NBS IR 74-469

Report No. DOT-TST-74-21

TRUCK NOISE I-A

NOISE EVALUATION TESTS OF MILITARY TRUCK TIRES

William A. Leasure, Jr.
Denzil E. Mathews
William J. Rinkinen

FINAL REPORT
FEBRUARY 1974

Prepared for
DEPARTMENT OF TRANSPORTATION
Office of the Secretary
Office of Noise Abatement
Washington, D.C. 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT-TST-74-21		NBSIR 74-469

4. Title and Subtitle	5. Report Date
Truck Noise I-A: Noise Evaluation Tests of Military Truck Tires	February 1974
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
William A. Leasure, Jr., Danzil E. Mathews, and William J. Rinkinen	
9. Performing Organization Name and Address	**10. Work Unit No.**
National Bureau of Standards Mechanics Division US Department of Commerce Washington, DC	**11. Contract or Grant No.** DOT-AS-10004
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
US Department of Transportation, Office of the Secretary, Office of Noise Abatement, Washington, DC 20590	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

This is a special report within a series of reports emanating from an interagency agreement with NBS to perform a wide variety of truck and passenger car tire noise research.

16. Abstract

This report presents the A-weighted sound level and one-third octave band spectral data resulting from a study conducted to characterize the noise generated by military truck tires. The study was conducted by the National Bureau of Standards in cooperation with the U.S. Department of Transportation under the sponsorship of the U.S. Army Tank-Automotive Command. The data base established will allow for comparison of the tire noise generated by military and commercial truck tires.

The study investigated the influence of load and speed on the noise generated by tires with four different tread designs: the standard Army tire, a retread of Army design and commercial tires with rib and cross-bar type tread patterns. Army and commercial trucks were utilized as test vehicles.

In addition, the report includes a discussion of the measurement and analysis techniques utilized for the establishment of this data base.

17. Key Words	18. Distribution Statement
noise, tire noise, truck tires, acoustics, sound, military vehicles	Availability is unlimited. Document may be released to the National Technical Information Service, Operations Division, Springfield, Virginia 22151, for sale to the public

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		52	

Form DOT F 1700.7 (8-69)

Table of Contents

1. Introduction

The U. S. Army Tank-Automotive Command is presently establishing data bases on the performance characteristics, including noise, of their vehicles and components, such as tires. Noise data are especially important since military vehicles frequently operate on public roads and therefore contribute to community noise levels.

The U. S. Department of Transportation and the National Bureau of Standards have been working in the tire noise area since 1970 and have established an extensive data base on commercial tire noise [1,2].[1/] Tread design, wear, load, speed and pavement surface were the major parameters investigated in these studies. On the basis of this experience and expertise in the tire noise area, the Army sponsored a study with DOT/NBS to investigate the noise generation characteristics of the standard Army tire, a retread of Army design and two commercial truck tires.

The test program was designed to be of optimum benefit to the Army and of necessity considered operational variables which are peculiar to real-world Army use as compared to nominal commercial use practices.

Briefly the testing included the following:

- Noise measurements were made at 25 and 50 feet as measured from the centerline of vehicle travel. These distances correspond to the standard European and American measurement locations.

- A 2-1/2 ton military vehicle (M35-A2C) equipped with 10 test tires was operated under the following conditions: (1) speeds of 35, 40, and 45 mph, vehicle loaded as per Army axle load recommendations, (2) speeds of 40 and 45 mph unloaded, (3) at each test condition both coast-by (engine shut-off) and powered drive-by runs.

- A commercial single-chassis truck equipped with 4 test tires on the drive axle and 2 quiet tires on the steering axle was tested. The truck was loaded (axle loading comparable to that for the loaded military vehicle) and operated at speeds of 40, 50, and 60 mph.

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

It was anticipated that such a program would provide the Army with tire noise data as presently reported in the public domain (4 test tires), the total tire noise output for a typical military vehicle (10 test tires), and the data to define the power plant/drive line (transmission/differential) noise characteristics for this type military vehicle.

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

2. Field Test Program

To ensure that the Army would derive maximum benefit from the existing tire noise data base, this test program was patterned after the previous DOT/NBS field test programs. The exceptions, of course, were in those areas where the standard operating procedures differed between the military and commercial applications. A discussion of the details associated with the test program for the evaluation of a sample of four specific tire types of interest to the Army follows.

2.1 Field Test Site

The research runway at the Wallops Island, Virginia, facility of the National Aeronautics and Space Administration was chosen as the test site for the road testing phase of the program. This location provided an adequate stretch of pavement (8750 feet) and a flat terrain providing a well-defined reflecting surface without any unusual reflection and attenuation effects. An agreement was reached with NASA for utilization of this facility for the data acquisition phase of the program.

On the 8750 foot length of research runway 4-22 (bearing 040° and 220°), a 600 foot test section was established. This test area was designated as the concrete test section. The nominal runway width was 150 feet with a center section (50 foot 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 wide and 20 feet long. For this test program, the truck ran in one of these 12 foot lanes. Due to the deteriorated condition of the pavement surface near the edge of the runway, the truck ran one lane in from the edge. Figure 1 shows an overall view of the research runway with the location of the test section noted. Appendix C contains a detailed discussion of the composition of the test section.

The concrete test section began 2850 feet from the northeast end of runway 4-22 and extended to 3450 feet. It consisted of a substrate of reinforced, air-entrained Portland Cement concrete with a "C" finish (smooth concrete). The "C" finish section of pavement was smoothed with a belt of canvas composition. Figure 2 is a detailed layout of the concrete test area while Figure 3 shows the actual surface in the smooth concrete section.

As is evident from Figure 2, a grooved pavement section existed along the centerline of the runway in a portion of the concrete test section. However, only a small corner of this grooved section was in the line of sight path from the test vehicle to the microphone array. 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 and 1 inch 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 (200-2000 Hz) where most of the tire noise is concentrated.

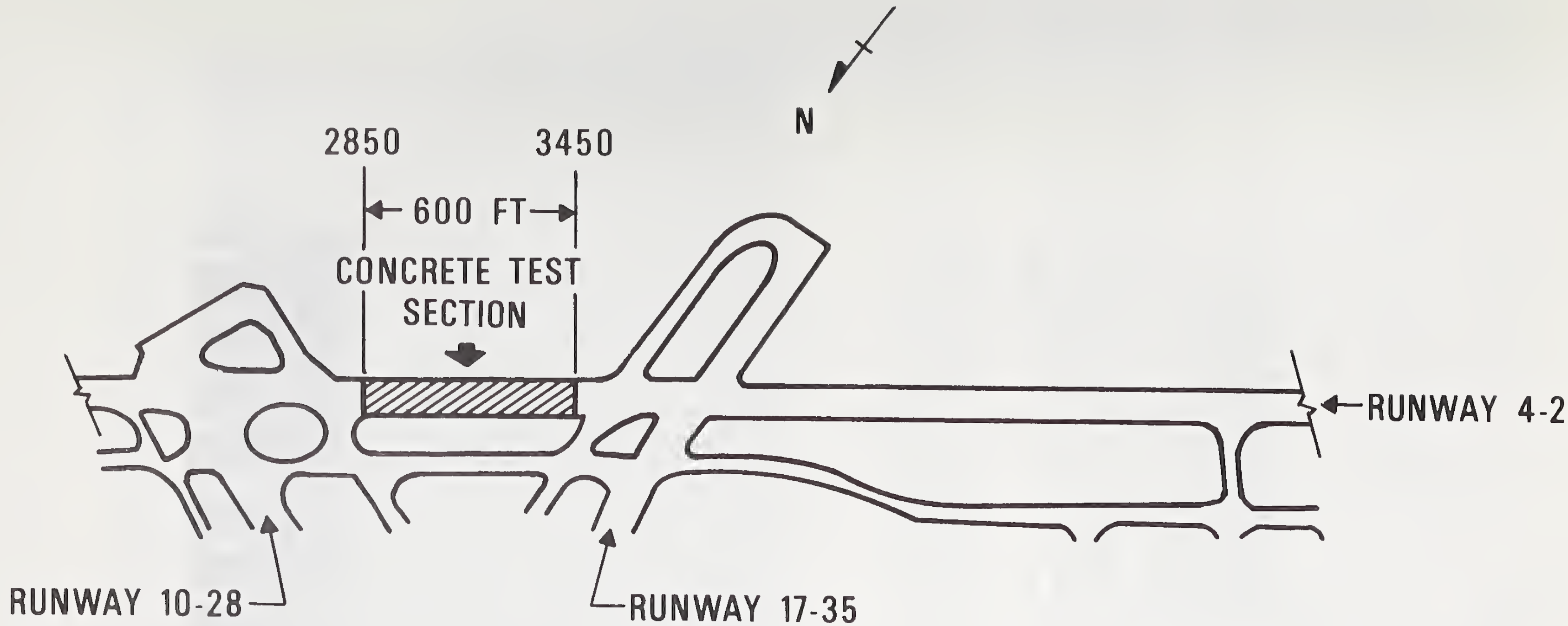

Figure 1. Plan of research runway 4-22 Wallops Station, Virginia, showing the location of the concrete test section.

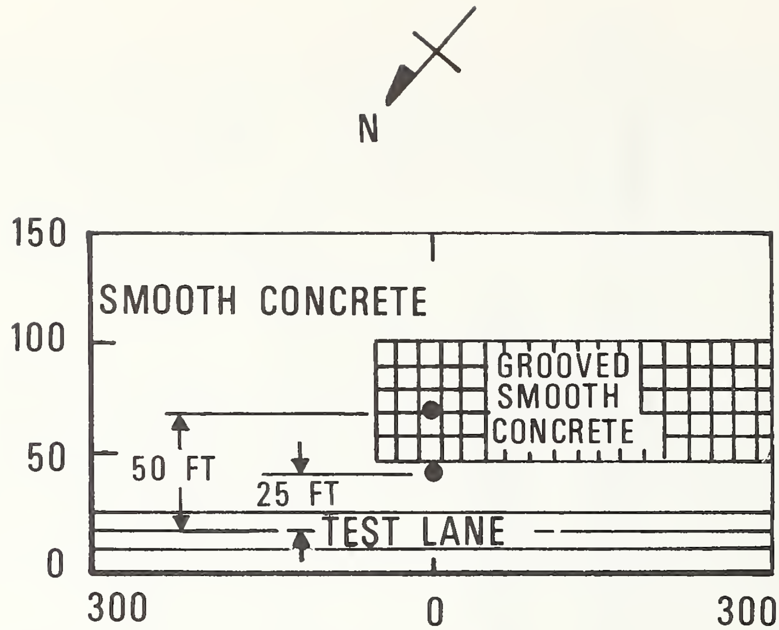

Figure 2. Plan of concrete test area on runway 4-22. Solid circles represent the two microphone locations. All dimensions are in feet.

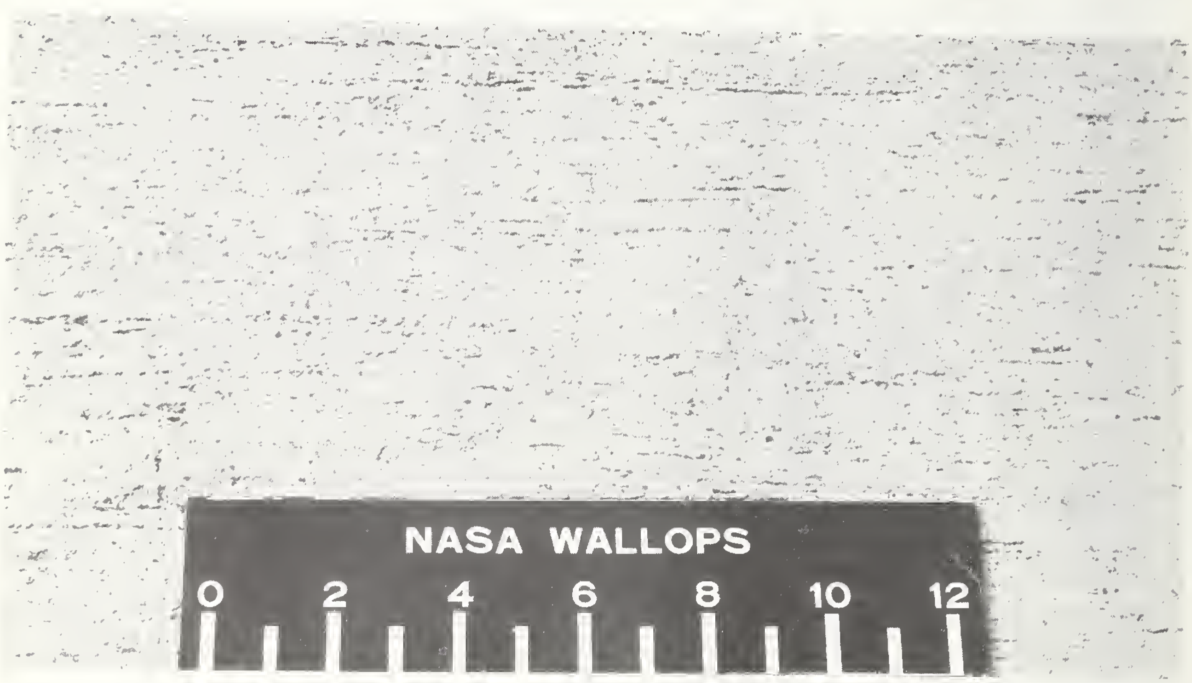

Figure 3. Smooth concrete surface on runway 4-22. Scale is in inches.

2.2. Test Tires

For this study, the Army selected a total of four tire types for evaluation. A photograph of each tire showing the tread design is shown in Appendix A. The test tires were size 9.00 x 20 and included the standard military tire, two commercial tires and a retread of Army design. The Army retread (tire-C) and one of the commercial tires (tire-D) utilized a radial unisteel carcass.

a. Tire Preparation, Break-In and Warmup

In accordance with standard operating procedure the tires utilized during this test program were not balanced.

When new tires are installed on a truck, balancing is not performed unless there is a definite handling problem or severe vibration reported which might jeopardize the safety of the vehicle. When such a problem arises, the entire front end assembly, not just the tires, is checked. Unlike the normal practice with automobile tires, only front (steering) tires are ever balanced on trucks.

A tire was not considered acceptable as a test specimen for the tire noise investigation until it had undergone a break-in period of sufficient mileage under actual driving conditions to ensure the removal of all mold marks and manufacturing irregularities.

In addition, a warm-up procedure was followed immediately prior to the actual testing of a given set of tires. This was done to eliminate the periodic vibrations caused by flatspots typically present on cold tires. Flat-spotting is a phenomena caused by a thermal shrinkage property common to some fabric-cord materials. The cord material shortens slightly when hot and as the loaded tire cools while stationary, the cords temporarily "set" at the shorter length in the road-contact area (flatspot) and do not equalize until their temperature has again been raised.

The normal procedure required a minimum of five round trips over the length of the research runway at the field test site (a total of approximately 10 miles). If the driver could sense any "thumping" or heavy vibration, as could be expected if the tires were cold, he then would continue the procedure until he felt that the vibration had been eliminated.

b. Tire Characteristic Measurements

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

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

The Shore hardness of the tread rubber was determined by ASTM test method D-2240-68[3]. 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 Vehicles

Two types of vehicles were utilized throughout this program -- a 4 x 2[2/] single-chassis commercial vehicle and a 6 x 6 single-chassis military vehicle.

The military vehicles -- two M35A2C 2-1/2 ton trucks with a gross vehicle weight capacity of 25,530 pounds -- were loaned to the research program for test purposes by the U. S. Army. The test tires (9.00 x 20) were mounted at all wheel positions; however, only the rear axles were driven (i.e., the truck was operated in a 6 x 4 configuration). One truck (Figure 4) was operated in an unloaded condition, while the other carried 10,510 pounds of load. Figure 5 shows the loading arrangement. Two concrete slabs and four sand bags were appropriately located such that maximum loading was attained on all tires. The test vehicles were weighed at the official scale of the State of Virginia near the Wallops Station test site resulting in the following weight breakdown:

[2/] 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. Thus, a 6 x 4 would have 10 tires mounted at 6 wheel positions, 4 of which are driven.

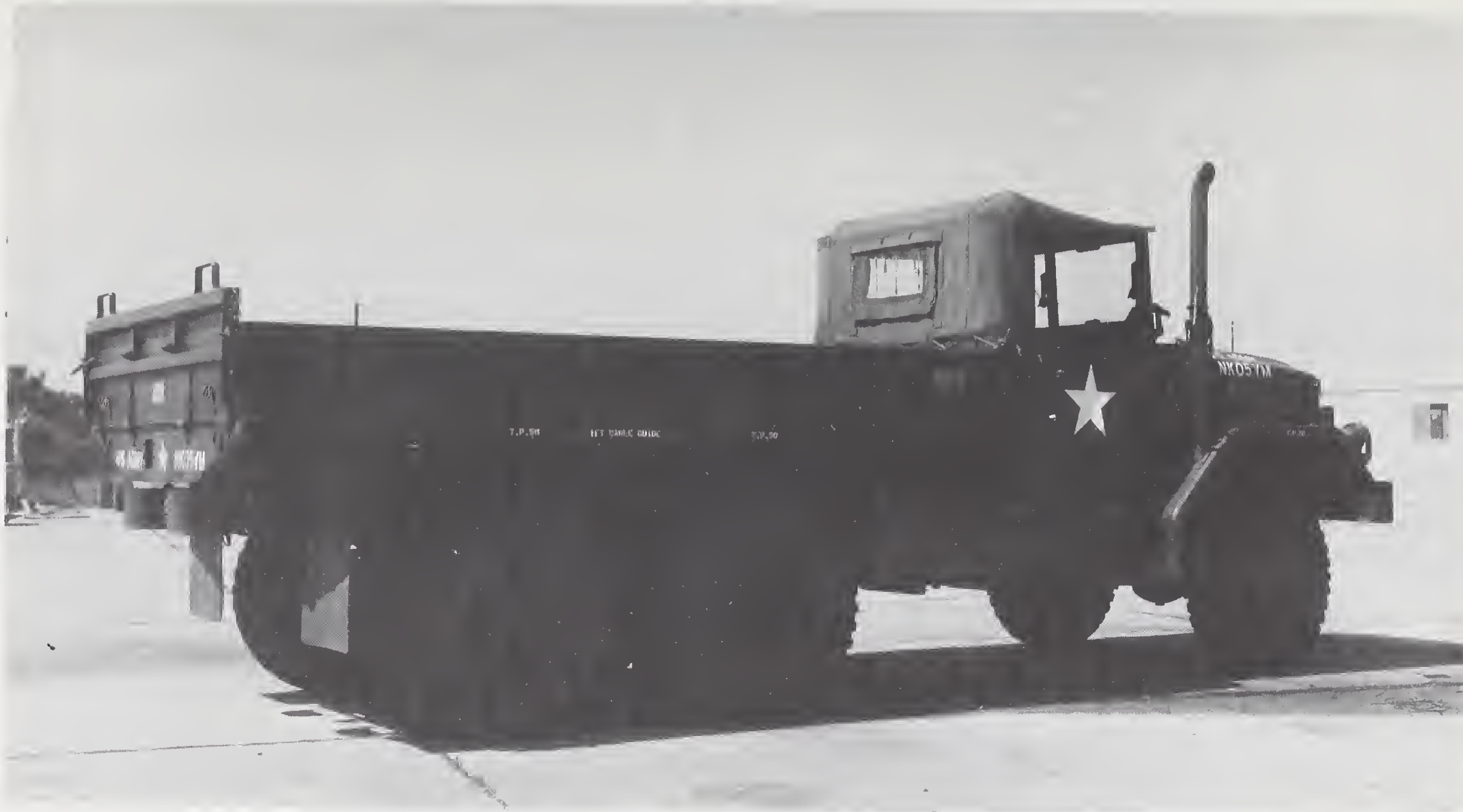

Figure 4. An M35A2C, 2-1/2 ton military vehicle which served as the 6 x 6 single-chassis test vehicle.

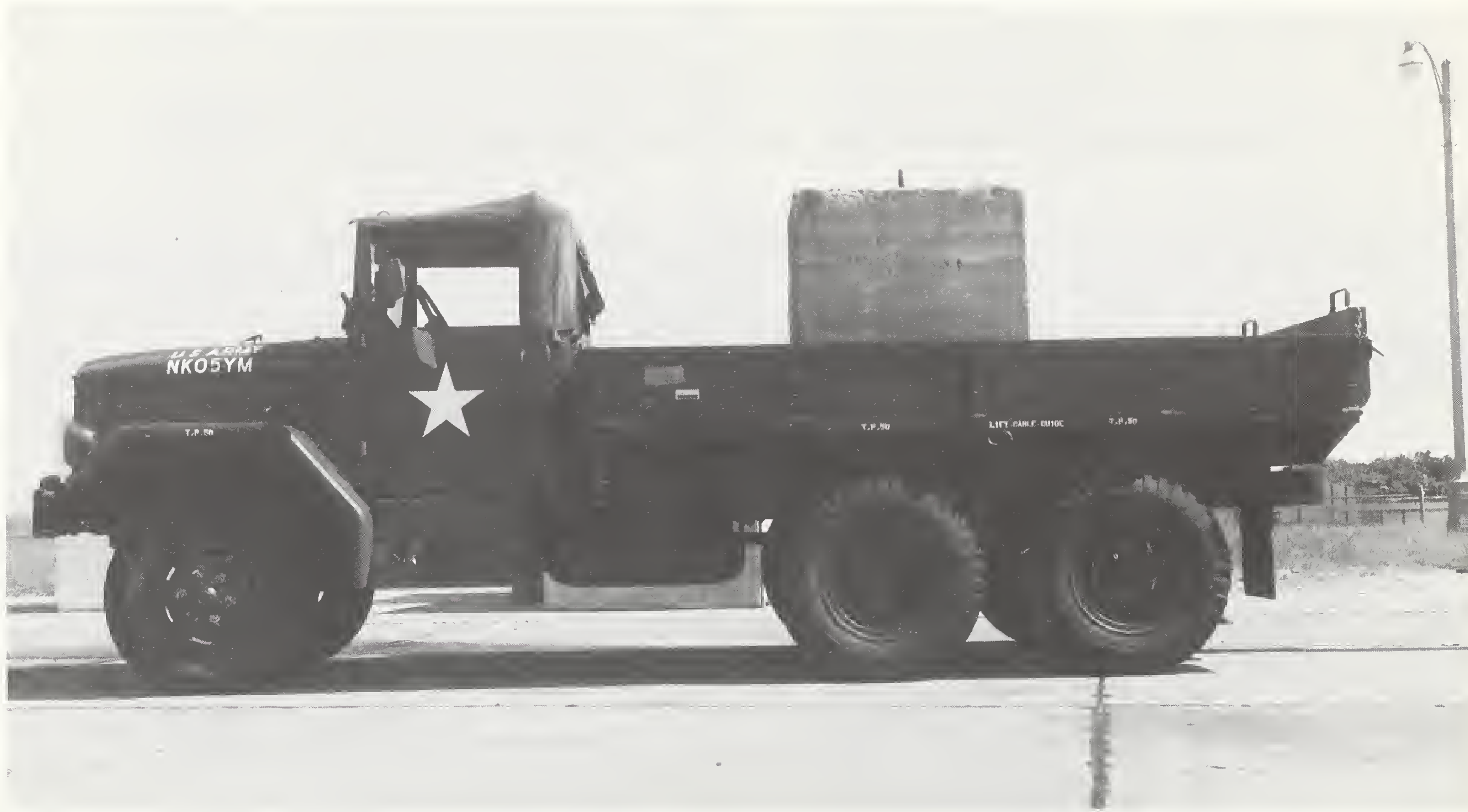

Figure 5. A view of the 6 x 6 single-chassis test vehicle showing placement of the two concrete slabs and four sand bags (10,510 pounds) used to provide maximum tire loading. (The second concrete slab and the sand bags are not visible in this view.)

Truck #1 (loaded)

front axle	6,850 pounds	(3,425 pounds/tire)
rear axles	16,660 pounds	(2,082 pounds/tire)
gross vehicle weight	23,510 pounds	

Truck #2 (unloaded)

front axle	5,930 pounds	(2,965 pounds/tire)
rear axles	7,070 pounds	(884 pounds/tire)
gross vehicle weight	13,000 pounds	

The 4 x 2 commercial single-chassis vehicle (similar to that utilized in the DOT/NBS [1,2] truck tire noise program) was an International[3/] Model 1600 chassis equipped with a 20-foot stake body which was rented from Ryder Truck Rental, Inc., Baltimore, Maryland. The vehicle was equipped with a 7,500 pound front axle, V-345 gasoline engine, 5-speed transmission, 2-speed, 17,000 pound rear axle and 10.00 x 20 tires (9.00 x 20 tires can also be mounted on this vehicle). The truck had a gross vehicle weight capacity of 25,000 pounds. Figure 6 gives an overall view of this vehicle.

This truck was operated in a loaded condition. Figure 7 shows the loading arrangement. Eleven 500 pound weights were distributed to develop loading per tire comparable to that for the loaded military vehicle. The resulting weight distribution was as follows:

front axle	6,830 pounds	(3,415 pounds/tire)
rear axle	8,570 pounds	(2,142 pounds/tire)
gross vehicle weight	15,400 pounds	

For this vehicle, the test tires were always mounted on the drive axle and rib tires whose characteristic tire noise level was known to be low were always mounted on the steering axle.

Tires on the loaded test vehicles were inflated to an air pressure of 50 pounds per square inch as specified by the Tire and Rim Association recommendations for the above loading conditions. The tires on the unloaded

---

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

Figure 6. An International Model 1600 chassis equipped with a 20-foot stake body served as the 4 x 2 single-chassis test vehicle.

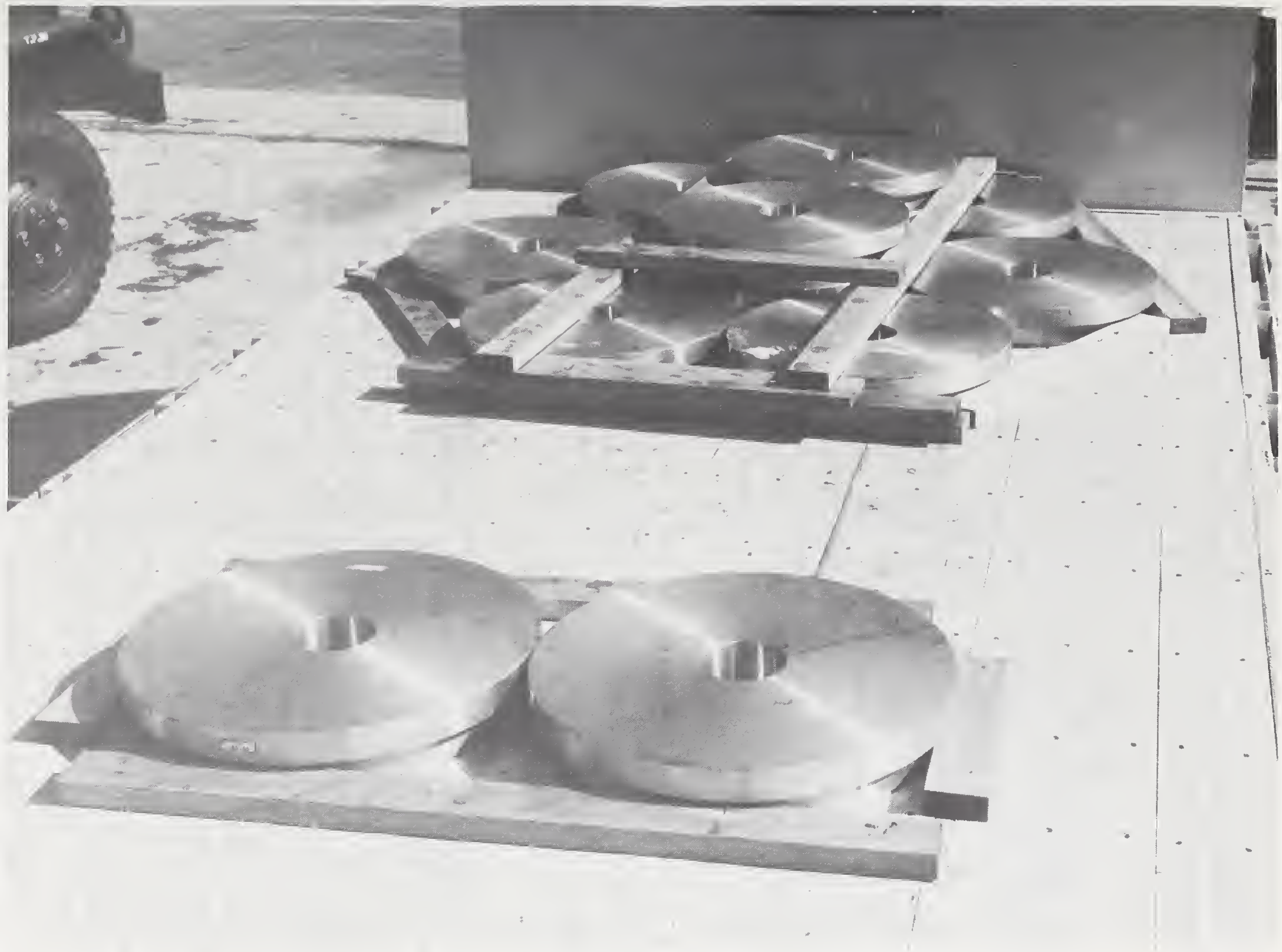

Figure 7. A view of the 4 x 2 single-chassis test vehicle body showing placement of the eleven 500 pound weights used to provide tire loading comparable to the loaded military vehicle.

vehicle also were inflated to 50 pounds per square inch even though the loading was significantly less. This follows standard operating procedure since the driver of an unloaded truck would not lower the air pressure in his tires simply because he had no load.

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 8 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 as measured 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, activiated by the truck running over a tape switch, were located along the test lane parallel to the path of the vehicle. Although not shown in Figure 8, the mobile instrumentation van was located 500 feet back from the edge of the runway. Coaxial cables connected the microphones with the tape recording and monitoring equipment housed in the instrumentation van.

For a nominal 40 mph run (the vehicle should be travelling 40 mph as it passed the microphone array) the driver of the test vehicle either maintained a constant speed (during powered drive-bys) or accelerated the truck to slightly more than the desired speed to compensate for the deceleration characteristics of the particular vehicle (during coast-bys with the engine off).

As the truck passed over the initial tape switch, the tape recorder in the instrumentation van 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 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 truck left the test section, a second tape switch was activated, the radio transmitter sent a signal to the tape recorder, a signal identifying the end of data was recorded and then the tape recorder was remotely turned off. The data start and data end signals were transmitted to the receiver in the instrumentation van 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 9 identifies the components that constituted the data acquisition system. To describe the workings of the system, the following example is cited with the contribution of each component discussed.

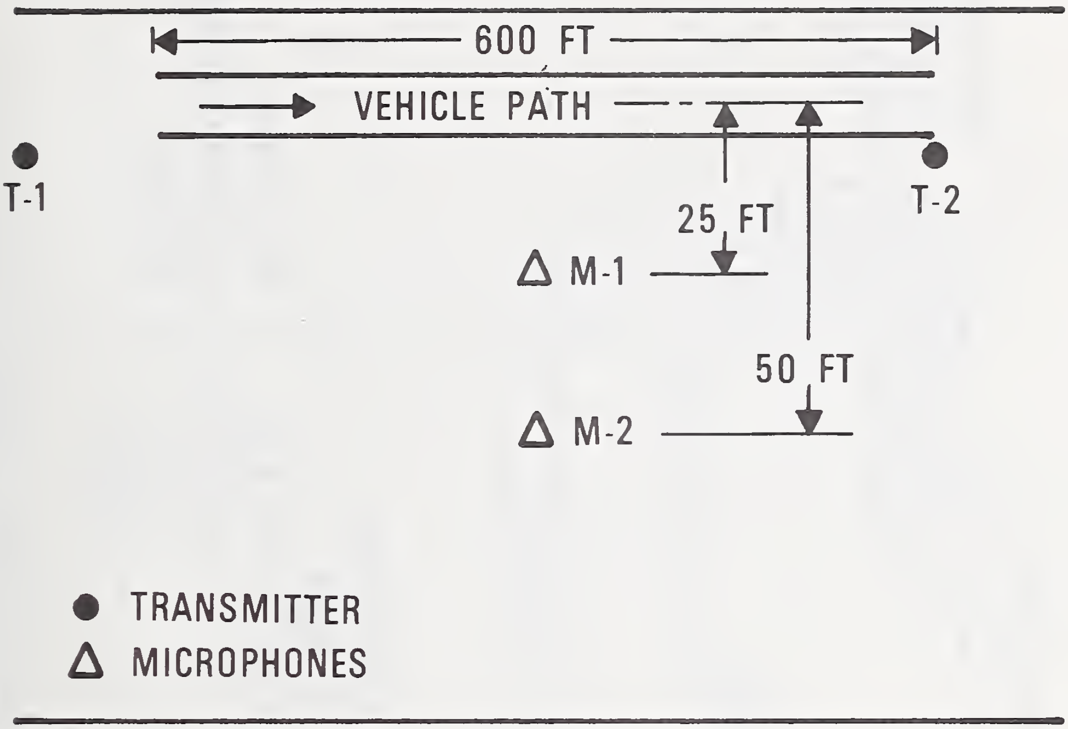

Figure 8. View of test section showing instrumentation placement plus vehicle path (not to scale). Microphones were placed at 25 and 50 feet as measured from the centerline of the lane in which the vehicle travelled and along a line perpendicular to the path of travel. Radio transmitters (activated by tape switches) remotely controlled the on/off sequence of the tape recorder.

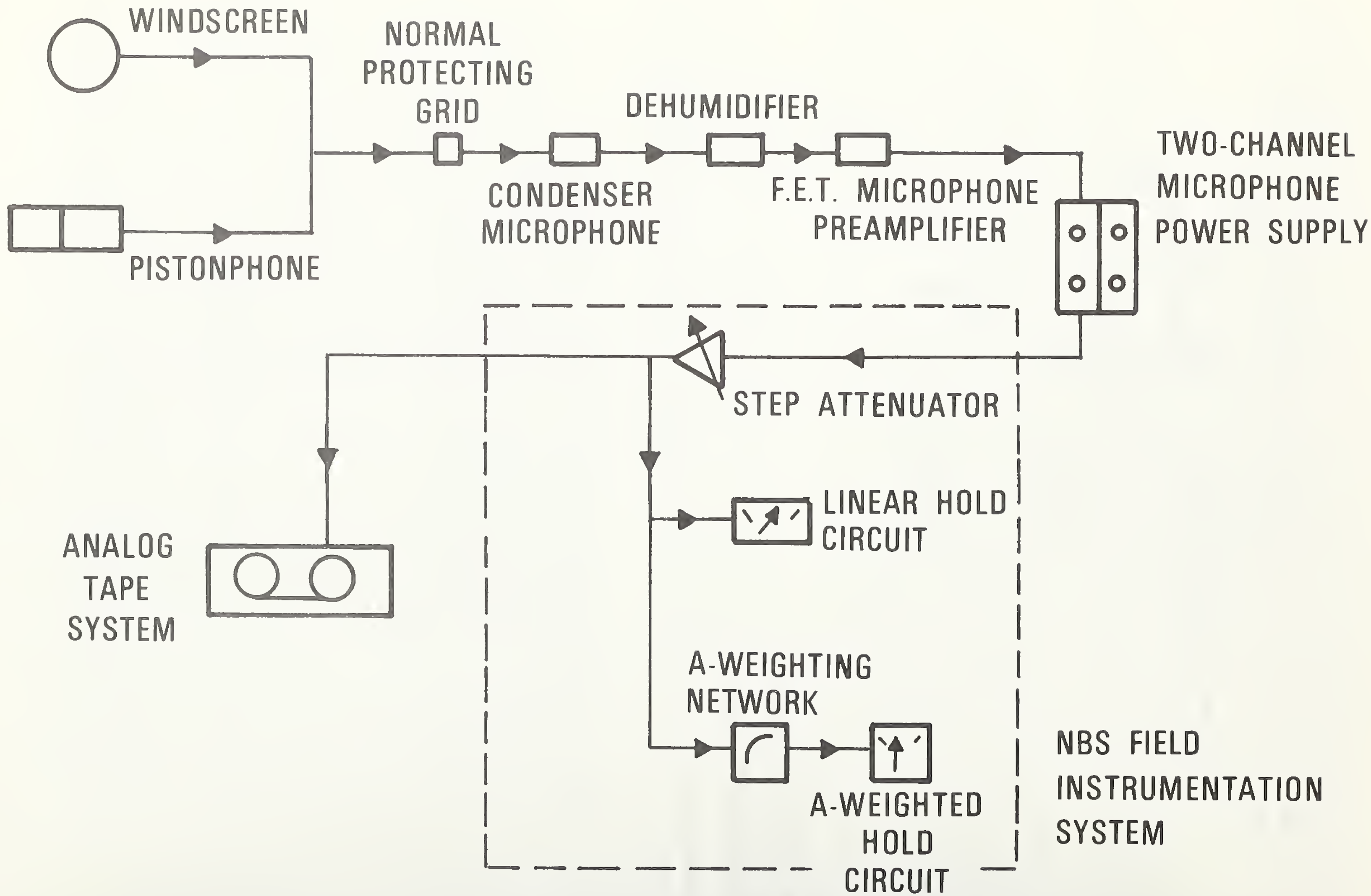

Figure 9. Data acquisition and recording system. Note that only one of the two microphone systems are shown.

Consider a truck passing an array of microphones (Figure 10). As the truck moved forward, it caused pressure fluctuations which travelled as waves and activated the microphone's diaphragm into vibration. These variations were transduced into an AC voltage which could be recorded for analysis at a later time. The microphone itself was a four-part subsystem comprised of a one-inch, free-field condenser microphone cartridge, protecting grid, dehumidifier, and a microphone preamplifier. The polarization voltage was supplied to the microphone by a battery-operated microphone power supply. Prior to recording the signal on the tape, there existed a need for signal conditioning. The step attenuator provided the capability for selection of attenuation over a range of 60 dB in 10 dB steps. The linear hold circuitry provided an indication as to whether or not a tape channel had become saturated (i.e., signal had exceeded the dynamic range of the recorder). Once saturation was detected, that particular data run was repeated. The signal was then recorded on one track of the tape recorder. In addition, the system included an A-weighting network and associated hold circuitry 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 20μPa) 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.

Once the data had been recorded, the analog tapes were returned to the National Bureau of Standards for reduction and analysis. Figure 11 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 2kHz and one which below 2kHz followed a straight line to 3.15 seconds at 12.5Hz 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 formated 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 truck passby.

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

Figure 10. Overall view of the microphone array with the test vehicle. The array consisted of two tripod-mounted microphones located at 25 and 50 feet from the centerline of vehicle travel along a line perpendicular to the vehicle path.

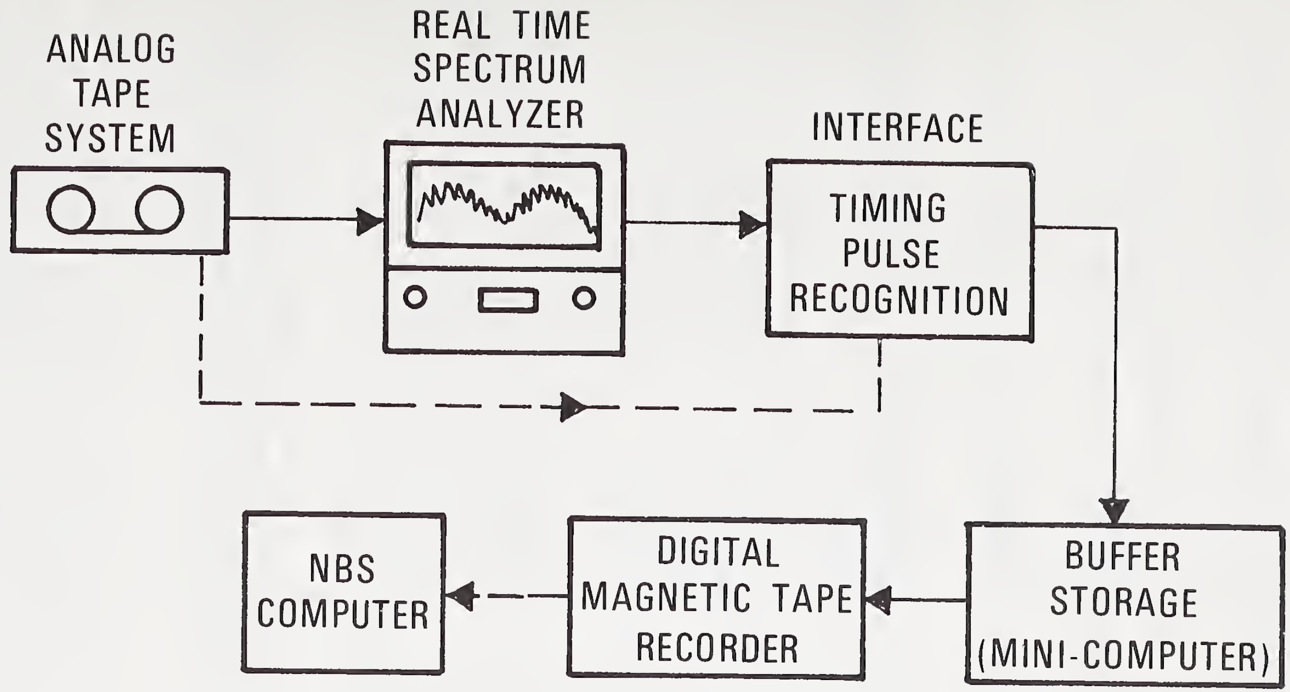

Figure 11. Data reduction and analysis system.

3. Parametric Study

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

- What are the noise generation characteristics of these tires?

- What is the effect of parameters such as speed and load on the noise level for these tires?

- Is a 6 x 6 military truck suitable as a vehicle for tire noise testing?

In order to develop the data base necessary to answer these questions the test matrix shown in Table 1 was established. The data acquisition program followed this well-defined test plan.

The extensive data base on truck tire noise existing in the public domain is based primarily on testing with a 4 x 2 vehicle with four test tires on the drive axle and quiet rib tires on the steering axle. To provide the necessary tie to this data base, the tires of interest to the Army were tested on a commercial 4 x 2 single-chassis vehicle over a speed range of 40-60 mph. Obviously, one is also quite interested in determining the total tire noise contribution for the 6 x 6 military vehicle, i.e., the noise generated when the test tires are mounted at all ten wheel positions. It is also important to define the total vehicle noise over the speed range which is representative of typical operational speeds of the vehicle. Such information provides some insight as to the importance of tire noise relative to other sources such as engine/exhaust noise. For this reason the military vehicle was operated in a powered drive-by in addition to the coast-by mode typically utilized for tire noise testing.

One Army vehicle was loaded to its maximum gross vehicle weight capacity, while the second vehicle was operated in the unloaded condition. The commercial vehicle was loaded such that the load per drive-axle tire corresponded to the load per drive-axle tire observed for the loaded Army truck.

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 four test tires and the associated tread depth and rubber hardness. In this section summary plots of the detailed A-weighted sound level data are presented to show the effect of tread design, speed and load on the noise level generated by these tires. Also presented are selected spectral data which provide additional insight into the tire noise problem.

Truck/Operational Mode	Tire Type	Load	Speed				
			35	40	45	50	60
Army Truck Drive-by	Tire-A	Loaded	X	X	X		
		Unloaded		X	X		
	Tire-B	Loaded	X	X	X		
		Unloaded		X	X		
	Tire-C	Loaded	X	X	X		
		Unloaded		X	X		
	Tire-D	Loaded	X	X	X		
		Unloaded		X	X		
Army Truck Coast-by	Tire-A	Loaded	X	X	X		
		Unloaded		X	X		
	Tire-B	Loaded	X	X	X		
		Unloaded		X	X		
	Tire-C	Loaded	X	X	X		
		Unloaded		X	X		
	Tire-D	Loaded	X	X	X		
		Unloaded		X	X		
Ryder Truck Coast-by	Tire-A	Loaded		X		X	X
	Tire-B	Loaded		X		X	X
	Tire-C	Loaded		X		X	X
	Tire-D	Loaded		X		X	X

Table 1. Test matrix for the noise evaluation tests of military truck tires. A minimum of two test runs were made for each operational condition.

Figures 12-15 show characteristic frequency spectra for each of the four tire types tested. Each figure contains three plots corresponding to: (1) test tires mounted at all ten wheel positions during a powered drive-by with the Army vehicle, (2) test tires mounted at all ten wheel positions during a coast-by (engine shut off) with the Army vehicle, and (3) a coast-by with the commercial vehicle with test tires at the four wheel positions on the drive axle and quiet rib tires on the steering axle. In all cases the vehicles were loaded and operated at a speed of 40 mph while running on a concrete surface.

A maximum exists in all the drive-by spectra at 100-125 Hz. This is the fundamental associated with the vehicle exhaust noise. In general, this peak is approximately 30 dB above the sound pressure level observed in this frequency band during the coast-by mode. A harmonic of the exhaust noise fundamental is also observed.

Maxima observed in the coast-by spectra, regardless of whether the test vehicle was a 6 x 6 military truck or a 4 x 2 commercial truck, appear to be attributable to the major tread element spacing and the rotational rate of the tire. The fundamental frequency in the one-third octave band spectra can be predicted on the basis of tread spacing and vehicle velocity according to the following relationship:

$$f = \frac{17.6V}{a} \qquad (1)$$

where, f = fundamental frequency, Hz
V = vehicle speed, mph
a = tread element spacing, in.

Table 2 shows the major tread spacing for each tire, the predicted frequency of the fundamental based on major tread spacing, and the one-third octave frequency band in which the fundamental was actually measured. The calculations are based on a vehicle speed of 40 mph. All of the test tires, with the exception of tire-A, had randomized tread-pattern pitch lengths as evidenced by the range in values for the tread spacing for these tires shown in Table 2. In all cases the maximum in the one-third octave band spectra was predictable on the basis of the tread spacing. This does not imply, however, that other noise generation mechanisms are not also major contributors to the overall noise levels observed. Our knowledge of tire noise generation mechanisms is limited at present and, therefore, we must be cautious in drawing any far-reaching conclusions.

A comparison of coast-by spectral data from the 4 x 2 commercial truck and the 6 x 6 military truck seems to indicate that the 6 x 6 Army truck can serve as a test vehicle during tire tests. At the onset of this program, there was some question as to the suitability of this 6 x 6 vehicle as a test truck due to the suspicion that the drive train/differential noise was much higher for military vehicles than for comparable commercial vehicles. Thus, even in a coast-by mode, the tire noise would be masked by the inherent vehicle noise.

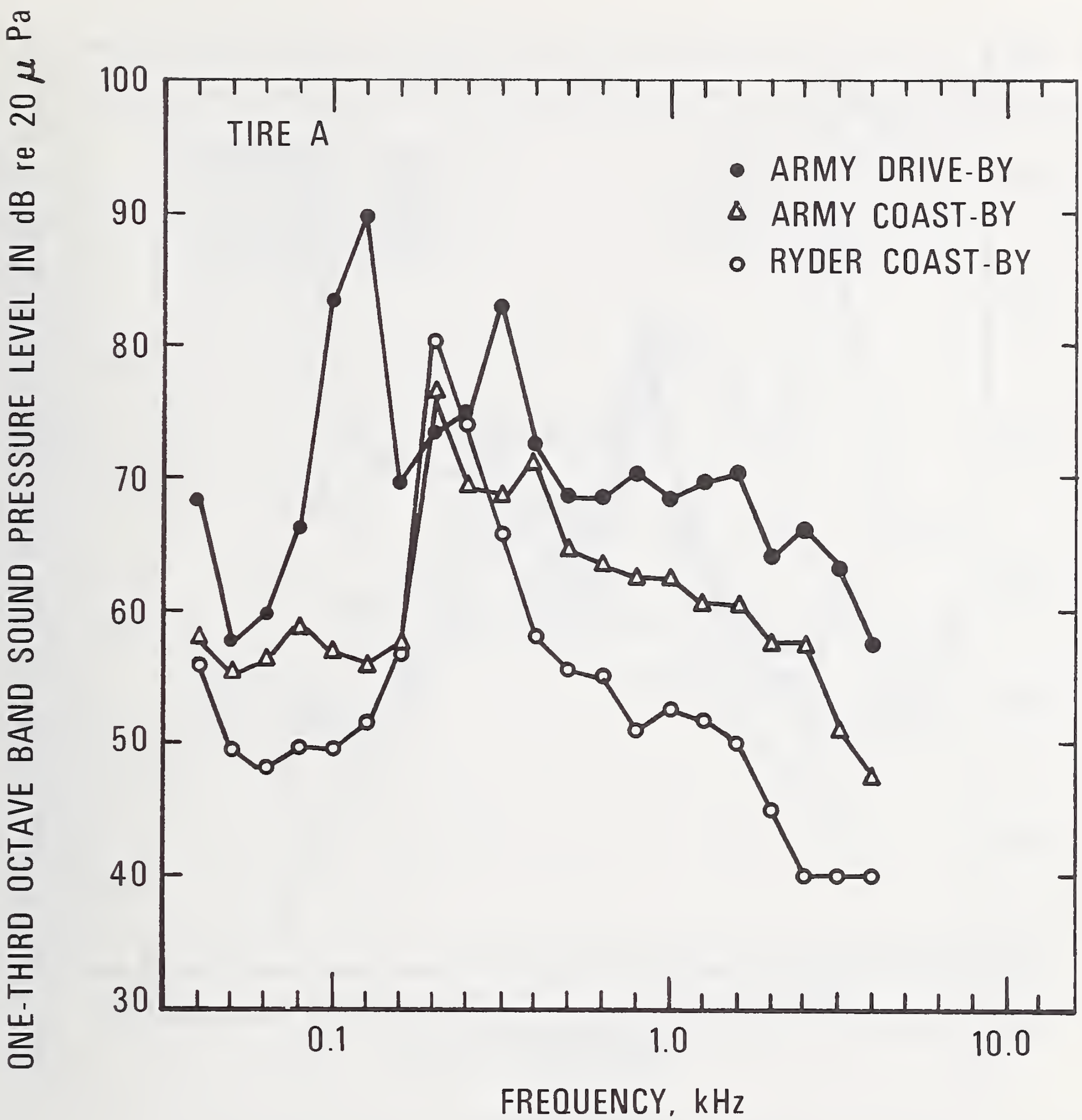

Figure 12. One-third octave band frequency spectra for tire-A as measured at 50 feet corresponding to operation of the Army vehicle (10 test tires) in drive-by and coast-by modes and the commercial vehicle (4 test tires) in a coast-by mode. The vehicles were loaded and operated at a speed of 40 mph while running on a concrete surface.

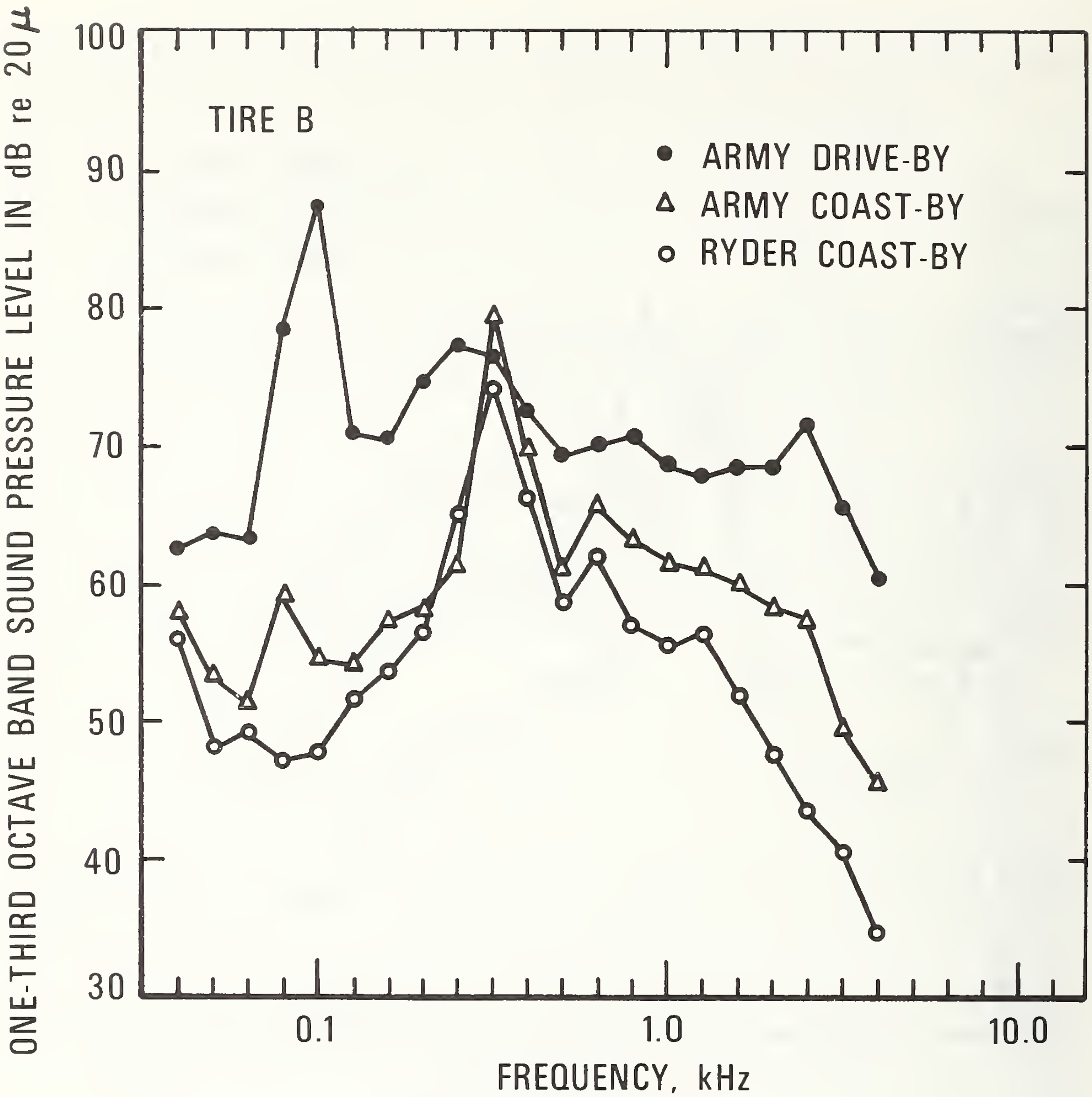

Figure 13. One-third octave band frequency spectra for tire-B as measured at 50 feet corresponding to operation of the Army vehicle (10 test tires) in drive-by and coast-by modes and the commercial vehicle (4 test tires) in a coast-by mode. The vehicles were loaded and operated at a speed of 40 mph while running on a concrete surface.

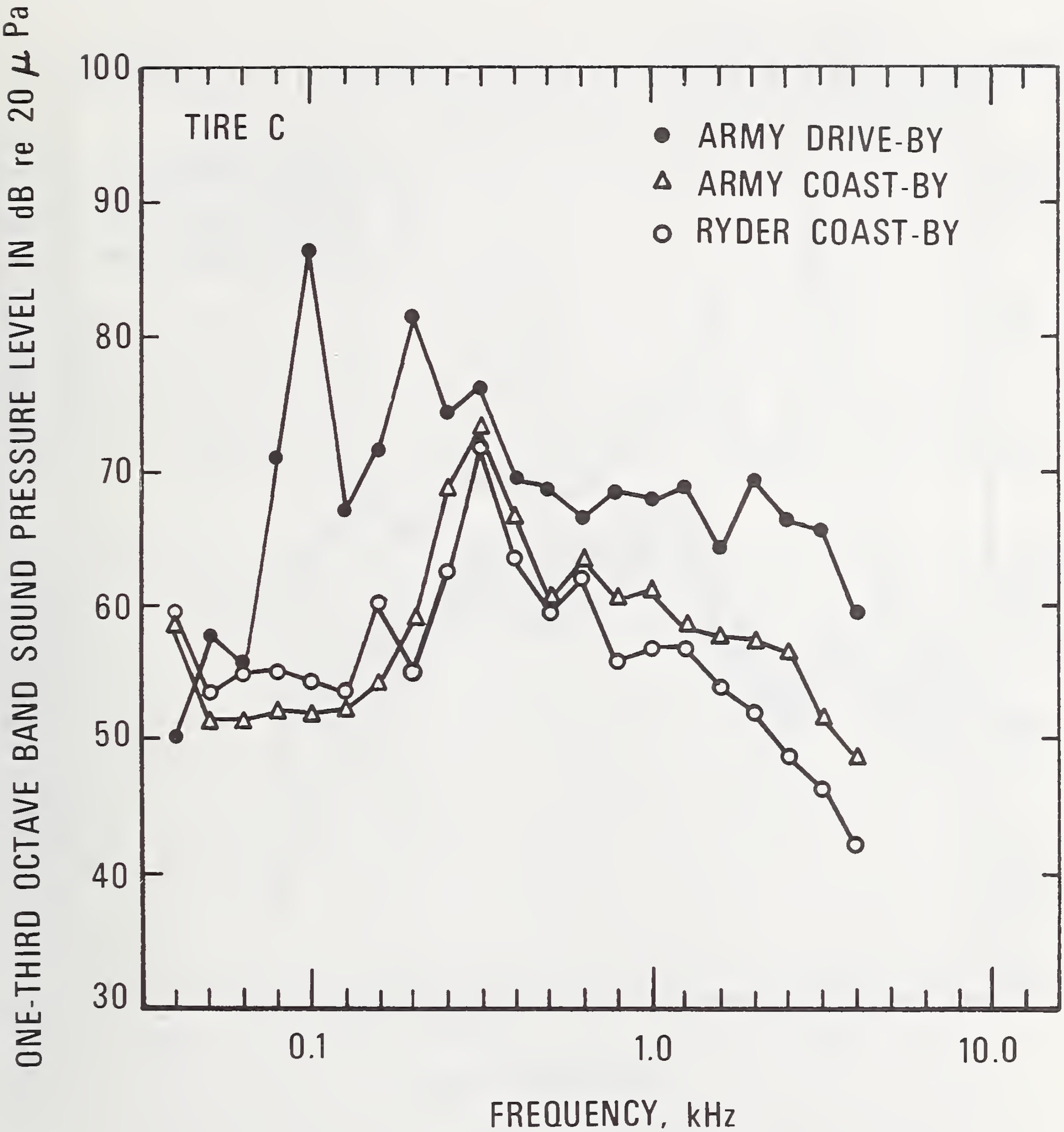

Figure 14. One-third octave band frequency spectra for tire-C as measured at 50 feet corresponding to operation of the Army vehicle (10 test tires) in drive-by and coast-by modes and the commercial vehicle (4 test tires) in a coast-by mode. The vehicles were loaded and operated at a speed of 40 mph while running on a concrete surface.

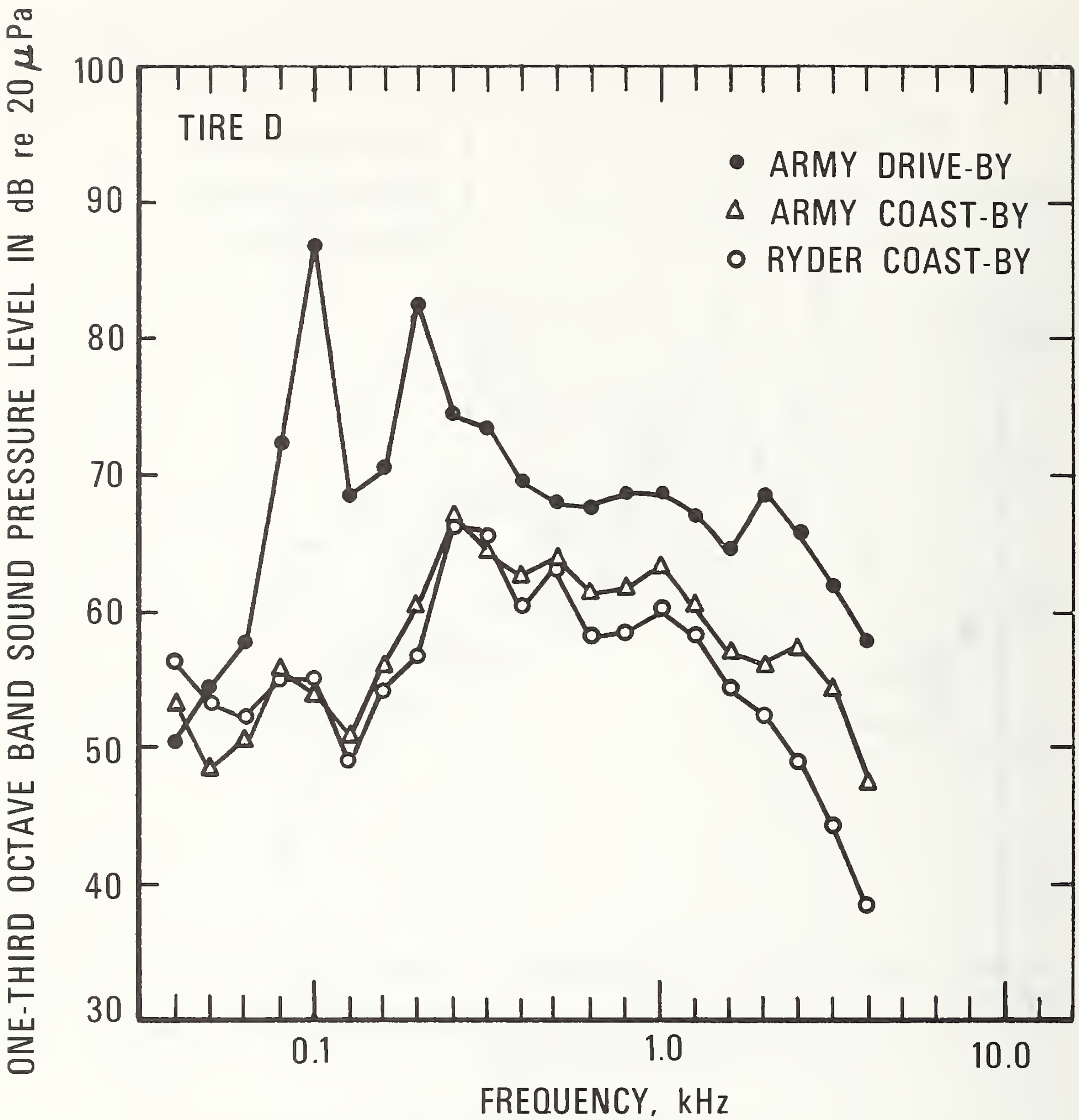

Figure 15. One-third octave band frequency spectra for tire-D as measured at 50 feet corresponding to operation of the Army vehicle (10 test tires) in drive-by and coast-by modes and the commercial vehicle (4 test tires) in a coast-by mode. The vehicles were loaded and operated at a speed of 40 mph while running on a concrete surface.

	Major Tread Spacing, in.	Predicted Fundamental Frequency, Hz	Center Frequency of One-third Octave Band Containing the Measured Fundamental Frequency, Hz
Tire-A	3.250	217	200
Tire-B	2.000-2.375	296-352	315
Tire-C	2.437-2.875	245-289	315
Tire-D	2.875-3.375	209-245	250

Table 2. Predicted and measured fundamental tire noise frequencies based on major tread spacing considerations corresponding to a vehicle speed of 40 mph.

In order to investigate the effect of tread design and speed on generated noise levels a plot of maximum A-weighted sound level versus speed with tread design as a variable was developed (Figure 16). These data represent measurements at 50 feet for coast-by runs of the loaded 4 x 2 single-chassis vehicle on a concrete surface. In every case, an increase in speed resulted in an increase in the maximum A-weighted sound level. In general, the increases were on the order of 6-8 dB for speed changes from 40 to 60 mph. This corresponds to sound level increasing as the third to fourth power of speed. The obvious exception to this general statement is tire-A which exhibited an increase of approximately 11 dB over the same speed range. Tire-A is approximately 2 dB higher than the next noisiest tire (tire-B) at a speed of 40 mph; however, the difference increases to 6 dB at 60 mph. Tire-B is approximately 2-2.5 dB noisier than tires-C and -D over the speed range studied. Tires-C and -D have nearly identical A-weighted sound level versus speed curves, with tire-D being slightly quieter at higher speeds. It is obvious that the choice of tires based on noise considerations is dependent on the speed range over which the vehicles are expected to operate. For well maintained trucks equipped with reasonable exhaust mufflers, tire noise can become a significant contributor to overall vehicle noise at speeds as low as 35-40 mph and the predominate contributor at speeds of 50 mph and higher. Also, these data are for new tires and in general an increase in the noise level is observed between the new and half-worn states of tire wear. Depending on the tire type, the increase can be significant. At this time no knowledge of the magnitude of the increase which could be expected for these tires exists.

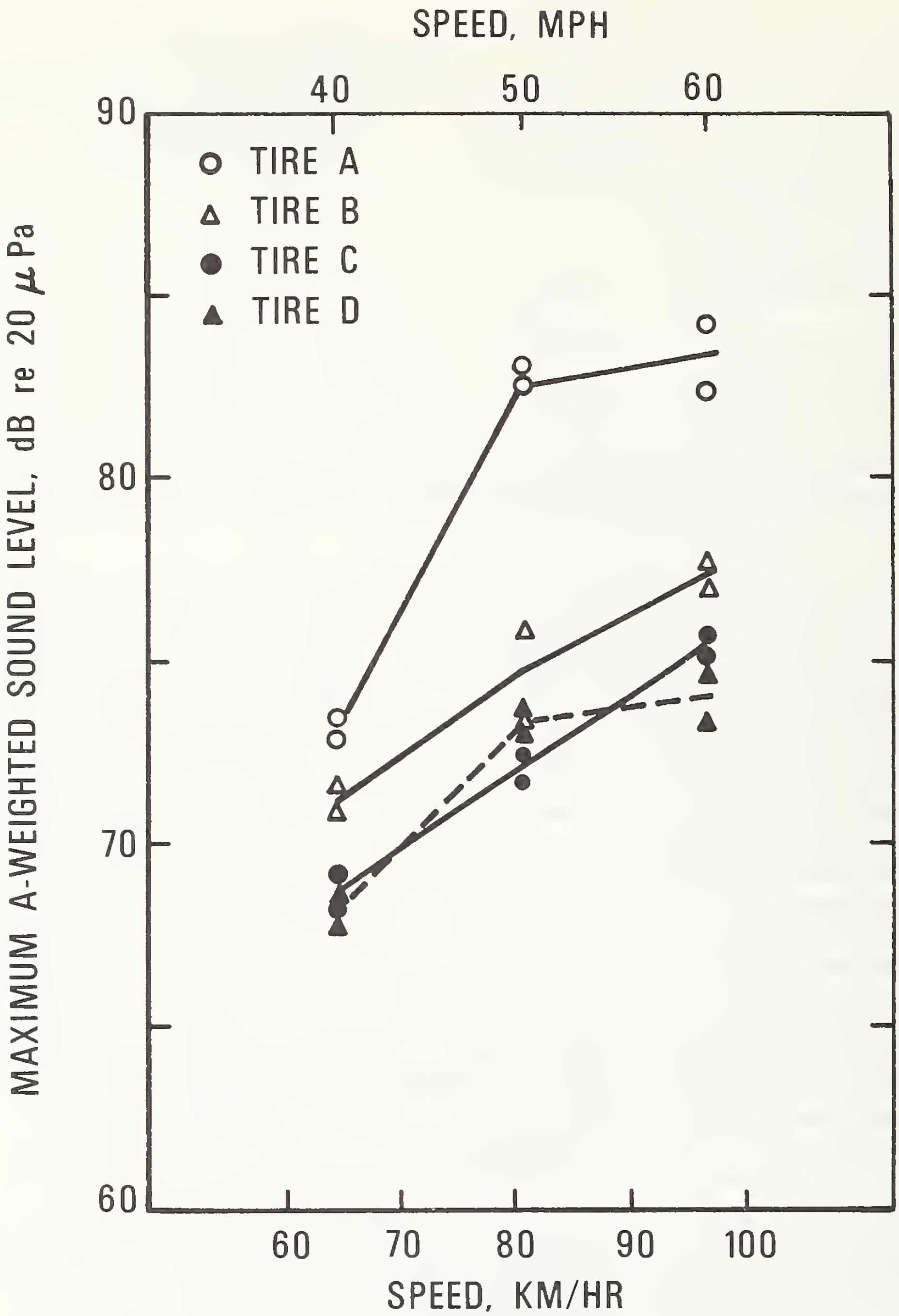

Figure 16. Maximum A-weighted sound level, as measured at 50 feet, versus speed for a loaded 4 x 2 single-chassis vehicle coast-by on a concrete surface. Various types of new tires were mounted on the drive axle.

Since Army vehicles are operated on public roads at typical highway speeds (when not in convoy), there exists a need to establish the high speed tire noise contribution to overall vehicle noise levels. Ideally, one would like to test the Army vehicle (10 test tires) under full load at speeds of 50 - 60 mph. Practical limitations did not allow such a test. The maximum attainable speed for the Army vehicle under full load in the available runway length (slightly greater than one mile) was 45 mph. For this reason, all of the high speed data in this report are based on tests utilizing the commercial single-chassis vehicle which was capable of attaining speeds of 60 mph within the available space limitations.

The impact of these practical constraints is shown by the data in Figures 17 and 18 where the maximum A-weighted sound levels versus speed as measured at the 50 foot microphone are plotted for tires-C and-D under the following test conditions: (1) driven Army vehicle (10 test tires) (2) coasting Army vehicle (10 test tires), and (3) coasting commercial vehicle (4 test tires). The vehicles were loaded and ran on a concrete surface.

The difference in sound level between the coasting Army truck and the coasting commercial truck is approximately 3 dB which is to be expected since the Army truck has an additional rear axle and therefore has twice the number of rear tires. It should be further noted that all tires are not characterized by a linear relationship between noise level and vehicle speed. For instance, the characteristic noise level versus speed curve for tire-C is linear over the speed range from 40 - 60 mph (a 3.5 dB increase in sound level is observed for each 10 mph increase in speed), while tire-D does not possess such a characteristic. Noise levels for tire-D increase at a given rate (5 dB/10 mph) between 40 and 50 mph and at a different rate (1 dB/10 mph) between 50 and 60 mph. The fact that a slope is defined over a limited speed range at lower speeds, does not allow one to extrapolate that trend in order to predict the noise level expected at higher speeds.

Load is another important parameter which influences tire noise levels. Past studies [1,2] have shown that changes in load can significantly affect the noise level generated by tires with cross-bar tread patterns while noise from tires with rib type tread patterns were relatively unaffected by load changes. In the case of cross-bar tires, as the load is increased, more of the tire load is carried on the outer edges of the tread where more drastic interruptions in tread pattern exist. Since the rib pattern is the same across the width of the tire, it may not be as important how much load is carried on the outer edges of the tire.

Figure 19 shows the effect of load on tire noise observed during this study based on 40 mph coast-by data for 6 x 6 military vehicle. A wide variation in noise level for nominally identical test conditions was observed in the data for tire-B. Thus the slope of the A-weighted sound level versus tire load curve is questionable for this tire. Tire-A (the standard Army tire), which is cross-bar in nature, behaved as would be expected on the basis of the existing tire noise data base.

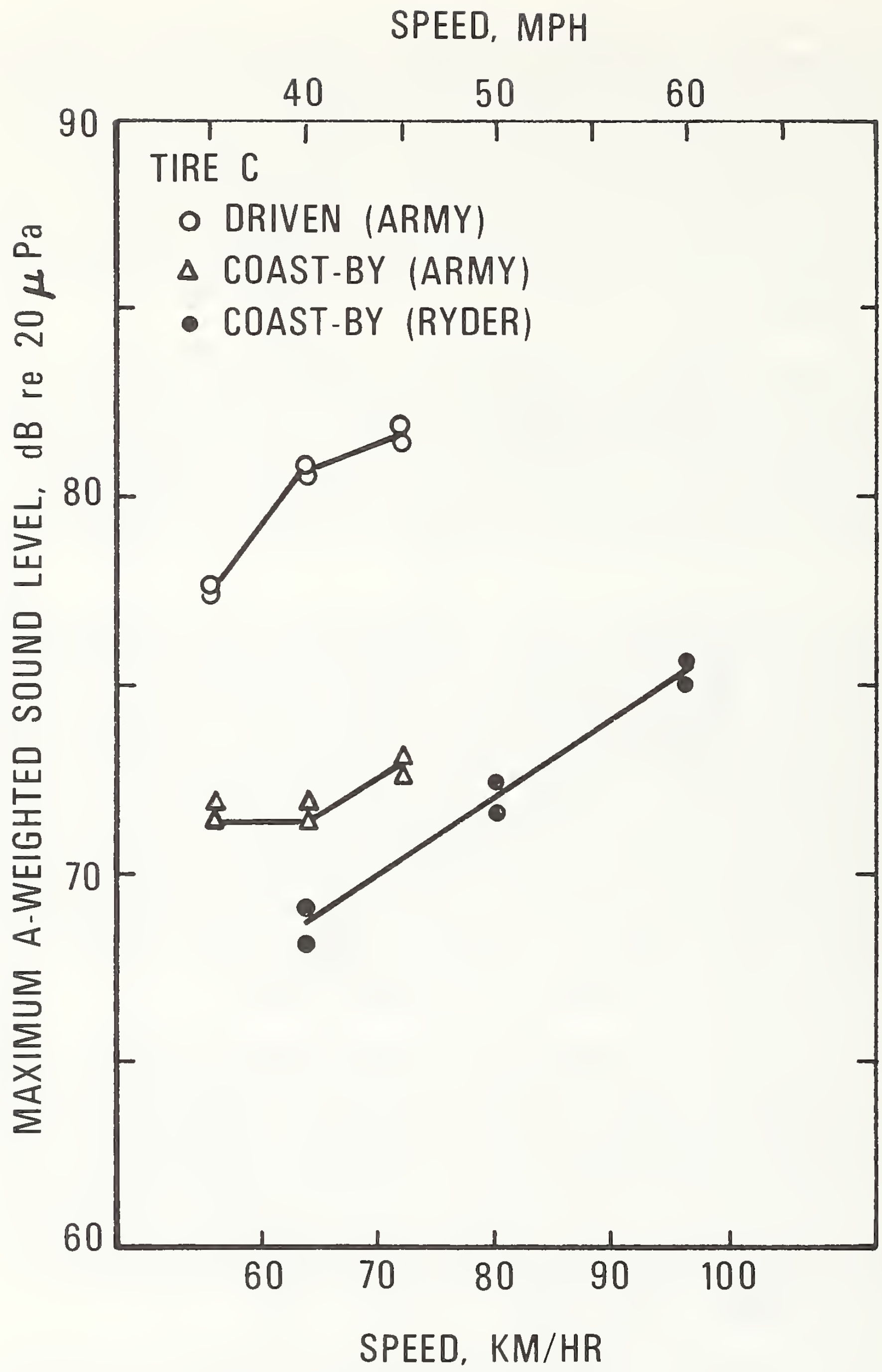

Figure 17. Maximum A-weighted sound level, as measured at 50 feet, versus speed for tire-C corresponding to operation of the Army vehicle (10 test tires) in drive-by and coast-by modes and the commercial vehicle (4 test tires) in a coast-by mode. The vehicles were loaded and ran on a concrete surface.

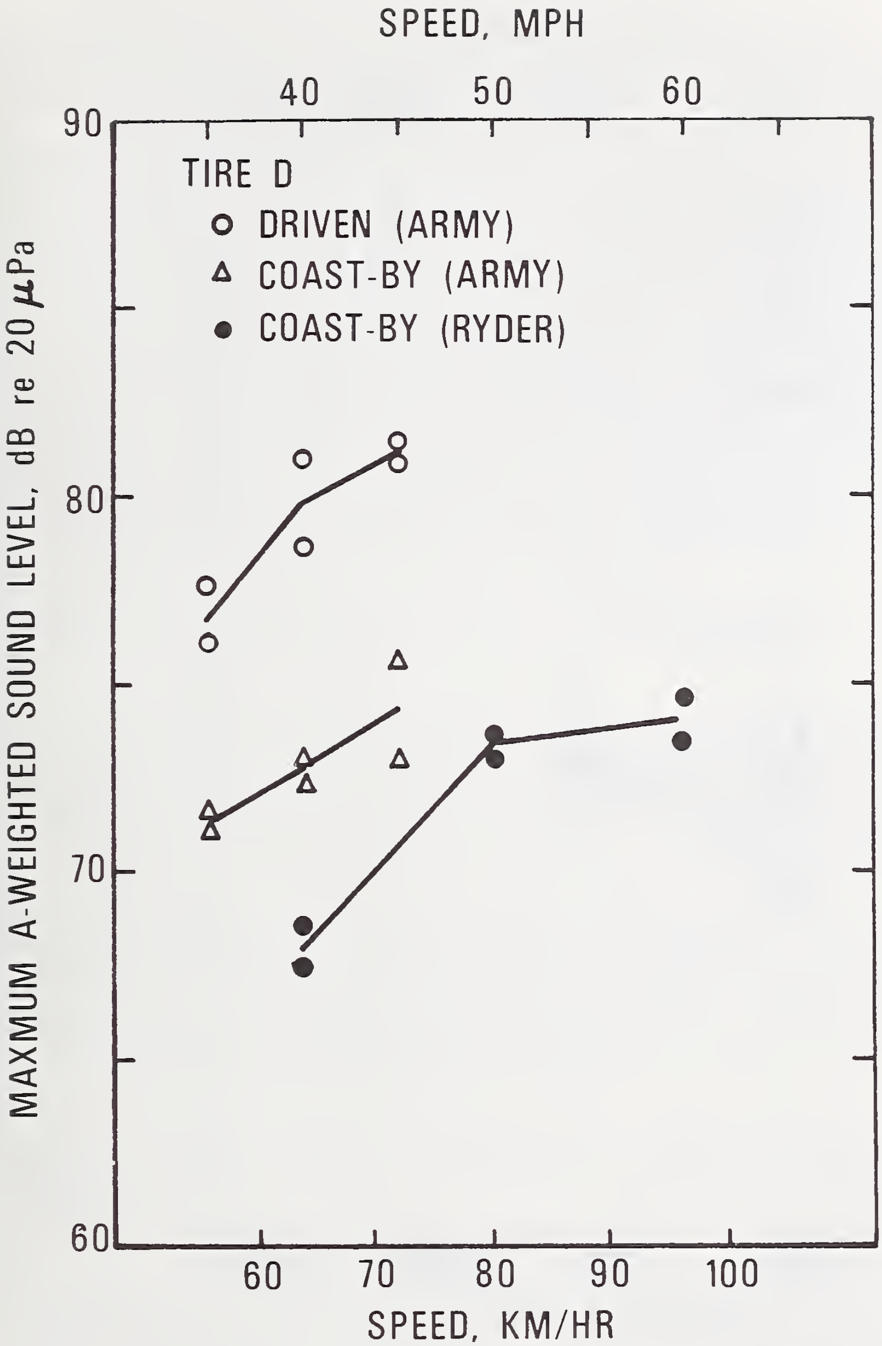

Figure 18. Maximum A-weighted sound level, as measured at 50 feet, versus speed for tire-D corresponding to operation of the Army vehicle (10 test tires) in drive-by and coast-by modes and the commercial vehicle (4 test tires) in a coast-by mode. The vehicles were loaded and ran on a concrete surface.

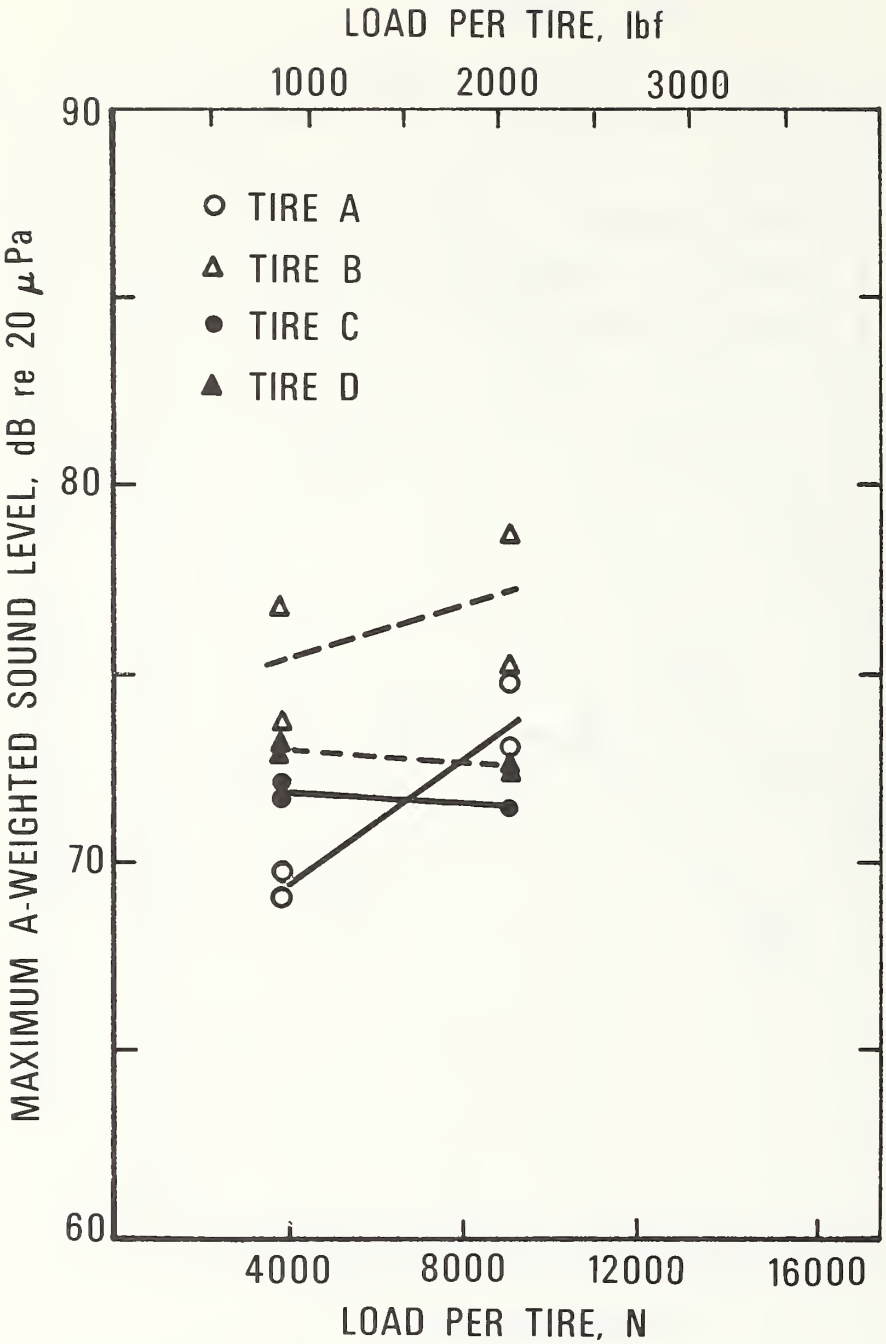

Figure 19. Maximum A-weighted sound level, as measured at 50 feet, versus the load per drive axle tire for a 40 mph coast-by of the 6 x 6 military vehicle on a concrete surface.

An increase in sound level was observed with increasing load. Of special interest is the fact that tire-A is the quietest tire when unloaded and even when loaded is only 1-2 dB noisier than tires-C and -D (at a speed of 40 mph). As noted earlier (Figure 16), on the basis of coast-by data utilizing the commercial vehicle, tire-A was the noisiest tire over the speed range 40-60 mph. A decrease in sound level was observed with an increase in load for tires-C and -D (Figure 19). The decrease was small (less than 1 dB) and is probably attributable to the fact that under load the drive train noise is slightly lower. It should further be pointed out that the tires in this study were not loaded in the same manner as in previous studies. As discussed previously in this report, the commercial vehicle was loaded such that the load per drive axle tire corresponded to the load per drive axle tire observed for the loaded Army truck. The military and commercial test vehicles had the same gross vehicle weight capacity (approximately 25,000 pounds), but since the military vehicle had an additional drive axle, the load per tire was about one-half the load that would be typical in normal commercial usage. This difference in loading explains the apparent discrepency between the data of Figures 16 and 19.

Based on the data obtained during the conduct of this test program, the following conclusions can be drawn:

- The data base established during this study provides the basis for comparison of the tire noise generated by military and commercial truck tires. There is a need to do some testing with a 4 x 2 single-chassis vehicle to ensure a tie with the extensive data base on tire noise which now exists in the public domain.

- It is possible to select tires which produce lower noise levels than the standard Army tire. Since the magnitude of the tire noise problem increases with speed, it is important to consider the typical operating cycle of these vehicles. Tires acceptable from a noise level standpoint at low speeds may be totally unacceptable at typical highway speeds.

- The 6 x 6 military truck can serve as a test vehicle for coasting tire tests; however, under full tire load an extremely long test site would be necessary to allow for the vehicle to attain speeds of 50-60 mph.

- For these particular military vehicles the engine/exhaust noise is such that tire noise is not a problem (at present) over the speed range studied (35-45 mph). It must be noted that the test tires in this study were all new. No knowledge exists at this time to predict the expected noise level for these tires over their wear cycle.

- Load is also a factor in the choice of tires, for instance the standard military tire which is the noisiest tire under load at higher speed, is actually the quietest tire under no-load conditions at a vehicle speed of 40 mph.

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 loading of the test tires and the speed and operation mode of the test vehicle. 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 A (standard Army tire). The nominal new tread depth for this tire was 21/32 inch. Shore hardness values ranging from 51-60 were observed with the average being 57.

TIRE A (STANDARD ARMY TIRE)

Army Truck Loaded - Drive-by
A-weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph							
	35	35	35	40	40	45	45	45
25	85.4	84.8	86.8	85.8	86.2	89.0	87.8	----
50	78.8	78.8	----	82.2	81.8	84.2	82.4	83.8

Army Truck Unloaded - Drive-By
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph			
	40	40	45	45
25	87.4	86.8	88.4	88.4
50	81.4	80.8	82.8	82.8

Army Truck Loaded - Coast-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph						
	35	35	40	40	45	45	45
25	76.0	75.8	77.2	77.6	82.0	81.4	80.4
50	71.2	71.8	73.0	74.6	75.0	77.0	76.8

Army Truck Unloaded - Coast-by

A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph			
	40	40	45	45
25	74.0	74.2	76.0	78.6
50	69.2	69.6	74.0	73.6

Ryder Truck Loaded - Coast-By

A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph							
	40	40	40	50	50	50	60	60
25	75.8	78.2	77.2	87.0	84.8	86.0	89.0	85.8
50	70.8	72.8	73.4	82.4	82.6	82.6	82.4	84.2

Figure A-2. Characteristic tread element pattern of tire B (commercial rib tire). The nominal new tread depth for this tire was 16/32 inch. Shore hardness values ranging from 60-64 were observed with the average being 61.

TIRE B (COMMERCIAL RIB TIRE)

Army Truck Loaded - Drive-by
A-Weighted Sound Levels, dB

Microphone	Nominal Speed, mph					
Location, ft.	35	35	40	40	45	45
25	85.0	85.8	86.0	86.2	88.8	87.2
50	80.4	80.8	81.0	81.2	83.2	82.2

Army Truck Unloaded - Drive-by
A-Weighted Sound Levels, dB

Microphone	Nominal Speed, mph			
Location, ft.	40	40	45	45
25	86.0	85.8	88.4	87.2
50	81.0	81.2	82.8	83.0

Army Truck Loaded - Coast-by
A-Weighted Sound Levels, dB

Microphone	Nominal Speed, mph					
Location, ft.	35	35	40	40	45	45
25	79.0	79.0	81.6	80.0	83.4	81.0
50	73.6	73.2	78.6	75.2	75.4	76.8

Army Truck Unloaded - Coast-by
A-Weighted Sound Levels, dB

Microphone	Nominal Speed, mph			
Location, ft.	40	40	45	45
25	78.0	79.6	80.8	80.4
50	73.6	76.8	74.6	75.8

Ryder Truck Loaded - Coast-by
A-Weighted Sound Levels, dB

Microphone	Nominal Speed, mph					
Location, ft.	40	40	50	50	60	60
25	75.4	75.8	78.6	79.4	80.6	81.0
50	71.6	70.8	73.4	75.8	77.8	77.0

Figure A-3. Characteristic tread element pattern of tire C (Army retread tire). The nominal new tread depth for this tire was 20/32 inch. Shore hardness values ranging from 58-64 were observed with the average being 62.

TIRE C (ARMY RETREAD TIRE)

Army Truck Loaded - Drive-by
A-weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph					
	35	35	40	40	45	45
25	83.4	82.8	85.8	84.8	86.0	87.2
50	77.4	77.6	80.6	80.6	81.4	81.8

Army Truck Unloaded - Drive-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph			
	40	40	45	45
25	85.8	85.2	87.2	89.0
50	81.0	80.6	83.8	83.4

Army Truck Loaded - Coast-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph					
	35	35	40	40	45	45
25	76.6	75.4	79.2	78.4	76.4	76.6
50	71.4	71.4	71.4	71.4	72.6	73.2

Army Truck Unloaded - Coast-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph			
	40	40	45	45
25	75.4	74.6	76.4	77.2
50	72.0	71.6	73.2	72.0

Ryder Truck Loaded - Coast-by
A-weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph					
	40	40	50	50	60	60
25	72.2	73.0	75.6	76.6	79.0	79.2
50	68.2	69.2	72.4	71.6	75.6	75.0

Figure A-4. Characteristic tread element pattern of tire D (commercial cross-bar tire). The nominal new tread depth for this tire was 19/32 inch. Shore hardness values ranging from 61-66 were observed with the average being 64.

TIRE D (COMMERCIAL CROSS-BAR TIRE)

Army Truck Loaded - Drive-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph					
	35	35	40	40	45	45
25	83.6	81.8	84.8	83.8	85.6	85.6
50	77.6	76.2	80.8	78.6	81.4	80.0

Army Truck Unloaded - Drive-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph			
	40	40	45	45
25	85.6	86.4	88.2	88.4
50	80.6	80.8	83.2	82.4

Army Truck Loaded - Coast-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph					
	35	35	40	40	45	45
25	76.0	75.6	77.8	78.6	80.6	81.6
50	71.2	71.6	73.0	72.4	75.6	73.0

Army Truck Unloaded - Coast-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph			
	40	40	45	45
25	78.0	77.8	79.4	78.2
50	73.2	72.8	74.6	74.2

Ryder Truck Loaded - Coast-by
A-Weighted Sound Levels, dB

Microphone Location, ft.	Nominal Speed, mph					
	40	40	50	50	60	60
25	73.2	72.6	78.0	77.6	80.0	79.0
50	68.6	68.0	73.0	73.6	74.6	73.4

5. Appendix B

Instrument Descriptions

Unless otherwise stated, all instruments are Brüel and Kjaer[4/] (B & K).

Type UA 0207 Windscreen: When a microphone is exposed to wind, the turbulence created around the microphone and wind velocity variations 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°C (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 Microphone: 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,

---

[4/] 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.

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.

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 8K (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. Appendix C

Concrete Test Section Substrate Details[5/]

Substrate details discussed in this appendix are not the exact details of the test pavements; however, they represent the specifications followed in the construction of the pavements. Since surface details are most important when considering the effect of the pavement on noise generation characteristics of tires, special note should be taken of the discussion of surface finishing techniques.

The surface utilized for these tests consists of a wearing surface of reinforced air-entrained Portland Cement concrete pavement with two types of finishes on a suitably prepared subbase.

1. <u>Materials</u>

The cement used in this work was a standard brand of Portland cement with air-entraining properties. The air-entrained cement conformed to A.S.T.M. designation C-175.

In no case was the use of pit run or naturally mixed coarse aggregates permitted. Naturally mixed aggregates were in every case screened and washed and all fine and coarse aggregates were stored separately and kept clean. In no case were aggregates containing lumps of frozen or partially cemented material used.

The coarse aggregate conformed to the requirements of A.A.S.H.O. Specification M-80. Also, at least sixty percent of the gravel aggregate had at least one fractured face. The coarse aggregate had no more than one percent of material removable by the decantation test, using A.A.S.H.O. Method T-11 nor more than one percent of shale, nor more than one percent of clay lumps. Chert did not exceed one percent. The total of shale, coal clay lumps, chert, soft fragments, and other deleterious materials did not exceed five percent. The coarse aggregate did not show evidence of disintegration nor show a total loss greater than twelve percent when subjected to five cycles of the sodium sulfate soundness test using A.A.S.H.O. Method T-104.

[5/] Details of the composition of this test section were taken from a National Aeronautics and Space Administration, Wallops Station, Virginia, Specification numbered P-1643, entitled "Modification to Runway 4-22", and dated April 18, 1967.

The coarse aggregate conformed to the following gradations:

Sieve Size Square Mesh	Percent Passing by Weight Gradation A	Gradation B
2 inch	100	-
1 1/2 inch	90-100	-
1 inch	20-55	100
3/4 inch	0-15	90-100
3/8 inch	0-15	20-55
No. 4	-	0-10
No. 8	-	0-5

The coarse aggregate were batched in two separate sizes which could be varied within a range from forty to sixty percent by weight to secure the most desirable and uniform gradation of the combined mix.

The fine aggregates conformed to the requirements of A.A.S.H.O. Specification M-6.

When subjected to five cycles of the sodium sulfate soundness test using A.A.S.H.O. Method T-104, the fine aggregate had a total loss less than ten percent by weight. It also contained less than three percent of material removable by the decantation test, using A.A.S.H.O. Method T-11. Permissible percentages of shale, clay lumps, etc. were the same as for the coarse aggregate.

The fine aggregate was well graded from fine to coarse and met the following gradation requirements, using A.A.S.H.O. Method T-27.

Sieve Designation (Square Mesh)	Percentage Passing by Weight
3/8 inch	100
No. 4	95-100
No. 16	45-80
No. 30	25-55
No. 50	10-30
No. 100	2-10

The water used in the concrete and for curing was clean, clear, and free of injurious amounts of sewage, oil, acid, strong alkalies, or vegetable matter, and, also, free of clay and loam.

2. Composition of Mixture

The weights of fine and coarse aggregate and the quantity of water per bag of cement were determined from the weights given in the following table:

Type of Aggregate	Minimum Cement Content Per Cubic Yard of Concrete	Maximum Net Water Content, Gallons Per Bag	Weights in pounds of dry Aggregate per bag of cement			Slump Range, Inches
			Fine Aggregate	Coarse Aggregate	Total	
Gravel	5.8 bags	5 1/2	169	394	563	1 1/2
Crushed Stone	5.8 bags	5 3/4	195	366	561	1 1/2

Yield tests in accordance with ASTM Specification C-138 were made to determine the cement content per cubic yard of concrete. If at any time, the content was found to be less than that specified, the batch weights were reduced until the requirements were met.

Air-entrained Portland cement concrete causes a bulking of the mortar of the concrete due to the amount of entrained air. To keep the cement factor specified at the correct amount, the weight of the fine aggregate was reduced as required. The air content of the fresh concrete was determined by ASTM Designation C-231.

The proportions in the above table produced a concrete of satisfactory plasticity and workability which attained, after fourteen days, a minimum compressive strength of 3000 pounds per square inch and a modulus of rupture of 700 pounds per square inch after twenty-one days. The specimens were cured and tested in accordance with A.A.S.H.O. Methods T-22, T-23 and T-97.

3. Placing and Finishing

The concrete was deposited and spread so that any segregation would be corrected and a uniform layer of concrete would be produced whose thickness was approximately one inch greater than that required for the finished pavement.

After the first operation of the finishing machine, additional concrete was added to all low places and the concrete rescreeded.

After the final pass of the finishing machine, the placing of all joints longitudinal and transverse, and before the concrete had started to dry, the surface of the pavement was finished with a longitudinal float.

After the concrete was brought to the required grade, contour, and smoothness, it was finished by means of a finishing belt. The belt was eight to twelve inches in width and at least two feet longer than the width of the pavement section to be finished. On the "C" (smooth) finish section of pavement a belt of canvas composition was used.

References for Appendix C

[1] American Society for Testing and Materials, C-175-69, Standard Specification for Air-Entraining Portland Cement in Part 10, Book of ASTM Standards, 1970 (ASTM, Philadelphia, Pennsylvania).

[2] American Association of State Highway Officials, M-80-51, Standard Specification for Portland Cement Concrete, Standard Specifications for Highway Materials and Methods of Sampling and Testing, Ninth Edition, 1966 (AASHO, Washington, D. C.).

[3] American Association of State Highway Officials, T-104-65, Standard Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate, Standard Specifications for Highway Materials and Methods of Sampling and Testing, Ninth Edition, 1966 (AASHO, Washington, D. C.).

[4] American Association of State Highway Officials, M-6-65, Standard Specification for Fine Aggregate for Portland Cement Concrete, Standard Specifications for Highway Materials and Methods of Sampling and Testing, Ninth Edition, 1966 (AASHO, Washington, D. C.).

[5] American Association of State Highway Officials, T-11-60, Standard Method of Test for the Amount of Material Finer than No. 200 Sieve in Aggregate, Standard Specifications for Highway Materials and Methods of Sampling and Testing, Ninth Edition, 1966 (AASHO, Washington, D. C.).

[6] American Association of State Highway Officials, T-27-60, Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates, Standard Specifications for Highway Materials and Methods of Sampling and Testing, Ninth Edition, 1966 (AASHO, Washington, D. C.).

[7] American Society of Testing and Materials, C-138-63 (1969), Standard Method of Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete in Part 10, Book of ASTM Standards, 1970, (ASTM, Philadelphia, Pennsylvania).

[8] American Society for Testing and Materials, C-231-68, Standard Method of Test for the Air Content of Freshly Mixed Concrete by the Pressure Method, Book of ASTM Standards, 1970 (ASTM, Philadelphia, Pennsylvania).

[9] American Association of State Highway Officials, T-22-64, Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (ASTM designation: C-39-66), Standard Specifications for Highway Materials and Methods of Sampling and Testing, Ninth Edition, 1966 (AASHO, Washington, D. C.).

[10] American Association of State Highway Officials, T-23-65, Standard Method for Making and Curing Concrete Compression and Flexural Test Specimens in the Field, Standard Specifications for Highway Materials and Methods of Sampling and Testing, Ninth Edition, 1966 (AASHO, Washington, D.C.).

[11] American Association of State Highway Officials, T-97-64, Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (ASTM designation: C-78-64), Standard Specifications for Highway Materials and Methods of Sampling and Testing, Ninth Edition, 1966 (AASHO, Washington, D.C.).

7. References

[1] Anon., Truck noise-I, peak A-weighted sound levels due to truck tires, (National Bureau of Standards, Washington, D. C., 1970) Department of Transportation Report OST-ONA-71-9.

[2] Leasure, Jr., W. A., Corley, D. M., Flynn, D. R. and Forrer, J. S., Addendum truck noise-I, peak A-weighted sound levels due to truck tires, (National Bureau of Standards, Washington, D. C., 1972), Department of Transportation Report OST/TST-72-1.

[3] American Society for Testing and Materials, D 2240-68, Standard Method of Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer in Part 27, 28, Book of ASTM Standards, 1970 (ASTM, Philadelphia, Pennsylvania).

Acknowledgements

The authors would like to recognize the contributions made by the following organizations which have greatly aided this research program: The U. S. Army Tank-Automotive Command, especially Mr. D. W. Rees and Mr. W. Bremerkamp, and the staff of the Wallops Station Facility of the National Aeronautics and Space Administration. Special thanks go to Mr. G. Godwin who was our liaison at Wallops Station.

The authors also express appreciation to the following members of the staff of the Applied Acoustics Section: Mrs. Mary L. Friend and Mrs. Marilyn A. Cadoff for their assistance in the assembly of the report, Mr. D. S. Blomquist and Mr. C. O. Shoemaker for instrumentation design and fabrication, and Mr. D. R. Flynn and Mr. W. H. Close (Office of Noise Abatement, U.S., Department of Transportation) for their review and comments.