardness values ranged from 60-64 with the average being 62.

Tire B (Bias-Ply Rib)

New Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	72.4	71.4	74.2	74.4	78.0	78.4
50 (15.2)	67.0	67.4	70.2	70.6	72.8	74.2

Worn Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	72.4	73.0	75.8	75.6	77.4	77.4
50 (15.2	67.0	67.4	69.8	70.8	72.6	72.8

New Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	73.8	74.0	75.4	76.8	79.0	79.8
50 (15.2)	69.2	69.2	71.4	70.8	74.2	75.0

Worn Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	75.2	74.6	77.8	77.0	79.2	80.0
50 (15.2)	70.6	70.0	72.6	72.2	74.0	74.8

New Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	81.4	81.8	84.0	83.2	85.2	86.8
50 (15.2)	75.8	74.2	77.6	77.2	78.6	79.0

Worn Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.4	80.2	83.2	83.4	84.8	85.6
50 (15.2)	73.6	73.8	76.4	76.4	80.0	80.4

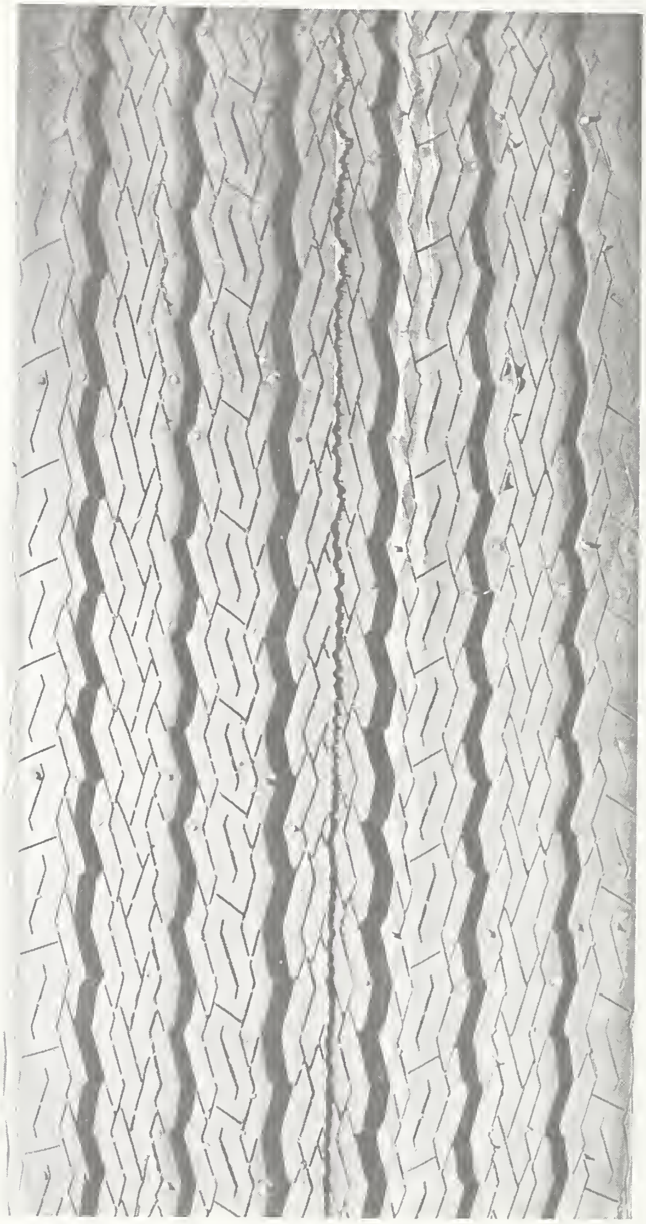

Figure A-2. Characteristic tread element pattern of tire-C (bias-belted rib). The nominal new tread depth for this tire was 13/32 inch. Shore hardness values ranging from 59-62 were observed with the average being 60. The nominal worn tread depth for this tire was 8/32 inch and the Shore hardness values ranged from 61-62 with the average being 61.

Tire C (Bias-Belted Rib)

New Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	71.2	72.0	74.2	75.4	76.4	78.6
50 (15.2)	67.0	67.4	69.6	70.2	72.6	72.6

Worn Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	72.4	72.4	75.0	76.6	78.2	77.8
50 (15.2)	67.6	68.2	70.2	71.2	72.8	72.6

New Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	72.8	72.4	74.6	76.0	77.6	78.0
50 (15.2)	67.2	68.4	70.8	70.0	72.8	73.6

Worn Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	74.6	73.8	74.8	75.0	79.6	78.8
50 (15.2)	69.0	68.4	71.4	71.6	73.4	73.6

New Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	80.0	80.8	82.2	83.8	86.8	86.4
50 (15.2)	74.4	73.8	75.8	76.4	79.6	80.2

Worn Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	81.4	80.6	83.2	84.0	85.6	85.6
50 (15.2)	74.2	72.8	77.2	76.2	78.0	79.2

Figure A-3. Characteristic tread element pattern of tire-D (radial rib). The nominal new tread depth for this tire was 11/32 inch. Shore hardness values ranging from 60-65 were observed with the average being 63. The nominal worn tread depth for this tire was 8/32 inch and the Shore hardness values ranged from 60-64 with the average being 62.

Tire D (Radial Rib)

New Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	73.6	73.0	75.0	75.6	76.0	77.2
50 (15.2)	69.4	68.4	70.0	69.6	71.4	72.2

Worn Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	73.2	73.8	76.2	75.4	77.0	76.8
50 (15.2)	67.6	68.4	71.2	70.6	72.0	73.0

New Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	72.6	73.4	76.0	75.2	78.2	78.6
50 (15.2)	67.8	67.4	71.4	70.8	72.8	73.8

Worn Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	74.6	72.6	76.6	75.6	78.0	78.4
50 (15.2)	69.6	67.6	71.2	71.2	73.4	73.8

New Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.6	81.6	84.2	83.4	86.2	86.2
50 (15.2)	74.2	74.2	76.4	77.6	79.6	79.0

Worn Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	81.4	80.8	81.6	83.0	85.4	84.6
50 (15.2)	74.6	75.2	76.4	76.8	79.8	80.0

Figure A-4. Characteristic tread element pattern of tire-E (radial snow). The nominal new tread depth for this tire was 14/32 inch. Shore hardness values ranging from 56-60 were observed with the average being 59. The nominal worn tread depth for this tire was 8/32 inch and the Shore hardness values ranged from 58-68 with the average being 60.

Tire E (Radial Snow)

New Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	78.2	78.8	80.2	79.8	81.4	81.4
50 (15.2)	74.4	73.0	77.4	76.0	76.8	76.8

Worn Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.2	78.8	83.6	82.2	85.8	85.8
50 (15.2)	74.0	75.0	78.2	77.0	80.0	80.4

New Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	76.8	77.0	79.2	80.0	83.8	81.8
50 (15.2)	72.2	71.4	74.0	74.6	76.4	77.0

Worn Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	75.4	76.6	77.0	78.6	81.2	81.2
50 (15.2	71.4	71.2	71.8	74.4	75.6	76.4

New Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.6	79.0	82.4	83.0	86.2	85.8
50 (15.2)	73.8	73.6	77.2	75.4	79.4	79.2

Worn Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	80.8	81.2	84.4	84.0	86.6	86.2
50 (15.2)	74.6	74.8	78.6	78.4	80.4	80.8

Figure A-5. Characteristic tread element pattern of tire-F (bias-ply snow). The nominal new tread depth for this tire was 13/32 inch. Shore hardness values ranging from 59-61 were observed with the average being 60. The nominal worn tread depth for this tire was 6/32 inch and the Shore hardness values ranged from 59-60 with the average being 60.

Tire F (Bias-Ply Snow)

New Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	76.4	76.4	79.2	78.4	82.4	81.2
50 (15.2)	72.4	71.6	73.0	74.8	77.4	77.2

Worn Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	77.8	78.2	81.4	82.8	81.4	81.0
50 (15.2)	73.8	73.6	76.4	76.4	76.0	76.6

New Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	76.2	76.2	78.0	78.8	No Data	
50 (15.2)	71.6	70.6	73.4	74.8	No Data	

Worn Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	77.2	76.8	80.2	80.8	No Data	
50 (15.2)	72.8	72.4	75.2	74.2	No Data	

New Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.8	79.8	82.4	83.0	86.2	87.4
50 (15.2)	72.6	73.6	77.4	77.4	80.4	81.6

Worn Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	81.4	83.2	84.6	86.0	86.8	87.0
50 (15.2)	77.2	75.0	79.0	79.2	81.6	80.6

Figure A-6. Characteristic tread element pattern of tire-G (bias-ply studded snow). The nominal new tread depth for this tire was 13/32 inch. Shore hardness values ranging from 55-60 were observed with the average being 58. The nominal worn tread depth for this tire was 6/32 inch and the Shore hardness values ranged from 60-62 with the average being 61.

Tire G (Bias-Ply Studded Snow)

New Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.4	79.0	82.8	81.0	84.2	85.4
50 (15.2)	74.6	74.6	77.0	76.2	81.0	79.8

Worn Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.4	81.4	86.6	85.8	87.6	87.4
50 (15.2)	75.8	75.6	81.0	80.4	83.4	83.4

New Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.4	79.0	81.4	82.2	83.8	85.4
50 (15.2)	74.2	74.6	77.4	77.0	79.0	79.6

Worn Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.8	79.6	81.4	82.0	84.0	85.8
50 (15.2)	74.8	75.4	77.2	78.0	81.0	81.4

New Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.6	80.2	82.8	83.2	87.8	86.2
50 (15.2)	74.6	74.6	78.4	77.6	81.6	81.0

Worn Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	82.2	82.4	85.0	85.6	87.2	87.0
50 (15.2)	75.0	75.4	78.8	79.2	82.8	82.6

Figure A-7. Characteristic tread element pattern of tire-BR (bias-ply rib retread). The nominal new tread depth for this tire was 10/32 inch. Shore hardness values ranging from 57-61 were observed with the average being 59.

Tire BR (Bias-Ply Rib Retread)

New Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	70.8	72.6	74.8	74.2	77.0	77.6
50 (15.2)	65.8	67.0	71.0	70.4	71.6	72.4

New Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	73.8	74.6	77.2	76.4	78.6	79.0
50 (15.2)	68.4	68.2	72.8	70.0	73.2	73.4

New Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	79.8	80.0	83.0	83.8	85.8	86.4
50 (15.2)	73.4	73.4	76.6	77.0	79.8	78.8

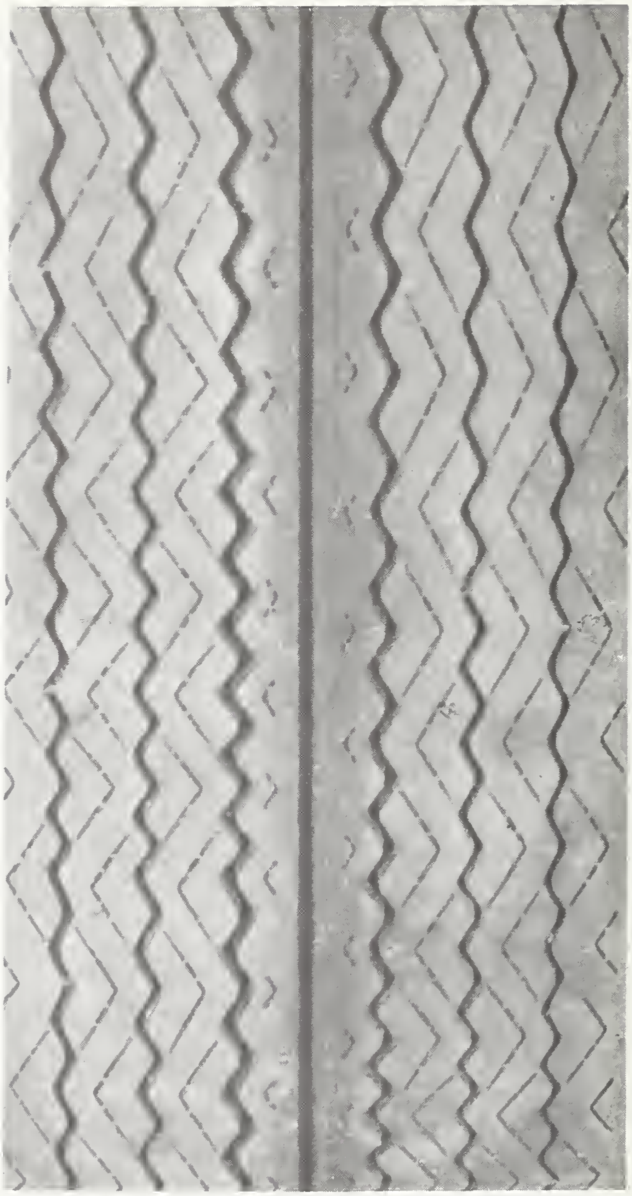

Figure A-8. Characteristic tread element pattern of tire-RR (radial rib retread). The nominal new tread depth for this tire was 10/32 inch. Shore hardness values ranging from 59-60 were observed with the average being 59.

Tire RR (Radial Rib Retread)

New Tires - Jointed Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	72.6	71.4	73.6	74.8	77.0	76.2
50 (15.2)	67.6	67.2	69.8	70.0	72.0	71.8

New Tires - Asphalt
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	72.4	72.0	76.0	74.8	76.2	78.6
50 (15.2)	66.4	66.4	70.6	69.2	72.6	72.4

New Tires - Continuous Poured Reinforced Concrete
A-weighted Sound Levels, dB

Microphone Location, ft (m)	Nominal Speed, mph (km/hr) 50 (80.5)	50 (80.5)	60 (96.5)	60 (96.5)	70 (112.6)	70 (112.6)
25 (7.6)	78.6	77.8	80.6	82.0	83.0	83.6
50 (15.2)	72.6	72.2	76.2	75.8	77.2	76.2

5. Appendix B

Instrument Descriptions

Unless otherwise stated, all instruments are Brüel and Kjaer[5/].

Type UA 0207 Windscreen: When a microphone is exposed to wind, and wind velocit variations, the turbulence created around the microphone cause a noise to be generated due to a variation of air pressure on the diaphragm. To reduce this extraneous wind noise, a spherical windscreen constructed of specially prepared porous polyurethane sponge was utilized.

Type 4220 Pistonphone: This instrument is a small, battery-operated precision sound source which provides quick and accurate direct calibration of sound measuring equipment. When fitted to a B & K microphone, the pistonphone produces a sound pressure level of 124 ±0.2 dB, re 20 μPa, at a frequency of 250 Hz ±1% (controlled by means of a transistor circuit). Maximum stability and a very low distortion (less than 3% at 250 Hz) result from the piston arrangement consisting of two pistons moving in opposite phase. The calibration of the pistonphone is performed at normal atmospheric pressure. Ambient pressure corrections are necessary for pressures other than 760 mm Hg. This calibration is not influenced by relative humidities up to 100% or temperatures within the range of 0 - 60° (32 - 140°F).

Microphone: When one speaks of a microphone, a three part minimum system is implied: (1) a protecting grid; (2) a condenser microphone cartridge; and (3) a microphone preamplifier or cathode follower. For this testing the following components were utilized.

Type 4161 One-inch Condenser Microphones: The one-inch free-field condenser microphone is a type possessing relatively high sensitivity and covering a range of applicability from 2 Hz to 18 kHz (frequency range) and 15 dB to 140 dB (dynamic range). A feature of these microphones is long-term stability under a variety of environmental conditions and insensitivity to temperature variations. Condenser microphones, in addition, were chosen because of their higher dynamic range, ease in calibration, and uniform frequency response. The cartridge which houses the microphone diaphragm is protected by the grid on one side and on the other is normally screwed onto the preamplifier. This particular microphone vents into a dehumidifier (which is located between the microphone and the preamplifier) rather than air. The silica gel drys the air used by the microphone for pressure equalization.

[5/] Commercial instruments are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the equipment identified is necessarily the best available for the purpose.

Type UA 0310 Dehumidifier: The dehumidifier is designed to be mounted between the 4161 condenser microphone and its amplifier. It contains silica gel to dry the air used by the microphone for pressure equalization. When used in 100% relative humidity situations, the silica gel requires drying approximately once a month. The drying is accomplished by heating the silica gel for some hours at a temperature of 100°C.

Type 2619 Half-inch FET Preamplifier: This preamplifier features a very high input impedance field-effect transistor, which represents virtually no load to the microphone cartridge. To mate the 2619 with the 4161 a suitable adapter must be utilized (model DB-0375).

Built into the preamplifier itself is a 6.3V heating coil to prevent condensation when operation must be carried out in cold or humid environments.

The above described microphone subassembly provides reliable operation over a wide range of temperature, humidity, and vibration and allows precision sound pressure measurements to be made over a wide frequency and dynamic range.

Type 2804 Two Channel Power Supply: This unit is a portable, battery-driven supply unit designed to provide the necessary polarization voltage for condenser microphones and their accompanying preamplifiers.

NBS Field Instrumentation: To facilitate data acquisition in the field, this battery-powered instrumentation system was designed and fabricated by NBS specifically for application to passby noise measurements. The unit contains a 60 dB variable gain amplifier which provides the needed signal conditioning (amplification/attenuation) prior to recording. In addition to recording the signal, weighting networks and hold circuitry are included to allow for direct reading of the linear and A-weighted fast response sound level observed during the passby. The hold circuitry and weighting networks meet the Type 1 requirements for the fast dynamic characteristic and the A-weighting response respectively of American National Standard Specification for Sound Level Meters, S1.4-1971. The linear hold circuitry provides an indication as to whether or not a tape channel had become saturated (i.e., the signal had exceeded the dynamic range of the recorder) and thus the data were not acceptable. The A-weighted hold circuitry allowed for direct reading of the A-weighted sound level observed during a passby without the necessity for returning the tape recordings to the laboratory for reduction and analysis.

Nagra Model SJ Tape Recorder: This unit is a portable 3-track (1/4 inch magnetic) tape recorder with two high quality amplitude modulated sound tracks (25 Hz to 35 kHz), plus a third FM track for recording very low frequencies (dc to 4 kHz), commentary, synchronization signals or timing information. The instrument records and reproduces at four speeds --

15, 7-1/2, 3-3/4, and 1-1/2 ips. The two-amplitude modulated channels can be fed from separate microphone inputs. The volume is controlled by separate step attenuators.

Type 3347 Real Time Analyzer: The real time analyzer is composed of two basic units: (1) type 2130 frequency analyzer and (2) type 4710 control and display unit.

The 2130 contains a measuring amplifier, filter channels with 1/3-octave bandwidth, a linear channel, weighting channels, true RMS detectors, and the synchronization system for scanning the channels.

The analyzer contains 38 parallel channels. 33 of these channels contain 1/3-octave filters with center frequencies from 12.5 Hz to 20 kHz. The remaining five channels are reserved for the four weighting network filters -- A, B, C, and D -- and one linear response channel.

The 4710 contains the circuitry for the 12-inch cathode ray tube (CRT), the Nixie displays, digital readout, and the logic control. The logic control section controls the analog/digital conversion and the communication sequence for external systems, as well as the internal synchronization in the 3347 during display or read-out modes.

The level in each channel can be read in dB directly on the screen, while a Nixie display shows the output level of any selected channel. This channel is indicated on the CRT as a brighter trace. The complete channel display is renewed every 20 msec.

Outputs are provided for both analog instruments (X-Y or level recorders) as well as digital (on-line computer or tape puncher). The digital output is in binary coded decimal (BCD) code.

Time constants may be selected from 20 msec to 20 sec so that confidence limits can be maintained throughout the frequency range.

Model 704 Raytheon Computer System: The Raytheon 704 computer system is a general purpose digital system that provides a 16-bit central processor unit with 900 nanosecond cycle time for on-line, real time applications.

The hardware configuration includes an 16K (expandable to 32K) memory system, direct input/output bus, automatic priority interrupt, direct and indexed addressing, and byte and word addressing and instructions. Standard peripherals such as high speed paper tape, ASR-33 teletype, card equipment, and a magnetic tape unit are also included.

6. References

[1] Anon., Truck Noise-1, 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., 1971).

[2] Tetlow, D., Truck Tire Noise, Sound and Vibration, 5(8), 17-23 (1971).

[3] Leasure, W. A., Jr., 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 OST/TST-72-1 (National Bureau of Standards, Washington, D. C., 1972).

[4] Leasure, W. A., Jr., and Mathews, D. E., Pecos Truck Tire Noise Study: A Summary of Results, NBSIR 74-446, National Bureau of Standards, Washington, D. C. (1974).

[5] Leasure, W. A., Jr., 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).

[6] Leasure, W. A., Jr. and Corley, D. M., Truck Noise 1-B, Spectral and Directional Characteristics of Noise Generated by Truck Tires, U. S. Department of Transportation Report DOT-TST-75-71 (National Bureau of Standards, Washington, D. C., 1975).

[7] Leasure, W. A., Jr., Automobile Tire Noise: A Review of the Open Literature, Proceedings of Noise-Con 73, Washington, D. C., 187-195 (1973).

[8] Hillquist, R. K. and Carpenter, P. C., A Basic Study of Automobile Tire Noise, Sound and Vibration, 8(2), 26-28, (1974).

[9] Richards, M. G., Automobile Tire Noise - A Comprehensive Study, Sound and Vibration, 8(5), 42-47 (1974).

[10] Veres, R. E., Tire Noise Investigation and Test Methods, Technical Report No. CRR 74-6 (Ford Motor Company, Dearborn, Michigan 1974).

[11] American Society for Testing and Materials, D2240-68, Standard Method of Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer in Part 37, Book of ASTM Standards (American Society for Testing and Materials, Philadelphia, Pennsylvania, 1974).

[12] Potts, G. R., Application of Holography to the Study of Tire Vibration, Tire Science and Technology, TSTCA, 1(3), 255-266 (1973).

[13] Yurkovski, B., Astrov, V. A., and Ivanteev, A. V., The Influence of Design Parameters on the Shock-Absorbing Capacity, Road-Handling, and Noise Level of Car Tyres (in Russian), Kauchuck i Rezina 26(5), 30-33 (1967).

[14] Wiener, F. M., Experimental Study of the Airborne Noise Generated by Passenger Automobile Tires, Noise Control 6(4), 13-16 (1960).

[15] Engler, G., Factors Contributing to Wheel Noise (in German), Kraftfahrzeug-Technik 14(12), 443-436 (1964).

[16] Rathe, E. J., Traffic Noise: The Influence of Road Surface and Traffic Volume, presented at the Thirteenth World Congress of the Road, Tokyo, Japan (1967).

[17] Waters, P. E., Commercial Vehicle Rolling Noise, Institute of Sound and Vibration Research Memorandum No. 359, University of Southampton, Southampton, England (1970).

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