NATIONAL BUREAU OF STANDARDS REPORT

10 359

AUTOMOBILE TIRE SOUNDS – ACOUSTICAL GRADING SYSTEM FEASIBILITY
2. COASTBY STUDY

Prepared for

The Office of Noise Abatement
Department of Transportation
Washington, D.C. 20590

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards [1] was established by an act of Congress March 3, 1901. Today, in addition to serving as the Nation's central measurement laboratory, the Bureau is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in four broad program areas. These are: (1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology.

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of an Office of Measurement Services and the following technical divisions:

Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic and Molecular Physics—Radio Physics [2]—Radio Engineering [2]—Time and Frequency [2]—Astrophysics [2]—Cryogenics.[2]

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; develops, produces, and distributes standard reference materials; relates the physical and chemical properties of materials to their behavior and their interaction with their environments; and provides advisory and research services to other Government agencies. The Institute consists of an Office of Standard Reference Materials and the following divisions:

Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations in the development of technological standards, and test methodologies; and provides advisory and research services for Federal, state, and local government agencies. The Institute consists of the following technical divisions and offices:

Engineering Standards—Weights and Measures — Invention and Innovation — Vehicle Systems Research—Product Evaluation—Building Research—Instrument Shops—Measurement Engineering—Electronic Technology—Technical Analysis.

THE CENTER FOR RADIATION RESEARCH engages in research, measurement, and application of radiation to the solution of Bureau mission problems and the problems of other agencies and institutions. The Center consists of the following divisions:

Reactor Radiation—Linac Radiation—Nuclear Radiation—Applied Radiation.

THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in the selection, acquisition, and effective use of automatic data processing equipment; and serves as the principal focus for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

Information Processing Standards—Computer Information — Computer Services — Systems Development—Information Processing Technology.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System, and provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world. The Office consists of the following organizational units:

Office of Standard Reference Data—Clearinghouse for Federal Scientific and Technical Information [3]—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT 42114-4080405

NBS REPORT 10 359

AUTOMOBILE TIRE SOUNDS – ACOUSTICAL GRADING SYSTEM FEASIBILITY
2. COASTBY STUDY

by

Arthur I. Rubin, John F. Halldane, Ronald L. Fisher, and John S. Forrer
Sensory Environment Branch
Building Research Division
National Bureau of Standards
Washington, D.C. 20234

Prepared for

The Office of Noise Abatement
Department of Transportation
Washington, D.C. 20590

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Automobile Tire Sounds - Acoustical Grading System Feasibility

2. Coastby Study

ABSTRACT

The present investigation is the second of two studies designed to determine the feasibility of establishing an acoustical grading system for automobile tires. In Study 1, where the data were collected, results indicated that subjective measures of acceptability and dBA scale readings resulted in the identical rank ordering of tires under a representative set of experimental conditions. The present study was a field replication of the earlier experiment. Tape recordings were again made of sounds from 5 experimental tires which coasted by a roadside microphone location at speeds of 30, 50 and 70 mi/h under two loading conditions. Test tapes were then developed based on an exhaustive set of paired comparisons for each of the six experimental conditions. Fifteen "naive" male subjects then judged the tire sounds on the basis of acceptability, and the tires were ranked accordingly. Rankings were then also obtained using peak dBA scale readings and peak PNdB levels. The physical and subjective measures resulted in essentially the same rank ordering as obtained in Study 1 although the results were not quite as consistent.

Table of Contents

List of Tables

List of Figures

Introduction

The present study represents part of a program of research designed to determine the feasibility of establishing an auditory/acoustical grading system for automobile tires. The first experiment in the program (Study 1) employed sounds taped at the NBS Endurance Wheel for making physical and subjective assessments. The results from this investigation indicated that subjects were able to consistently rank order a sample of tires on the basis of the "acceptability" of the sounds produced under a variety of experimental conditions. It was further learned that the rankings closely correlated with physical measurements made on a dBA scale. The current investigation is designed as a follow-up "field" study to partially validate the "laboratory" findings obtained earlier.

Since the first study was conducted essentially in a well controlled laboratory environment, it was considered necessary to determine whether similar results occur in a "more realistic" setting. This study was therefore designed to replicate the experimental conditions employed earlier to the extent possible. Consistent with the same objective, the methodology and data analysis of both physical and subjective measurements closely approximated those used in the earlier investigation. However, the inherent difficulty of maintaining a rigidly controlled experimental environment in a field situation imposed natural limits on the ability to replicate the Endurance Wheel Study. For example, sounds of aircraft, trucks, automobiles, birds, etc. were often present during recording despite all efforts to tape only during quiet intervals.

A major difference between the two studies concerned the methodology that was used to record the sounds. The procedures employed were dictated by the laboratory vs field conditions which were the basis for the experiments. The laboratory setting was essentially a static one, with the microphone placed in a fixed position relative to the Endurance Wheel. Once an optimum position for microphone placement was established, a sample sound of any duration could be obtained with little concern about its variability or the presence of uncontrolled ambient sounds. In contrast to Study 1, the field situation was a very dynamic one since the experimental tires were mounted on a vehicle which coasted by the microphone following a predetermined course at a fixed speed. During each "experimental run", a five second sample of tire sound was recorded. In order to obtain an acceptable sample for each experimental condition, several runs had to be made and then evaluated at the laboratory. As noted earlier, in many instances the sample sounds had to be selected on the basis of having relatively low levels of extraneous sounds rather than the absence of them.

Objectives

1. Using sounds taped at roadside, determine the degree of consistency between tire sound rankings based on physical measures and those derived from subjective assessments.
2. Determine whether the results of the present study are consistent with those obtained in Study 1.

General Approach

As noted previously, the parameters selected for the first study were intended to serve as experimental conditions for a series of studies to be conducted in the automobile tire sound program. These variables were initially selected as being representative of typical speed and loading conditions on a "popular" sample of tires. Since the data obtained in the Endurance Wheel Study did not invalidate the rationale for the selection of the variables or the levels employed, they were also acceptable for the field investigation. Table 1 (p. 4) outlines the basic experimental design which was common to the two studies.

While it was feasible to have common experimental conditions in the two studies, the data collecting methodologies were quite difficult. The contrasting approaches used in the two studies typify the characteristics associated with a field study in one instance and a laboratory investigation in the other case. Table 2 (p. 5) provides a summary of the common and equivalent features of the experimental environment as well as the conditions used to collect data in each study.

Physical Data Collection

Several possible sites were examined before selecting a roadway suitable for the field study. The test track finally chosen was an unopened segment of a concrete highway with a slight grade. A vehicle fitted with experimental tires on the rear axle and experimental skid tires* on the front, was used for data collection. Since tire temperature was thought to be a critical parameter associated with tire sound, the automobile was first loaded appropriately and then several trial runs made to stabilize the tire temperatures. A test path was marked (with starting and termination points at distances which would permit a five second sample of tire sound, 2 1/2 seconds before and after a center marker. At the center point a microphone and other appropriate measuring and recording instruments were located. When the vehicle approached the starting marker, the engine was turned off, resulting in a "coastby" condition for the test. This procedure served to minimize the vehicle noise not associated with tire sound. A detailed description of the recording procedure appears in Appendix A, p. 42.

---

*See p. 6 for footprint of these "quiet" tires.

Table 1. Experimental conditions.

Tire types	Speeds					
	A		B		C	
	Load-Pressures		Load-Pressures		Load-Pressures	
	1	2	1	2	1	2
I	IA_1	IA_2	IB_1	IB_2	IC_1	IC_2
II	IIA_1	IIA_2	IIB_1	IIB_2	IIC_1	IIC_2
III	$IIIA_1$	$IIIA_2$	$IIIB_1$	$IIIB_2$	$IIIC_1$	$IIIC_2$
IV	IVA_1	IVA_2	IVB_1	IVB_2	IVC_1	IVC_2
V	VA_1	VA_2	VB_1	VB_2	VC_1	VC_2

Tires

I. Firestone Champion 7.75-14
II. Michelin Champion 195R-14
III. General Standard Skid Tire - 750-14
IV. Goodrich Silvertown Trailmaker, HT 770 F78-14
V. Goodrich Silvertown 75-14

Speeds

A. 30 mi/h
B. 50 mi/h
C. 70 mi/h

Loading/Pressure Conditions

1. Maximum load - 1500 lb, pressure - 32 lb/in^2
2. Medium load - 1150 lb, pressure - 24 lb/in^2

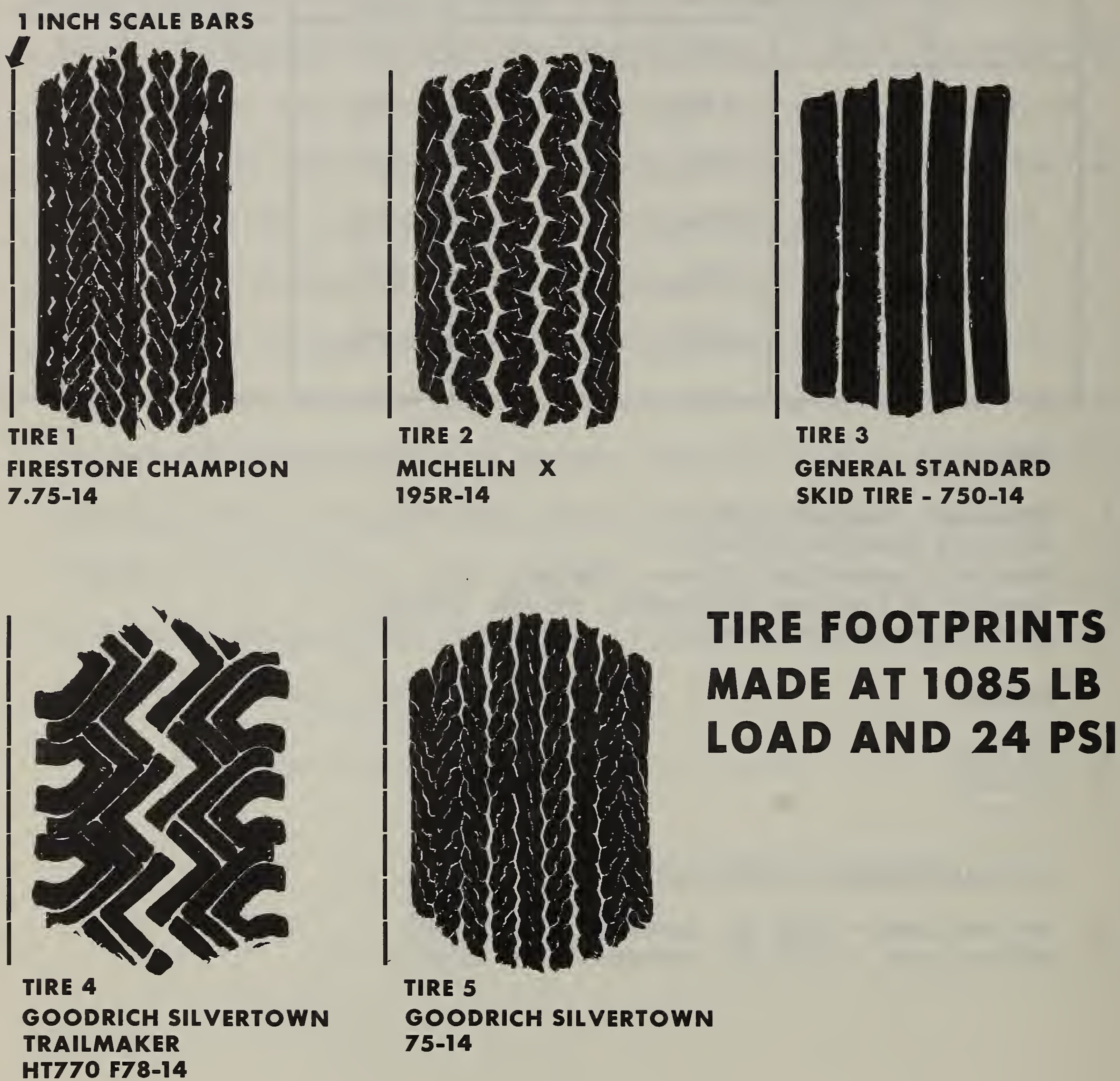

Figure 1. Footprints of experimental tires.

Table 2. Comparison of Conditions of Study 1 and Study 2.

	Common Features	Equivalent Features	
		Study 1	Study 2
Tires			
Designations	7.75 14 195R 14 7.50 14 HT 770 F78 14 75 14		
Number		1	2
Inflation-Loading	1500 lb-32 lb/in^2 1150 lb-24 lb/in^2		
Speeds	30 mi/h 50 mi/h 70 mi/h		
Microphone Position (Relative to Test Tire)	43"	43"	50'- '
Tire Mount		Endurance Wheel	Vehicle
Test Environment		Laboratory	Road Under Construction
Ambient Temperature		100 °F	54°-74° F

Subjective Data Collection

The collection of subjective data in a manner consistent with that used in Study 1 did not present any special difficulty. The judgements of relative acceptability were identical although slightly more difficult to make because of the greater apparent similarity among sounds. The only modification introduced concerned the instruction content. The subjects were given information as to the method used to collect data because of the **recognizability** of the tire sound on a moving vehicle and the presence of extraneous environmental sounds. The instructions used in the study appear in Appendix C (p. 55).

Subjects

The experimental subjects were 15 male volunteers between the ages of 20 and 50 who were tested for normal hearing. The observers, although employees of the National Bureau of Standards, were a different group than those participating in the first study.

Results

The rankings of tire sounds on the basis of acceptability for the present study are in agreement with those obtained in Study 1. Table 3 (p.10) indicates the summary data for all subjects under all experimental conditions. An inspection of the table reveals that the order of preference (3, 5, 1, 2, 4) is identical with that obtained in the earlier study. Furthermore, in each instance except for tire 4 (where the numbers are extremely small), as the table is read from left to right there is an upward progression. This result indicates that for combined data there were consistent findings as to relative preferences, i.e., when tire 3 was preferred over 5 and 5 preferred over 1, then 3 was preferred over 1. Tables 4 (p.11) and 5 (p.12) present the acceptability data by major conditions of speed and loading respectively. It can be seen that when the loading conditions are examined, that although some reversals in preferences are noted, generally the data are similar to those obtained with combined data. As for the major variable, loading conditions did not seem to be a major factor associated with tire sound acceptability in either of the two studies. On the other hand, the data presented in Table 5, where the loading conditions were combined, indicate a great deal of variability associated with different speed conditions. Although the "best" order of preference on the basis of acceptability for all conditions was the same as obtained for the combined data, several reversals are apparent, especially in the 50 mi/h condition.

Table 6 (p.14) presents the acceptability data of all possible comparisons by experimental condition, for the two experiments. An inspection of these data indicate that the spread of scores for the paired comparisons in Study 1 was far greater than those obtained in Study 2. In several instances in Study 2, no clearcut preference was evident between a tire pair since the acceptability scores were so similar. The 1150 lb load, 70 mi/h condition contains several examples of this finding. In contrast, the preferences in Study 1 were quite definitive, the smallest ratio being greater than 2:1 among the paired conditions.

With respect to physical measures of the data, peak dBA readings were obtained for all tires under each experimental condition. A summary of these data as well as the comparable findings obtained in Study 1 are presented in Table 7 (p.15). An inspection of these results indicates that the range of scores in Study 2 is considerably smaller than that obtained earlier and the absolute levels are much lower.

A PNdB analysis using maximum 1/3-octave band readings was then performed on the data obtained during both studies. The computations were made by means of a computer program based on techniques detailed by Pinker (ref. 8). An inspection of Table 8 (p. 16), indicates that the PNdB level provides essentially the same orderings of tires and separations between them as did the dBA readings detailed previously. Based on these results, there was nothing gained by computing PNdB levels when simple dBA readings provided equally good ordering for the sample of experimental conditions and tires employed in these investigations.*

*A further analysis is currently underway obtaining PNdB as a function of time.

Table 3. Order of preference of acceptability (Coastby experiment.) Total responses (N = 1080).

Tire	3	5	1	2	4
3		579	640	766	1045
5	501		560	697	1037
1	440	520		688	1054
2	314	383	392		1017
4	35	43	26	63	

Read: Left to right (less acceptable)

(The table format is designed to facilitate paired comparisons, e.g., Tire 3 is rated more acceptable than Tire 5, 579 times of a total of 1080 responses.)

Table 4. Combined results of acceptability data, loading conditions 1150 and 1500 lb. (Coastby experiment: 1150 lb and 1500 lb load/pressures combined).

Tire Number	3	5	1	2	4	Speed
3		227 147 205	278 175 187	324 218 224	355 344 346	30 50 70
5	133 213 155		217 156 187	290 197 210	349 338 350	30 50 70
1	82 185 173	143 204 173		264 228 196	351 357 346	30 50 70
2	36 142 136	70 163 150	96 132 164		322 350 345	30 50 70
4	5 16 14	11 22 10	9 3 14	38 10 15		30 50 70

Table 5. Combined results of acceptability data (Coastby experiment: 30, 50, 70 mi/h combined).

Tire Number	3	5	1	2	4	Loading & Pressure
3		297	317	385	525	Max
		282	323	381	520	Med
5	243		314	359	520	Max
	258		246	338	517	Med
1	223	226		349	522	Max
	217	294		339	532	Med
2	155	181	191		491	Max
	159	202	201		526	Med
4	15	20	18	49		Max
	20	23	8	14		Med

Table 6. Summary.

Acceptability data for all comparisons. (Study 1: Endurance Wheel; Study 2: Coastby)

Tire Pairs	1500 lb load 30 mi/h		1150 lb load 30 mi/h		1500 lb load 50 mi/h		1150 lb load 50 mi/h		1500 lb load 70 mi/h		1150 lb load 70 mi/h		Total	
	Study 2	Study 1	Study 2	Study 1	Study 2	Study 1	Study 2	Study 1	Study 2	Study 1	Study 2	Study 1	Study 2	Study 1
1	140	114	124	155	106	128	122	86	103	144	93	140	688	767
2	40	66	56	25	74	52	58	94	77	36	87	40	392	313
1	29	18	53	8	120	12	65	0	74	4	99	7	440	49
3	151	162	127	172	60	168	115	180	106	176	81	173	640	1031
1	174	175	177	180	178	178	179	174	170	179	176	179	1054	1065
4	6	5	3	0	2	2	1	6	10	1	4	1	26	15
1	44	24	99	131	104	53	100	19	78	46	95	85	520	358
5	136	156	81	49	76	127	80	161	102	134	85	95	560	722
2	11	40	25	4	93	11	49	4	51	4	85	1	314	64
3	169	140	155	176	87	169	131	176	129	176	95	179	766	1016
2	146	179	176	177	176	179	174	177	169	177	176	177	1017	1066
4	34	1	4	3	4	1	6	3	11	3	4	3	63	14
2	24	28	46	14	97	33	66	34	60	21	90	23	383	153
5	156	152	134	166	83	147	114	146	120	159	90	157	697	927
3	179	179	176	179	171	179	173	180	175	179	171	180	1045	1076
4	1	1	4	1	9	1	7	0	5	1	9	0	35	4
3	110	112	117	173	76	158	71	166	111	166	94	177	579	957
5	70	68	63	3	104	22	109	14	69	14	86	3	501	123
4	1	0	10	2	15	0	7	0	4	1	6	0	43	3
5	179	180	170	178	165	180	173	180	176	179	174	180	1037	1077

Table 7. Sound pressure levels, dBA-loadings high and low at 30, 50, 70 mi/h.

Tire No.	Load, 1500 lb Pressure, 32 lb/in^2			Load, 1150 lb Pressure, 24 lb/in^2			
	Speeds 70	50	30 mi/h	70	50	30 mi/h	
4	101	96	91	99	93	90	Endurance Wheel Study
2	94	90	84	93	89	83	
1	91	87	84	90	87	81	
5	90	87	82	89	85	81	
3	81	80	80	80	79	76	
4	78.5	73.0	65.0	79.0	72.0	62.5	Coastby Study
2	75.0	67.5	61.0	73.5	67.5	60.0	
1	74.0	68.0	62.0	74.5	68.0	60.5	
5	73.0	67.5	60.0	74.0	68.0	59.0	
3	73.5	67.5	58.0	74.0	67.0	59.0	

Table 8. PNdB levels - Studies 1 and 2.

Tire	Load-1500 lbs, Pressure 32 lb/in^2			Load-1150 lbs, Pressure 24 lb/in^2			
	Speeds-mi/h			Speeds-mi/h			
	30(A)	50(B)	70(C)	30(A)	50(B)	70(C)	
4	102	107	110	101	106	111	Endurance Wheel Study
2	95	103	106	94	102	105	
1	96	100	103	92	98	102	
5	94	100	103	93	98	102	
3	92	92	93	88	90	92	
4	79	86	92	77	86	92	Coastby Study (Based on maximum readings)
2	77	83	89	76	83	88	
1	77	83	88	76	83	89	
5	77	83	88	76	83	88	
3	75	83	88	76	83	89	

The acceptability data were then analyzed by means of scale scores* to determine the extent to which the difference among preferences were similar among the five tires. This analysis, which was also performed on the data obtained in Study 1, goes one step beyond the search for a consistent rank ordering among tire sounds. It is directed toward determining the extent that the intervals between adjacent categories, are equal. The data, which appear in Tables 10 (p. 19) and 11 (p. 25) indicate in more detail the differences in responses between the two studies. It is apparent that the range of scores and consequently the differences among tires in adjacent categories (3-5, 5-1, etc.) were much greater in the earlier study than in the coastby study. A closer inspection of these scores indicate that the judgements associated with tire 3 account for much of the difference between the results of the two studies. Apparently the texture of the surface (smooth on the Endurance Wheel and rough for the coastby on concrete) and the rise and fall of the sound associated with the moving vehicle, both contributed to make the

---

*Let a_{ij} = number of times tire i is prefered to tire j ($i \neq j$)

$n = a_{ij} + a_{ji}$ = number of comparisons.

Then for one experiment, or for a group of experiments combined, calculate the ith scale score by:

$$\nu_i = \frac{1}{5}\left[\sum_j \frac{a_{ij}}{n} - 2\right], \quad i = 1, 2, 3, 4, 5$$

The factor 1/5 is quite arbitrary. With this definition, the scores computed from any combination of experiments lie between $\pm$ 0.4; with a "perfect" scale being +.4, +.2, 0, -.2, -.4. Comparisons are made against this perfect scale, not among experimental conditions directly.

Discussion with NBS Statistician, Dr. Joan Rosenblatt.

Table 9. Scale scores ν_i for differences among tire judgement (+.4, -.4) - Studies 1 and 2.

Study 2

	Tire 3	Tire 5	Tire 1	Tire 2	Tire 4
Conditions					
30/1500 lb	.277	.201	-.030	-.154	-.353
30/1150	.239	.098	.103	-.063	-.377
50/1500	.038	.076	.164	-.089	-.367
50/1150	.144	.129	.118	-.014	-.377
70/1500	.179	.119	.072	-.003	-.367
70/1150	.090	.083	.114	.087	-.374
Combined Loads					
30	.258	.149	.067	-.109	-.365
50	.091	.102	.141	.037	-.372
70	.134	.101	.093	.042	-.371
Combined Speeds					
1500 lb	.164	.132	.089	-.023	-.362
1150 lb	.158	.103	.112	.003	-.376
All Data Combined	.161	.118	.100	-.010	-.369

Study 1

	Tire 3	Tire 5	Tire 1	Tire 2	Tire 4
Conditions					
30/1500 lb	.259	.218	-.032	-.052	-.392
30/1150	.382	.040	.127	-.156	-.393
50/1500	.349	.129	.012	-.094	-.396
50/1150	.380	.157	-.090	-.057	-.390
70/1500	.374	.140	.014	-.136	-.393
70/1150	.389	.082	.057	-.132	-.396
Combined Loads					
30	.321	.129	.047	-.104	-.393
50	.364	.143	-.039	-.076	-.393
70	.382	.111	.036	-.134	-.394
Combined Speeds					
1500 lb	.327	.162	-.002	-.094	-.394
1150 lb	.384	.093	.031	-.115	-.393
All Data Combined	.356	.128	.015	-.104	-.393

Table 10. Scale scores ν_i for differences among five judgements (+.4 to -.4) - Studies 1 and 2

(Individual Subjects - All Conditions)

Coastby Study

Subject	Tire 3	Tire 5	Tire 1	Tire 2	Tire 4
16	.183	.122	.094	-.017	-.383
17	.133	.106	.103	.033	-.375
18	.081	.125	.058	.003	-.267
19	.161	.125	.128	-.025	-.389
20	.153	.67	.156	-.106	-.369
21	.192	.081	.064	.044	-.381
22	.158	.100	.103	.028	-.389
23	.133	.114	.103	.031	-.381
24	.186	.042	.119	.044	-.392
25	.189	.122	.081	-.025	-.367
26	.181	.100	.050	.006	-.336
27	.181	.083	.081	-.003	-.342
28	.172	.144	.158	-.094	-.381
29	.167	.186	.089	-.044	-.397
30	.147	.147	.119	-.025	-.389

Endurance Wheel Study

Subject	Tire 3	Tire 5	Tire 1	Tire 2	Tire 4
1	.367	.161	-.014	-.117	-.397
2	.389	.114	.017	-.122	-.397
3	.375	.189	-.028	-.139	-.397
4	.350	.136	-.017	-.078	-.392
5	.372	.167	-.050	-.092	-.397
6	.386	.117	.022	-.125	-.400
7	.397	.097	.044	-.139	-.400
8	.256	.186	-.017	-.033	-.392
9	.308	.133	.053	-.100	-.394
10	.261	.192	-.017	-.042	-.394
11	.389	.114	.014	-.122	-.394
12	.375	.036	.036	-.078	-.369
13	.378	.117	.036	-.139	-.392
14	.331	.153	.019	-.114	-.389
15	.400	.003	.119	-.128	-.394

results associated with the skid test tire, atypical when compared with the others. For example, when comparing the judgements between tire 1 and 3 (Table 6, p. 14) for the 1150 lb load, 70 mi/h condition, a very noticeable shift in preference is evident. The results for Study 1 indicate a 173 to 7 preference for tire 3 while the comparable data in Study 2 are a 99 to 81 selection in favor of tire 1. However, these data can readily be explained by the intensity levels associated with the physical stimuli. Figure 2 (p. 21) presents the results of a peak 1/3 octave band analysis performed on the data for both studies. The data indicate that for Study 1, at approximately 150 cps, the dB levels for tire 3 dropped sharply and were well below those of tire 1 throughout the entire frequency spectrum. These findings are consistent with the judgements of an overwhelming preference for tire 3, which actually occurred. The data for the coastby study are not at all clearcut. They indicate that the dB levels for the two tires were very similar throughout with tire 1 peaking at some low frequencies and tire 3 producing higher intensities at some of the higher frequencies. The subjective data support these physical measures as there is no great difference between the judgements of acceptability of the tire sounds.

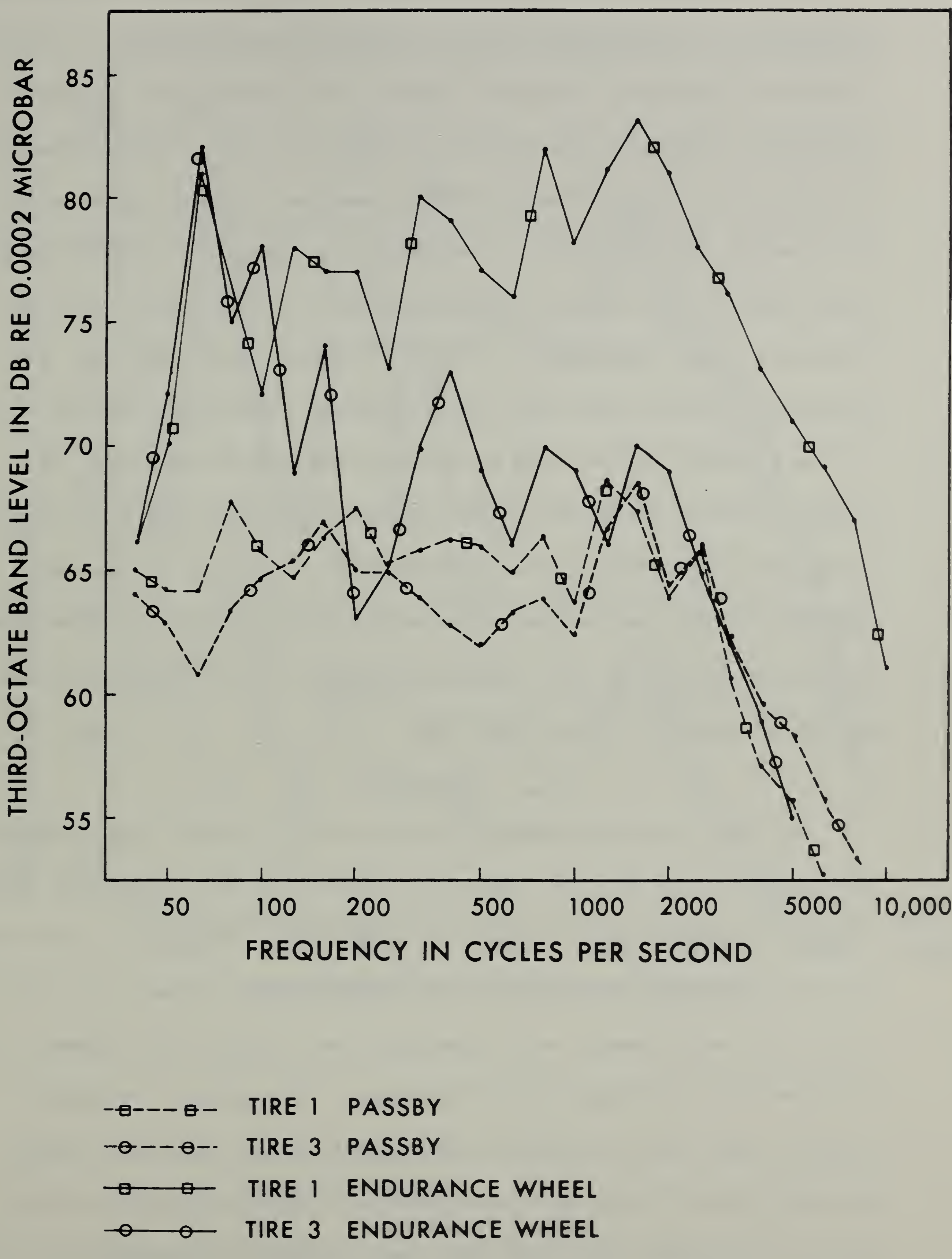

Figure 2. Acceptability reversal.

In contrast to the previous example, when there was a reasonable explanation of preferences based on physical measurements, in several instances preference reversals between the studies were "partially explained" during the debriefing. Figure 3 (p. 23) illustrates one of the typical instances where physical measures did not fully account for the reasons for the change in subjective judgements. These data are also based on a 1/3 octave band analysis of tires 1 and 5 in this instance, under conditions of 1500 lb loading and 50 mi/h (p. 23). The dBA levels for the two tires being compared were quite similar in each of the studies, however the preference data for Study 1 was 127 to 53 in favor of tire 5 while 104 of 180 responses favored tire 1 in Study 2. During the debriefing of the coastby study there was an expressed dislike for the low frequency hum associated with tire 5. The other debriefing indicated that subjects preferred tire 5 because it was generally quieter and had less hum.

Discussion

The major accomplishment associated with the two tire sound studies now completed is that the essential findings of the laboratory investigation were replicated under field conditions. However, a cautionary note is necessary in comparing the results in any detail. In the earlier study, the measurements were consistent and clearcut for almost all experimental conditions for all subjects. The results obtained in the coastby study are not nearly as unambiguous. As indicated earlier, the grouped data for both speed and loading conditions exhibited some reversals of preferences but even when the rankings were consistent, the absolute differences in numbers were quite small in several instances.

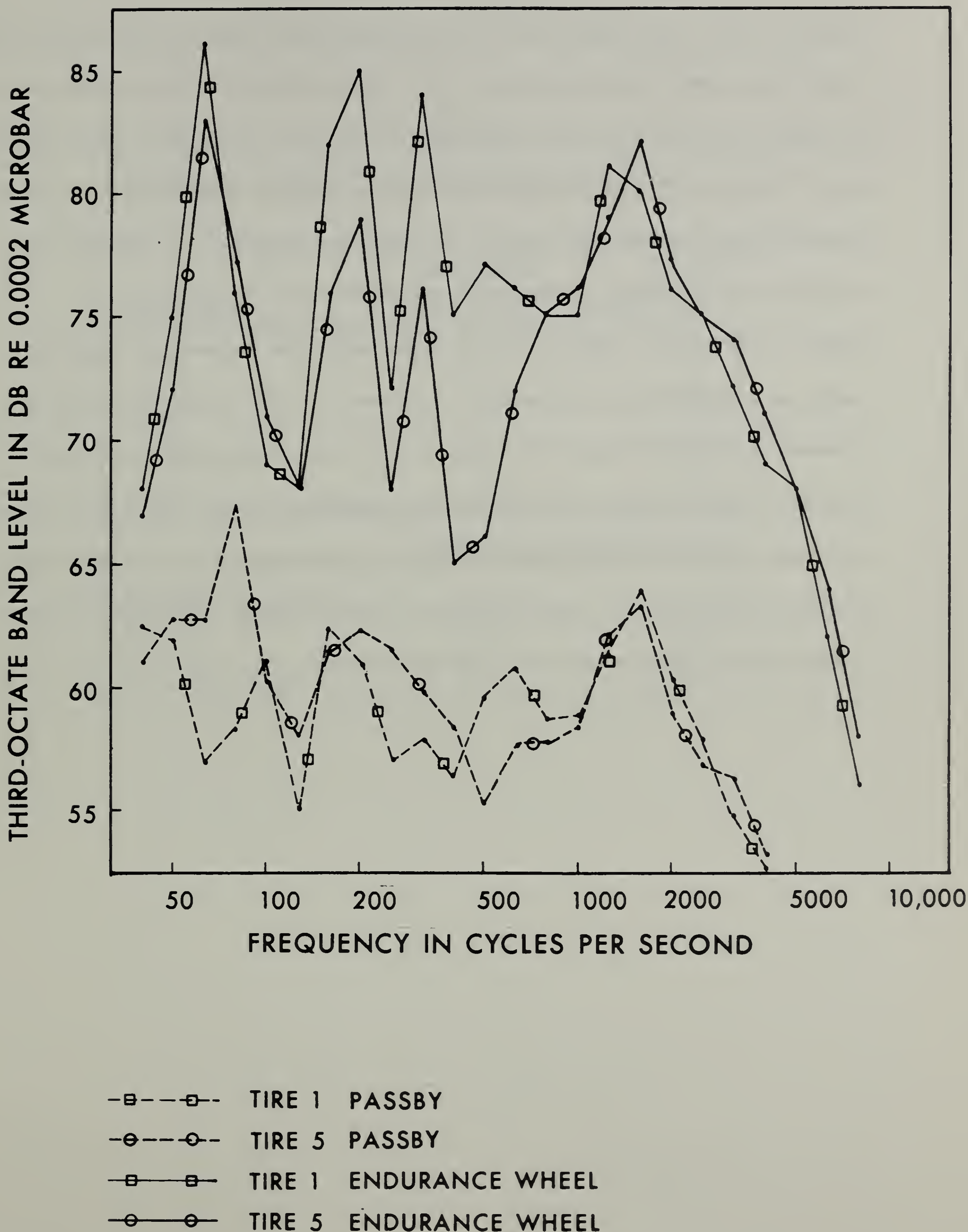

Figure 3. Acceptability reversal.

The subjective responses made during the present study exhibited a much greater degree of variability than those obtained in Study 1. These results were anticipated by the experimenters from the time that the recordings were monitored prior to constructing the experimental lists. It appeared then that the judgements required in Study 2 were considerably more "difficult" than those made in the earlier investigation because of the similarities among several of the tire sounds. A summary of reliability measures obtained in the two studies appears in Table 11 (p. 25). These scores represent the degree of agreement among acceptability responses. A score of 1.00 would indicate no reversals in preference from trial to trial for <u>each</u> subject and throughout the entire study. The data are presented first for each condition and then for all conditions combined. An inspection of these data indicate the greater consistency of the findings obtained in the laboratory as compared with the field study.

Table 11. Summary of consistency measures.

Condition	LABORATORY	FIELD
	Average of 15 Subjects	
A1	.70	.60
A2	.82	.49
B1	.71	.41
B2	.77	.42
C1	.79	.40
C2	.78	.37
	Average of 6 Conditions	
Average of 15 S's	.76	.45
Minimum	.66	.31
Maximum	.87	.56
Std. deviation	.07	.07

The responses were then examined to determine whether acceptability judgements varied as a function of practice. This analysis was important because it is possible that the training provided by the practice lists was not sufficient to stabilize judgements of acceptability. If this were the case then the responses made during the first half of the study would not agree with those obtained later because learning of the task would still be occurring. Table 12 (p. 27) presents the combined data for the first six and final six comparisons. An inspection of the body of the table indicates a somewhat greater spread among responses in adjacent categories for the second set of trials as compared with the first, although the results are quite uniform throughout. These results would tend to rule out learning and might be attributed to fatigue or boredom. The analogous data from the Endurance Wheel study are presented in Table 12 as a basis for comparison. It can readily be seen that the absolute differences among tire preferences for the first and last half of the trials are less than those obtained in the Coastby Study. These data also support the findings of greater variability among responses in the present investigation because of the greater difficulty of the task.

Table 12. Response Comparisons. (First six trials vs last six trials.)

Coastby Study

	3	5	1	2	4	Trials
3		300 279	323 317	372 394	520 525	1-6 7-12
5	240 261		287 273	325 372	514 523	1-6 7-12
1	217 223	253 267		337 351	525 529	1-6 7-12
2	168 146	215 168	203 189		503 514	1-6 7-12
4	20 15	26 17	15 11	37 26		1-6 7-12

Endurance Wheel Study

	3	5	1	2	4	Trials
3		476 481	512 519	503 513	537 539	1-6 7-12
5	64 59		358 364	466 461	539 538	1-6 7-12
1	28 21	182 176		373 394	532 533	1-6 7-12
2	37 27	74 79	167 146		529 537	1-6 7-12
4	3 1	1 2	8 7	11 3		1-6 7-12

The judgements of acceptability were ultimately dependent upon the quality of the samples of tire sound used as experimental stimuli. In the field investigation there were several factors which served to degrade the "purity" of the signal. The environmental conditions were beyond the control of the experimenters and therefore undesired sounds produced by other vehicles, birds and other natural phenomena could not be completely eliminated from the tape. In order to minimize these extraneous noise sources, several coastbys were recorded for each experimental condition. The tapes were then monitored and the cleanest sample selected to be used in the study. Unfortunately, the best tape recording under some circumstances was not free of extraneous sounds. Another factor which degraded the signal was the method that was used to construct the test lists. It was necessary to reproduce the tire sound one additional time as compared with Study 1 because the taped sample was of 5 seconds duration as compared with several minutes that was available in Study 1. In Study 1, the lists were constructed by cutting 5-second samples from the original tape and then reproducing them. In the present study, the 5 second tape segment had to be reproduced prior to list construction to provide samples for all experimental trials and then had to be rerecorded for the actual lists construction. This additional step added to the ambient noise already present on the tape. One additional circumstance might have contributed to the absolute differences in measures among the variables, found in the two studies. Bolt Beranek and Newman, in their "Highway Noise" study (ref. 2), indicated that the preferred distance for measurements on passenger cars is 25 feet. They indicate that measurements made at greater distances makes it difficult to maintain satisfactory signal-to-noise ratios. It is possible that since a distance of 50 feet was used in the present investigation, some of the sound characteristics associated with one or more of the tires were effectively masked under a number of the experimental conditions. The 50 foot distance was selected because of its relative standardization in traffic noise regulations. However, the controls were directed at sounds transmitted from the entire vehicle, not merely the tires, and in many instances were primarily designed for regulating trucks rather than passenger vehicles.

The physical measurement procedures available for the coastby study posed a set of difficulties analogous to those associated with the subjective data. In the Endurance Wheel Study, a straightforward and highly standardized methodology based on dBA readings and a 1/3 octave band analysis, provided the required data as the sounds were relatively uniform over time. In the coastby situation, the signals can be described as changing in frequency and intensity as a function of time, building to a peak intensity and then falling again. Standardized measurement techniques for describing this type of signal are beyond the present state of the art and consequently methods had to be adapted to characterize the attributes of the signals. Two analyses were performed to measure the physical data. First, dBA readings were taken, based on peak intensities for each tape sample. As noted earlier (p. 16), they revealed little separation among tire sounds under several experimental conditions. Then, by means of a computer progran, PNdB values were computed, using maximum 1/3 octave band readings obtained for the 5 second tape sample. The method for computing PNdB is taken directly from the SAE Aerospace Recommended Practice, Table II [7]. NGTE Note NT. 684 by Pinker is the original source material [8]. A system is being implemented to digitally record the 1/3 octave band outputs every 100 ms on computer tape using a small general purpose computer. This tape will then be run on the large NBS main computer to calculate PNdB every 100 ms for each 5 second tape sample. Peak PNdB for each 5 second sample will be found and correlated with the subjective results. These peak PNdB values should be more realistic than the ones found using peak 1/3 octave band levels.

A major difficulty in "noise research" is the identification of the relevant parameters associated with the stimulus (sound) as well as those describing the characteristics of the response. In an initial effort designed to investigate this problem, a number of pilot investigations were conducted. Their objective was to determine whether subjects by describing <u>why</u> preferences were made, could provide a useful assist in the design of valid and reliable techniques of scaling subjective responses. The approach employed was as follows:

During the debriefing phase of Study 1, the subjects were asked to specify the criteria used to make their "acceptability" judgements. These data were collected at two levels of detail. First, the practice list of ten pairs was played, and after each judgement the subjects indicated the reasons for their selection based on the characteristics of the two tire sounds. When responses had been made to all of the pairs, they were requested to identify the major criteria employed throughout the study in making their judgements. A compilation was made of the descriptors used by all subjects to specify the characteristics of the sounds. Table 13 (p. 32), which also appears in the earlier report, summarizes these data. On examining the list of descriptors, it was apparent that many of the terms had synonymous meanings. In order to determine whether the list of 25 descriptors actually referred to a much more limited number of characteristics associated with the sounds, an exploratory study was designed. The experimental plan consisted of familiarizing those subjects who participated in the experiment with the words used to describe the tire sounds. They were then asked to group terms with similar meanings with reference to the sounds heard in the experiment. The object was to make as many discrete groupings as necessary for the twenty-five terms and then to name the characteristic represented by the grouping, if possible. Each subject performed this task by stacking a numerically coded set of 3" x 5" cards containing the descriptors. The groupings and their titles were then compared across all subjects to determine whether any consistent pattern emerged. The instructions for the task appears in Appendix C, p. 59.

Table 14 (p. 33) presents a matrix of possible groupings for the 25 descriptors. The numbers in the body of the table indicate the number of subjects, of a possible 15, who agreed on common categorizations. Further research is obviously required to determine the generalizability of any or all of these descriptors and their possible application in measurement of subjective responses. Figure 4 (p. 34) indicates graphically, the nature of the interrelationships among the 25 descriptors employed in the study. Table 15 (p. 35) provides the actual descriptors that formed the groupings. These categories appear to agree very well with the judgement criteria indicated during debriefing during Study 1 (Table 16, p. 36).

Table 13. Descriptors (alphabetical order as used) - Study 1.

1.	Annoying beat	14.	Penetrating
2.	Aperiodic	15.	Periodic
3.	Apparent distance	16.	Piercing
4.	Chatter	17.	Powerful
5.	Compatibility of frequency	18.	Pure sound
6.	Complex	19.	Pure tone components
7.	High frequency	20.	Reverberant
8.	Knocking	21.	Sharp
9.	Loud	22.	Shrill
10.	Low frequency hum	23.	Smooth
11.	Machine-like	24.	Steadiness
12.	Modulated	25.	Vibrating
13.	Out of balance		

Table 14. Matrix of subjective groupings made in Study 1.

Item Code	7	14	16	21	22	9	17	1	4	8	13	11	25	20	15	12	10	23	24	18	19	2	3	5	6
7	-	11	10	9	11	3	3		1			2	1	1			1					1			
14	11	-	14	13	15	6	4	3	2	1	1	1								1		1			
16	10	14	-	13	14	7	5	4	1	2	2				1					1					
21	9	13	13	-	13	5	5	3	1	1	1			1						2					
22	11	15	14	13	-	6	4	3	2	1	1	1								1		1			
9	3	6	7	5	6	-	10	4	1	3	3				1	1				1					
17	3	4	5	5	4	10	-	2		1	1			1	1	1				2					
1		3	4	3	3	4	2	-	6	10	8	3	4	3	3	2		1		2	1	4			
4	1	2	1			1		6	-	9	4	6	6	4	2	2						3			2
8		1	2	1	1	3	1	10	9	-	8	5	5	3	3	1		1				4			1
13		1	2	1	1	3	1	8	4	8	-	3	4	3	5	1						5			
11	2	1			1			3	6	5	3	-	4	3	3	2	5	1	3	1		3	2		
25	1							4	6	5	4	4	-	6	5	2	1	1	1			1	1		1
20	1			1			1	3	4	3	3	3	6	-	4	4	1	2	1	2	1	1			1
15			1			1	1	3	2	3	5	3	5	4	-	6	3	2	4	2	2	1	1	3	
12																									
10	1											5	1	1	3	3	-	7	8	3	2		3	3	
23						1		1	1			1	1	2	2	3	7	-	12	7	5		4	4	
24												3	1	1	4	4	8	12	-	7	5		5	4	
18		1	1	2	1	1	2	2				1		2	2	2	3	7	7	-	7		1	3	
19								1						1	2	3	2	5	5	7	-			5	
2	1	1		1				4	3	4	5	3	1	1	1	1						-			
3												2	1		1	1	3	4	5	1			-	2	
5															3	5	3	4	4	3	5		2	-	
6									2	1		1	2	1		1									-

Figure 4. **GRAPHICAL DISPLAY OF RELATIONS BETWEEN WORDS**

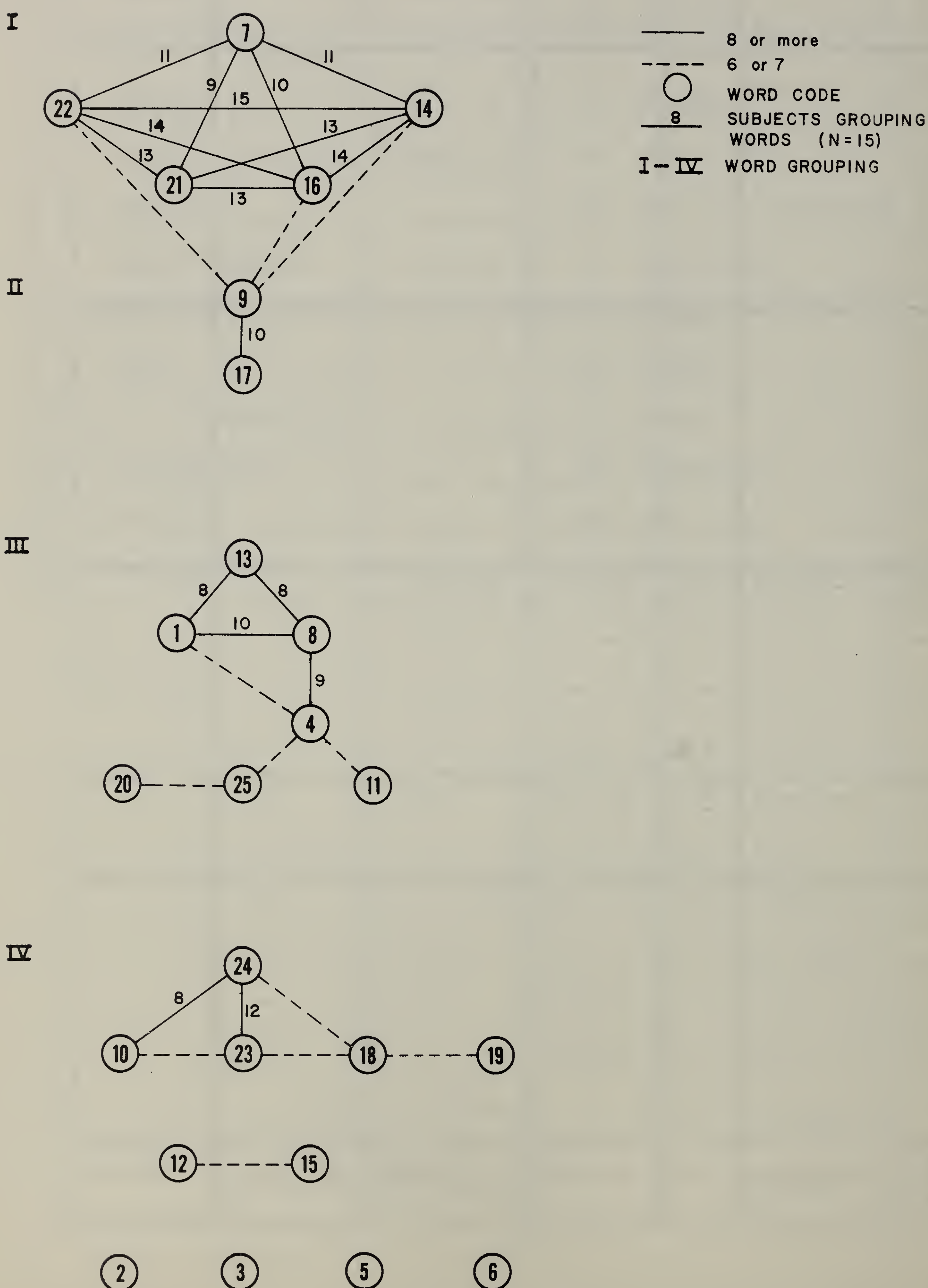

Table 15. Endurance Wheel word groupings.

Groupings	Numerical Code	Descriptors
I	7	High Frequency
	14	Penetrating
	16	Piercing
	21	Sharp
	22	Shrill
II	9	Loud
	17	Powerful
III	1	Annoying Beat
	8	Knocking
	13	Out of Balance
	4	Chatter
	11	Machine Like
	20	Reverberent
	25	Vibrating
IV	10	Low Frequency Hum
	18	Pure Sound
	19	Pure Tone Components
	23	Smooth
	24	Steadiness
V	12	Modulated
	15	Periodic
	2	Aperiodic
	3	Apparent Distance
	5	Compatibility of Frequency
	6	Complex

Table 16. Summary of subjective findings (Criteria for judgements (Studies 1 and 2)).

Study 2

Description	Frequency of Response	Order of Response 1	2	3
Truck Engine Noise	8	3	3	1
Pitch				
High (Whine, Whistle)	9	5	2	1
Low (Hum, Roar)	6		3	3
Change	4		1	2
Even	4		1	3
Loudness	12	6	4	

Study 1

Description	Frequency of Response	Order of Response 1	2	3
Loudness	15	14		
Pitch				
High (Shrill)	12	1	9	2
Low (Hum)	5			4
Regularity				
Smooth	1		1	
Periodic	7		4	2
Complexity				
(Tonal Components)	4		1	2

Descriptors and criteria derived from Study 2 appears in Tables 17 and 16, respectively. There is evidently some correspondence between the terms employed in the two studies although the complexity of the sound pattern in the second study led to a greater number of terms as well as more of them connoting a high degree of interpretation (truck engine, shrieking, waterfall, singing, etc.).

As indicated in the report describing the Endurance Wheel Study (ref. 1), there are three lines of investigation that have been followed among those concerned with tire sound. The two completed studies of the NBS program represent two of these approaches. The first study used a laboratory methodology similar to that employed by some tire manufacturers for minimizing tonal components produced by tires. The coastby investigation typified the methodology used in establishing acceptable sound levels produced by vehicles and directed toward the control of environmental noises. The other method often used by tire manufacturers is instrumenting a vehicle in a manner to permit evaluations of tire sounds heard within the automobile. It is evident that any tire sound research program which purports to be comprehensive must encompass all of the aforementioned approaches if its goal is to establish a commonly acceptable acoustical grading system for tires. An additional replication of the basic design employed in the first two studies using stimuli consisting of tire sounds heard within the vehicle might prove useful in at least

Table 17. Descriptors (alphabetical order as used) - Study 2.

1. Accentuated	21. Quiet
2. Aesthetic quality	22. Roar (dull, steady)
3. Buzz	23. Rougher
4. Chatter	24. Rumble (low)
5. Crescendo	25. Rushing
6. Distant sound	26. Shrieking
7. Dramatic change	27. Shrill
8. Euphonic whoosh	28. Singing
9. Even	29. Solid
10. Friction	30. Staccato
11. Gutteral sound	31. Throbbing
12. Hum (low, acute)	32. Truck engine noise
13. Harsh	33. Varied (pitch, sound)
14. Hissing (high pitched)	34. Volume
15. Increase of pitch	35. Vibrating
16. Loud	36. Waterfall
17. Mild	37. Whistling
18. Piercing	38. Whine
19. Pitch (high, low)	39. White background noise
20. Pressure	

three ways. It would provide data concerning the correlations among both physical and subjective measurements made under "all" sets of experimental conditions. A viable test procedure for establishing an acoustical grading system might be indicated if rankings based on judgements of acceptability are consistent for all studies. Finally, it might permit investigators to interrelate some of the findings obtained under diverse data collection procedures.

Conclusions

1. Physical and subjective findings based on automobile tire sounds taped at roadside were generally in agreement with one another.
2. The results of the coastby experiment were consistent with those obtained with the NBS Endurance Wheel.
3. After the completion of two studies, one in the laboratory and the other under field conditions, there is some evidence that an auditory/acoustical grading system for this might be feasible.

References

[1] Rubin, Arthur I., John F. Halldane, Ronald L. Fisher, and John S. Forrer, Automobile Tire Sounds - Acoustical Grading System Feasibility, 1. Endurance Wheel Study, NBS Report No. 10292, (National Bureau of Standards, Washington, D.C. 20234, 1970).

[2] Galloway, William J., Welden E. Clark, and Jean S. Kerrick, Bolt, Beranek and Newman, Highway Noise, Measurement, Simulation, and Mixed Reactions, NCHRP Report 78 (Highway Research Board, Washington, D.C., 1969).

[3] Chalupnik, James D. (ed.), Transportation Noise - A Symposium on Acceptability Criteria (University of Washington Press, Seattle, Washington, 1970).

[4] Measuring the Footprint of a Tire, Technical News Bulletin 54, No. 1, 128-129 (National Bureau of Standards, Washington, D.C., 1970).

[5] Sound Level for Passenger Cars and Light Trucks, SAE Standard J986a (Society of Automotive Engineers, July 1968).

[6] Noise Standards: Aircraft Type Certification, Part 36, Federal Aviation Regulations, 3 (Federal Register, November 18, 1969).

[7] Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise, Aerospace Recommended Practice ARP 865A (Society of Automotive Engineers, Inc., August 15, 1969).

[8] Pinker, R. A., Mathematical Formulation of the Noy Tables, Journal of Sound and Vibration, 8, 488-493 (1968).

Appendix A

Physical Measures

Test Vehicle

The vehicle used in the coastby recording sessions was a 1970 Fury III Plymouth sedan with a 318 engine, troqueflight transmission, and power steering. This automobile was fitted with a velocity measuring Track Test fifth wheel using a tach generator to a Weston meter (accurate to better than 0.5 mi/h). The two rear tire loadings of 1150 lb and 1500 lb (per wheel) were effected by using marked sand bags and lead shot in both the trunk and rear seat area in a manner which kept the front tire load (1270 lbs) the same for both rear tire loads (Figure A1, p. 43). Skid test tires (General 7:50-14) were used at all times on the front of the car to minimize tire sounds produced by the front tires. (The Endurance Wheel experiment showed that the skid test tire was the quietest tire from the standpoint of both physical and subjective measurements.)

Recording and Monitoring Instrumentation

The instrumentation at the coastby site performed three basic functions (Figure A2, p. 44). One was the tape recording of the coastby sound. The second function was the measurement of sound pressure levels. The monitoring of wind velocity was third. Figure A3 (p. 45) is a scale diagram depicting the road, vehicle coastby path, and general location of the instrumentation. The Mobile Acoustical Laboratory furnished regulated 117 VAC power (via an inverter) to the recording and monitoring instrumentation. The coastby signal from the recording B & K condensor microphone with windscreen was amplified by a B & K model 2107 Frequency Analyzer in a linear all pass mode. The amplified signal from the 2107 recorder output was recorded on the Nagra III recorder using the balanced line input.

Figure A1. Loading test vehicle.

Figure A2. Instrumentation at coastby site.

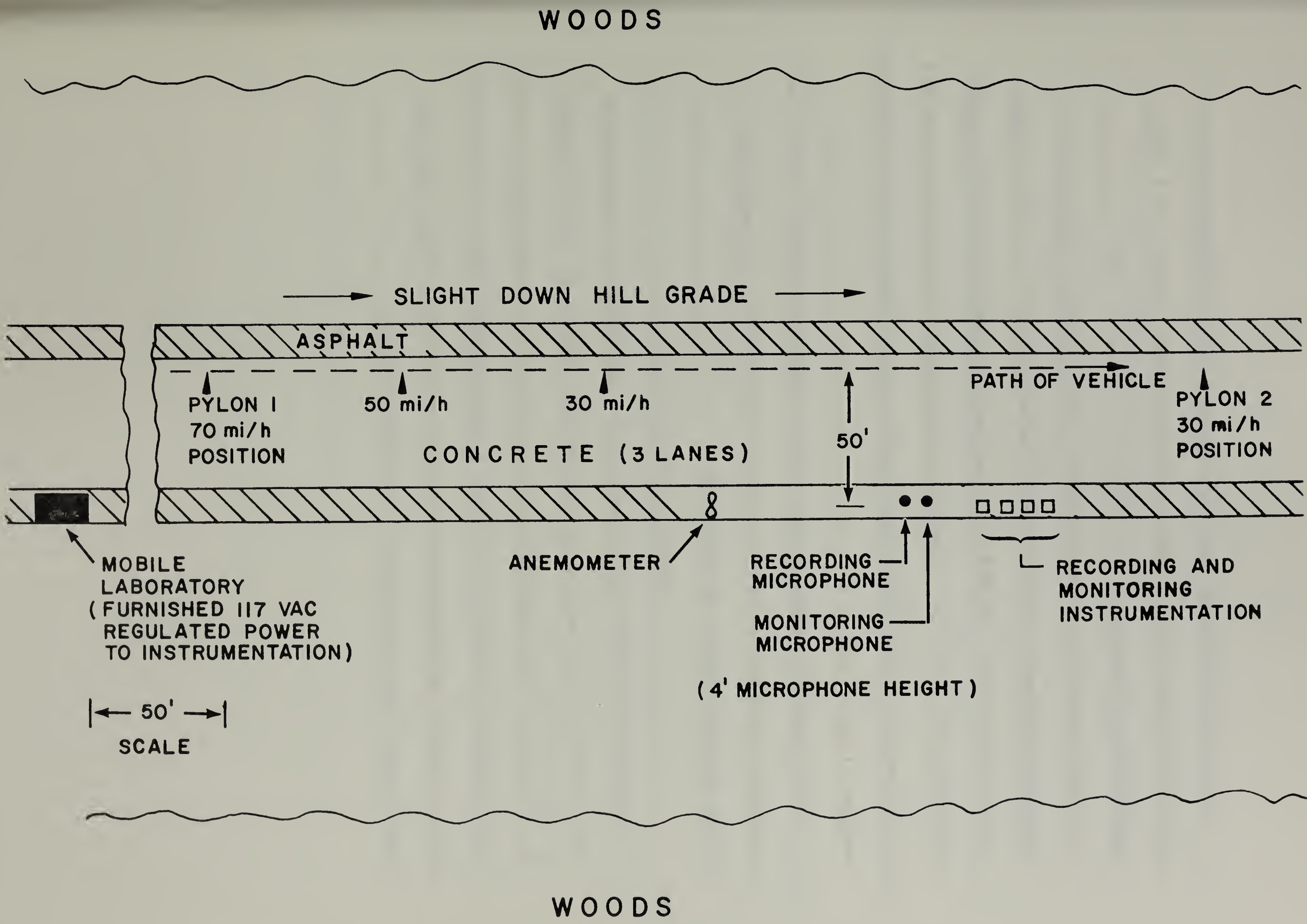

Figure A3. Detail of coastby recording site.

Live dB(A) readings were made using a B & K condenser microphone with windscreen, a B & K 2204 Sound Level Meter, and a B & K 2305 Graphic Level Recorder.

Wind velocity was monitored with aid of a Model 27100 Gill Propeller Anemometer and a volt-ohm meter (Figure A2, p. 44). When calibrated with an 1800 RPM synchronous motor the unit has an accuracy of better than 0.5 mi/h. Communication between the recording crew and the automobile driver were maintained by using transceivers on government assigned frequencies.

Tire pressure gauges, jacks, wheel changing equipment, fifth wheel, automobile, and driver were supplied by the Vehicle Systems Group at the National Bureau of Standards.

Recording Procedure

Stimulus material for the subjective experiment was obtained by tape recording the sound of an automobile coasting by the microphone at a distance of 50 feet (Figure A3, p. 45). Two movable pylons marked off a distance equivalent to a five second coastby time at a particular speed. Special attention was given to monitoring ambient background sound levels, vehicle velocity, and wind velocity.

For a typical coastby session the background noise level was checked for evidence of aircraft or truck noise and the wind velocity was verified to be less than 12 mi/hr. A hand held transceiver was used to inform the driver of the desired speed and to give him the verbal go ahead. The experimenter began tape recording with the Nagra III before the car reached the first pylon position. As the car reached the pylon a short 1000 Hz beep was manually introduced on the Nagra III as an aid in identifying the five second portion of the signal to use in the subjective portion of the experiment. When the car passed the second pylon the experimenter manually recorded a second beep on the Nagra III. The driver returned the car to the starting position and radioed the coastby velocity for the run. After the experimenter recorded the particulars of the run on tape by talking into the recording microphone, the pylons were moved if the next run was to be a different speed.

In general three runs were made for each speed, load, and tire condition. Additional runs were made if the peak dB(A) on two runs (with the same conditions) did not agree within 2 dB. A run was also repeated if the coastby velocity at the microphone position was more than 2 mi/h off the desired speed.

List Construction

The "raw data" for the lists consisted of coastby tire sounds recorded in the field during the thirty experimental conditions (5 tires x 2 loadings/pressures x 3 speeds). The lists were constructed by splicing together samples of tire sounds, prerecorded list and pair identifications and "blank" tape lengths. Each list was prepared in the following manner. An introductory identification of the list lasting 10 s was followed by 5 s of tire sound, next, a blank interval of 2 s duration, then a 5 s sample of another tire sound and finally a 5 s period containing the pair identification number to indicate when to respond and the appropriate place on the answer sheet. The sequence of sound-pause-sound-interval was repeated ten times during each list. The lists were therefore three minutes in duration (17 s x 10 s + 10 s introduction). The sequencing of the particular list was determined on the basis of Table C1, p. 56.

A practice list was constructed using the same format as that employed in the test lists, but the pairs consisted of sounds produced under <u>different</u> experimental conditions.

Generation of Stimulus Tapes

The generation of stimulus tapes for use on the Ampex AG500 tape recorder required the splicing of tire sound coastbys and the copying of these spliced lists along with calibration tones on the Ampex machine.

The original recordings of the coastbys were reviewed on the Ampex and the best 30 coastbys (one for each condition) were picked. Twelve copies of each sound were made on the Nagra III recorder. These copies along with recorded pair and list numbers were spliced together to form ten pair lists.

These spliced master lists were copied on the Ampex AG500 to obtain splice-free stimulus tapes. The 20 s pistonphone calibration signal from a tire sound tape made in the field was played back on the Nagra III recorder and recorded on the Ampex AG500, establishing an 84 dB reference tone. Three spliced lists were recorded on the Ampex to complete one stimulus tape consisting of a 250 Hz pistonphone tone and three stimulus lists.

Stimulus Presentation System

The coastby tire sound tapes were played back on the system depicted in Figures C10 and C11 of the first report. The monitor earphone attenuator was set to zero. The pistonphone reference tone was at 84 dB instead of 104 dB as before. These two changes set up a pistonphone reference level of 0.88 volts on the volt ohm meter during the subjective runs.

Tire Footprints

Tire footprints (ref. 4) of the five types of tires used in the experiment are shown in Figure 1. Tire 2 is a radial ply tire and the others are of bias ply construction. Tire 4 is a snow tire (no studs). Tire 3 is a standardized skid test tire choosen in this study for its inherent quit tread design (no crossbars).

Tire sounds that were recorded but not used in this study included:

1. Coastby on asphalt; power by (with engine running) on concrete for tires 1-5.
2. Coastby on concrete, and asphalt; power by on concrete with a studded snow tire.

Data Analysis

Procedure for obtaining peak dB(A)

Lists one through six were played on the Ampex AG500 tape recorder. The resulting signals were "A-weighted" using a B & K 2204 Sound Level Meter and then a hard copy was produced on the B & K 2305 Graphic Level Recorder. The peak values were read for each of the 30 tire sounds.

Procedure for obtaining peak 1/3 octave bands

Lists one through six were played on the Ampex AG500 tape recorder. Using a peakhold mode the 1/3 octave bands were displayed on a B & K 3347 Real Time Analyzer. With the aid of the analyzer's built-in digital volt meter the 1/3 octave band levels were measured and are found in Table 7.

Equipment List

1. Model 2305 B & K Graphic Level Recorder
2. Model 2204 B & K Precision Sound Level Meter
3. Two Model 4131 B & K (Condensor) Microphones/Stands
4. Two Model 222-2 B & K Conditioners (Microphone Amplifiers)
5. Model AG500 Ampex Tape Recorder
6. Three Koss 727 Headsets (8Ω)
7. Amplifier Ballast & Voltage Divider
8. J. B. Lansing Amplifier Model SE408S
9. Nagra III Tape Recorder
10. 203-1/4-1800 Scotch Magnetic Tape
11. S-3 Editall Splicer
12. Editab Splices
13. Reeves Soundcraft Leader Tape
14. Power Extension Cords and Shielded Cable
15. Two B & K 2619 Microphone Preamplifiers
16. B & K Pistonphone Type 4220
17. Model 800 Triplet VOM
18. Sharpe HA-10A Headset (100Ω)
19. Model 3347 B & K Real Time Analyzer
20. 1970 Fury III Plymouth Sedan with 318 engine, torqueflight transmission, and power steering
21. Test Track fifth wheel with Weston meter
22. Automobile jack, calibrated tire pressure gauge, and tire changing equipment

Appendix B

Recording Site

Recording Site

Preliminary inspections were made of three possible sites for tape recording vehicle coastby for use as stimulus material in a psychophysical tire sound experiment. Site 1 was the Beltsville airport (Beltsville, Maryland) which had two runways in the form of a cross. The one runway for which permission to run a vehicle was obtained (when planes were not landing) was not suitable for acoustical experiments because the asphalt surface was cracked and full of weeds. Site 2 was a three lane section of I95 under construction a few miles northeast of the Washington Beltway. The concrete road surfaces were in good condition but it was under construction. It was doubtful that the road surface would remain clear of gravel, sand and dirt which spilled from the trucks carrying building materials during the day. The third location viewed was a 3 lane section of I95 crossing the Washington Beltway (Figure B1, p. 54). This 3-mile portion of I95 was under construction at one end and terminated in a wooded area. Except for an occasional construction truck passing by on the parallel three lane I95 leg to the east, and aircraft flyovers, this site presented an acceptable acoustical environment and was chosen for recording the automobile coastbys.

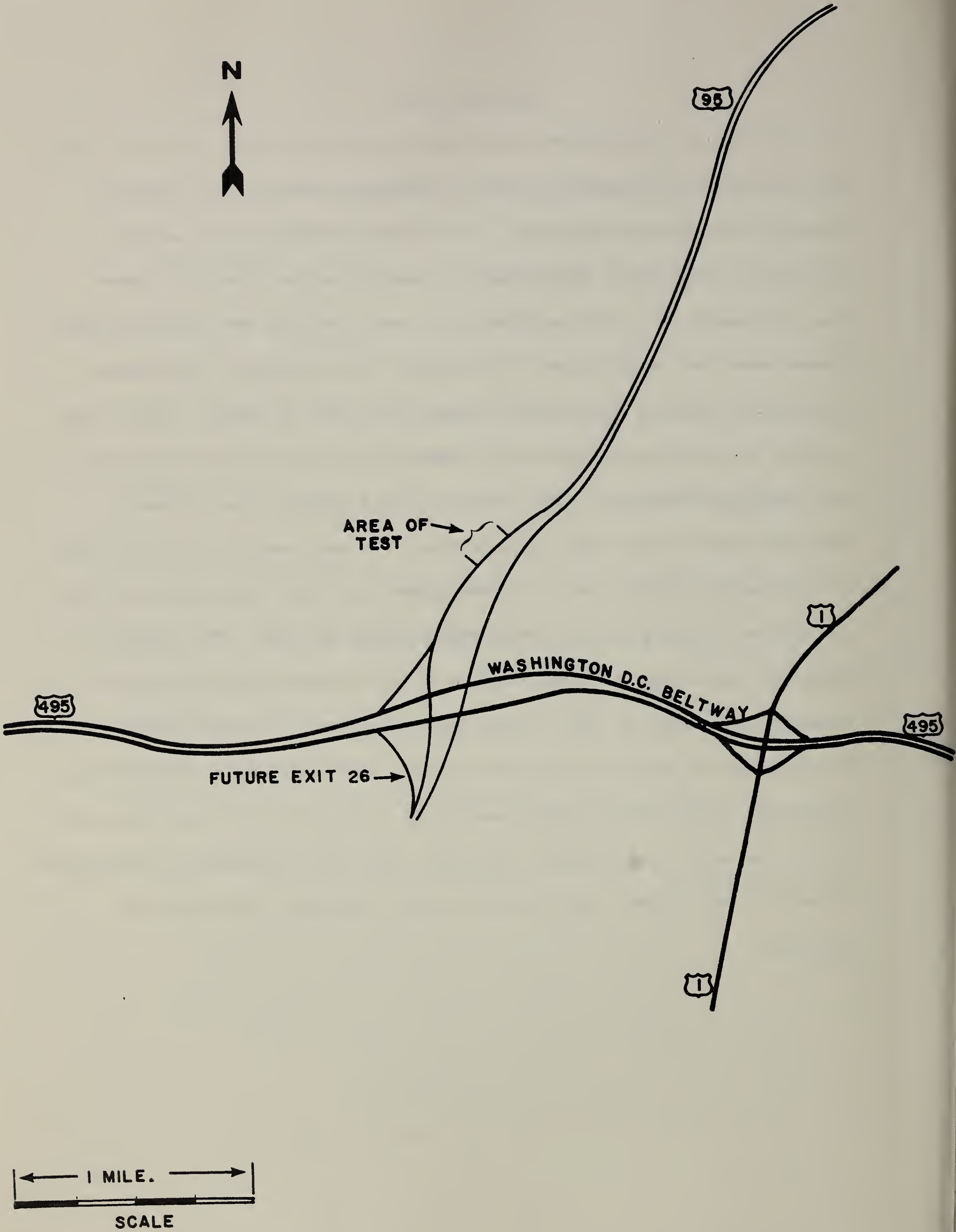

Figure B1. Location of recording site.

Appendix C

Subjective Responses

Table C1. Test lists.

Pairs	A_1	A_2	B_1	B_2	C_1	C_2
1	IIA_1-IVA_1	$IIIA_2$-IA_2	VB_1-IVB_1	$IIIB_2$-IB_2	VC_1-$IIIC_1$	IC_2-IIC_2
2	III-Iv	V-II	V-I	V-III	IV-I	V-II
3	V-III	II-III	III-V	IV-V	I-V	III-II
4	IV-I	I-V	II-I	I-V	I-III	V-III
5	I-II	I-IV	I-III	II-I	II-III	IV-I
6	V-II	IV-III	II-IV	IV-II	IV-II	III-IV
7	V-IV	II-IV	I-IV	IV-I	II-V	I-III
8	II-III	I-II	V-II	II-V	I-II	II-IV
9	I-V	V-III	III-IV	III-IV	V-IV	I-V
10	III-I	V-IV	III-II	II-III	IV-III	V-IV

Pairs	A_1	A_2	B_1	B_2	C_1	C_2
1	IIA_1-VA_1	$IIIA_2$-VA_2	IVB_1-IB_1	IIB_2-IVB_2	IIC_1-IC_1	IIC_2-IC_2
2	I-III	II-V	IV-V	III-II	V-I	IV-V
3	IV-V	II-I	IV-III	I-III	II-IV	IV-III
4	V-I	III-IV	I-II	IV-III	III-IV	I-IV
5	I-IV	V-I	V-III	I-IV	III-I	IV-II
6	IV-III	III-II	III-I	III-V	IV-V	V-I
7	III-II	I-III	II-V	I-II	III-II	II-V
8	II-I	II-IV	II-III	V-IV	III-V	II-III
9	III-V	IV-I	IV-II	V-I	I-IV	III-I
10	IV-II	IV-V	I-V	V-II	V-II	III-V

Instructions

The primary purpose of the tests being conducted is to determine how people feel about the relative acceptability of one type or level of automobile tire sound when compared with another type of level of automobile tire sound.

You will hear a series of sounds from automobile tires. The sounds will occur in "pairs" and your task is to judge which sound in each pair is more acceptable to you if heard alongside a road or at home.

You will be listening to pairs of sounds which were taped at roadside while a moving vehicle passed by. In some instances, sounds are present which are obviously not associated with the vehicle -- please disregard them in making your judgements. The sound pairs are all of the same duration and therefore the termination of the sound is not uniform. That is, the sound gradually fades some of the time and the judgement is made on the basis of the entire sound, not on any characteristics associated with its termination.

After you have heard each sound pair, please quickly decide which of the two you feel would be more acceptable to you. If the second sound of a pair is more acceptable, circle B for that pair. If the first sound of the pair is more acceptable, circle A.

Please concentrate on the judgement at hand and respond either A or B even though the two sounds may seem approximately equal in acceptability. If you can't detect any difference in acceptability between the two sounds, please make the best guess that you can.

There are no "right" or "wrong" answers. We are interested in how you judge the differences in acceptability among tire sounds and how your judgements compare with those of others.

An announcement will be made, identifying the list of sound pairs to be judged. Each list consists of ten paired sounds. After the presentation of each sound pair, the pair will be identified numerically as an aid in keeping track of your place in the list. Please record your judgement immediately after hearing the identifying number as there will not be much time between presentation of sound pairs.

If you want to change your selection, cross out the first one and circle the alternative.

Instructions for "Word Grouping" Study

This is a followup to the study that you participated in. These are words and phrases used to describe the characteristics of **tire sound**. Keeping the study in mind, I have here a deck of 3 x 5 cards on which a single word or phrase is written. I would like you to look these cards over carefully and familiarize yourself with them. Some of these words or phrases may seem to you to have similar or identical meanings. If so, group these cards together into categories. Separate each of the individual cards and then review all cards for final selection. There is no time limit and you are free to change your initial groupings.

After the Grouping has been Accomplished:

Is it possible for you to give each of these categories of cards a name?

Acknowledgements

The authors were greatly aided in their research by several sources within the National Bureau of Standards. The Office of Vehicle Systems provided administrative support by Mr. Paul Brown and Mr. Jerry Harrington and technical assistance of Mssrs. F. W. Barton and Peter Newfeld. Dr. Joan Rosenblatt, Chief, Statistical Engineering Section, provided statistical support. Assistance in acoustical measurements was given by Mr. Donald Blomquist while Miss Marilyn McPherson and Miss Lorraine Uhlaner, all members of the Applied Acoustics and Illumination Section, conducted portions of the subjective experimentation. Mr. Charles Starkey of the Maryland State Roads Commission aided in selecting a coastby recording site. The Scientific and Professional Liaison Section furnished well executed figures and drawings.

USCOMM-NBS-DC

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS