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BOLT BERANEK AND NEWMAN INC

CONSULTING · DEVELOPMENT · RESEARCH

BBN Report 4550

Measurements of the Impulsiveness and Annoyance of Compression-Release Engine Brake Noise

Sanford Fidell and Richard Horonjeff

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EPA REPORT 550/9-82-100

Submitted to:

Office of Noise Abatement and Control
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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

I. INTRODUCTION AND SUMMARY

The research described in this report was undertaken to evaluate the potential contribution to the overall annoyance of heavy truck noise of the impulsive character of exhaust noise created by engine compression-release braking devices. Although growing numbers of trucks are likely to be equipped with these safety devices in the future, current methods for assessing health and welfare effects of traffic noise on residential populations make no specific provision for annoyance associated with impulsive noise sources.

The two major goals of the current research were 1) to quantify the impulsive emissions generated by compression-release engine brakes in the course of typical operation of heavy vehicles so equipped, and 2) to quantify the annoyance associated with such emissions. A program of physical field measurements designed to meet the first goal is described in Section III of this report. Subjective judgment experimentation conducted under laboratory conditions to meet the second goal is reported in Section IV.

The major findings included the following:

1) Compression-release engine brake use can (but does not necessarily) increase the level of heavy vehicle noise emissions, as measured by conventional noise metrics.

2) Measures of vehicle noise specifically intended to characterize impulse noise rise by 2 dB at most during properly muffled use of compression-release engine brakes.

3) Subjectively, noise of heavy vehicles operating at constant velocity with compression-release engine brakes can be as much as 5 dB more annoying than noise emissions of heavy vehicles operating without such brakes, simply because noise emissions under such conditions are correspondingly higher in level. There is little reason to believe, however, that the character of the noise emissions of a properly muffled vehicle using a compression-release engine brake significantly increases its annoyance.

II. BACKGROUND

A. Nature and Use of Compression-Release Engine Brakes

The primary use for which compression-release engine brakes are designed and purchased is as an aid in maintaining a controllable velocity on long, steep down grades. Service brakes of heavily loaded vehicles can quickly overheat and fail on these grades unless velocity is restricted to a value far below which a vehicle with greater braking horsepower would be safely controllable.

In this principal mode of use, the driver uses the compression-release engine braking system to supply the additional braking horsepower which, when added to that provided by rolling friction and air resistance, brings into equilibrium the force of gravity (acting to accelerate the vehicle downhill) and the retarding forces that act to decelerate the vehicle. The general relationships among these forces may be seen in Figure 1, which shows approximate braking horsepower requirements of a typical heavy truck as a function of road speed, for several grade conditions.

The dashed lines in the figure show the braking horsepower requirements (ordinate) to maintain a constant downhill speed (abscissa) for several different grades. The thin solid lines show the braking horsepower naturally afforded by rolling friction (tire/pavement interaction) and by air resistance. The solid heavy line shows the sum of these two retarding powers, plus an additional 20 horsepower for engine accessories and minimal drive train losses.

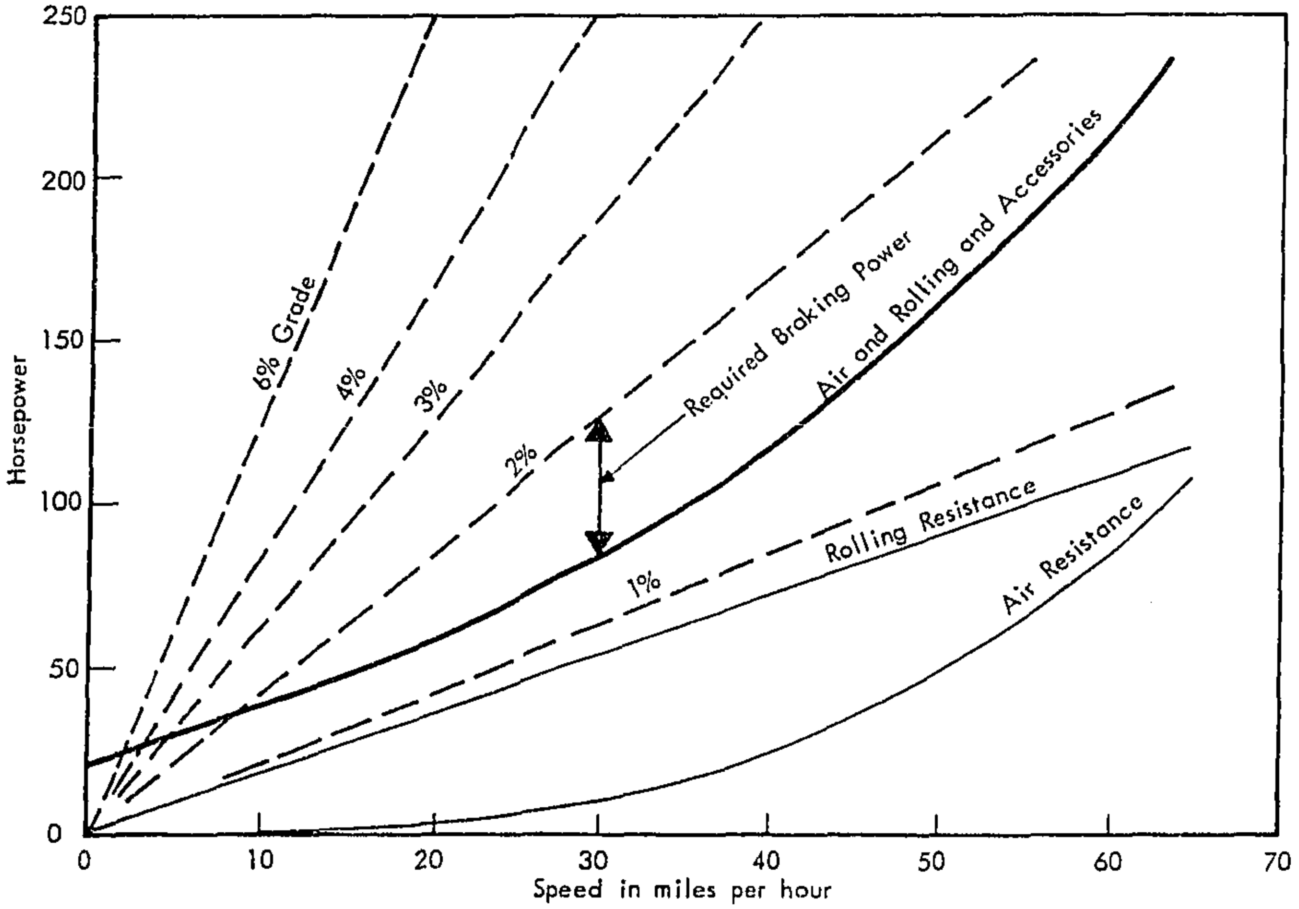


FIGURE 1. TYPICAL BRAKING HORSEPOWER REQUIREMENTS FOR MAINTAINING CONSTANT SPEED IN AN 80,000 LB VEHICLE

The retarding horsepower needed from engine brakes, service brakes, or a combination of the two, is the difference between the solid line and dashed curves. For example, 110 horsepower of braking is required for an 80,000 pound gross weight vehicle to maintain 20 mph on a 4 percent downgrade.

When the accelerating and decelerating forces are in balance, the vehicle will maintain a constant downhill velocity. If the sum of the retarding forces exceeds the accelerating force, the vehicle will eventually slow to a stop. If the accelerating force exceeds the sum of applied braking horsepower and other retarding forces, the vehicle's velocity will continually increase. Eventually, a critical velocity will be reached beyond which the total braking horsepower available from service brakes, compression-release engine brakes, and all other retarding forces is insufficient to check further acceleration. At this point, the vehicle is a runaway, literally unable to stop for lack of sufficient braking horsepower.

On grades less than about 2%, normal engine compression, unaided by the specialized braking systems of present interest, ordinarily provides sufficient braking horsepower for even heavily loaded trucks and buses to maintain constant downgrade velocity at posted or safely controllable limits. Intermittent use of service brakes (to provide for cooling to prevent or recover from brake fade) on grades up to about 3% can provide sufficient additional braking horsepower for long periods of time. On grades exceeding 4%, however, a heavily loaded truck or bus without a source of braking horsepower other than the service brakes may not be continuously safely operated at speeds anywhere near typical posted limits.

The acceleration imparted to a truck on a downgrade is a product of grade and load. For constant available braking horsepower, steep grades may be safely negotiated at high speeds only if a vehicle is lightly loaded. Shallower grades may be safely negotiated at high speeds at higher gross weights. The driver of a vehicle equipped with compression-release engine brakes generally engages only as much braking horsepower as is necessary to maintain a constant road speed, often in the gear he desires to use at the bottom of the grade.

Thus, a driver at the top of a grade may with some models engage two cylinders of compression-release braking to provide for a gradual initial application of retarding force. Thereafter, he may apply four or six cylinders of braking as necessary to limit further speed increases. Engine speed is commonly maintained close to maximum governed rpm (on the order of 2000 rpm for many diesel engines) to avoid unnecessary shifting of gears at the bottom of the grade when the driver once again wishes to accelerate.

Although the primary use of compression-release engine brakes is to maintain a constant long term downhill speed, they are also occasionally used for shorter periods for deceleration. In this mode of operation, the compression-release brakes are used intermittently and for short durations only.

Owners and operators of heavy vehicles used in mountainous terrain generally favor engine braking systems not only for safety reasons, but also because in some applications they permit shorter transit times, and reduce maintenance costs. Much greater detail of the design and use of compression-release and other engine braking systems is available to the interested reader in the comprehensive study of the costs and benefits of engine retarders of Fancher et al. (1981). Some of the observations of Fancher et al. about the manner of operation and extent of use of compression-release engine brakes are quoted or paraphrased below.

According to Fancher et al., only two compression-release engine brakes are marketed in the U.S. One of these is offered by Mack Truck as an option on some of their engines, while the other, manufactured by Jacobs Engineering, is sold as an after-market item. Response times for both manufacturers' brakes are short (on the order of several tenths of a second). The engine brake retarder provides a more-or-less constant torque resisting the rotation of the flywheel. The greatest retarding force is developed at the maximum rated engine speed, however. This occurs when the gearing is the lowest that can be selected at a given vehicle speed.

Although performance of a compression-release retarder depends on the design of its components, the torque limitations are ultimately imposed by engine size and compression ratio. The absorbed-power limitation in turn depends on both the torque and the maximum rated engine speed. Absorbed power capability ranges from 60-100 percent of the power-producing engine specification, with the higher figure applicable to turbo-charged engines with high rpm ratings. Since many other forces act to retard a commercial vehicle besides the engine, the overall performance of an engine-brake retarder acting together with other frictional forces is generally comparable to the engine acting as a power plant against the other frictional forces. From the point of view of the truck driver, this means a given grade can be safely descended without use of the foundation brakes at the same speed and gearing that it can be ascended.

The engine brake type of retarder offers a great deal of flexibility, since the retarding level is greatly dependent on the driver's choice of gears. Potential problems exist, however, as an inappropriate choice of gears can result in overly high engine speed and resulting engine damage unless the driver resorts to the vehicle foundation brakes. Should the engine speed increase beyond the rated maximum, shifting to a lower gear to obtain more retarding torque is not possible. An attempt to do so will leave the driver with the transmission in neutral (or a high gear with less retarding torque) and completely dependent on the foundation brakes of the vehicle.

Fancher et al. estimate that the current annual sales of supplementary braking devices in the United States is 33,000-46,000 units. The majority of the devices (about 50 percent) are installed on class-eight heavy-duty trucks.

The western United States is, by far, the area of greatest market penetration. It is estimated that about 80 percent of installations into class-eight trucks are found in this area. The mountainous terrain makes supplementary braking devices a necessary safety protection on large trucks that are heavily loaded and operating over the steep grades.

Heavy-duty trucks are also equipped with retarders in the mountainous areas of the eastern United States for much the same reason.

Transit vehicles use retarders because of the lower operating costs due to increased brake life (this benefit occurs regardless of terrain). Therefore, retarder installations on this class of vehicle are most directly related to the transit vehicle population. This explains the greater number of retarder installations in the eastern United States.

There are about 1.1 million trucks, class eight and larger (over 33,000 lb GVW), in the United States. About 15 percent of these vehicles are in the eleven western states; however, the greatest penetration of retarders is found in this area. About 40-70 percent are retarder equipped; the heavier the vehicle, the greater the retarder share.

According to Fancher et al., isolated communities, particularly in the Pacific Northwest, rigidly enforce local noise ordinances concerning retarder use. Operators indicate that in some of these communities the use of a retarder is interpreted by the local police officer as being a de facto violation of the ordinance.

B. Noise Emissions of Compression-Release Engine Brakes

Compression-release engine brakes work by forcing the momentum of the vehicle to compress a fuelless cylinder charge, which is then exhausted near top dead center of the piston stoke, rather than being retained (as in normal engine operation) to return the piston to the bottom of its stoke. When engaged, compression-release engine brakes generate repetitive impulsive noise at periodic rates determined by engine speed and number of cylinders in use. These factors depend in turn on road speed, load, and grade. The duration of each exhaust pulse is typically on the order of 0.5 ms, with a rise time of 0.2 ms. The crest factor of the impulse is about 15 dB. Repetition rates in normal operation range from about 30 to 100 Hz.

The contribution of the impulsive noise to the levels of normal exhaust emissions depends heavily on the adequacy of the vehicle's exhaust muffling. If a heavy truck or bus is equipped with proper muffling, the contribution of impulsiveness due to compression-release engine brakes to overall exhaust noise may be negligible. If the muffler is in poor condition, or has been altered or tampered with, use of compression-release engine brakes can increase engine exhaust noise levels significantly, and also greatly alter the character of the exhaust noise.

C. Annoyance of Impulsive Noise

Research on the annoyance of impulsive noise (e.g. that of Leverton, 1972, Galloway, 1977, and others, as summarized by Sutherland (1979)) suggests that people may find some types of repetitive impulsive noises as much as 6 dB more annoying than non-impulsive noises of similar spectral shape. Development of measurement schemes to account for the annoyance of impulsive noise is a matter of international concern. Much of this concern is related to economic interests in the aircraft industry. In addition to truck engine retarder noise, other sources of impulsive noise (blasting and artillery noise, rail car coupling noise, industrial impact noise, sonic boom, etc.) have also received attention in recent years.

A variety of metrics has been proposed to account for the "excessive" annoyance (that is, greater than predicted by metrics such as EPNL and A-level) of impulsive noise. The International Standards Organization has defined an impulse coefficient known as CI. CI is the mean fourth power divided by the mean square of the A-weighted sound pressure level. The impulse correction is calculated from CI by 0.8x[10log(CI-1)-3], truncated between 0 and 5.5 dB. (CI for a sine wave is 1.5, and for Gaussian noise is 3.0).

Available research findings do not demonstrate the clear superiority of metrics of impulsiveness based on any single property of an impulsive signal (crest factor, repetition rate, rise time, etc.). It is also an empirical question whether a "correction" for impulsiveness is needed at all for noises containing various mixtures of steady state and impulsive components.

D. Regulatory Implications of Compression-Release Engine Brake Noise

Because heavy trucks and buses generally produce higher peak noise levels during acceleration than during deceleration, existing regulations that limit noise emissions for heavy trucks and buses (e.g., 40CFR205) apply only to noise levels produced during acceleration. If compression-release engine brake noise increased truck noise emissions during deceleration, or if its impulsive nature were more annoying than the non-impulsive noise produced during acceleration, then there would be reason to question the continued efficacy of existing regulations.

If, on the other hand, it could be shown empirically that compression-release engine brake noise did not appreciably increase noise emissions during deceleration over levels produced during acceleration, and if the character of noise emissions produced by the engine compression-release brakes were not significantly more annoying than noise produced during acceleration, then there would be little reason to question the applicability of existing regulations to vehicles equipped with compression-release engine braking systems.

E. Approach to Current Investigation

1. Characterization of Compression-Release Engine Brake Noise

Although the general principles and mechanisms whereby heavy vehicles equipped with compression-release engine brakes generate impulsive noise are understood, there is a paucity of detailed information about their noise emissions in regular operation. A series of acoustic measurements of vehicles equipped with compression-release engine brakes was therefore planned to collect such data as described in Section III.

Among the goals of these field measurements were 1) recording of noise emissions of a variety of vehicles; 2) collection of compression-release engine brake noise emission information under a range of operating conditions; and 3) collection of information about noise emissions of the same vehicles operating without compression-release engine brakes.

2. Characterization of Annoyance due to Compression-Release Engine Brake Noise

The second part of the current investigation was an empirical study of the annoyance of compression-release engine brake noise. Psychoacoustic experimentation was conducted during which people judged the relative annoyance of recordings excerpted from the field measurements. This testing was planned, as described in Section IV, (1) to determine whether in fact the noise of heavy vehicles using compression-release engine braking is more annoying than the noise of heavy vehicles accelerating, and 2) to investigate other technical isssues related to assessment of annoyance of impulsive noises.

III. FIELD MEASUREMENTS

A. Method

Noise emissions produced by three vehicles equipped with engine brakes were recorded on three separate days at two test sites. The goal of making acoustic measurements at the first site was to characterize noise emissions from test vehicles maintaining various road speeds on a downgrade by means of engine compression braking. The goal of making acoustic measurements of test vehicles at the second site was to characterize noise emissions produced by engine compression brakes during deceleration.

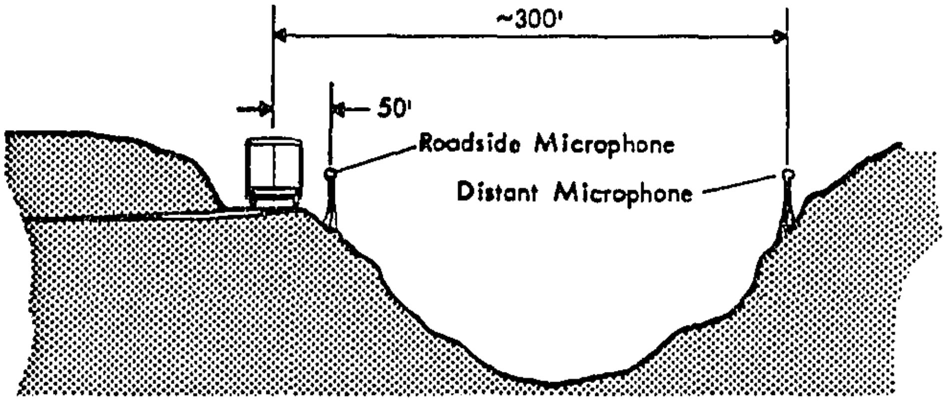
1. Test Sites

a. Acceleration and Deceleration Measurement

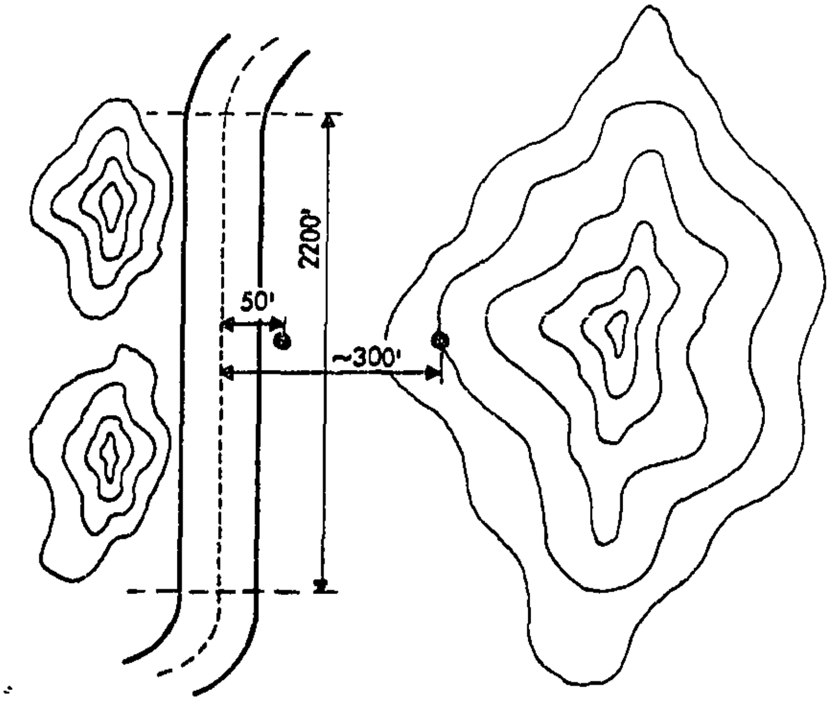
Measurements of engine brake noise emissions made during deceleration, and of vehicle noise during acceleration, were made at two nearby sites conforming to the geometry specified in SAE Standard J366B, "Exterior Sound Level for Heavy Trucks and Buses".

b. Constant Velocity Measurements

All measurements of engine brake noise emissions produced while maintaining a constant downgrade velocity were made at a single site in Los Angeles County. Roadside and distant measurement positions were established along a lightly travelled rural portion of a county road as shown schematically in Figure 2. The test section was bordered



ELEVATION VIEW



PLAN VIEW

FIGURE 2. SCHEMATIC PLAN AND ELEVATION VIEWS OF SITE FOR CONSTANT VELOCITY MEASUREMENTS (Not to Scale)

by sloping terrain to the west, and a canyon to the east. This portion of road included approximately one mile of a constant 7.3% grade, comprised of two straight sections (a lead-in section about a quarter of a mile long, and a test section almost a half mile long) connected by a gentle curve, and a quarter-mile run-out section of gently curving roadway. The road surface was in excellent condition from recent paving, and regular through traffic by vehicles in excess of 14,000 pounds was prohibited. Ambient noise levels in the vicinity of the site were typically 40 dB or more lower than the noise emissions of the test vehicles.

2. Test Vehicles

Noise emissions produced by one primary test vehicle and two secondary test vehicles were measured. The vehicles (described in Table 1) were operated for most tests at full gross vehicle weight ratings. Both the tanker truck/trailer and fire engine carried water (approximately 56,000 and 4,000 pounds, respectively), while the bus was loaded with 12,000 pounds of sand. The primary test vehicle was operated both with and without proper exhaust muffling. The secondary test vehicles were operated only with normal exhaust mufflers.

3. Test Conditions

a. Acceleration and Deceleration Measurements

Procedures specified in SAE Standard J366b were followed for all acceleration and deceleration measurements. Deceleration measurements were made both with and without the use of the test vehicles' engine brakes. All vehicles were properly muffled for these measurements.

TABLE 1. DESCRIPTION OF TEST VEHICLES

VEHICLE	TYPE	MANUFACTURER AND MODEL	ENGINE AND TRANSMISSION	EXHAUST POSITION	JACOBS ENGINE BRAKE
Primary Test Vehicle	3 axle, 10 wheel truck with 4400 gallon Aluminum tank: GVWR = 50,000 lbs. Towed load = 30,000 lb. 2 axle tanker trailer	Kenworth 1980 Model W900A, manufactured in 1979	Cummins (California model) Turbocharged NTC400 4 stroke, 6 cylinder diesel rated at 400 HP, governed at 2150 rpm; 13 speed manual transmission	Right side, behind cab, 12 feet above road level (3 feet when unmuffled)	Model 30E, 2/4/6 cylinders selectable
Secondary Test Vehicle	3 axle, 10 wheel, 49 passenger intercity bus, GVWR = 36,000 lbs.	MCI Model 8, manufactured late 1970's	Detroit Diesel V-8, 2 stroke diesel rated at 300 HP, governed at 1900 rpm; 6 speed locking automatic transmission	Rear left side below chassis	All 8 cylinders operation only
Secondary Test Vehicle	3 axle, 10 wheel, fire engine with 500 gallon water tank; GVWR = 36,000 lbs.	Crown Pumper, manufactured in late 1960's	Cummins N-series 4 stroke, 6 cylinder diesel rated at 295 HP, governed at 2100 rpm; 6 speed automatic transmission unlocking below 1300 rpm	Middle of vehicle, right side, below chassis	All 6 cylinders operation only

2. Constant Velocity Measurements

Measurements of noise emissions produced by the test vehicles were made at various roadspeeds, loads, gear ratios, modes of engine brake use, with and without exhaust muffling, and in both downhill and uphill directions. Table 2 summarizes these test conditions in terms of the variables of interest: engine speed (rpm), roadspeed (mph), and a number of cylinders of engine braking. Simultaneous recordings were made at the roadside and distant microphones.

4. Instrumentation

Field recordings of vehicular passbys were obtained using high quality, battery powered instrumentation. A typical instrumentation package is shown in Figure 3. The microphone consisted of either a Bruel & Kjaer (B&K) 1-inch (Model 4145) or 1/2-inch (Model 4133) condenser microphone powered by a GenRad Model 1560-P42 microphone preamplifier. The 1/2-inch microphone was used at the roadside measurement (nominal 50' location), while the greater sensitivity 1-inch microphone was employed at the remote (nominal 285') location. Microphones were mounted vertically on a tripod, 5' above ground level. With the microphone in the vertical position, the sound source was at a grazing (90°) angle of incidence to the source. Microphones were fitted with open cellular foam (3" or 7" diameter) windscreens to minimize wind noise and protect the microphone from dust and other particulate matter.

The output of the preamplifier was fed to a B&K Model 2203 precision sound level meter which acted as a decading amplifier

TABLE 2. SUMMARY OF TEST CONDITIONS UNDER WHICH AT LEAST ONE CONSTANT VELOCITY MEASUREMENT WAS MADE

PRIMARY TEST VEHICLE

DOWNGRADE				UPGRADE		
Engine Speed (RPM)	Road Speed (MPH)	No. of Cylinders Braking	With or Without Muffler	Engine Speed (RPM)	Road Speed (MPH)	With or Without Muffler
1650	25	0	W	1900	35	W
2000	33	0	W	2000	35	W
2000	24	2	W	2100	35	W
2000	20	2	WO	2000	32	WO
1650	21	4	W	2000	35	WO
2000	23	4	W	2100	20	WO
2000	24	4	WO	2100	35	WO
1400	22	6	W			
1650	26	6	W			
1950	30	6	W			
1400	22	6	WO			
1650	26	6	WO			
2000	24	6	WO			
2000	32	6	WO			

SECONDARY TEST VEHICLES

TRANSMISSION GEAR	ROAD SPEED (MPH)	NO. OF CYLINDERS BRAKING	
3	26	8	(NUMEROUS REPEATED RUNS)
3	27	8	
3	28	8	
4	48	8	
3	20	6	
4	30	6	
5	45	6	

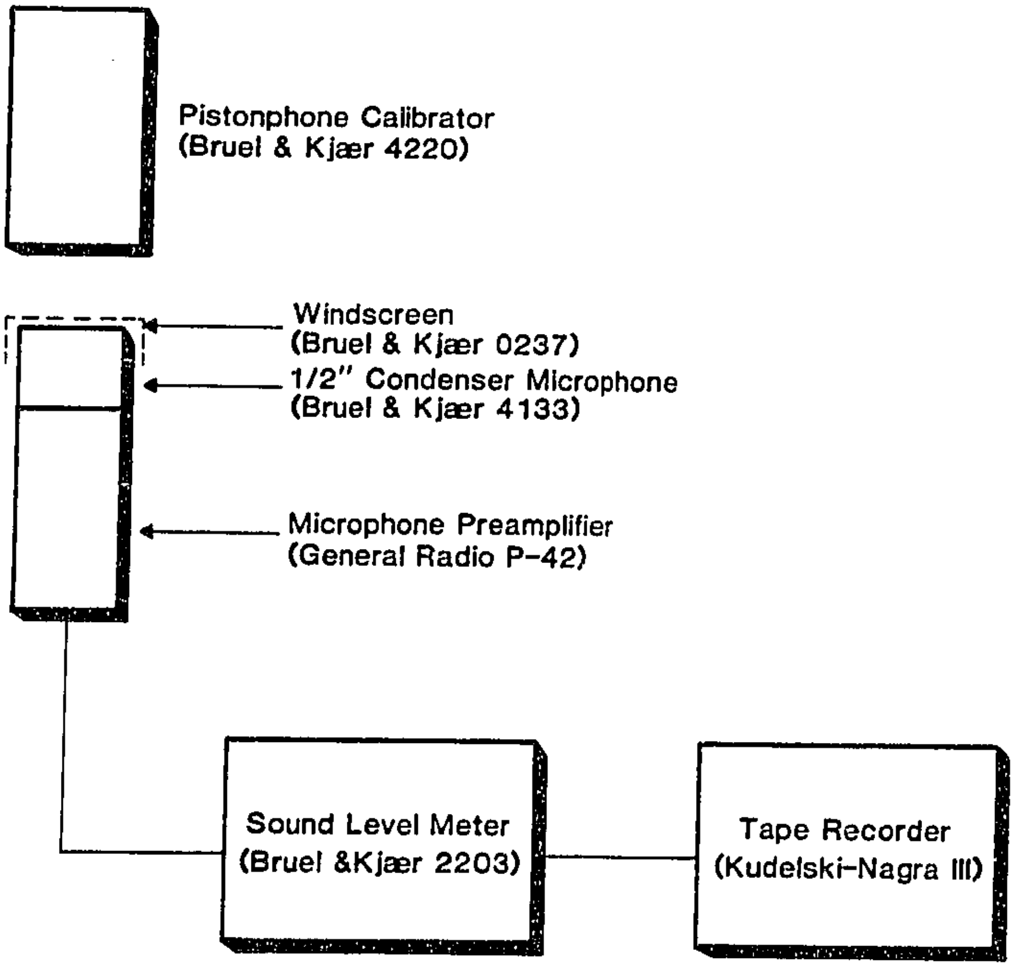


FIGURE 3. BLOCK DIAGRAM OF FIELD MEASUREMENT EQUIPMENT

between the preamplifier and the magnetic tape recorder. The sound level meter was always in the "linear", or unweighted, position.

Either a Nagra III or a Nagra IV-SJ was used to record the signal on magnetic tape. Both machines used direct record (not FM) electronics, and operated at a speed of 15 inches/sec.

A B&K Model 4220 pistonphone calibrator was used to apply a sinusoidal signal of known frequency and amplitude to the microphone, and this signal was recorded at the beginning and end of each data tape. On playback, this signal provided the necessary reference amplitude, as well as serving as a continuing check on system performance. Measured frequency response characteristics of the entire measurement system, including the windscreen, were incorporated in the data analysis process and are reflected in reported one-third octave band and A-weighted sound levels.

B. Results

1. Acceleration and Deceleration Measurements

Tables 3, 4, and 5 show the results of the SAE J-336 acceleration and deceleration sound level measurements for the tank truck, intercity bus, and fire pumper truck, respectively. Individual acceleration and deceleration runs are tabulated in the order they were recorded on magnetic tape. Operational parameters for each run include the transmission gear used, the side of the vehicle facing the microphone, the distance from the

TABLE 3. TANK TRUCK ACCELERATION/DECELERATION MEASUREMENTS

RUN	GEAR	SIDE OF VEH FACING MICR	DIST (FT)	ACCEL OR DECEL	ENGINE BRAKE (Y/N)	A-LEVEL MAX	PNL MAX	PNLT MAX	ISO IMPULSE CORR
2	5	R	50	A	--	79.9	93.9	96.0	0.0
3	5	L	62	A	--	76.5	90.6	92.7	0.0
4	5	R	50	A	--	79.8	95.4	97.7	0.0
5	5	L	62	A	--	76.2	90.8	92.7	0.0
6	5	R	50	A	--	80.0	95.0	96.9	0.0
7	5	L	62	D	Y	78.6	92.5	94.1	2.1
8	5	R	50	D	Y	85.3	100.9	103.1	2.7
9	5	R	50	D	Y	85.4	100.2	102.6	3.1
10	5	R	50	D	Y	85.2	100.7	103.5	2.6
11	5	R	50	D	N	77.4	91.0	92.6	0.0
12	5	R	50	D	N	77.7	90.9	92.9	0.0
13	5	R	50	D	N	77.2	91.0	93.2	0.0
14	5	L	50	A	--	78.6	92.6	94.6	0.0
15	5	L	50	A	--	79.7	93.1	95.5	0.0
16	5	L	50	D	Y	80.6	94.3	96.2	0.0
17	5	L	50	D	Y	80.6	94.4	96.1	0.0
18	5	L	50	D	N	78.0	91.0	92.7	0.0
19	5	L	50	D	N	77.7	90.9	92.5	0.0

TABLE 4. INTERCITY BUS ACCELERATION/DECELERATION MEASUREMENTS

RUN	GEAR	SIDE OF VEH FACING MICR	DIST (FT)	ACCEL OR DECEL	ENGINE BRAKE (Y/N)	A-LEVEL MAX	PNL MAX	PNLT MAX	ISO IMPULSE CORR
1	1	R	50	A	--	81.3	92.7	93.7	0.0
2	1	R	50	A	--	81.8	93.4	94.3	0.0
3	1	R	50	A	--	82.0	94.0	95.0	0.0
4	1	R	50	A	--	81.7	93.5	94.5	0.0
5	2	R	50	D	Y	81.4	93.2	94.5	0.0
6	2	R	50	D	Y	81.2	94.0	94.6	0.0
7	3	R	50	D	Y	78.8	91.1	93.1	0.0
8	2	R	50	D	Y	80.6	93.3	94.1	0.0
9	2	R	50	D	Y	81.5	93.7	94.5	0.0
10	1	L	50	A	--	85.3	97.1	98.2	0.0
11	1	L	50	A	--	85.8	97.7	98.9	2.0
12	1	L	50	A	--	85.5	96.9	98.0	0.0
13	2	L	50	D	Y	82.0	93.6	94.8	2.5
14	2	L	50	D	Y	81.9	93.6	95.2	2.3
15	2	L	50	D	Y	81.9	93.5	95.2	0.0

TABLE 5. FIRE PUMPER TRUCK ACCELERATION/DECELERATION MEASUREMENTS

RUN	GEAR	SIDE OF VEH FACING MICR	DIST (FT)	ACCEL OR DECEL	ENGINE BRAKE (Y/N)	A-LEVEL MAX	PNL MAX	PNLT MAX	ISO IMPULSE CORR
3	--	R	50	A	--	81.4	96.5	98.1	2.6
4	--	L	62	A	--	76.9	90.1	91.6	2.8
5	--	R	50	A	--	81.6	96.7	98.3	0.0
6	--	L	62	A	--	76.8	90.3	92.0	2.6
7	--	R	50	A	--	81.7	96.8	98.3	2.0
8	--	L	62	A	--	76.6	90.0	91.4	2.1
9	--	R	50	D	Y	86.2	99.3	100.1	2.3
10	--	L	62	D	Y	78.6	91.9	92.8	0.0
11	--	R	50	D	N	77.9	91.6	93.1	0.0
12	--	L	62	D	N	77.0	89.1	90.4	0.0
13	--	R	50	D	Y	84.6	98.9	99.9	3.0
14	--	L	62	D	Y	78.7	91.7	92.8	0.0
15	--	R	50	D	N	77.8	91.6	93.0	0.0
16	--	L	62	D	N	77.0	89.0	90.3	0.0
17	--	R	38	A	--	84.1	99.2	100.5	2.6
18	--	L	50	A	--	78.5	92.0	93.5	2.8
19	--	R	38	A	--	83.9	99.0	100.5	0.0
20	--	L	50	A	--	78.5	92.0	93.5	0.0
21	--	R	38	A	--	84.1	99.3	100.8	2.6
22	--	L	50	A	--	78.7	91.8	93.3	0.0
23	--	R	38	D	Y	86.5	100.6	101.5	2.3
24	--	L	50	D	Y	80.1	93.8	94.7	0.0
25	--	R	38	D	Y	86.9	101.1	101.7	0.0
26		L	50	D	Y	80.1	93.3	94.8	0.0
27		R	38	D	N	79.9	93.8	95.1	0.0
28		L	50	D	N	78.2	90.3	91.5	0.0
29		R	38	D	N	79.0	93.7	95.2	0.0
30		L	50	D	N	78.5	90.7	92.3	0.0

vehicle centerline to the microphone, whether the vehicle was accelerating or decelerating, and whether the engine brake was engaged during deceleration.

The sound levels were calculated by reproducing the data tape through a Hewlett-Packard Real Time Audio Spectrum Analyzer (Model 80-4A) linked to a Digital Equipment Corporation PDP-8 computer. The analyzer used "fast" sound level averaging characteristics. The computer read five complete one-third octave band sound level spectra per second, and computed the A-weighted sound level, perceived noise level and tone corrected perceived noise level for each spectrum. The table lists the maximum values of these parameters for each passby. Additional one-third octave band spectra for these field recordings may be found in Appendix A.

Using different software, the proposed ISO impulsiveness correction for helicopters was also computed per Draft Addendum ISO 3891/DAD 1, "Acoustics-Procedure for describing aircraft noise heard on the ground. ADDENDUM 1: Measurement of noise from helicopters for certification purposes." This index of impulsiveness is by definition computed every one-half second. The highest value of the correction during the passby is reported in the tables. For deceleration runs, the analysis was started approximately one-half second before the throttle was released.

2. Constant Velocity Measurements

Tables 6, 7, and 8 present results of analyses of constant velocity passbys. These passbys include both uphill (positive power) and downhill (negative power) conditions. Operational parameters for the intercity bus (Table 7)

TABLE 6. TANK TRUCK 7% GRADE MEASUREMENTS

											50 FEET FROM ROADWAY					285 FEET FROM ROADWAY				
RUN	TIME	W/ TRLER (Y/N)	W/ MUFLER (Y/N)	GEAR	ENG SPEED (RPM)	VEH SPEED (MPH)	GRADE (UP/ DOWN)	ENG BRAKE (Y/N)	CYL OF BRAK-ING	SERV BRAKE ASST (Y/N)	A-LEVEL MAX (∫)	PNL MAX (∫)	PNLT MAX (∫)	TONE CORR @MAX (BAND)	IM-PULSE CORR MAX (Δ∫)	A-LEVEL MAX (∫)	PNL MAX (∫)	PNLT MAX (∫)	TONE CORR @MAX (BAND)	IM-PULSE CORR MAX (Δ∫)
1	11:12	Y	N	5-D	2000	24	D	Y	6	N	95.3 (100.9)	107.9 (113.5)	110.1 (115.8)	2.2 (100)	3.7 (0.2)	81.4 (88.4)	93.7 (100.7)	95.8 (102.8)	2.1 (200)	0.0 (0.0)
2	11:20	Y	N	5-D			U				94.9 (100.2)	108.6 (113.6)	109.7 (114.7)	1.1 (160)	0.0 (0.0)	77.6 (87.1)	89.3 (99.1)	90.4 (100.5)	1.1 (2000)	3.0 (0.5)
3	11:29	Y	N	4	2000	24	D	Y	6	N	99.2 (104.9)	111.6 (117.8)	114.3 (120.4)	2.7 (100)	5.0 (0.3)	82.8 (94.5)	93.7 (105.8)	96.2 (108.0)	2.5 (100)	0.0 (0.0)
4	11:36	Y	N	4	2100	20	U				95.1 (101.0)	110.5 (115.8)	113.1 (118.3)	2.6 (100)	0.0 (0.0)	77.1 (87.4)	89.6 (99.7)	91.9 (102.0)	2.3 (100)	3.6 (0.1)
5	11:41	Y	N	5-D	2000	24	D	Y	4	Y	96.0 (101.9)	108.1 (114.4)	109.6 (116.0)	1.9 (100)	3.9 (2.2)	83.8 (93.4)	94.2 (104.2)	95.4 (105.8)	1.2 (200)	4.0 (1.5)
6	11:48	Y	N	4	2100	20	U									77.7 (88.0)	89.9 (100.3)	92.2 (102.4)	2.3 (100)	2.3 (0.1)
7	11:58	Y	N	5-D		20	D	Y	2	Y	92.9 (99.3)	105.7 (111.6)	106.3 (112.4)	0.8 (160)	5.6 (3.6)	78.0 (88.9)	88.9 (100.4)	90.2 (101.4)	1.5 (800)	3.7 (1.2)
8	12:16	N	N	6-D	2000	32	D	Y	6	N	96.9 (102.3)	109.1 (114.9)	111.1 (116.5)	2.0 (100)	4.5 (0.3)	86.6 (94.1)	96.6 (104.8)	98.5 (106.4)	1.9 (100)	
9	12:20	N	N	6-D	2000	35	U				92.6 (97.0)	106.8 (110.4)	109.5 (112.9)	2.7 (100)	2.4 (0.1)	76.7 (86.6)	88.6 (98.3)	90.7 (100.6)	2.1 (100)	3.2 (0.1)
10	12:24	N	N	6-D	2000	32	D	Y	6	N	99.5 (103.9)	112.3 (116.9)	115.0 (119.4)	2.7 (100)	3.0 (1.0)	84.1 (94.2)	94.4 (105.1)	96.7 (107.2)	2.3 (100)	3.2 (0.3)
11	12:29	N	N	6-D	2000	32	U				94.0 (97.6)	108.3 (111.6)	111.0 (114.1)	2.7 (100)	0.0 (0.0)	75.1 (85.3)	87.0 (96.8)	89.5 (99.2)	2.5 (100)	2.5 (0.1)
12	12:33	N	N	6-D	1650	26	D	Y	6	Y	98.8 (104.6)	111.2 (117.6)	113.1 (119.3)	2.0 (160)	2.5 (0.9)	82.8 (93.2)	93.3 (103.9)	94.9 (105.5)	2.0 (160)	2.6 (0.2)
13	12:38	N	N	6-D	2100	35	U				95.3 (98.9)	110.5 (113.6)	112.9 (115.8)	2.4 (100)	2.2 (0.0)					
14	12:41	N	N	6-D	1400	22	D	Y	6	Y	92.5 (98.9)	105.2 (111.7)	106.1 (112.4)	1.1 (800)	4.0 (2.0)	79.0 (85.7)	89.4 (96.5)	90.5 (97.4)	1.1 (200)	
16	12:49	N	N	5-D	2000	23	D	Y	4	N	96.1 (101.9)	108.1 (114.5)	109.4 (115.8)	1.3 (100)	5.0 (2.5)	84.3 (94.0)	94.5 (104.7)	96.1 (106.4)	1.6 (100)	4.7 (2.2)
17	13:48	N	Y	6-D	1950	30	D	Y	6	N	79.4 (84.9)	93.9 (99.8)	95.9 (101.6)	2.1 (100)	3.3 (0.2)	65.0 (76.6)	77.6 (88.9)	79.5 (91.0)	1.9 (1000)	2.2 (0.1)
18	13:53	N	Y	6-D			U				80.4 (84.4)	94.9 (98.7)	97.1 (100.7)	2.2 (100)	0.0 (0.0)	62.6 (72.4)	74.2 (84.5)	76.0 (86.4)	2.0 (100)	0.0 (0.0)
19	13:56	N	Y	6-D	1650	26	D	Y	6	Y	78.8 (83.0)	93.1 (97.4)	95.3 (99.4)	2.3 (1000)	0.0 (0.0)	65.1 (76.5)	77.1 (88.4)	79.3 (90.5)	2.2 (1000)	0.0 (0.0)
20	14:02	N	Y	6-D	2100	35	U				79.2 (83.5)	94.3 (98.2)	96.5 (100.3)	2.2 (100)	0.0 (0.0)	61.4 (72.0)	73.9 (84.1)	75.7 (85.6)	1.8 (100)	0.0 (0.0)
21	14:05	N	Y	6-D	1400	22	D	Y	6	Y	77.1 (83.3)	91.3 (97.7)	93.3 (99.6)	2.0 (1000)	2.5 (0.5)	64.0 (75.5)	76.2 (87.1)	78.6 (89.5)	2.4 (1000)	2.8 (0.3)
22	14:11	N	Y	6-D	1900	35	U				79.9 (83.8)	94.3 (98.2)	96.0 (99.9)	1.8 (100)	0.0 (0.0)					
23	14:14	N	Y	6-D	2000	23	D	Y	4	Y	77.9 (84.5)	92.1 (98.9)	93.8 (99.9)	1.7 (1000)	4.2 (0.7)					

TABLE 6. (Continued)

											50 FEET FROM ROADWAY					285 FEET FROM ROADWAY				
RUN	TIME	W/ TRLER (Y/N)	W/ MUFLER (Y/N)	GEAR	ENG SPEED (RPM)	VEH SPEED (MPH)	GRADE (UP/ DOWN)	ENG BRAKE (Y/N)	CYL OF BRAK-ING	SERV BRAKE ASST (Y/N)	A-LEVEL MAX (∫)	PNL MAX (∫)	PNLT MAX (∫)	TONE CORR #MAX (BAND)	IM-PULSE CORR MAX (A∫)	A-LEVEL MAX (∫)	PNL MAX (∫)	PNLT MAX (∫)	TONE CORR #MAX (BAND)	IM-PULSE CORR MAX (A∫)
24	14:20	N	Y	6-D	2000	35	U				80.7 (85.4)	95.0 (99.3)	96.6 (100.8)	1.6 (100)	0.0 (0.0)					
25	14:22	N	Y	6-D	2000	24	D	Y	2	Y	76.2 (83.3)	90.5 (97.1)	91.6 (98.1)	1.1 (160)	3.9 (0.7)					
26	14:33	N	Y	5-D	1650	21	D	Y	4	Y	76.4 (83.8)	91.2 (98.2)	92.7 (99.8)	1.5 (1000)	4.1 (2.3)	62.1 (72.8)	74.2 (84.5)	75.6 (85.9)	1.4 (250)	2.6 (1.0)
27	14:43	N	Y	6-D	2000	33	D	N	0	Y	73.1 (79.1)	86.6 (91.9)	87.8 (93.0)	1.2 (100)	0.0 (0.0)	57.5 (68.9)	68.3 (79.7)	69.4 (80.6)	1.1 (250)	0.0 (0.0)
29	14:50	N	Y	6-D	1650	25	D	N	0	Y	68.2 (75.2)	81.8 (88.5)	82.3 (89.1)	0.5 (200)	0.0 (0.0)	52.5 (65.0)	63.2 (75.7)	63.7 (76.4)	0.5 (800)	0.0 (0.0)

TABLE 7. INTERCITY BUS 7% GRADE MEASUREMENTS

								50 FEET FROM ROADWAY				
RUN	TIME	VEH SPEED (MPH)	TRANS-MISSION GEAR	GRADE (UP/DOWN)	ENG BRAKE (Y/N)	CYL OF BRAK-ING	SERV BRAKE ASSIST (Y/N)	A-LEVEL MAX (∫)	PNL MAX (∫)	PNLT MAX (∫)	TONE CORR #MAX (BAND)	IMPULSE CORR MAX (A∫)
1	11:42	30	3	U	---	---	---	78.0 (83.4)	89.5 (95.1)	90.9 (96.6)	1.5 (125)	0.0 (0.0)
2	11:46	26	3	D	Y	8	N	77.4 (82.3)	88.9 (93.9)	90.3 (95.3)	1.5 (100)	0.0 (0.0)
3	11:50	28	3	U	---	---	---	78.4 (84.0)	90.9 (96.4)	91.9 (97.5)	1.0 (125)	0.0 (0.0)
4	11:54	20	3	D	Y	8	N	81.2 (85.3)	94.4 (98.3)	96.2 (99.8)	1.8 (2500)	0.0 (0.0)
5	11:58	28	3	U	---	---	---	78.9 (84.4)	90.9 (96.4)	92.4 (98.2)	1.5 (125)	0.0 (0.0)
6	12:01	27	3	D	Y	8	N	81.1 (85.4)	94.4 (98.1)	96.2 (99.5)	1.8 (2500)	0.0 (0.0)
7	12:10	48	4	D	Y	8	N	81.9 (84.3)	94.1 (96.4)	95.0 (97.1)	0.9 (500)	2.1 (0.3)
9	12:16	48	4	D	Y	8	N	81.0 (84.2)	93.2 (96.3)	94.5 (97.2)	1.1 (1250)	0.0 (0.0)
10	12:19	28	3	U	---	---	---	78.5 (82.0)	90.0 (93.5)	91.5 (95.1)	1.5 (125)	0.0 (0.0)
11	12:22	48	4	D	Y	8	N	82.8 (85.8)	95.1 (98.1)	96.0 (98.7)	0.9 (500)	0.0 (0.0)
13	12:31	28	3	D	Y	8	N	80.5 (85.0)	94.0 (97.9)	95.7 (99.3)	1.7 (2500)	0.0 (0.0)
14	12:35	28	3	U	---	---	---	78.1 (83.8)	89.9 (95.9)	91.4 (97.7)	1.5 (125)	0.0 (0.0)
15	12:38	28	3	D	Y	8	N	81.0 (85.6)	93.0 (97.2)	94.4 (98.3)	1.4 (1250)	0.0 (0.0)
17	12:46	48	4	D	Y	8	N	81.1 (84.3)	93.5 (96.5)	94.0 (97.0)	0.9 (1250)	0.0 (0.0)
18	12:49	20	3	U	---	---	---	78.2 (82.6)	89.4 (94.0)	90.6 (95.7)	1.2 (125)	0.0 (0.0)
19	12:52	48	4	D	Y	8	N	81.3 (84.3)	93.4 (96.3)	94.2 (97.0)	0.8 (500)	0.0 (0.0)
20	12:54	28	3	U	---	---	---	78.1 (82.9)	89.6 (94.5)	91.3 (96.2)	2.0 (125)	2.2 (0.2)
21	12:58	26	3	D	Y	8	N	80.2 (84.4)	93.0 (96.7)	94.5 (97.8)	1.5 (2500)	0.0 (0.0)
22	1:01	28	3	U	---	---	---	78.2 (83.3)	89.6 (94.8)	91.3 (96.5)	1.8 (125)	
23	1:04	28	3	D	Y	8	N	80.4 (84.6)	93.9 (97.3)	95.5 (98.4)	1.6 (2500)	0.0 (0.0)

TABLE 8. FIRE PUMPER TRUCK 7% GRADE MEASUREMENTS

								50 FEET FROM ROADWAY					265 FEET FROM ROADWAY				
RUN	TIME	TRANS-MISSION GEAR	VEH SPEED (MPH)	GRADE (UP/DOWN)	ENG BRAKE (Y/N)	CYL OF BRAK-ING	SERV BRAKE ASSIST	A-LEVEL MAX (∫)	PNL MAX (∫)	PNLT MAX (∫)	TONE CORR #MAX (BAND	IM-PULSE CORR MAX (Δ∫)	A-LEVEL MAX (∫)	PNL MAX (∫)	PNLT MAX (∫)	TONE CORR #MAX (BAND)	IM-PULSE CORR MAX (Δ∫)
1	11:21	--	--	D	--	--		79.9 (83.5)	94.5 (98.1)	95.9 (99.4)	1.4 (125)	0.0 (0.0)	63.4 (72.7)	76.1 (84.6)	77.3 (85.5)	1.2 (125)	0.0 (0.0)
2	11:27	--	--	U	--	--		80.2 (85.0)	96.0 (100.7)	97.8 (102.4)	1.9 (100)	0.0 (0.0)					
3	11:32	5	45	D	Y	6	N	78.9 (82.6)	93.5 (97.3)	94.9 (98.7)	1.4 (125)	0.0 (0.0)	61.3 (69.7)	74.2 (82.1)	75.4 (83.2)	1.2 (125)	0.0 (0.0)
4	11:36	--	--	U	--	--	--	81.1 (85.7)	97.3 (101.3)	99.2 (103.3)	1.9 (125)	0.0 (0.0)	63.2 (73.7)	76.4 (87.3)	78.4 (89.1)	2.0 (125)	0.0 (0.0)
6	11:47	4	30	D	Y	6	N	79.4 (83.8)	94.2 (98.7)	95.0 (99.6)	0.8 (125)	0.0 (0.0)					
7	11:51	--	--	U	--	--	--	80.5 (85.3)	96.7 (101.1)	98.3 (102.6)	1.7 (125)	0.0 (0.0)					
8	11:54	4	30	D	Y	6	N	79.3 (83.6)	94.0 (98.4)	95.1 (99.4)	1.1 (125)	0.0 (0.0)					
9	11:58	--	--	U	--	--	--	80.8 (85.7)	97.0 (101.4)	98.5 (102.8)	1.5 (125)	0.0 (0.0)					
10	12:01	4	30	D	Y	6	N	79.1 (83.9)	93.7 (98.6)	94.9 (99.7)	1.6 (125)	0.0 (0.0)					
12	12:08	4	31	D	N	--	Y	76.5 (80.4)	90.8 (94.6)	91.9 (95.8)	1.1 (250)	0.0 (0.0)					
14	12:16	4	31	D	N	--	Y	75.9 (80.0)	90.1 (94.0)	90.9 (95.1)	0.8 (125)	0.0 (0.0)	58.6 (67.2)	70.1 (78.5)	71.9 (79.7)	1.8 (630)	0.0 (0.0)
16	12:23	4	31	D	N		Y	75.3 (79.9)	89.2 (93.8)	90.3 (94.9)	1.1 (125)	0.0 (0.0)	60.4 (69.7)	71.2 (80.7)	72.5 (82.0)	1.3 (10000)	0.0 (0.0)
17	12:30	3	20	D	*	6	Y	77.1 (82.0)	92.7 (97.0)	93.3 (98.1)	0.6 (160)	0.0 (0.0)					
21	12:39	--	--	D	--	--	--	79.1 (84.6)	94.3 (99.8)	94.9 (100.7)	0.6 (800)	0.0 (0.0)	61.7 (70.4)	75.0 (83.0)	76.5 (84.5)	1.5 (125)	0.0 (0.0)
22	12:46	3	21	D	*	6	Y	74.9 (80.9'	88.7 (94.9)	90.2 (96.3)	1.5 (125)	0.0 (0.0)	58.1 (68.1)	70.1 (79.6)	71.8 (81.3)	1.7 (125)	0.0 (0.0)
24	12:52			D				75.5 (81.4)	89.3 (95.2)	91.3 (96.9)	2.0 (125)	0.0 (0.0)					

* ENGAGED ABEAM MICROPHONE

and pumper truck (Table 8) include the vehicle speed, the transmission gear used, whether the vehicle was traveling uphill (positive power) or downhill (negative power), whether the engine brake was employed on a downhill run, and if so, the number of cylinders engaged and whether the service brake was used. Additional operational parameters for the tank truck (Table 6) include whether the truck was pulling an additional 30,000 pound trailer, whether it was operating with or without a muffler, and the engine speed.

Measured sound levels included the A-weighted sound level, the perceived noise level (PNL), and the tone corrected perceived noise level (PNLT). Reported in the tables are the maximum level during the run and the integrated level (in parentheses) over the upper 10 decibels of the signal, normalized to a 1 second duration. Note that the sound exposure level (SEL) may be determined by reading the integrated A-level, while the effective perceived noise level (EPNL) may be determined by subtracting 10 decibels from the integrated PNLT. Supplementary information regarding the PNLT is the magnitude of the tone correction when PNLT reached a maximum and the one-third octave band center frequency, in Hertz (in parentheses), where the tone was observed.

In addition to these standard analyses, the proposed ISO impulsiveness correction (discussed earlier) was also computed. Reported in the tables is the maximum value of the correction at any time during the run, and an estimate of how much the integrated sound level would be increased by adding the impulse correction to one of the standard measures such as A-level, PNL, or PNLT.

For illustrative purposes the impulse correction was added to the A-weighted sound level and the difference between this integrated impulse corrected A-level and the integrated A-level alone is reported (in parentheses) in the table.

C. Discussion

1. Acceleration and Deceleration Measurements

Levels of noise emissions of properly muffled heavy vehicles can increase by 3 to 7 dB when compression-release engine brakes are engaged during deceleration. The side of the vehicle on which the measurement is made (that containing the exhaust pipe or the side opposite the exhaust pipe) accounts for the range of values.

It is also possible for the level of noise emissions of some heavy vehicles decelerating with compression-release engine braking to exceed the levels produced during acceleration, by as much as 5 dB. Not all test vehicles showed this increase in noise emissions during deceleration, however, and there was a strong dependence on the side of the vehicle facing the microphone. For example, noise levels measured on the left side of the intercity bus during deceleration with compression-release engine braking were 3.6 dB lower than those produced during acceleration.

2. Constant Velocity Measurements

Figure 4 compares noise measurements made of the primary test vehicle at various engine speeds under different operating conditions on a constant 7.3% downgrade. Note first that even without engine braking (open squares), the noise emissions of the vehicle increase slowly with engine speed. The slope of the relationships is approximately 1 dB per hundred rpm. The absolute levels, however, are not greatly different from those of passenger vehicles operating under the same conditions.

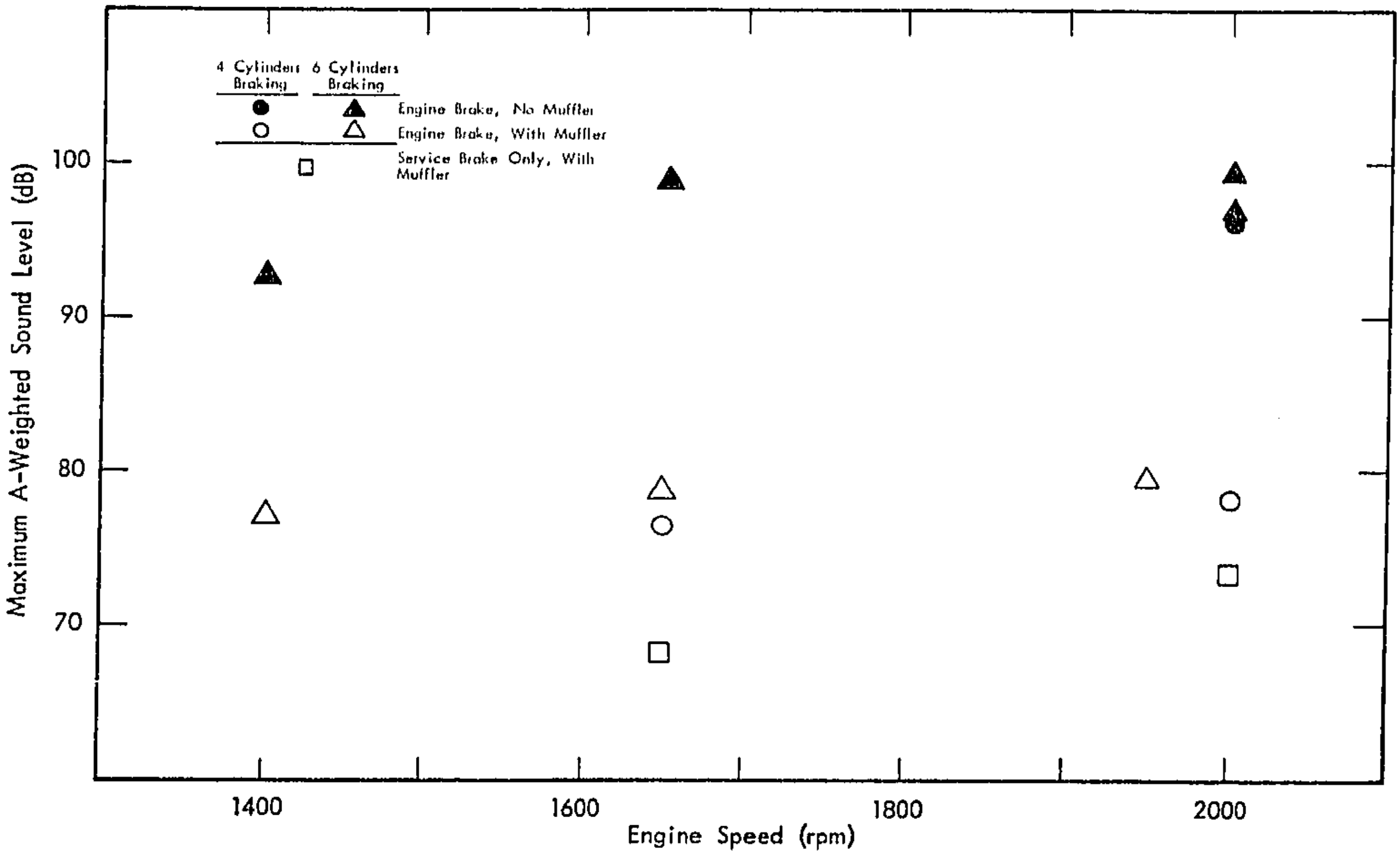


FIGURE 4. MEASURED SOUND LEVELS (TANK TRUCK) 50 FEET FROM VEHICLE

The next noisiest operating condition is use of properly muffled compression-release engine braking to maintain constant speed. The open circles and triangles show a similar relationship between levels of noise emissions and engine speed to that observed when service brakes alone are used to maintain speed.

Differences in noise levels attributable to use of greater numbers of cylinders in compression-release braking are negligible. Unmuffled use of compression-release engine braking is clearly the noisiest operating condition, by at least 15 dB at all engine speeds.

IV. LABORATORY MEASUREMENTS OF ANNOYANCE

A. Method

1. Signal Presentation Conditions

The focus of concern of assessment of annoyance due to heavy truck noise exposure is the home. It follows that acoustic conditions of the subjective judgment testing should resemble those prevailing in a residential setting. Vehicle noise emissions were therefore filtered so that their spectra resembled those of exterior sounds heard indoors. The levels at which test signals were heard were appropriate for the home (on the order of 75 dBA for trucks), rather than for roadside levels. Additionally, ambient noise similar in spectral shape to that of typical residences was present throughout all testing. All annoyance judgments were made under free field listening conditions by individual subjects seated in an anechoic chamber.

2. Nature of Annoyance Judgment

A relative measure of annoyance is preferred to an absolute measure because the relative judgment is most directly pertinent to the central issue: a determination of the degree to which the noise of trucks decelerating with engine brakes may be *more* or *less* annoying than noise of the same level produced by accelerating trucks. For reasons of cost-effectiveness and precision of measurement, a computer based adaptive paired comparison trial procedure was used. Test subjects were instructed to press a button to indicate which of a pair of sounds heard in random order (one invariant in level, one variable in level) was the more annoying. The computer then adjusted the level of the variable level signal in accordance with the subject's preferences for subsequent judgments. Appendix B contains further information about signal presentation conditions.

3. Signal Selection

a. Variable Level Signal

The annoyance of all test signals was judged relative to the annoyance of a single signal of variable level. This signal was a recording of the noise of a properly muffled truck maintaining a constant velocity while descending a 7% grade.

b. Invariant Level Signals

Six criteria were used to select signals from among the 160-odd recordings made of three test vehicles operating under many different conditions:

1) inclusion of recordings from all three vehicles;
2) inclusion of recordings of both uphill and downhill constant velocity emissions;
3) inclusion of recordings of both acceleration and deceleration conditions in the SAE J366b procedure;
4) inclusion of recordings made both with and without proper muffling;
5) inclusion of recordings of downhill runs both with and without the use of

the engine brake system; and,

6) inclusion of recordings of emissions produced by the engine brake operating at a range of impulse repetition rates.

Additionally, several realistic and synthetic signals were prepared to permit comparisons of the annoyance of truck noise and other noise sources.

Table 9 identifies the thirty six signals presented in counterbalanced order for annoyance judgments. Spectra for the above signals, as heard in the anechoic chamber, are plotted in Appendix A. Unless otherwise specified in the table, the duration of all signals was six seconds. The peak signal level of the recorded truck drivebys occurred in the middle of this interval.

Annoyance judgments for six other signals (three truck passbys of 12 seconds' duration, and an equal number of truck passbys of three seconds' duration) were collected under identical conditions at the same time, as part of an independent study. Annoyance judgments made of these signals are reported here along with those from the main study.

B. Results

1. Raw Data

Three male and twelve female subjects (average age = 25 years) were paid an hourly wage to adjust the level of the variable signal to the point of subjective equality

TABLE 9. SIGNAL IDENTIFICATION

Signal Number	Description*	Integrated A-wtd. Presentation Level (dB)
A4	Tank Truck, downhill, 2 cylinders braking	75.7
A5	Tank Truck, downhill, 4 cylinders braking	74.1
A6	Tank Truck, downhill, 4 cylinders braking, no muffler	78.6
A7	Tank Truck, downhill, 6 cylinders braking	74.6
A8	Tank Truck, downhill, 6 cylinders braking	71.8
A9	Tank Truck, downhill, 6 cylinders braking, no muffler	79.4
A10	Tank Truck, downhill, service brake only	77.3
A11	Tank Truck, accelerating	74.6
A12	Tank Truck, decelerating, 6 cylinders braking	76.5
A13	Intercity bus, uphill	78.1
A14	Intercity bus, downhill, 8 cylinders braking	80.2
A15	Intercity bus, downhill, 8 cylinders braking	78.6
A16	Intercity bus, accelerating	79.3
A17	Intercity bus, decelerating, 8 cylinders braking	78.5
A18	Automobile, accelerating	76.8
A19	Automobile, decelerating	72.2
A21	(Same as A8, but out-of-doors)	81.2
A22	(Same as A11, but out-of-doors)	84.9
B3	Fire Pumper Truck, downhill, service brake only	75.1
B4	Fire Pumper Truck, downhill, 6 cylinders braking	76.7
B5	Fire Pumper Truck, uphill	73.2
B6	Fire Pumper Truck, accelerating	76.8
B7	Fire Pumper Truck, decelerating, 6 cylinders braking	78.8
B8	Dump Truck, downhill, with engine brake	79.4
B9	Motorcycle passby	77.1
B10	Helicopter hover	79.6
B11	Aircraft flyover	76.7
B12	Impulse Wave Train, 400 Hz sinusoid, 5 Hz repetition rate	62.6
B13	Impulse Wave Train, 400 Hz sinusoid, 40 Hz repetition rate	71.6
B14	Impulse Wave Train, 400 Hz sinusoid, 100 Hz repetition rate	76.1
B15	Gaussian noise spectrally shaped to resemble truck	75.2
B16	Octave Band white noise, centered at 1 kHz	85.3
B17	Octave Band pink noise, centered at 1 kHz	85.4
C6	Tank Truck, downhill, service brake only (3 sec. duration)	75.0
C7	Tank Truck, downhill, service brake only	77.3
C8	Tank Truck, downhill, service brake only (12 sec. duration)	78.0
C9	Tank Truck, downhill, 2 cyl. braking, no muffler (3 second duration)	75.1
C10	Tank Truck, downhill, 2 cyl. braking, no muffler	77.3
C11	Tank Truck, downhill, 2 cyl. braking, no muffler (12 second duration)	78.3
C12	Tank Truck, downhill, 6 cyl. braking, no muffler (3 second duration)	76.8
C13	Tank Truck, downhill, 6 cyl. braking, no muffler	78.2
C14	Tank Truck, downhill, 6 cyl. braking, no muffler (12 second duration)	79.3

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*Unless otherwise specified, vehicles equipped with muffler and recorded signals passed through frequency weighting filter approximating transmission loss of typical residential construction.

of annoyance with each of the 42 signals seen in Table 9, by means of the PEST procedure (Taylor and Creelman, 1967). The basic datum for each signal pair was the mean level of the variable signal when it was adjusted to the point of subjective equality of annoyance, averaged over all 15 subjects' determinations. Each subject's determination was itself the mean of at least two PEST runs, each comprised of multiple paired comparisons.

These basic data may be seen in Tables 10, 11, 12, and 13, reported in terms of eighteen different physical measures of signal levels. Each cell of the matrix contains the mean level (for fiteen subjects) of the variable signal at the point of subjective equality of annoyance. Peak and integrated measures of the level of the variable signal at the point of subjective equality are presented in units of A-weighted level, Tone-Corrected Perceived Noise Level, A-Level adjusted for the ISO-recommended impulse noise correction, A-level adjusted for crest factor three different ways (by subtracting constants of 11 and 12 dB, and by multiplying the crest factor by 0.6), Tone-Corrected Perceived Noise level adjusted by the ISO-recommended impulse noise correction, and Tone-Corrected Perceived Noise Level adjusted two ways for crest factor (by subtracting a constant of 12 dB, and by multiplying the crest factor by 0.6).

These various measures of signal levels represent a gamut of indices that have been or could reasonably be used to quantify the annoyance of impulsive noises. The ISO procedure evolved from prolonged international technical debate about ways to characterize the impulsiveness of helicopter noise emissions. The various crest factor

Level of Variable Signal - Fixed Signal at Point of Subjective Equality of Annoyance, in dB

			A-LEV		PNLT		A-LEV+ISU		ALEV+CF-11		ALEV+CF-12		ALEV+CF+.6		PNLT+ISU		PNLT+CF-12		PNLT+CF+.6	
			MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT
1*	A-03	STANDARD	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7
2	A-04	T,DN,28,M	8.4	7.3	7.4	6.6	8.4	7.3	7.9	7.1	8.4	7.3	7.7	7.1	7.4	6.6	7.4	6.5	8.0	6.4
3	A-05	T,DN,48,M	6.5	8.3	7.3	6.7	6.4	7.2	7.8	7.5	8.5	7.4	7.7	7.6	5.2	5.6	7.3	6.2	7.0	6.0
4	A-06	T,DN,48,NM	3.1	3.3	4.3	4.1	1.7	2.8	2.5	3.1	3.1	3.3	2.6	3.0	3.2	3.6	4.3	4.0	4.6	3.8
5	A-07	T,DN,68,M	6.4	6.4	5.6	4.9	6.4	6.4	6.4	6.5	6.4	6.5	7.3	7.3	5.6	4.9	5.6	4.9	7.3	5.9
6	A-08	T,DN,68,M	7.1	7.3	6.6	6.2	7.1	7.3	7.1	7.2	7.1	7.3	7.6	7.5	6.6	6.2	6.6	6.1	7.0	6.3
7	A-09	T,DN,68,NM	.3	.6	.9	.9	.3	.6	.1	.6	.3	.7	0.0	.7	.9	.9	.9	.8	1.1	1.0
8	A-10	T,DN,MB,M	2.1	1.4	2.2	1.4	2.1	1.4	1.6	1.3	2.1	1.5	1.4	1.3	2.2	1.4	2.2	1.3	2.0	1.4
9	A-11	T,AC,M	4.9	5.5	3.7	4.6	4.9	5.5	4.0	4.9	4.9	5.2	4.4	5.1	3.7	4.6	3.7	4.3	3.6	4.2
10	A-12	T,DE,68,M	6.4	6.1	5.0	4.4	6.4	6.1	6.4	6.1	6.4	6.1	6.5	6.4	5.0	4.4	5.0	4.4	5.8	4.9
11	A-13	B,UP	.7	1.0	1.4	1.2	.7	1.0	-.2	.9	.7	1.0	-.0	.8	1.4	1.2	1.4	1.1	1.2	1.0
12	A-14	B,DN,88	-1.7	-.3	-.8	.7	-1.7	-.3	-1.7	-.3	-1.7	-.2	-1.6	-.3	-.8	.7	-.8	.6	-.1	.7
13	A-15	B,DN,88	-4.0	-1.4	-1.5	.5	-4.0	-1.4	-4.6	-2.0	-4.0	-1.7	-4.4	-1.8	-1.5	.5	-1.5	-.0	-1.4	.2
14	A-16	B,AC	-.6	1.0	1.1	2.2	-.6	.6	-.6	.6	-.6	.9	-.5	.8	1.1	1.8	1.1	2.1	1.7	1.9
15	A-17	B,DE,88	-.4	1.7	.6	2.9	-.4	1.7	-.4	1.5	-.4	1.8	-.7	1.5	.6	2.9	.6	2.7	.8	2.0
16	A-18	AUTO,AC	3.5	4.4	3.6	4.5	3.5	4.4	3.2	3.8	3.5	4.3	2.9	3.6	3.6	4.5	3.6	4.3	3.5	3.8
17	A-19	AUTO,DE	10.0	11.5	7.9	9.2	10.0	11.5	9.5	11.0	10.0	11.2	9.7	11.1	7.9	9.2	7.9	6.7	7.9	6.6
18	B-03	P,DN,MB	.3	1.4	-.1	.9	.3	1.4	.3	1.3	.3	1.4	1.2	1.8	-.1	.9	-.1	.8	.7	1.1
19	B-04	P,DN,68	1.6	2.6	1.1	1.8	1.6	2.6	1.3	2.4	1.6	2.5	1.4	2.6	1.1	1.8	1.1	1.6	1.3	1.9
20	B-05	P,UP	2.7	3.6	.2	1.5	2.7	3.6	2.7	3.8	2.7	3.7	3.8	4.4	.2	1.5	.2	1.5	1.8	2.3
21	B-06	P,AC	2.1	2.4	.7	1.8	2.1	2.4	1.4	2.1	2.1	2.4	1.4	2.0	.7	1.8	.7	1.8	1.2	1.4
22	B-07	P,DE,68	.7	1.1	.7	.8	.7	1.1	.7	1.0	.7	1.1	1.1	1.3	.7	.8	.7	.7	1.8	1.1
23	B-08	ASPTRK,DN	-.6	.8	1.6	1.6	-1.0	-1.1	-3.0	-1.6	-2.0	-.4	-2.1	-1.0	-.5	-.5	-.0	-.1	.2	-.2
24	B-09	MOTORCYCLE	4.4	6.4	6.3	7.7	4.4	6.4	4.4	6.5	4.4	6.5	4.5	7.0	6.3	7.7	6.3	7.7	7.3	8.4
25	B-10	HELIC,HVR	4.9	3.3	7.0	5.2	1.1	.1	.6	.9	1.6	1.8	2.1	1.5	3.6	2.0	4.2	3.6	5.2	3.4
26	B-11	AIRCRFT,FO	.5	1.2	1.7	2.5	.5	1.2	-.2	.4	.5	.9	-.3	.5	1.7	2.5	1.7	2.1	1.6	1.8
27	B-15	SHAPD NOIS	5.6	5.4	4.4	3.8	5.6	5.4	5.6	5.1	5.6	5.4	5.4	5.0	4.4	3.8	4.4	3.7	4.7	3.4
28	B-16	1KHZ OBWHT	-5.8	-7.5	2.7	.5	-5.8	-7.5	-5.8	-7.6	-5.8	-7.5	-6.2	-7.6	2.7	.5	2.7	.4	2.6	.4
29	B-17	1KHZ OBPNK	-4.8	-6.7	3.8	2.0	-4.8	-6.7	-5.9	-7.1	-4.9	-6.9	-5.4	-7.2	3.8	2.0	3.8	1.6	3.9	1.4
		STD DEV	4.01	4.10	2.84	2.55	3.89	4.12	4.07	4.14	4.03	4.12	4.09	4.20	2.68	2.55	2.79	2.54	2.84	2.59

TABLE 10. SUMMARY OF ANNOYANCE JUDGMENTS FOR SIX SECOND DURATION, INDOOR VEHICULAR SIGNALS

Level of Variable Signal - Fixed Signal at Point of Subjective Equality of Annoyance, in dB

			A-LEV		PNLT		A-LEV+ISO		ALEV+CF-11		ALEV+CF-12		ALEV+CF+.6		PNLT+ISO		PNLT+CF-12		PNLT+CF+.6	
			MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT
1	A-20	STANDARD	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8
2	A-21	T,DN,6dB,MU	9.7	10.2	9.3	8.9	9.7	10.2	9.8	10.1	9.7	10.2	10.0	10.3	9.3	8.9	9.1	8.7	9.3	8.9
3	A-22	T,AC,MU	6.3	6.7	5.1	5.9	6.3	6.7	5.4	6.4	5.7	6.5	5.9	6.6	5.1	5.9	5.1	5.6	5.6	5.8
		MEAN	4.7	5.0	4.2	4.3	4.7	5.0	4.5	4.9	4.5	5.0	4.7	5.0	4.2	4.3	4.1	4.2	4.4	4.3
		STD DEV	5.91	6.17	5.60	5.52	5.91	6.17	5.86	6.09	5.84	6.15	5.99	6.20	5.60	5.52	5.51	5.39	5.65	5.51

TABLE 11. SUMMARY OF ANNOYANCE JUDGMENTS FOR SIX SECOND DURATION, OUTDOOR VEHICULAR SIGNALS

Level of Variable Signal - Fixed Signal at Point of Subjective Equality of Annoyance, in dB

			A-LEV		PNLT		A-LEV+ISO		ALEV+CF-11		ALEV+CF-12		ALEV+CF+.6		PNLT+ISO		PNLT+CF-12		PNLT+CF+.6	
			MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT
1	A-03	STANDARD	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7
2	B-12	400SIN,5R	28.5	26.7	33.2	31.1	22.5	20.7	18.1	16.0	19.1	16.9	22.0	19.9	27.2	25.1	23.5	21.2	26.9	24.3
3	B-13	400SIN,40R	16.9	15.1	21.0	18.9	10.9	9.1	15.4	13.3	16.4	14.2	15.7	13.6	15.0	12.9	20.5	17.6	20.3	17.4
4	B-14	400SIN,100	15.0	13.0	17.9	15.4	11.7	10.3	15.0	13.1	15.0	13.0	16.3	14.2	14.6	12.7	17.9	15.3	19.6	16.6
		MEAN	14.7	13.3	17.6	15.9	10.9	9.6	11.7	10.2	12.2	10.6	13.1	11.5	13.8	12.3	15.1	13.2	16.3	14.2
		STD DEV	12.44	11.66	14.46	13.54	9.90	9.16	9.04	8.03	9.42	8.36	10.25	9.25	11.86	10.96	11.40	10.19	12.43	11.12

TABLE 12. SUMMARY OF ANNOYANCE JUDGMENTS FOR SIX SECOND DURATION, SYNTHETIC IMPULSIVE SIGNALS

3 SECOND OBSERVATION INTERVAL

			A-LEV		PNLT		A-LEV+ISU		ALEV+CF-11		ALEV+CF-12		ALEV+CF+.6		PNLT+ISU		PNLT+CF-12		PNLT+CF+.6	
			MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT
1.	C-03	STANDARD	-.0	0.0	0.0	0.0	-.0	0.0	-.0	0.0	-.0	-.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	C-06	DN,NB,M-3	1.9	1.3	1.5	.9	1.9	1.3	1.1	1.0	1.1	1.2	1.4	1.1	1.5	.9	1.0	.8	1.0	.7
3	C-09	DN,2B,NM-3	6.0	6.1	6.0	6.1	3.3	3.9	3.5	4.2	3.5	4.5	4.5	4.9	3.3	4.0	3.5	4.7	4.4	4.9
4	C-12	DN,6B,NM-3	1.7	2.2	.7	1.1	1.7	2.2	1.7	2.0	1.7	2.1	1.6	2.2	.7	1.1	.7	1.1	.5	1.1
		STD DEV	2.55	2.63	2.70	2.76	1.35	1.04	1.46	1.80	1.46	1.91	1.89	2.10	1.42	1.73	1.53	2.09	1.99	2.20

6 SECOND OBSERVATION INTERVAL

			A-LEV		PNLT		A-LEV+ISU		ALEV+CF-11		ALEV+CF-12		ALEV+CF+.6		PNLT+ISU		PNLT+CF-12		PNLT+CF+.6	
			MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT
1.	C-04	STANDARD	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8
2	C-07	DN,NB,M-6	1.5	.4	1.4	.1	1.5	.4	.6	.4	1.0	.4	.8	.3	1.4	.1	.9	-.0	.6	0.0
3	C-10	DN,2B,NM-6	4.5	4.2	5.1	4.7	.8	2.1	.7	2.1	1.1	2.5	2.1	2.8	2.3	2.7	2.3	3.0	3.1	3.3
4	C-13	DN,6B,NM-6	1.5	2.3	1.0	1.5	1.5	2.3	1.1	2.1	1.5	2.0	1.7	2.4	1.0	1.5	.8	1.0	1.2	1.5
		STD DEV	1.65	1.72	2.03	2.03	.40	.94	.22	.88	.29	.99	.66	1.21	.67	1.11	.73	1.26	1.10	1.41

12 SECOND OBSERVATION INTERVAL

			A-LEV		PNLT		A-LEV+ISU		ALEV+CF-11		ALEV+CF-12		ALEV+CF+.6		PNLT+ISU		PNLT+CF-12		PNLT+CF+.6	
			MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT	MAX	INT
1.	C-05	STANDARD	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
2	C-08	DN,NB,M-12	2.3	1.3	2.8	1.1	2.3	1.3	1.8	1.1	1.8	1.2	1.9	1.2	2.8	1.1	2.4	1.0	2.2	1.0
3	C-11	DN,2B,N-12	4.6	4.0	5.4	4.7	.4	2.2	1.3	2.1	1.3	2.7	2.5	2.8	2.2	3.3	3.0	3.7	3.6	3.7
4	C-14	DN,6B,N-12	-.1	.8	-.1	.1	-.1	.8	-.1	.7	-.1	.8	-.2	1.1	-.1	.1	-.4	.1	-.6	.4
		STD DEV	1.98	1.45	2.35	2.00	1.06	.58	.82	.59	.82	.63	1.16	.80	1.26	1.34	1.49	1.54	1.64	1.95

TABLE 13. SUMMARY OF ANNOYANCE JUDGMENTS FOR VEHICULAR SIGNALS OF 3, 6 AND 12 SECOND DURATION

adjustments have been employed to quantify degrees of impulsiveness with respect to Gaussian noise (which has a crest factor of about 13 dB).

2. Validity, Reliability, and Variability of Judgments

All test subjects compared the annoyance of the six second long variable signal with itself six times during the course of data collection. The average within-subject difference in level observed for these judgments was 1.4 dB, a figure which justifies reasonable confidence in the subjects' understanding of their instructions, the meaningfulness of the test procedures, and the usefulness of the data set.

A smaller number of comparisons was also made of the annoyance of the three and twelve second long variable signals with themselves. The average differences in levels observed across signals for these judgments were 0.9 and 2.7 dB, for the three and twelve second long signals, respectively. Taken together, the data for the 3, 6, and 12 second duration signals show an inverse relationship between signal duration and validity of judgments.

The 15 subjects were required to repeat their judgments of the 42 signals at least once in all but 13 of the 630 cases. For these 617 test-retest cases, the absolute value of the within-subjects mean difference in the level of the variable signal at the point of subjective equality was 0.86 dB. In other words, the annoyance judgments proved to be repeatable, on average, to within one decibel.

The average standard deviation among subjects for the annoyance judgments of the 42 test signals was 5.7 dB. Ninety-five percent confidence intervals for these signals were between 1.5 and 3 dB.

Thus, the validity and repeatability of annoyance judgments within subjects, and the variability among subjects (i.e., standard error of measurement), were all roughly comparable for the six second long signals. All things considered, the resolution of annoyance judgments in the present data set is thus on the order of 1.5 dB. Smaller differences are likely to have arisen by chance alone, and are not likely to be repeatable.

3. Relative Ability of Noise Measures to Predict Annoyance Judgments

One measure of the utility of a noise metric is its ability to reduce the variability of a set of annoyance judgments. The bottom lines of Tables 10-13 contain the standard deviations of the differences between levels of the fixed and variable signals when adjusted by the 15 subjects to the point of subjective equality of annoyance. In principle, a "perfect" noise metric would reduce this standard deviation to zero, since it would assign the same value to the levels of both the fixed and variable signals. In practice, even a perfect noise metric would be unable to reduce the standard deviation to a value smaller than the fundamental resolution of the experimental method. In the present case, this residual experimental error is (as discussed in the preceding section) about one to one and a half decibels.

Examination of Tables 10-13 reveals a ratio between the standard deviations of the noise metrics with the smallest and greatest standard deviations of 1.65. This ratio is unlikely to have arisen by chance alone ($F_{28,\ 28} = 2.73$, $p < .01$). However, it is also apparent that many of the 18 noise metrics are about equally effective in reducing the variability of the set of annoyance judgments. It follows that no special merit can be claimed in the present data set for any particular adjustment made to A-weighted or Perceived Noise Level measurements for impulsiveness.

The reason for this lack of improvement in prediction of annoyance from incorporation of impulse noise adjustments is fairly clear: none of the many recordings of automotive noise emissions was sufficiently impulsive to merit a sizeable adjustment. Many of the impulsive adjustments to A-Level and Perceived Noise Level resulted in changes of tenths of a decibel or less for the automotive signals. Even when operated without a muffler, the A-Level of the noise emissions of the primary test vehicle were increased by only about 2 dB by addition of a term sensitive to the crest factor.

4. Effects of Mode of Operation of Test Vehicles

As is apparent from Table 10, there is no evidence to suggest that any improvement in accuracy of prediction of annoyance could be secured by use of different impulse noise metrics for different operating conditions of the test vehicles.

This point is further reinforced by the judgments of the annoyance of six other automotive noise recordings of vehicles other than those of which recordings were made specifically for present purposes. The central tendency of these data (the rightmost points in Figures 5 and 6) closely resembles that of the other data points. There is, however, reason to believe that EPNL reduces the variability of annoyance judgments to a greater degree than does A-Level.

Figures 5 and 6 group the average annoyance judgments for the recordings made while test vehicles were accelerating, decelerating, climbing, and descending with and without engine braking. The only difference between the figures is the noise metric: A-Level for Figure 5, EPNL for Figure 6.

It is clear from both figures that for equivalent noise levels, there are no meaningful differences in the annoyance of vehicle noise emissions in the different operating modes.

5. Effects of Spectral Shape on Annoyance of Compression-Release Engine Brake Noise

Figure 7 compares the relative annoyance of the test vehicles' noise emissions as they would be heard indoors and outdoors. (Spectra for these signals are plotted in Figure 8). Subjects found the two "outdoor" engine braking noise recordings more annoying than the two "indoor" recordings. The differences were slight, however, and of little practical importance.

6. Effects of Duration of Observation Interval

Figure 9 displays average judgments of the annoyance of the same three signals when heard for durations of 3, 6

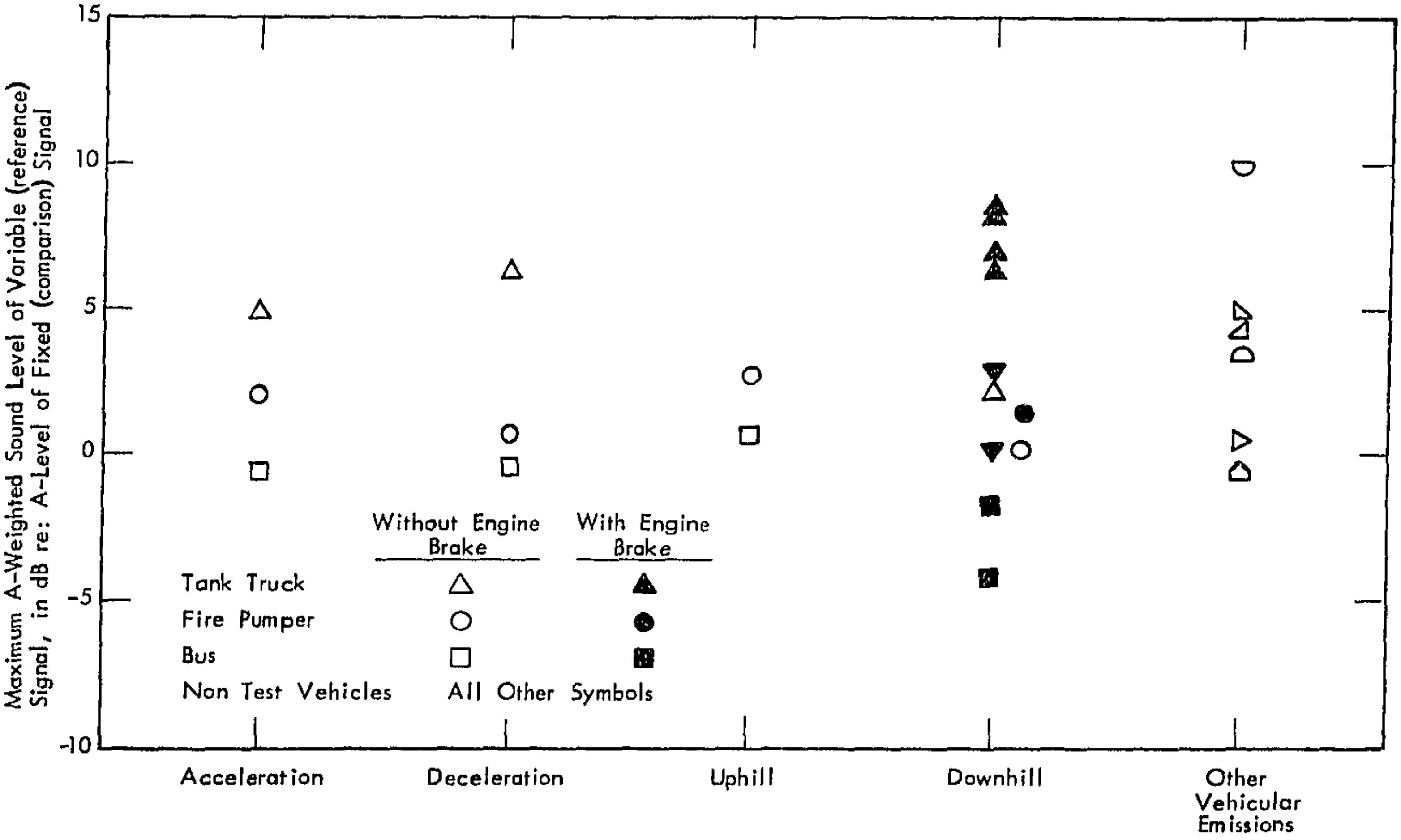

FIGURE 5. RELATIVE MAXIMUM A-WEIGHTED SOUND LEVELS OF EQUALLY ANNOYING VEHICULAR SOUNDS

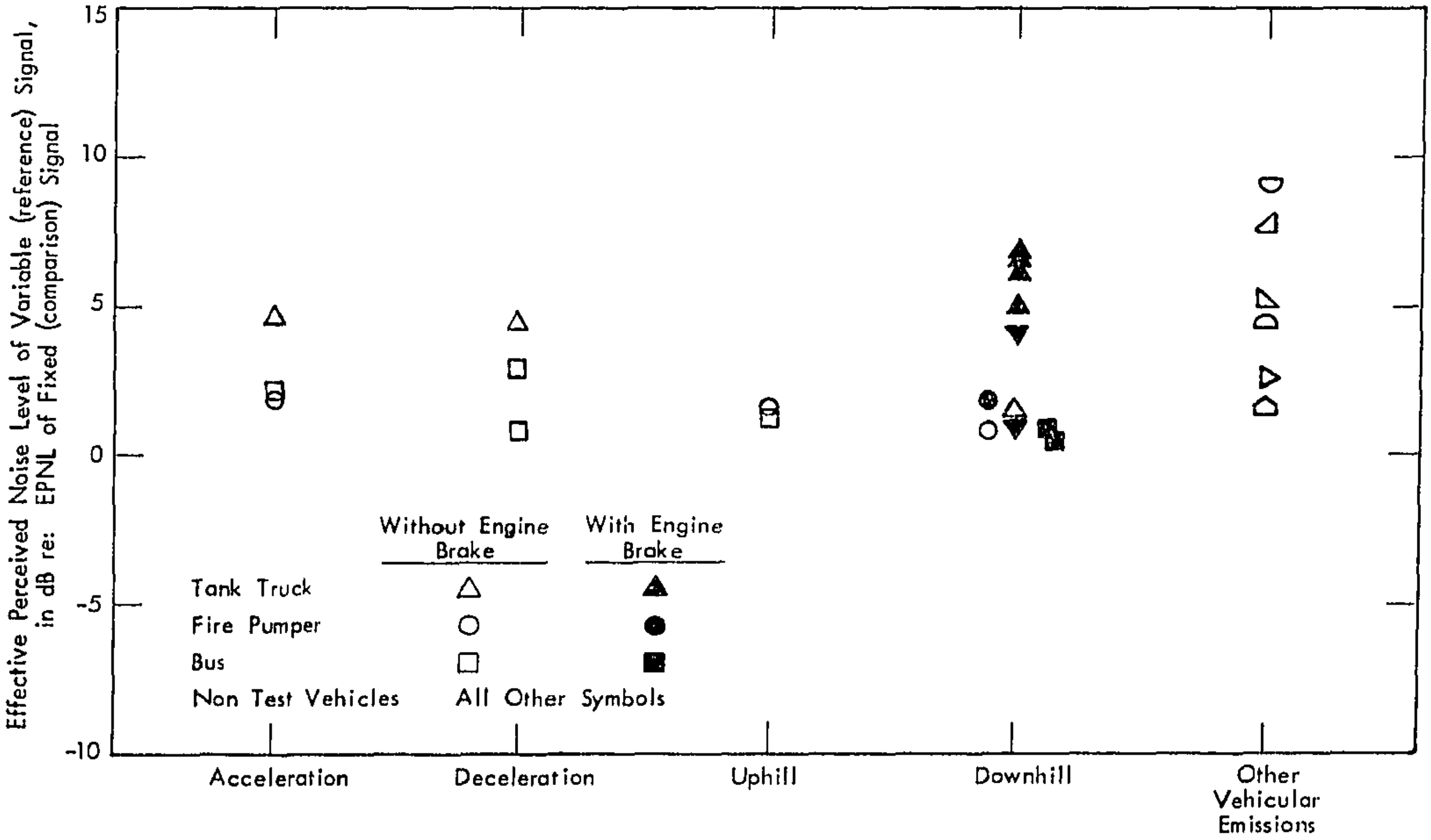

FIGURE 6. RELATIVE EFFECTIVE PERCEIVED NOISE LEVELS OF EQUALLY ANNOYING VEHICULAR SOUNDS

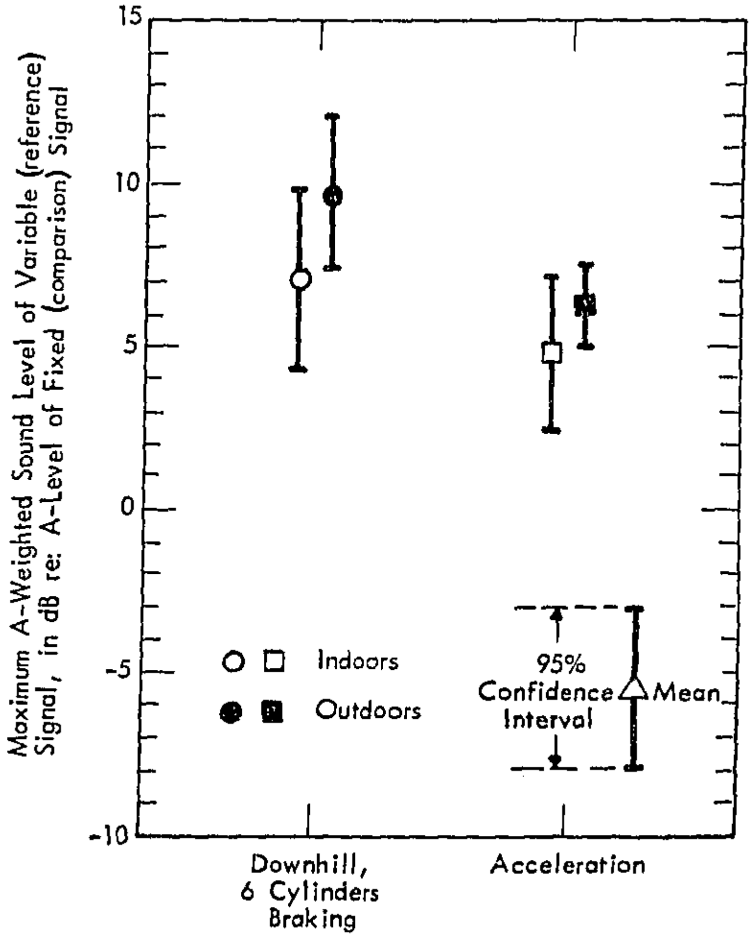

FIGURE 7. OBSERVED EFFECTS OF INDOOR/OUTDOOR SPECTRAL SHAPE ON RELATIVE ANNOYANCE

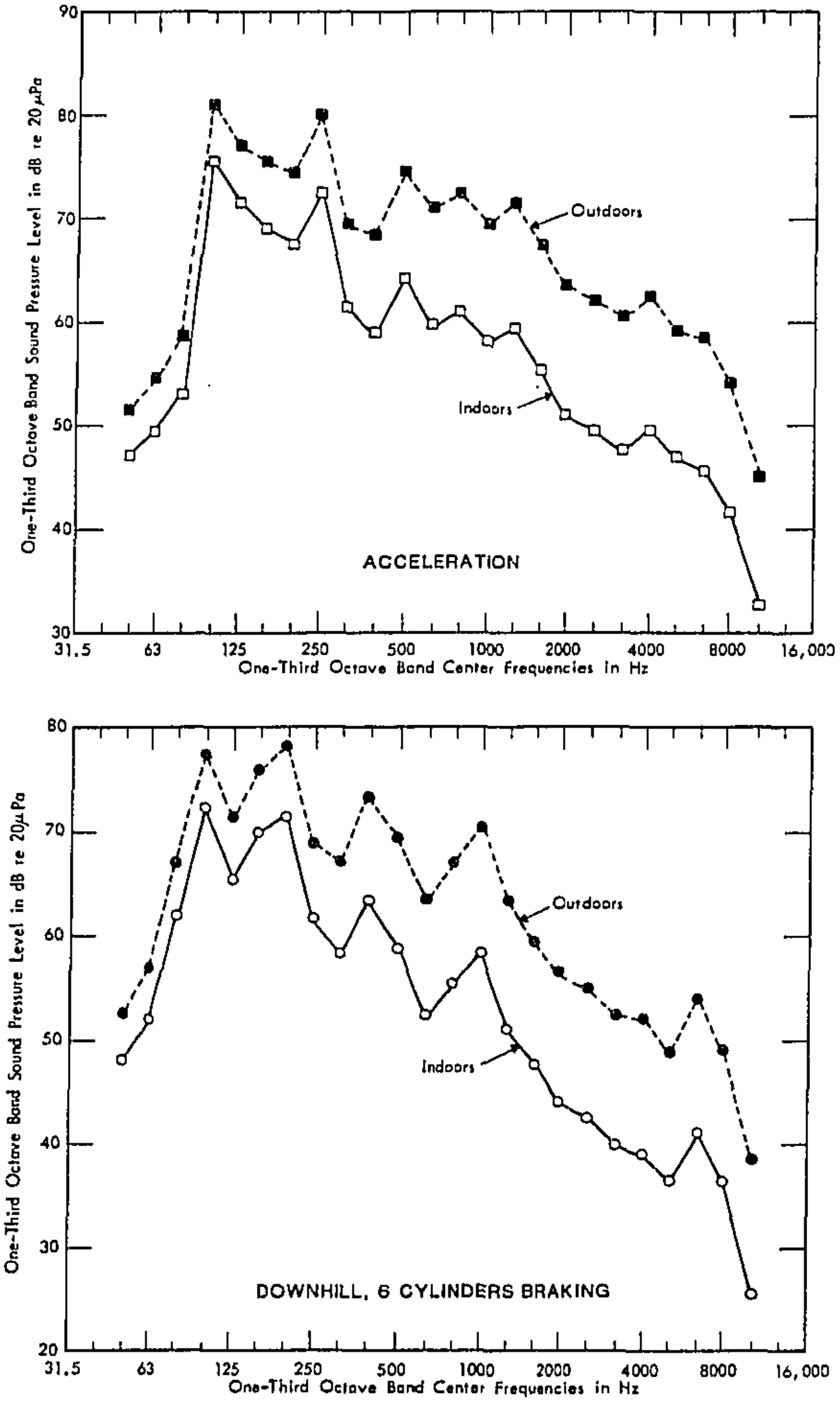

FIGURE 8. SPECTRAL CONTENT OF INDOOR/OUTDOOR SIGNALS

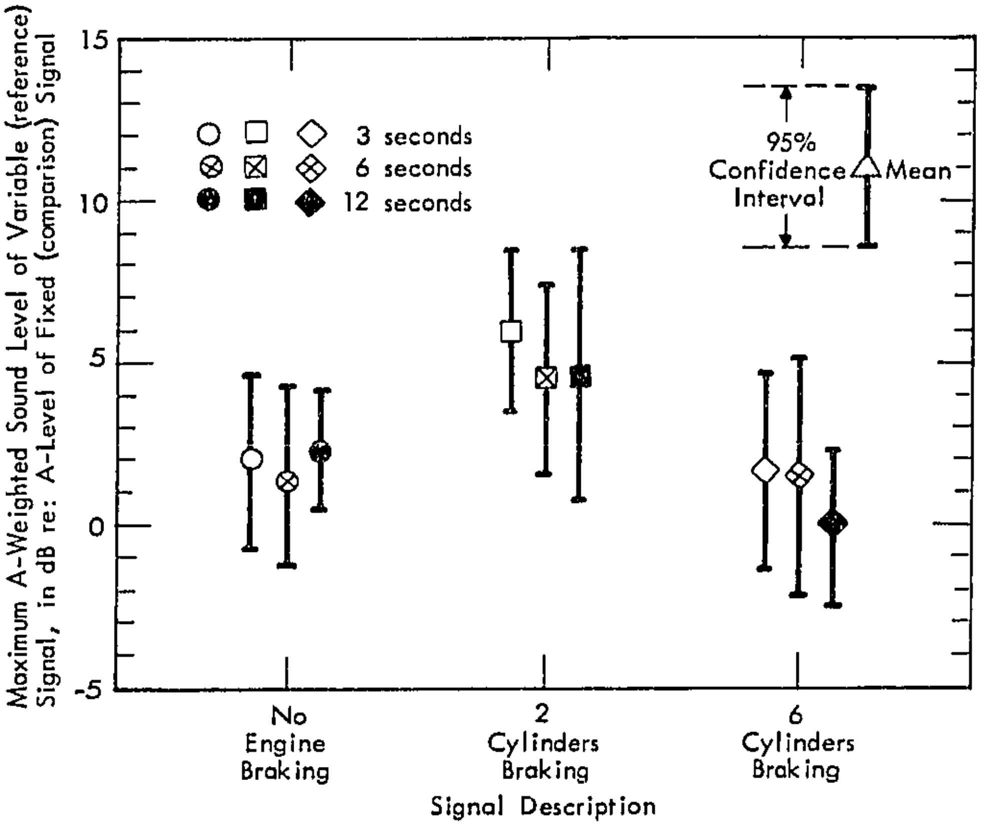

FIGURE 9. EFFECTS OF OBSERVATION INTERVAL DURATION ON RELATIVE ANNOYANCE

and 12 seconds. The lack of any systematic trend in these data demonstrates that the duration of the signal did not affect the subjects' mean annoyance judgments. It is interesting to note in Table 13, however, that the variances of the annoyance judgments for the shortest duration signals were about 20% smaller than for the longer duration signals.

7. Annoyance Judgments for Impulsive Signals

As may be seen in Table 11, noise metrics that take account of crest factor do a much better job than other noise metrics of reducing the variability of annoyance judgments for highly impulsive signals. For example, the ranges of annoyance judgments in A-weighted and EPNL units are 13 and 16 dB, respectively, for the impulsive signals in Table 11. The ranges for the ISO-corrected units are 11 and 13 dB, respectively - a slight improvement. However, units that take into consideration the crest factors (peak:rms ratios) of these impulsive signals reduce the range of annoyance judgments to only about 3-7 dB.

Considering the lesser complexity of crest factor calculations, as well as the greater reduction in variability of annoyance judgments they provide, this data set does not support use of the ISO impulse coefficient to characterize the annoyance of impulsive signals.

V. CONCLUSIONS

1. Use of compression-release engine braking during deceleration can (but does not necessarily) modestly increase heavy vehicle noise emissions over levels produced during acceleration.

2. Noise emissions of properly muffled heavy vehicles maintaining constant velocity on a downgrade are largely independent of the number of cylinders of engine braking engaged, over the range of typical engine speeds.

3. Noise emissions of properly muffled heavy vehicles using compression-release engine braking are not highly impulsive.

4. When heard at the same A-level, there are no large differences in the relative annoyance of noise emissions produced by heavy vehicles when accelerating, and when decelerating with the aid of compression-release engine brakes.

5. Noise emissions produced by properly muffled vehicles maintaining constant velocity on a downgrade with the aid of compression-release engine brakes can be as much as 5 dB more annoying than noise emissions produced under the same conditions without the use of compression-release braking, by virtue of the higher noise levels produced by the compression-release engine brakes.

6. Measurement of noise emissions of heavy vehicles in units of maximum A-weighted sound pressure level is sufficient for purposes related to health and welfare analyses of effects of compression-release engine braking noise.

7. There is no need for an impulse correction to account for the annoyance of noise emissions produced by heavy vehicles using compression-release engine brakes, even though a correction based on crest factor can greatly reduce the variability of annoyance judgments of highly impulsive signals.

8. An adjustment based on crest factor is a much simpler and more effective measure to account for the annoyance of impulsive signals than the ISO impulse correction.

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APPENDIX A

ONE-THIRD OCTAVE BAND SPECTRA OF SELECTED FIELD RECORDINGS

Tables A-1 through A-8 contain one-third octave band spectra (at the time of occurrence of the maximum A-level) of field recordings described in Tables 3 through 8 in this report. Each run corresponds to one vehicular passby and can be matched to the information in Tables 3 through 8 by the vehicle type and run number.

TABLE A-1. TANK TRUCK ACCELERATION/DECELERATION MEASUREMENTS

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	2	3	4	5	6	7	8	9	10	11
50	66.9	65.8	66.8	64.9	66.6	69.0	70.9	69.9	70.9	62.4
63	67.3	61.4	66.3	60.7	65.5	58.6	72.9	72.1	72.5	67.4
80	66.2	64.0	66.7	64.7	70.5	68.5	76.7	78.0	79.2	68.9
100	78.4	81.8	87.4	82.0	83.6	82.0	93.0	92.7	94.9	78.1
125	81.9	80.2	82.5	81.5	83.5	74.0	79.7	78.5	77.2	77.5
160	71.8	71.4	72.1	74.0	72.3	74.0	74.7	73.5	73.6	67.8
200	72.2	71.2	72.6	73.0	73.7	77.4	76.1	79.2	78.0	64.6
250	82.1	75.8	80.8	73.3	83.1	67.9	78.9	78.3	76.7	72.3
315	70.3	65.0	71.1	66.1	71.4	68.4	82.4	83.0	82.7	63.4
400	67.7	67.0	69.7	64.7	68.2	72.8	83.5	82.4	82.9	68.3
500	71.3	67.3	71.4	67.5	69.6	70.0	73.3	73.5	74.7	69.2
630	68.7	67.6	69.9	65.5	68.4	67.3	70.7	70.1	71.1	69.6
800	73.7	68.2	71.8	66.6	69.9	69.7	75.1	74.8	72.8	71.6
1000	68.2	67.4	68.1	67.5	69.2	71.1	75.1	76.5	73.3	66.9
1250	67.4	64.6	67.2	64.5	67.4	65.1	69.5	69.4	68.5	65.7
1600	66.2	62.8	66.1	64.1	66.3	65.0	70.1	70.9	69.9	66.2
2000	65.9	63.2	66.5	63.1	66.4	64.7	69.0	70.0	68.6	64.4
2500	63.8	60.5	63.4	60.1	64.2	66.1	71.6	72.1	71.8	62.2
3150	62.9	59.9	63.5	59.9	63.4	63.4	69.1	70.5	70.8	60.7
4000	61.0	58.8	62.4	59.4	62.7	62.5	68.3	68.5	69.3	59.1
5000	60.4	59.1	62.1	59.9	62.5	61.8	69.3	69.0	68.9	59.5
6300	57.3	55.3	59.0	55.3	59.1	62.6	72.1	72.1	72.9	56.8
8000	55.4	53.9	58.0	54.2	57.4	60.4	68.3	69.0	70.2	55.1
10000	55.3	52.4	56.6	53.0	56.7	56.1	64.8	65.8	66.0	53.5

1/3 OB CENTER FREQUENCY	RUN NUMBER							
	12	13	14	15	16	17	18	19
50	66.4	63.7	62.0	65.9	68.0	68.2	58.4	57.3
63	66.8	65.6	62.5	61.3	60.9	61.8	60.4	63.5
80	69.1	67.1	64.8	63.4	68.4	68.2	60.4	63.9
100	82.2	75.0	83.7	84.2	79.8	81.9	70.7	72.7
125	75.5	76.0	78.2	76.2	72.5	74.5	77.1	77.1
160	71.2	63.9	73.6	75.6	77.0	75.9	70.4	67.6
200	72.5	59.5	71.6	74.5	81.5	80.5	66.1	67.2
250	77.3	74.8	79.9	78.6	71.1	72.5	77.8	76.1
315	65.7	65.3	68.3	71.1	73.6	72.0	67.2	65.9
400	66.6	67.2	65.7	69.2	75.3	72.1	70.6	67.6
500	67.4	69.4	68.3	70.8	68.1	72.2	72.2	73.4
630	68.9	66.9	68.3	68.3	67.2	67.7	68.5	67.4
800	67.4	71.2	69.1	70.2	69.6	69.5	68.0	68.4
1000	69.7	66.7	68.3	70.3	72.3	72.3	67.9	66.9
1250	69.0	67.0	69.0	71.3	68.8	69.3	66.7	67.2
1600	66.0	66.2	67.1	68.4	67.6	67.7	66.7	66.1
2000	64.0	64.5	63.4	64.9	66.4	66.8	65.3	64.8
2500	61.3	62.7	62.7	63.5	68.0	67.7	62.4	62.6
3150	59.2	61.0	62.3	63.2	67.4	67.1	61.7	62.2
4000	57.7	59.4	63.5	64.2	65.5	66.2	60.3	60.8
5000	56.1	59.4	61.6	63.2	63.2	63.8	59.8	60.5
6300	55.2	57.0	58.2	58.7	65.2	66.8	58.2	58.6
8000	54.0	54.6	56.9	56.9	62.9	65.1	56.3	57.0
10000	53.1	51.9	57.1	55.7	58.4	59.3	55.5	55.7

TABLE A-2. INTERCITY BUS ACCELERATION/DECELERATION MEASUREMENTS

1/3 OB CENTER FREQUENCY	RUN NUMBER 1	2	3	4	5	6	7	8	9	10
50	65.9	67.1	70.5	66.5	65.4	68.2	64.0	67.2	68.2	64.6
63	65.3	67.2	66.3	67.5	67.5	67.4	64.4	65.7	68.5	67.4
80	67.9	70.9	71.2	69.6	70.2	71.6	71.4	70.9	70.6	69.0
100	68.2	67.3	68.7	68.2	67.0	68.3	71.0	67.3	65.4	68.9
125	69.1	69.6	70.2	72.8	73.1	72.1	66.3	70.1	73.1	75.5
160	72.9	74.6	74.6	75.2	70.3	72.8	69.0	74.6	71.6	79.6
200	70.0	70.6	70.5	69.6	66.4	70.7	70.0	69.1	67.7	74.7
250	71.8	72.7	72.5	72.5	68.1	70.2	68.2	69.7	68.9	77.5
315	71.4	71.9	72.1	71.9	72.1	70.9	69.0	71.2	70.5	76.0
400	71.9	72.9	72.3	73.2	69.6	70.8	66.6	70.0	69.0	76.9
500	74.0	75.6	75.1	75.3	68.1	71.0	65.0	70.0	68.6	81.8
630	71.8	73.1	71.8	72.2	68.6	72.1	66.8	70.8	70.5	79.9
800	73.4	73.6	73.2	73.4	72.0	72.8	68.2	71.6	72.9	78.2
1000	72.3	72.7	73.2	72.0	72.8	72.7	67.3	72.8	73.8	73.9
1250	74.4	73.9	74.6	74.5	75.7	72.6	74.2	72.6	74.6	73.4
1600	70.6	70.6	71.0	70.8	70.8	70.8	68.6	69.3	70.9	71.2
2000	65.7	66.3	66.8	65.6	67.1	66.1	62.9	65.5	66.5	67.4
2500	65.3	66.2	67.1	66.4	67.1	66.9	63.2	66.2	67.5	69.3
3150	65.3	66.0	67.4	66.4	66.4	68.0	65.0	67.2	67.7	69.0
4000	63.9	64.7	65.4	64.5	65.7	66.6	62.6	65.8	66.6	67.4
5000	63.1	63.8	64.5	63.2	64.6	65.5	61.1	65.0	65.2	66.5
6300	60.9	61.6	61.9	61.1	63.0	64.0	60.2	63.9	63.6	63.9
8000	58.2	59.6	59.8	59.0	60.6	62.0	58.1	60.8	61.1	62.5
10000	54.9	57.0	56.9	56.4	58.3	59.7	55.8	58.8	58.9	61.0

1/3 OB CENTER FREQUENCY	RUN NUMBER 11	12	13	14	15
50	67.4	66.4	64.9	65.9	67.1
63	69.8	68.4	69.5	71.5	69.6
80	71.1	68.1	67.6	68.1	67.0
100	70.8	68.4	68.8	68.4	67.2
125	76.3	74.3	77.8	79.3	79.5
160	76.9	79.6	71.6	70.4	71.4
200	74.1	74.7	70.6	69.8	67.9
250	76.4	75.9	77.2	76.8	76.7
315	75.5	76.7	74.4	74.3	74.3
400	76.0	76.9	74.9	73.1	72.9
500	82.0	82.0	77.6	77.7	76.5
630	80.8	80.4	76.2	76.2	75.7
800	78.2	78.6	73.3	72.8	73.1
1000	74.5	74.9	71.0	71.4	71.9
1250	74.2	73.9	72.4	72.0	72.5
1600	72.0	71.5	70.4	70.2	72.3
2000	67.6	66.8	65.1	64.4	65.7
2500	68.9	66.9	64.2	64.2	63.6
3150	68.8	66.7	61.6	62.7	60.5
4000	69.0	66.4	61.6	62.4	59.6
5000	68.9	65.4	62.2	62.4	61.0
6300	67.0	62.3	60.1	59.0	59.8
8000	66.6	61.5	57.1	58.2	57.9
10000	66.3	59.4	55.0	56.2	55.0

TABLE A-3. FIRE PUMPER TRUCK ACCELERATION/DECELERATION MEASUREMENTS

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	3	4	5	6	7	8	9	10	11	12
50	69.6	58.2	70.5	57.9	71.1	58.2	65.3	60.7	64.2	59.3
63	72.9	60.6	73.6	61.5	74.1	61.9	67.8	67.7	65.8	63.0
80	75.4	64.8	76.4	63.5	75.8	64.4	66.0	66.6	78.7	63.1
100	89.1	75.5	88.5	74.9	88.7	75.7	65.7	69.9	70.3	62.3
125	90.0	81.1	90.7	81.2	90.6	81.1	79.5	80.1	82.4	74.4
160	74.6	68.7	75.1	68.9	75.9	69.3	69.5	78.0	76.2	68.9
200	79.4	71.6	79.9	71.5	81.3	71.7	66.8	76.3	74.2	66.5
250	78.8	71.6	80.0	72.4	79.3	71.0	71.1	77.6	75.5	73.9
315	77.3	68.5	77.6	69.3	77.5	67..8	74.1	71.9	72.7	67.4
400	75.6	69.1	75.9	68.7	74.8	68.5	72.4	70.7	69.0	66.5
500	75.3	70.4	75.4	69.7	76.0	69.4	76.5	71.8	70.7	70.4
630	71.1	70.0	70.6	69.2	70.7	69.6	74.6	69.6	70.3	70.6
800	71.5	68.3	71.4	67.9	71.4	68.0	74.0	69.3	70.1	70.0
1000	68.0	67.1	68.1	67.4	67.8	66.6	73.7	68.1	66.4	67.5
1250	64.6	64.6	64.7	64.9	64.7	64.7	74.5	66.2	64.9	65.4
1600	65.7	66.4	65.5	66.1	66.0	66.5	74.8	64.9	63.4	64.0
2000	61.9	61.8	62.0	62.1	62.2	61.9	75.9	65.1	62.4	63.0
2500	60.4	58.6	60.1	58.9	60.6	58.5	73.8	63.8	61.7	61.2
3150	62.0	59.6	62.3	59.9	62.5	59.6	68.6	62.0	62.4	60.7
4000	61.7	59.5	61.8	59.9	62.1	59.8	69.5	61.3	60.4	59.8
5000	59.6	57.8	59.2	58.3	59.9	58.3	74.0	59.0	58.3	58.4
6300	56.4	54.9	56.2	55.3	56.5	55.0	73.7	56.6	55.7	55.3
8000	53.6	52.5	53.6	52.3	53.9	52.3	67.2	54.1	52.7	52.4
10000	--	49.4	--	49.3	--	49.3	60.4	51.3	--	49.5

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	13	14	15	16	17	18	19	20	21	22
50	73.6	58.6	66.1	57.5	72.8	59.8	72.4	60.0	71.4	60.3
63	81.5	66.1	69.1	62.1	75.2	62.0	75.6	63.2	76.4	61.8
80	84.7	66.9	78.5	62.5	76.5	64.9	76.5	65.4	77.4	64.0
100	81.6	68.3	70.0	61.4	91.7	77.7	90.6	77.7	89.5	76.2
125	88.0	80.1	81.5	74.1	92.4	82.8	92.6	81.1	93.2	82.2
160	86.5	78.0	76.9	68.8	78.3	71.4	78.2	72.1	78.4	71.7
200	87.4	75.5	73.9	66.3	83.3	73.1	82.6	75.4	82.8	74.0
250	84.8	77.1	75.5	72.9	82.0	74.1	80.8	75.5	81.5	75.8
315	83.6	71.3	73.2	67.3	81.3	72.2	80.7	72.3	81.1	72.1
400	77.0	70.5	69.3	66.2	79.8	71.8	79.1	71.9	79.2	72.4
500	76.2	71.0	70.3	70.6	77.4	70.8	78.3	71.1	78.4	71.6
630	71.3	70.4	69.3	70.7	72.7	69.9	72.6	69.9	72.4	71.5
800	72.3	69.4	69.3	70.0	72.3	69.5	72.5	69.4	72.5	69.3
1000	70.0	68.4	67.0	67.4	70.4	69.2	69.5	68.6	70.2	68.8
1250	67.4	66.6	64.7	65.9	67.0	66.6	66.4	66.0	66.6	66.3
1600	67.0	65.7	63.7	64.3	68.8	68.2	68.1	68.4	67.8	67.8
2000	67.6	65.5	63.2	63.2	64.0	62.9	64.6	63.3	64.5	63.3
2500	66.6	64.1	62.8	61.8	63.1	59.8	63.2	60.0	63.5	60.0
3150	64.5	62.5	62.9	60.9	64.5	60.7	64.8	60.8	64.8	61.1
4000	63.5	61.8	60.8	60.1	64.7	61.1	64.6	60.8	64.3	61.0
5000	60.5	59.7	58.8	58.0	61.9	60.5	62.3	59.9	62.1	59.9
6300	58.9	57.0	55.4	54.8	59.1	56.9	59.3	56.9	59.3	56.9
8000	55.8	54.5	52.7	52.4	56.7	54.7	56.9	54.0	56.9	54.2
10000	52.8	51.4	--	49.2	54.5	52.0	54.2	51.3	54.3	51.7

TABLE A-3. (CONTINUED)

1/3 OB CENTER FREQUENCY	RUN NUMBER 23	24	25	26	27	28	29	30
50	76.4	59.7	74.4	61.3	66.4	59.1	65.3	57.5
63	83.9	68.2	83.5	66.9	68.7	64.1	68.4	63.5
80	85.7	69.2	86.2	68.4	80.3	66.6	80.8	62.0
100	83.9	70.0	82.8	68.9	72.3	63.2	71.5	61.9
125	90.0	82.1	90.8	81.8	83.9	74.3	84.0	76.9
160	88.4	78.6	88.5	78.1	79.5	70.3	78.3	68.3
200	89.9	77.5	90.0	75.7	76.2	67.8	76.3	66.7
250	87.4	78.8	88.5	78.1	77.4	74.6	77.5	75.7
315	85.5	73.8	86.2	74.5	75.6	70.1	75.3	70.7
400	80.3	72.6	80.0	72.5	72.2	68.7	71.8	69.1
500	79.4	72.2	78.3	72.4	72.1	72.0	73.7	72.1
630	72.4	71.9	72.7	71.9	71.8	71.1	72.1	71.1
800	72.6	71.0	73.6	70.9	71.2	70.1	70.6	70.2
1000	70.2	70.1	71.4	70.0	67.8	68.9	68.2	69.3
1250	67.7	67.7	68.0	68.1	67.3	67.5	66.8	67.8
1600	66.2	66.7	66.9	67.1	66.0	65.4	65.5	66.0
2000	66.5	66.2	67.4	66.7	65.4	64.9	65.1	64.6
2500	66.3	64.9	67.1	65.4	64.1	63.1	64.2	63.4
3150	65.4	63.6	66.1	64.1	64.8	62.8	64.5	63.1
4000	64.6	63.1	64.8	63.1	62.8	61.8	62.4	62.0
5000	62.0	61.8	62.5	61.5	60.6	60.4	60.1	60.8
6300	59.6	58.9	59.9	59.0	58.1	57.3	57.2	56.8
8000	57.2	56.5	57.8	56.2	55.2	55.0	55.4	54.6
10000	54.5	53.9	55.2	53.3	52.6	52.4	52.2	51.5

TABLE A-4. TANK TRUCK 7% GRADE (50 FEET FROM ROADWAY CENTERLINE)

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	1	2	3	4	5	7	8	9	10	11
50	62.7	76.7	64.2	70.5	63.2	62.8	64.0	69.2	61.2	70.0
63	73.6	79.6	72.3	72.5	80.2	81.9	72.2	74.2	73.8	74.6
80	78.9	99.7	80.9	81.4	79.3	74.6	88.4	84.9	80.9	86.4
100	94.7	87.8	99.6	106.0	94.2	80.8	96.8	101.1	99.6	102.8
125	80.3	84.4	85.2	100.2	86.5	86.2	80.4	84.8	85.2	86.4
160	86.3	92.4	92.4	85.3	80.2	89.5	87.5	81.8	91.1	83.9
200	92.8	87.3	93.4	93.0	87.7	89.6	90.9	89.2	93.7	89.7
250	86.7	85.8	91.3	87.7	93.3	87.3	93.3	82.2	90.8	83.0
315	90.5	75.4	96.9	82.6	90.6	87.4	92.1	80.6	95.8	81.4
400	82.7	75.4	88.4	79.7	84.3	84.4	86.8	77.2	88.5	78.3
500	82.2	80.8	85.4	81.8	82.2	80.4	84.8	79.3	85.9	79.9
630	88.5	83.3	91.1	84.2	88.4	83.6	88.4	81.0	91.2	82.5
800	88.7	86.1	92.8	85.9	90.2	86.2	90.4	82.8	93.0	84.1
1000	85.2	84.4	89.9	84.2	87.2	84.7	87.5	82.2	90.0	83.6
1250	84.1	85.9	86.2	84.2	83.2	80.8	85.6	83.4	87.2	85.1
1600	85.4	85.0	88.8	84.1	85.7	83.5	87.0	83.7	88.7	84.6
2000	82.2	86.5	84.8	85.0	81.9	79.3	82.8	84.0	86.4	85.5
2500	81.0	81.8	85.2	79.6	81.8	77.6	82.8	78.0	86.9	78.9
3150	77.6	80.5	81.5	78.2	77.7	72.6	78.9	76.3	83.9	77.9
4000	76.6	79.1	78.9	75.9	74.9	71.2	77.2	73.6	81.1	75.9
5000	74.5	76.8	80.3	73.8	75.5	70.4	76.6	72.1	82.7	74.5
6300	73.4	76.1	77.9	73.0	72.0	68.4	74.1	70.9	79.6	72.6
8000	71.8	73.8	77.9	71.4	71.4	67.9	74.4	68.8	79.6	70.1
10000	71.7	70.3	76.4	67.6	69.4	66.4	71.6	64.9	77.7	65.8

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	12	13	14	16	17	18	19	20	21	22
50	70.5	70.1	66.0	62.6	71.2	67.0	72.9	63.3	71.5	65.5
63	73.2	72.9	90.6	79.1	68.3	72.4	69.2	72.7	80.4	72.8
80	92.1	80.5	81.7	83.1	79.5	76.0	82.9	72.8	81.1	79.7
100	88.0	105.3	82.9	92.5	87.1	88.2	75.5	88.1	74.6	86.9
125	84.5	101.4	90.2	86.2	74.1	74.2	75.8	76.2	80.9	72.4
160	95.0	85.2	88.7	82.3	78.4	73.7	84.8	76.6	81.3	74.0
200	86.4	91.9	92.1	92.1	80.9	76.6	73.8	76.3	77.4	81.1
250	97.6	89.7	89.7	91.4	72.6	79.3	76.9	79.5	70.7	75.6
315	92.0	84.2	89.9	91.8	72.1	72.3	70.4	73.6	70.6	70.4
400	87.9	81.4	84.4	85.6	75.5	75.0	76.9	72.4	75.0	72.0
500	84.8	81.8	78.5	81.9	70.4	71.8	73.1	68.8	72.0	72.4
630	90.1	83.0	83.6	87.5	65.6	71.7	64.4	69.0	61.5	72.1
800	93.2	84.8	86.1	89.2	68.4	70.3	64.3	70.3	62.6	69.7
1000	90.0	83.5	83.1	87.2	72.7	69.6	70.2	68.6	68.2	69.1
1250	86.2	84.6	80.0	85.6	66.0	70.9	62.3	66.5	60.2	70.7
1600	87.3	85.0	80.6	86.7	63.5	67.5	59.8	66.3	57.7	67.0
2000	84.6	85.6	77.4	83.6	62.6	65.2	59.7	63.9	58.4	64.6
2500	85.1	80.5	75.5	81.1	61.9	62.9	60.4	60.8	59.2	61.8
3150	82.1	79.1	72.3	76.1	59.9	61.8	58.9	61.1	56.3	61.7
4000	79.5	76.8	68.9	74.6	58.1	61.7	56.0	60.6	53.8	60.7
5000	80.5	75.1	68.5	74.4	56.6	59.8	54.4	58.2	52.0	59.4
6300	76.7	74.0	65.6	71.7	58.5	57.8	55.8	57.0	53.3	57.8
8000	75.9	72.8	64.2	71.3	59.0	58.8	57.0	58.0	53.2	58.1
10000	73.7	68.9	62.6	68.8	54.7	58.9	54.0	58.0	51.5	57.8

TABLE A-4. (CONTINUED)

1/3 OB CENTER FREQUENCY	RUN NUMBER 23	24	25	26	27	29
50	67.8	66.1	63.8	80.7	57.6	60.7
63	77.8	66.5	73.8	71.2	62.5	57.2
80	74.9	70.7	64.4	78.9	62.9	69.1
100	82.3	87.3	73.3	77.2	74.2	62.0
125	77.8	84.4	75.9	75.4	70.4	66.1
160	78.4	73.7	81.1	81.2	68.3	69.4
200	79.1	76.5	79.2	77.2	69.9	70.3
250	73.7	80.1	73.4	70.4	72.9	67.3
315	72.1	73.1	68.4	69.6	67.4	63.8
400	72.9	73.2	69.5	74.0	67.9	62.1
500	68.8	72.5	65.6	68.5	62.9	56.0
630	66.9	70.8	64.5	61.7	61.4	56.4
800	66.4	72.5	65.6	64.2	63.5	58.7
1000	70.4	70.7	66.8	68.5	64.0	58.3
1250	64.2	68.4	62.3	61.3	62.1	55.5
1600	63.1	68.0	60.9	58.8	59.9	53.7
2000	61.7	65.9	60.2	58.5	59.4	53.7
2500	61.1	63.0	59.9	58.8	57.1	51.9
3150	60.2	61.9	58.4	57.3	55.0	50.0
4000	58.3	61.8	56.0	54.7	54.5	49.0
5000	58.0	60.5	55.0	53.4	54.4	48.3
6300	58.0	59.3	55.8	55.2	54.6	47.2
8000	58.1	60.8	55.0	54.6	55.4	45.6
10000	55.9	61.5	52.3	52.3	52.8	43.0

TABLE A-5. TANK TRUCK 7% GRADE MEASUREMENTS (285 FEET FROM ROADWAY CENTERLINE)

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	1	2	3	4	5	6	7	8	9	10
50	44.9	58.1	52.2	51.7	49.7	56.5	55.5	61.8	57.3	47.9
63	45.5	55.9	59.1	59.1	62.7	54.3	61.2	61.7	57.3	57.8
80	49.1	65.7	58.4	59.9	56.1	56.9	52.3	65.4	62.1	54.6
100	65.2	61.1	76.0	80.3	68.5	81.3	56.4	73.6	76.7	72.3
125	62.6	70.3	62.9	73.3	68.1	78.4	64.7	58.1	65.7	62.8
160	65.7	76.2	75.5	61.8	66.1	68.3	74.0	71.0	68.5	74.2
200	86.0	72.1	74.2	74.0	80.5	76.8	77.9	78.4	77.3	76.4
250	76.9	66.5	72.2	66.5	83.5	69.3	74.8	79.1	63.3	75.0
315	72.9	63.4	76.4	63.7	75.9	71.3	69.6	76.8	62.9	76.9
400	73.5	60.3	71.6	59.6	74.2	64.1	70.1	75.0	63.9	73.8
500	75.9	65.7	71.9	63.1	71.3	67.6	67.7	74.4	63.5	74.2
630	75.5	66.1	76.9	63.4	75.4	65.7	68.3	79.7	64.5	76.5
800	69.7	70.4	76.6	66.4	78.4	68.6	73.1	81.4	67.7	79.9
1000	70.1	69.3	73.7	68.6	75.0	68.5	69.1	78.5	67.8	76.2
1250	68.6	68.9	70.2	67.6	71.9	66.5	66.0	75.3	66.5	70.5
1600	67.1	68.2	73.9	68.5	73.0	70.0	67.1	77.6	69.1	71.9
2000	67.2	68.8	69.2	70.0	70.2	67.7	63.3	73.0	68.1	70.6
2500	63.7	62.8	68.9	62.4	64.8	60.7	58.6	70.2	60.4	69.8
3150	58.6	57.6	62.7	57.9	60.2	57.6	52.8	64.6	56.9	65.1
4000	54.2	54.4	57.7	53.7	53.7	53.2	48.7	58.7	52.5	59.7
5000	47.4	49.3	56.2	47.8	49.8	48.5	44.3	54.8	47.4	58.0
6300	41.2	45.2	50.1	43.1	45.6	44.7	43.2	49.2	44.1	51.8
8000	38.8	41.5	47.0	39.6	--	42.1	44.9	47.9	40.6	50.1
10000	40.2	39.3	44.5	39.5	--	41.0	47.4	48.4	39.2	49.2

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	11	12	14	16	17	18	19	20	21	26
50	53.1	54.5	54.7	55.9	55.6	50.4	56.4	49.6	57.1	45.8
63	57.2	55.6	72.7	64.4	48.9	52.1	58.4	53.7	64.1	45.6
80	55.2	69.0	59.1	62.6	54.3	50.3	60.7	53.1	62.1	48.8
100	71.6	60.6	60.4	72.7	54.8	61.2	61.8	64.7	48.8	63.8
125	62.6	64.7	68.8	61.1	55.2	51.8	60.5	54.4	67.6	63.4
160	64.7	79.9	72.4	62.4	65.7	55.3	70.0	58.5	66.0	51.5
200	72.1	76.2	77.8	75.5	69.7	64.0	64.9	60.8	67.3	60.4
250	63.1	81.0	73.3	75.2	56.2	63.4	65.3	63.5	60.0	64.1
315	60.2	72.9	69.9	74.3	56.1	50.8	57.8	56.2	58.8	52.9
400	61.3	78.1	73.7	73.2	61.8	55.7	64.1	52.3	62.3	57.8
500	60.5	72.0	73.3	72.8	52.2	55.5	55.2	54.3	54.1	52.5
630	64.0	72.7	73.7	76.7	49.9	54.3	52.0	50.8	49.9	52.1
800	67.4	75.9	70.6	80.1	54.6	52.9	51.7	51.6	51.2	52.7
1000	67.3	74.7	70.3	76.1	59.5	52.6	56.0	50.8	55.9	52.1
1250	65.6	74.5	68.4	72.3	50.0	53.9	47.1	49.6	45.8	50.0
1600	67.5	70.4	63.3	75.3	47.2	48.8	46.5	48.3	45.2	49.2
2000	65.3	67.0	62.6	69.9	45.1	45.0	45.4	46.0	44.8	46.6
2500	58.4	64.7	58.6	68.0	44.7	41.0	44.9	41.4	44.0	42.8
3150	55.9	61.0	52.6	61.5	38.9	38.0	39.5	40.5	38.0	40.2
4000	51.2	55.1	46.2	56.7	35.1	35.1	36.4	38.9	34.8	37.0
5000	46.7	54.1	41.9	52.8	33.0	33.1	32.4	33.3	30.7	33.6
6300	42.7	47.8	41.6	47.4	34.1	32.4	29.2	30.2	29.0	29.6
8000	39.5	46.6	44.7	46.5	36.0	34.7	29.3	28.9	28.4	28.2
10000	38.6	--	47.6	--	38.1	37.4	30.2	30.6	29.5	--

TABLE A-5. (CONTINUED)

1/3 OB CENTER FREQUENCY	RUN NUMBER	
	27	29
50	46.9	45.2
63	48.0	46.3
80	47.6	49.0
100	50.9	51.3
125	47.6	45.0
160	47.0	48.7
200	52.5	49.7
250	58.4	48.7
315	50.7	44.7
400	51.6	46.6
500	49.7	43.5
630	49.6	45.4
800	49.8	46.1
1000	48.0	43.9
1250	47.2	42.0
1600	44.1	39.5
2000	42.8	36.6
2500	37.6	33.4
3150	33.8	29.3
4000	30.8	25.2
5000	27.5	23.6
6300	25.6	23.7
8000	--	26.3
10000	30.2	29.0

TABLE A-6. INTERCITY BUS 7% GRADE MEASUREMENTS

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	1	2	3	4	5	6	7	9	10	11
50	63.2	69.1	59.1	60.2	67.0	63.4	63.0	64.2	59.7	63.4
63	64.2	62.8	67.0	61.0	66.9	61.2	64.0	65.7	66.9	61.5
80	63.9	62.4	62.9	61.4	63.4	65.2	67.6	66.1	63.8	63.8
100	68.5	68.6	70.1	61.7	69.1	67.1	66.3	67.7	69.9	65.8
125	76.2	60.0	79.7	67.7	76.3	67.7	68.5	69.2	76.0	67.2
160	68.0	61.8	77.0	63.6	65.8	62.4	70.1	69.3	63.8	70.7
200	70.6	71.5	70.7	66.8	68.8	66.3	69.4	68.9	68.6	70.5
250	74.3	69.7	74.8	70.8	74.8	69.0	74.0	74.3	74.2	73.0
315	70.8	71.8	70.2	71.4	70.6	70.6	74.7	76.8	70.9	73.8
400	71.2	68.1	70.6	73.9	69.7	71.6	72.0	71.9	69.9	72.8
500	72.6	67.2	71.7	76.2	74.3	74.2	75.5	72.5	72.6	76.0
630	70.7	66.9	70.2	72.7	71.7	73.7	73.3	73.2	71.1	73.8
800	68.9	68.0	69.1	71.5	70.6	71.5	74.7	73.4	70.5	74.2
1000	68.8	69.3	69.1	68.1	68.8	68.3	72.6	70.1	69.1	73.0
1250	69.2	71.4	68.4	70.5	69.3	72.1	71.9	72.0	70.2	73.6
1600	64.9	65.4	66.0	69.3	65.4	69.2	70.5	69.1	65.7	71.6
2000	61.8	60.6	64.0	68.5	63.6	67.8	67.0	67.6	62.6	68.1
2500	63.1	62.5	64.1	72.4	65.5	72.6	69.0	68.5	63.7	70.5
3150	57.8	60.5	60.9	66.0	60.4	66.8	66.7	65.8	59.4	69.4
4000	56.4	60.1	59.7	63.7	59.4	63.6	65.9	63.1	58.8	68.1
5000	55.5	57.1	58.6	60.6	57.8	60.8	65.1	60.8	57.9	67.1
6300	53.3	54.4	56.0	59.4	55.2	58.7	61.9	58.7	54.9	62.9
8000	51.1	52.8	54.8	59.6	53.6	58.4	59.3	57.8	52.9	59.9
10000	50.5	52.3	54.5	59.1	52.6	59.7	59.6	58.5	52.0	59.7

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	13	14	15	17	18	19	20	21	22	23
50	64.4	63.0	62.1	63.7	61.2	62.3	62.9	64.2	63.1	57.6
63	61.8	65.0	61.5	65.4	67.8	63.8	66.5	64.6	64.8	60.8
80	63.8	63.1	64.5	65.5	63.1	65.1	62.0	62.8	65.8	61.0
100	61.7	67.3	64.8	66.2	69.1	66.6	68.0	63.2	68.8	60.8
125	67.1	72.2	66.6	67.1	74.8	68.9	76.1	67.5	74.0	66.1
160	61.6	67.5	61.1	69.5	65.7	70.2	65.0	62.1	66.8	62.2
200	65.3	69.7	66.6	69.5	67.7	69.7	68.2	65.1	68.6	64.4
250	70.1	75.0	67.2	73.0	74.2	73.7	74.2	69.1	74.3	68.1
315	72.1	70.5	71.6	73.9	70.6	75.9	70.3	71.2	70.9	71.5
400	71.1	70.3	70.0	71.5	70.4	71.9	69.9	70.3	70.5	69.6
500	73.2	73.9	72.2	74.0	72.6	74.9	72.6	74.3	73.7	71.9
630	72.7	70.4	73.4	72.0	72.1	72.8	71.7	72.7	71.5	72.4
800	70.9	69.6	71.2	72.7	70.2	73.5	70.2	72.1	70.1	70.7
1000	68.4	67.4	70.3	71.7	69.3	71.1	68.7	69.5	68.3	69.1
1250	69.2	67.8	74.3	72.3	68.0	71.8	68.4	69.8	68.4	69.8
1600	68.7	65.1	69.8	70.0	64.9	69.2	65.2	66.6	64.1	69.1
2000	66.8	63.4	65.5	66.8	61.6	66.5	62.0	65.2	61.4	65.1
2500	72.3	64.5	69.2	68.2	62.7	67.9	63.5	70.3	63.6	71.1
3150	67.4	58.4	67.0	66.0	58.5	66.6	58.9	66.4	57.9	67.7
4000	64.9	58.0	66.2	65.9	57.6	65.8	57.8	65.1	57.2	67.2
5000	61.3	56.3	63.8	65.1	56.1	64.3	56.8	62.3	55.9	66.3
6300	57.7	54.1	60.5	62.4	53.9	61.4	54.1	59.0	53.2	63.9
8000	58.2	52.1	56.7	60.1	51.6	58.4	52.0	56.3	51.1	62.3
10000	59.2	51.3	56.8	59.8	51.2	58.4	51.6	55.3	50.2	62.5

TABLE A-7. FIRE PUMPER TRUCK 7% GRADE MEASUREMENTS (50 FEET FROM ROADWAY CENTERLINE)

1/3 OB CENTER FREQUENCY	RUN NUMBER									
	1	2	3	4	6	7	8	9	10	12
50	74.0	74.4	68.7	70.9	63.9	71.4	62.6	70.2	63.9	64.7
63	70.6	70.5	68.9	73.5	69.5	71.4	71.6	70.0	70.5	64.0
80	73.4	73.0	68.8	74.0	68.0	72.8	69.5	72.8	68.3	65.9
100	70.9	90.1	66.8	86.7	74.4	87.8	72.6	87.9	70.3	65.1
125	82.0	86.3	80.6	91.6	82.5	90.5	83.0	90.7	81.2	75.6
160	77.0	75.9	77.2	76.5	81.0	75.1	80.5	75.0	81.5	73.3
200	81.1	83.8	80.7	82.2	82.3	81.5	81.5	80.5	80.8	70.5
250	78.1	77.3	76.2	80.6	80.7	79.4	79.3	79.4	80.2	75.9
315	73.2	76.2	73.5	76.7	73.6	75.3	72.6	74.7	74.7	67.9
400	70.7	71.6	69.5	71.8	70.1	70.7	70.4	71.3	69.4	65.6
500	69.2	71.4	68.0	69.3	68.5	69.2	67.8	71.1	66.7	65.9
630	64.9	63.6	63.8	64.6	63.0	64.3	63.6	64.9	63.0	64.1
800	67.5	67.1	65.2	67.3	63.7	68.1	65.1	67.6	64.9	64.2
1000	65.8	66.8	64.3	68.0	63.6	67.3	63.9	68.0	64.0	63.9
1250	65.9	64.7	64.7	65.6	64.1	65.2	64.9	65.8	64.4	64.4
1600	65.9	63.3	64.9	64.3	63.2	64.1	64.4	64.4	63.9	63.6
2000	68.4	61.9	66.2	62.5	65.2	62.4	65.9	63.2	65.2	63.4
2500	67.1	61.6	65.7	62.6	64.7	62.9	65.0	63.2	64.3	62.8
3150	66.3	62.8	65.1	63.2	64.2	63.3	64.8	64.2	64.3	64.2
4000	66.4	63.6	65.9	64.3	64.4	64.4	65.3	66.0	64.6	63.4
5000	66.7	62.9	66.0	63.0	64.8	63.3	65.5	65.0	64.5	64.2
6300	65.2	61.4	65.2	61.5	63.9	61.7	64.0	63.4	63.8	63.7
8000	65.8	62.0	65.1	62.5	63.7	62.9	64.1	63.7	63.9	63.8
10000	64.4	60.0	63.7	60.8	62.7	61.0	63.6	61.2	62.9	62.7

1/3 OB CENTER FREQUENCY	RUN NUMBER					
	14	16	17	21	22	24
50	60.8	59.0	69.1	68.2	59.4	59.6
63	60.3	61.7	73.2	69.9	68.0	66.7
80	66.9	64.4	81.3	67.8	67.3	63.0
100	65.8	64.8	78.6	79.1	63.4	64.6
125	74.5	75.4	74.9	81.5	74.7	78.5
160	73.1	73.1	82.6	81.9	68.6	68.2
200	70.3	70.6	82.6	83.3	72.1	70.2
250	74.1	74.0	74.7	78.9	73.5	73.0
315	67.5	67.8	72.2	74.0	67.3	67.7
400	65.6	65.3	69.8	69.1	63.9	64.9
500	64.1	63.2	64.7	66.4	63.2	65.0
630	64.0	64.5	60.9	62.5	63.3	64.6
800	64.6	64.8	62.1	64.5	65.1	65.9
1000	64.4	64.4	61.2	63.1	64.9	65.2
1250	64.0	64.2	60.8	62.8	63.7	63.3
1600	63.3	62.3	60.0	63.1	61.6	62.1
2000	63.4	62.2	62.4	65.0	61.6	62.2
2500	62.0	60.9	61.5	64.2	60.2	61.1
3150	63.3	61.7	59.4	63.3	60.9	61.4
4000	63.1	61.3	58.4	63.6	60.8	61.7
5000	63.3	61.2	57.9	64.5	60.6	62.0
6300	62.2	61.0	57.0	62.5	60.4	61.6
8000	62.4	61.7	57.2	62.0	61.1	62.2
10000	62.7	61.7	56.4	61.1	61.3	62.4

TABLE A-8. FIRE PUMPER TRUCK 7% GRADE MEASUREMENTS (285 FEET FROM ROADWAY CENTERLINE)

1/3 OB CENTER FREQUENCY	RUN NUMBER						
	1	3	4	14	16	21	22
50	59.1	57.1	55.5	52.4	48.2	53.1	59.2
63	55.2	55.4	56.6	50.0	51.6	54.6	54.0
80	57.6	56.8	56.2	51.2	53.2	54.3	49.9
100	54.1	52.9	65.4	51.2	53.7	62.2	49.1
125	62.2	61.3	69.4	53.6	54.7	66.9	53.8
160	55.7	54.7	51.5	47.5	51.2	56.7	45.1
200	62.9	57.6	61.3	49.2	54.5	64.0	50.8
250	64.6	63.1	64.5	59.5	57.0	62.8	56.7
315	60.7	59.8	62.3	54.1	55.0	60.0	54.0
400	57.4	56.3	56.7	50.8	52.3	55.8	51.1
500	52.8	52.8	53.6	47.1	53.7	52.0	48.0
630	53.6	50.9	52.8	53.6	53.3	49.7	53.0
800	52.4	50.4	50.3	49.5	52.2	50.6	49.1
1000	50.8	47.2	53.0	48.1	51.2	47.6	47.9
1250	49.9	46.4	47.6	46.3	49.9	45.4	47.2
1600	49.4	45.9	47.0	45.5	49.1	45.1	44.4
2000	51.4	47.9	45.6	44.4	46.3	46.2	43.6
2500	49.2	46.5	44.2	41.3	43.8	43.8	40.6
3150	46.3	43.9	43.0	40.9	42.9	41.4	40.8
4000	44.1	41.7	41.2	37.4	38.7	38.9	38.5
5000	40.3	37.5	38.1	34.1	35.4	35.8	34.6
6300	36.2	33.2	33.5	30.3	31.2	31.3	32.8
8000	35.3	31.3	33.3	27.7	28.4	28.1	29.1
10000	--	28.2	28.7	--	33.5	28.1	29.0

APPENDIX B

SUPPLEMENTARY INFORMATION ABOUT SUBJECTIVE TESTING

APPENDIX B

Figure B-1 is a schematic representation of the laboratory equipment used to administer the adaptive paired comparison judgment tests. Figures B-2 through B-33 are one-third octave band spectra (at the time of occurrence of the maximum A-level) of the signals presented for annoyance judgments. The subjects' instructions and additional details of the adaptive procedure are also included in this Appendix.

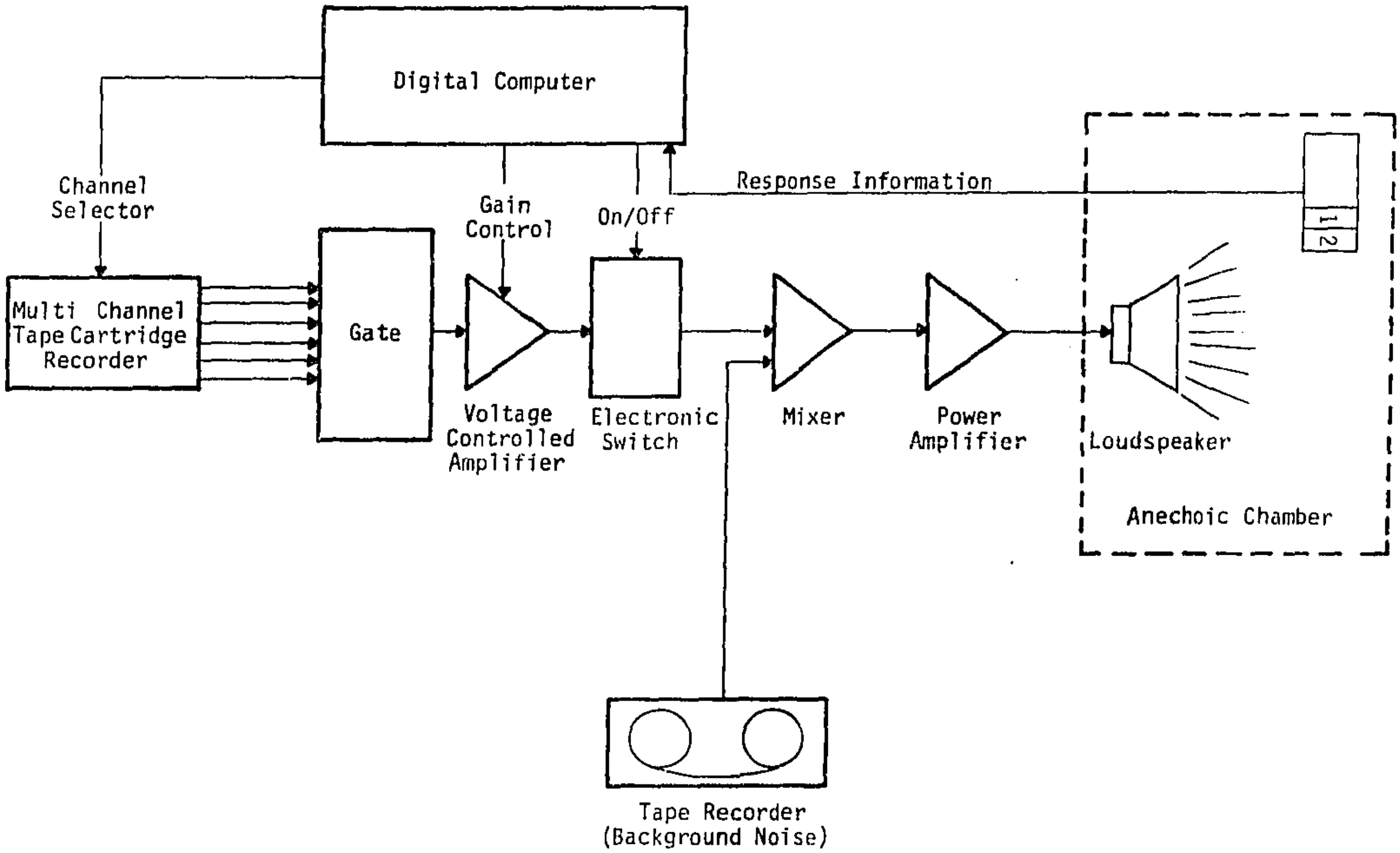

FIGURE B-1. SCHEMATIC REPRESENTATION OF EQUIPMENT USED IN SUBJECTIVE JUDGMENT TESTING

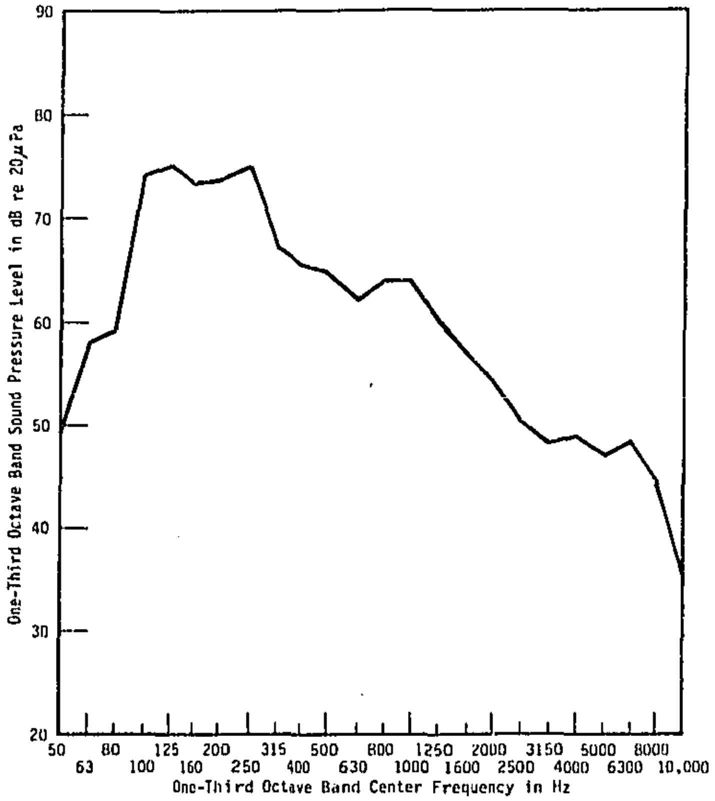

FIGURE B-2. VARIABLE LEVEL SIGNAL (PRIMARY TEST VEHICLE, DOWNHILL, NO ENGINE BRAKING)

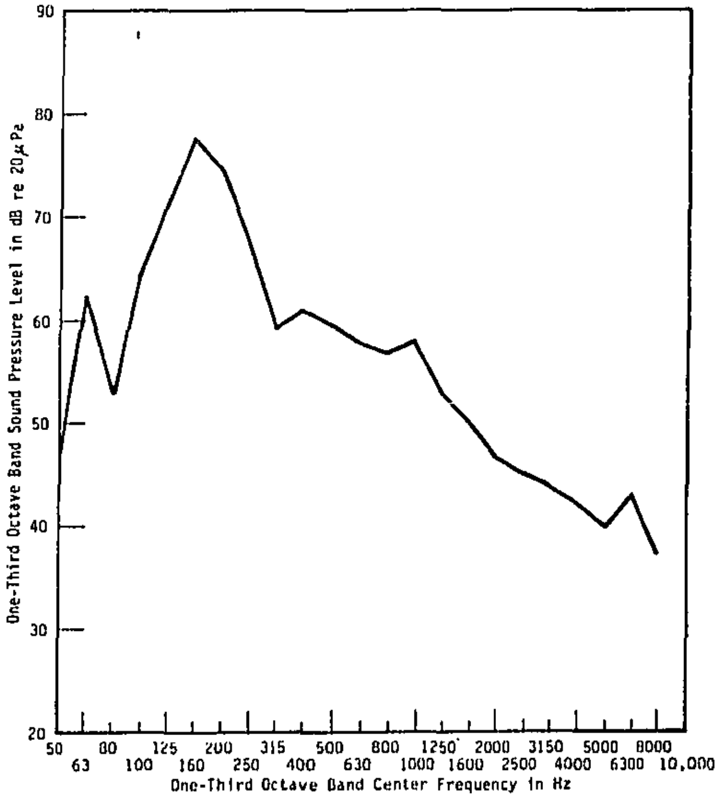

FIGURE B-3. SIGNAL A4 (TANK TRUCK, DOWNHILL, 2 CYLINDERS BRAKING)

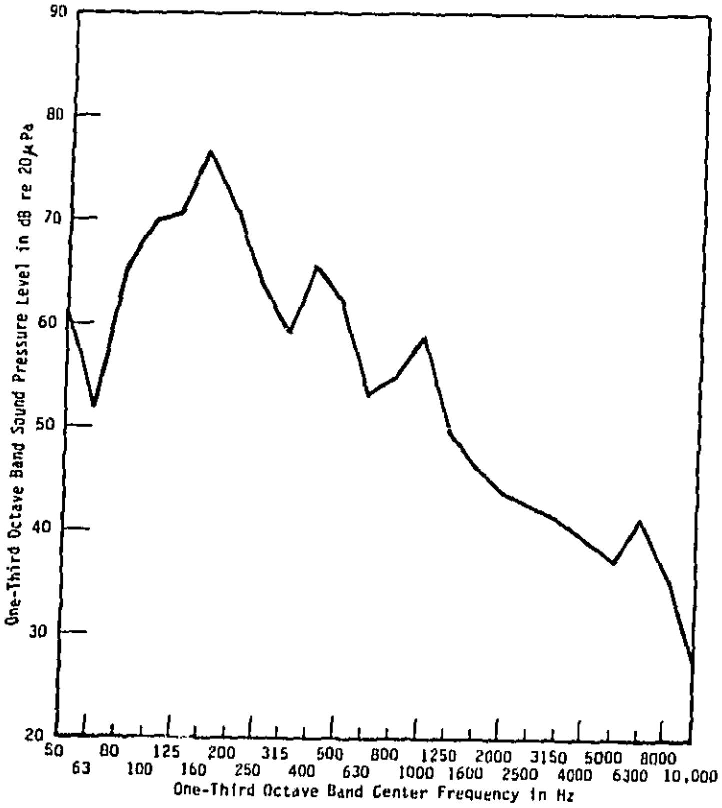

FIGURE B-4. SIGNAL A5 (TANK TRUCK, DOWNHILL, 4 CYLINDERS BRAKING)

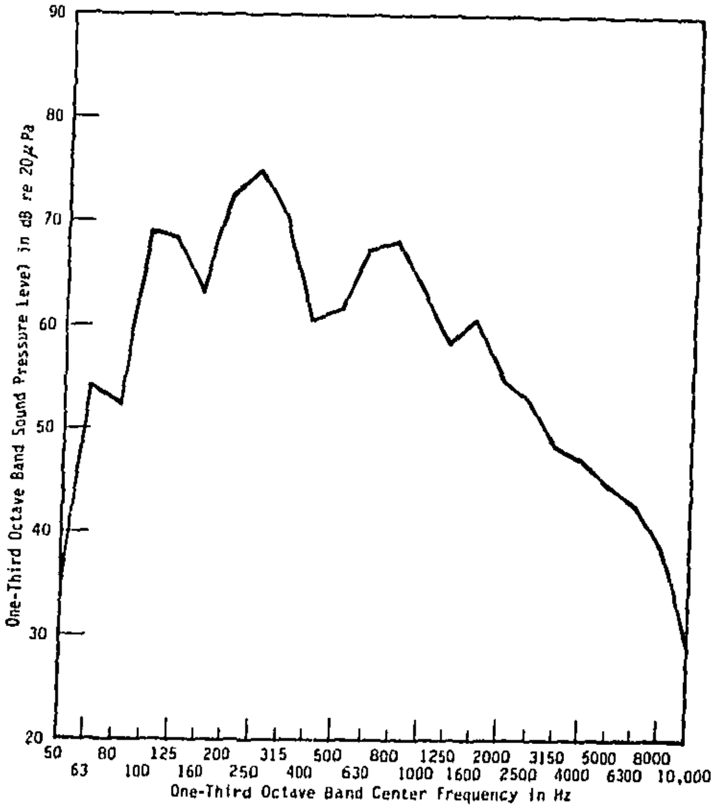

FIGURE B-5. SIGNAL A6 (TANK TRUCK, DOWNHILL, 4 CYLINDERS BRAKING, NO MUFFLER)

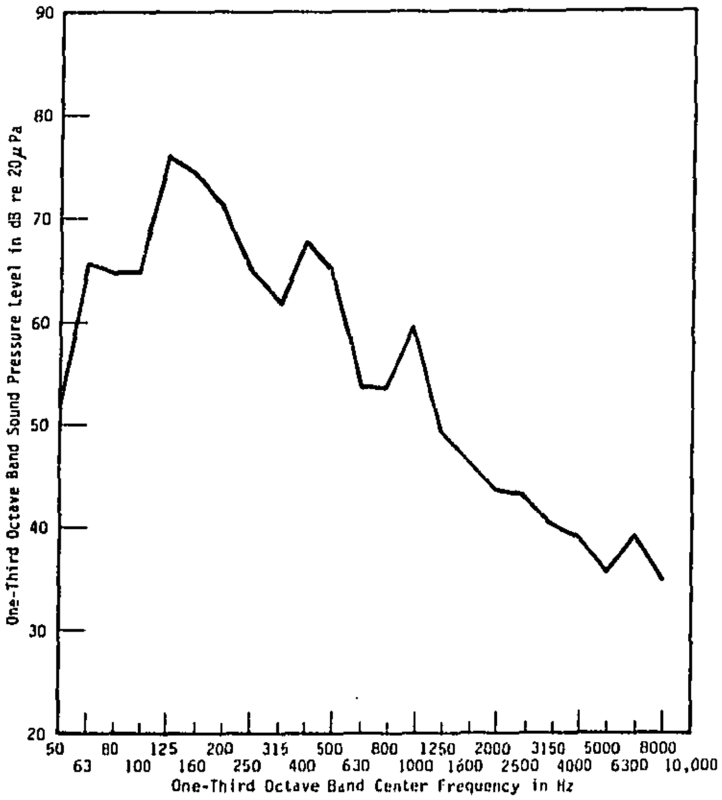

FIGURE B-6. SIGNAL A7 (TANK TRUCK, DOWNHILL, 6 CYLINDERS BRAKING)

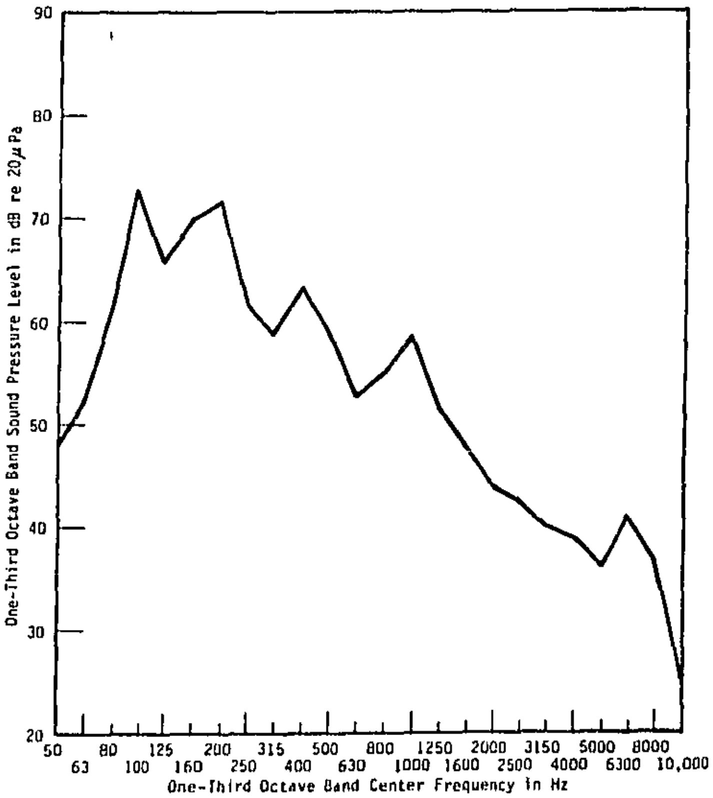

FIGURE B-7. SIGNAL A8 (TANK TRUCK, DOWNHILL) 6 CYLINDERS BRAKING)

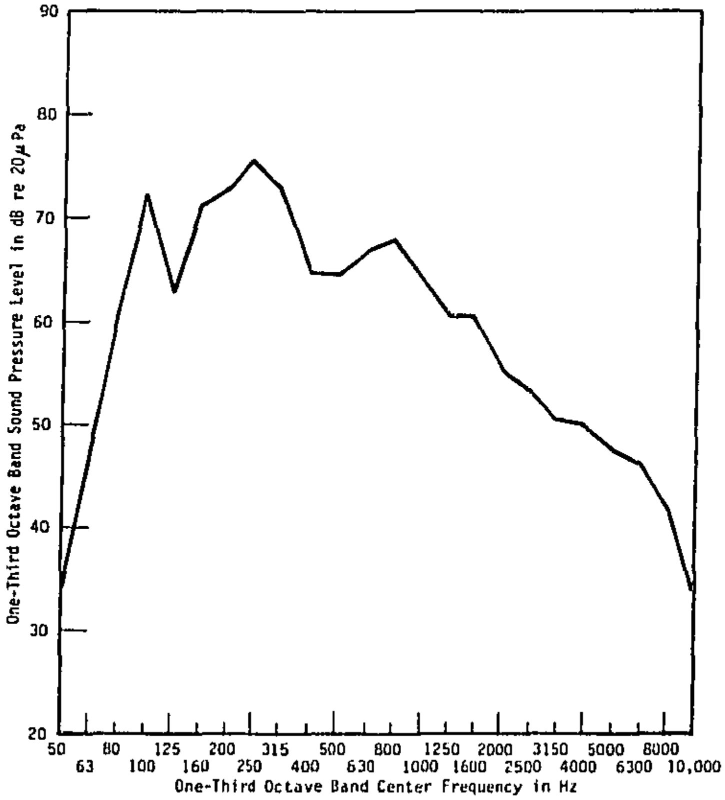

FIGURE B-8. SIGNAL A9 (TANK TRUCK, DOWNHILL, 6 CYLINDERS BRAKING, NO MUFFLER)

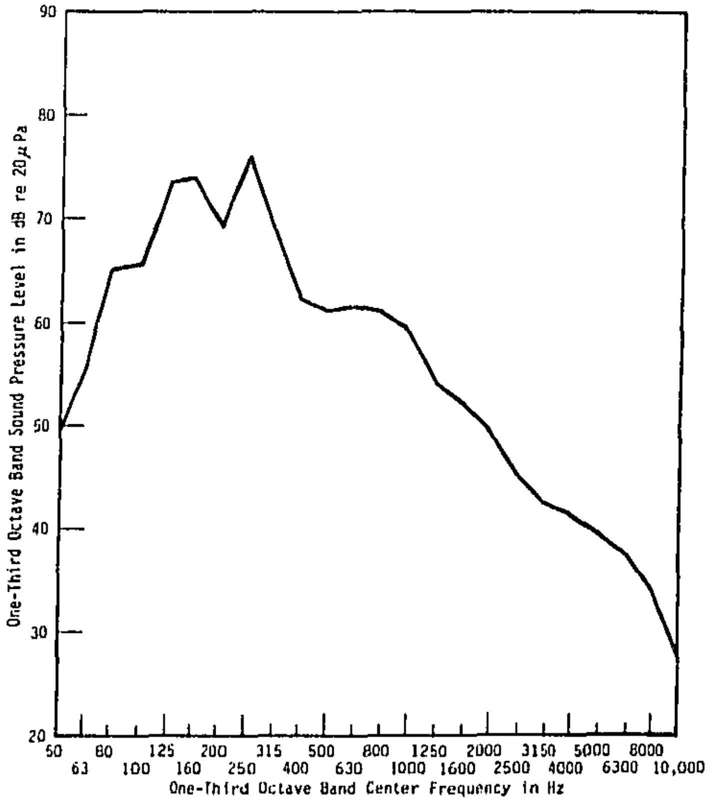

FIGURE B-9. SIGNAL A10 (TANK TRUCK, DOWNHILL, SERVICE BRAKE ONLY)

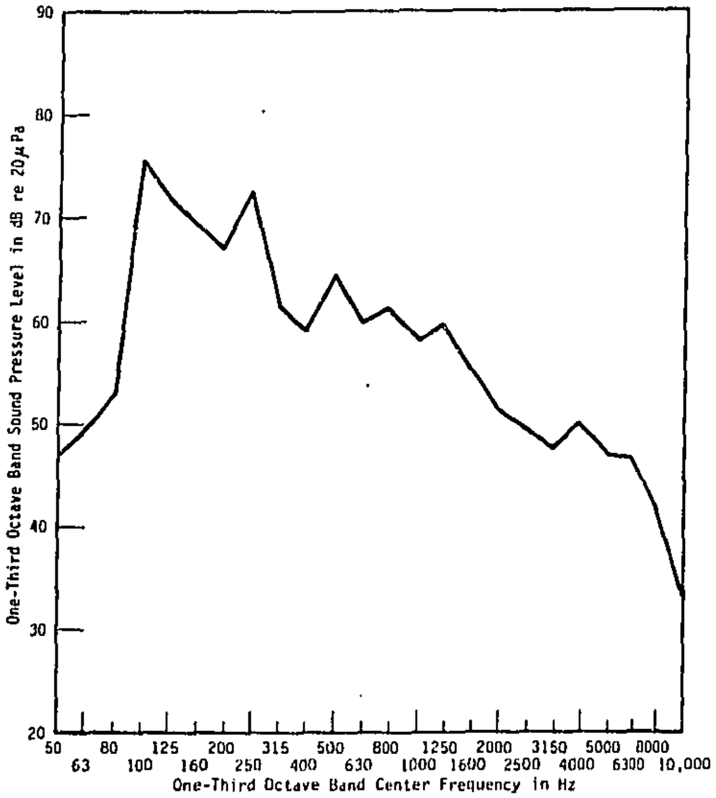

FIGURE B-10. SIGNAL A11 (TANK TRUCK, ACCELERATING)

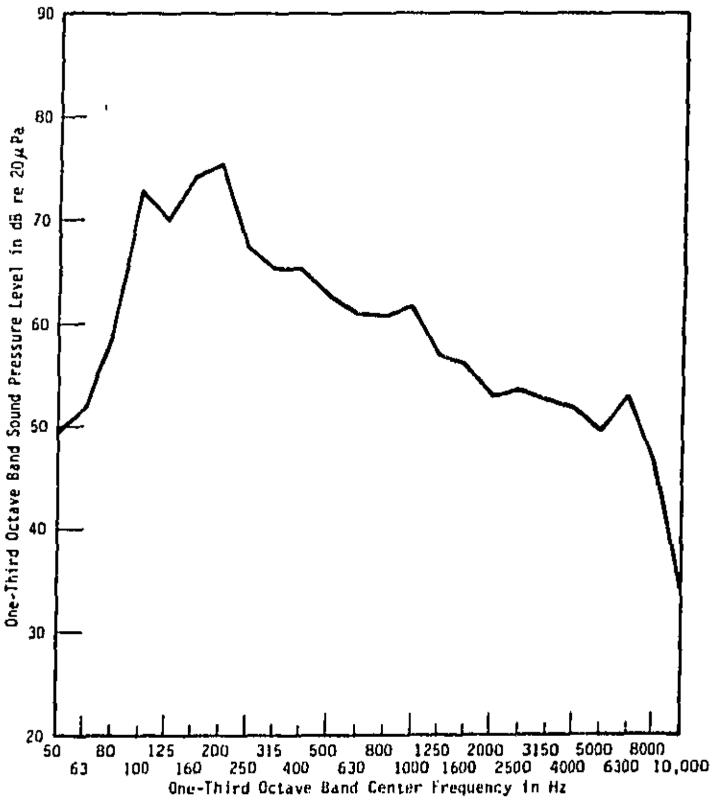

FIGURE B-11. SIGNAL A12 (TANK TRUCK, DECELERATING, 6 CYLINDERS BRAKING)

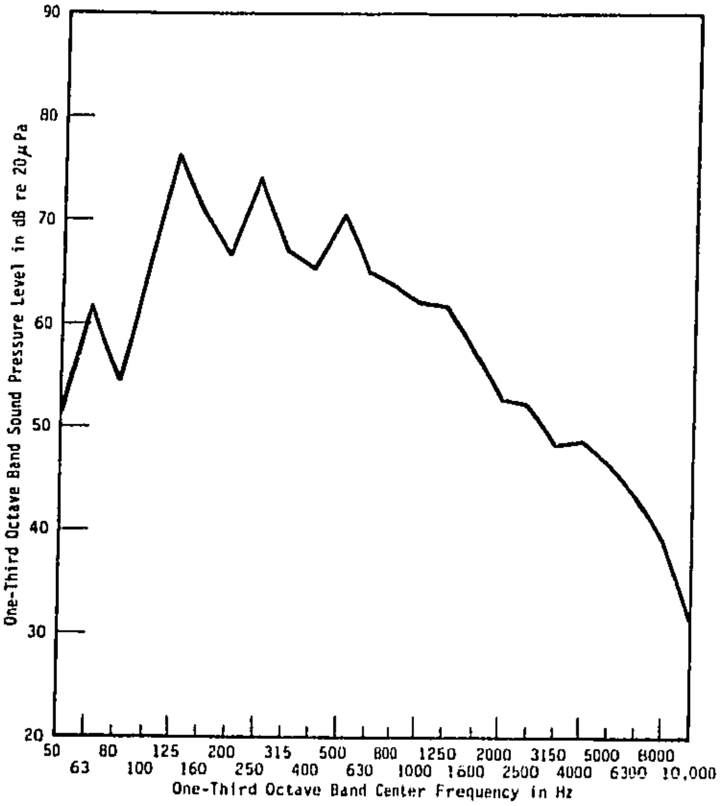

FIGURE B-12. SIGNAL A13 (INTERCITY BUS, UPHILL)

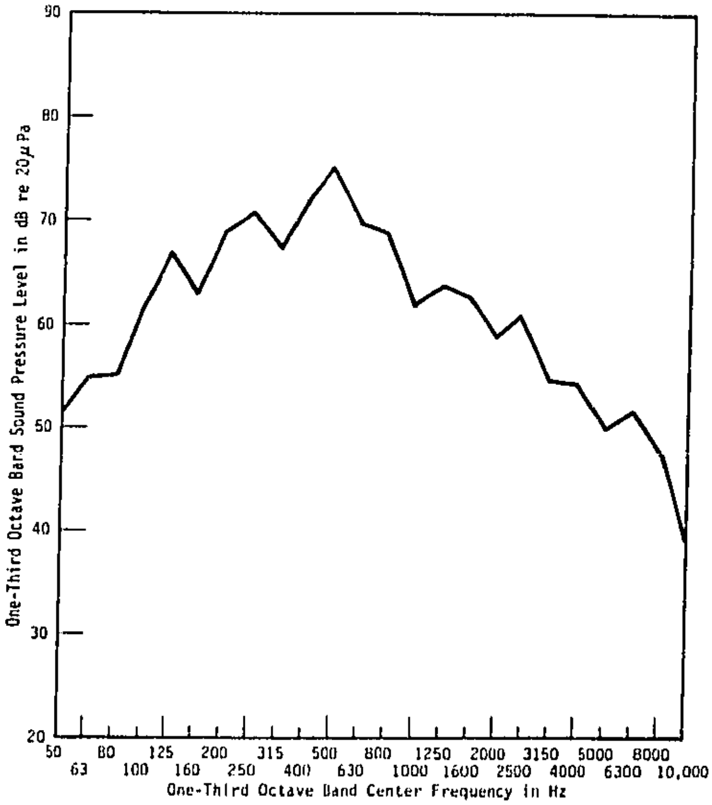

FIGURE B-13. SIGNAL A14 (INTERCITY BUS, DOWNHILL,
8 CYLINDERS BRAKING)

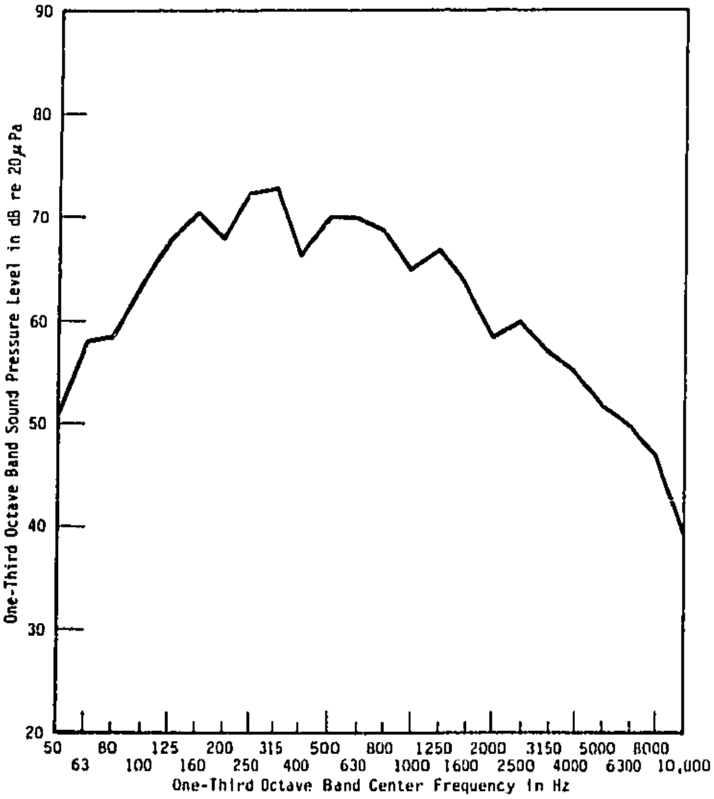

FIGURE B-14. SIGNAL A15 (INTERCITY BUS, DOWNHILL, 8 CYLINDERS BRAKING)

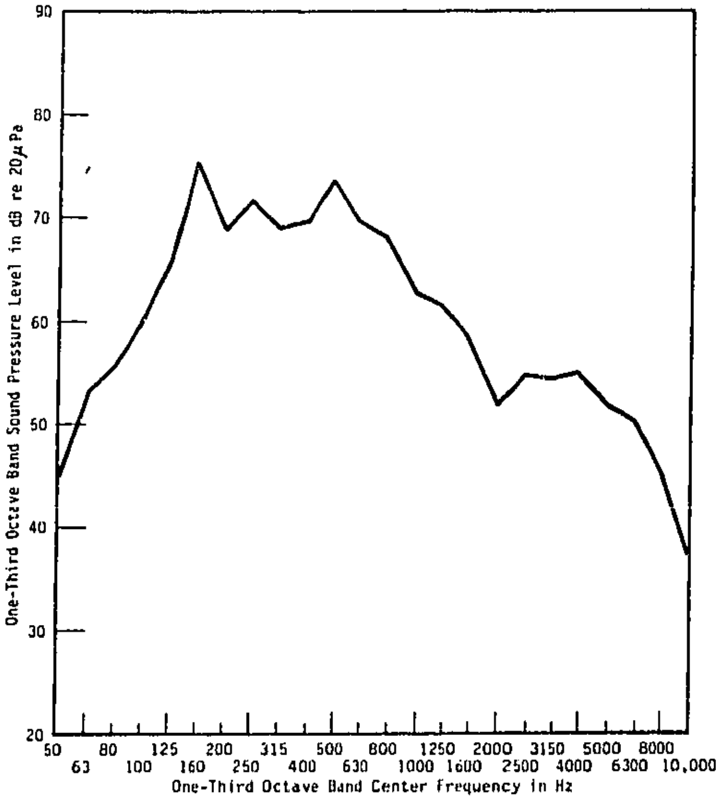

FIGURE B-15. SIGNAL A16 (INTERCITY BUS, ACCELERATING)

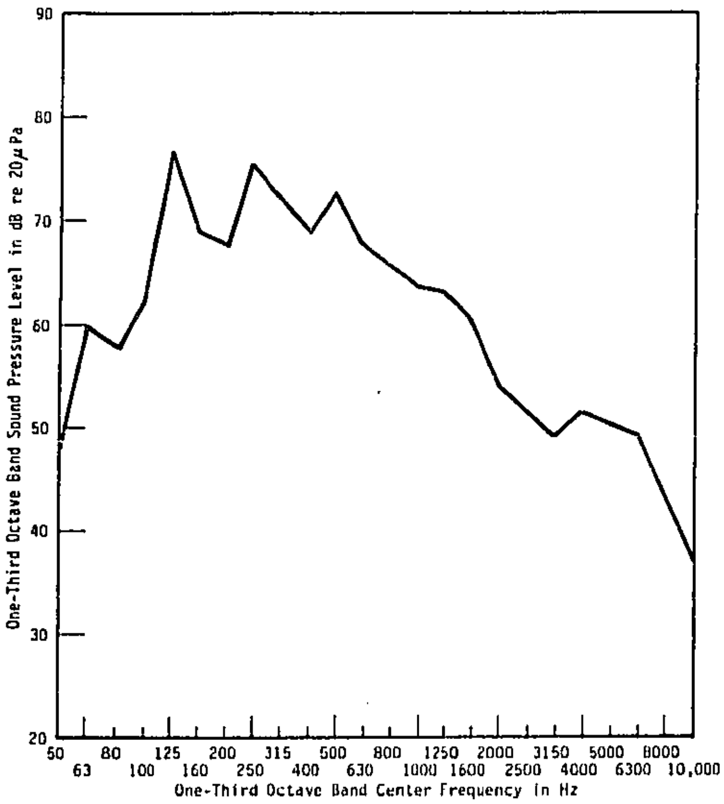

FIGURE B-16. SIGNAL A17 (INTERCITY BUS, DECELERATING, 8 CYLINDERS BRAKING)

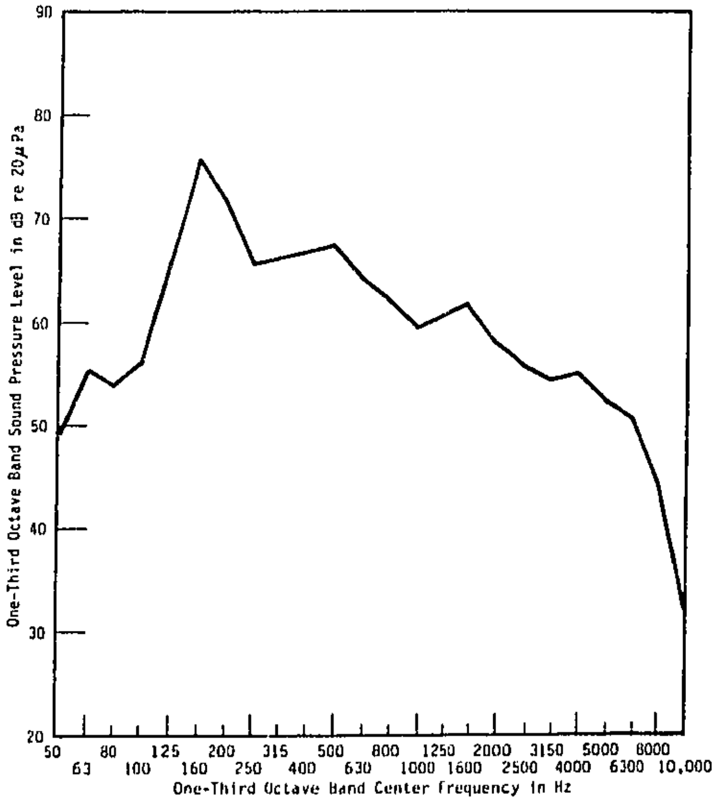

FIGURE B-17. SIGNAL A18 (AUTOMOBILE, ACCELERATING)

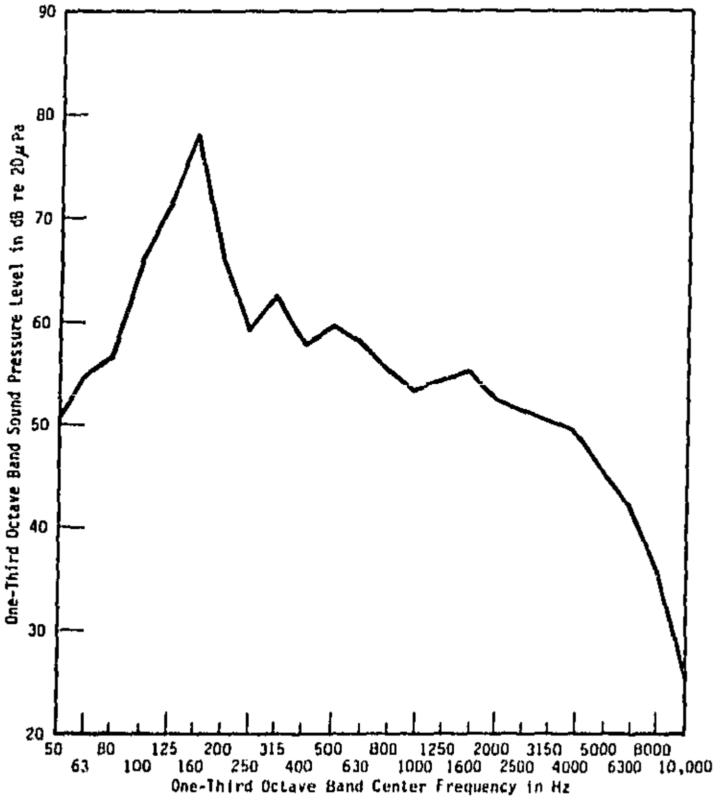

FIGURE B-18. SIGNAL A19 (AUTOMOBILE, DECELERATING)

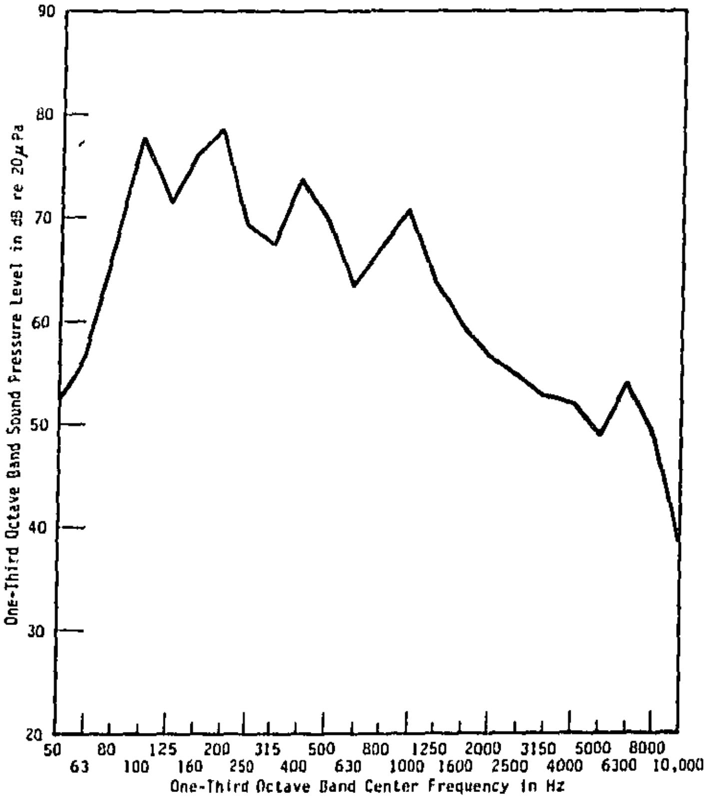

FIGURE B-19. SIGNAL A21 (SAME AS A8, BUT OUT-OF-DOORS)

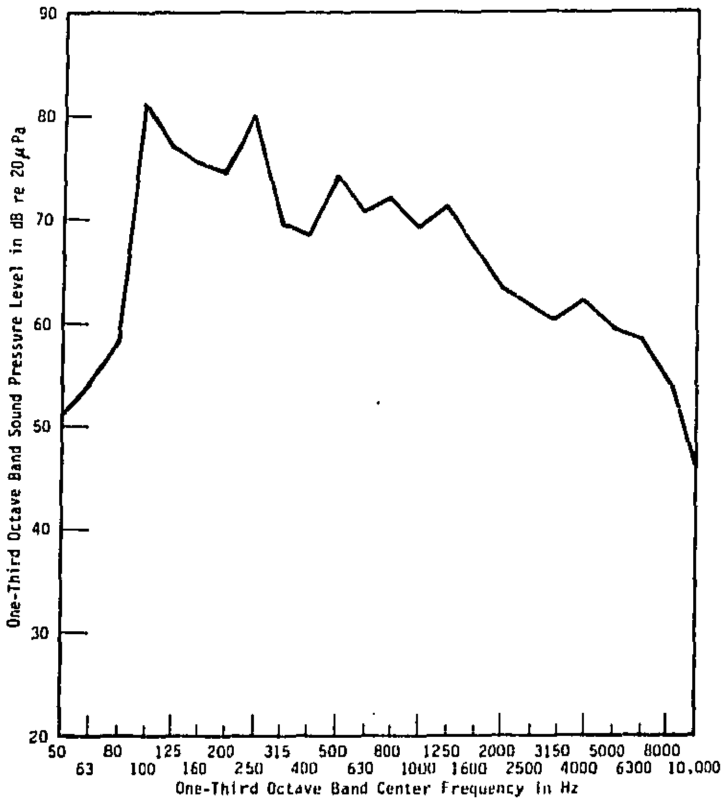

FIGURE B-20. SIGNAL A22 (SAME AS A11, BUT OUT-OF-DOORS)

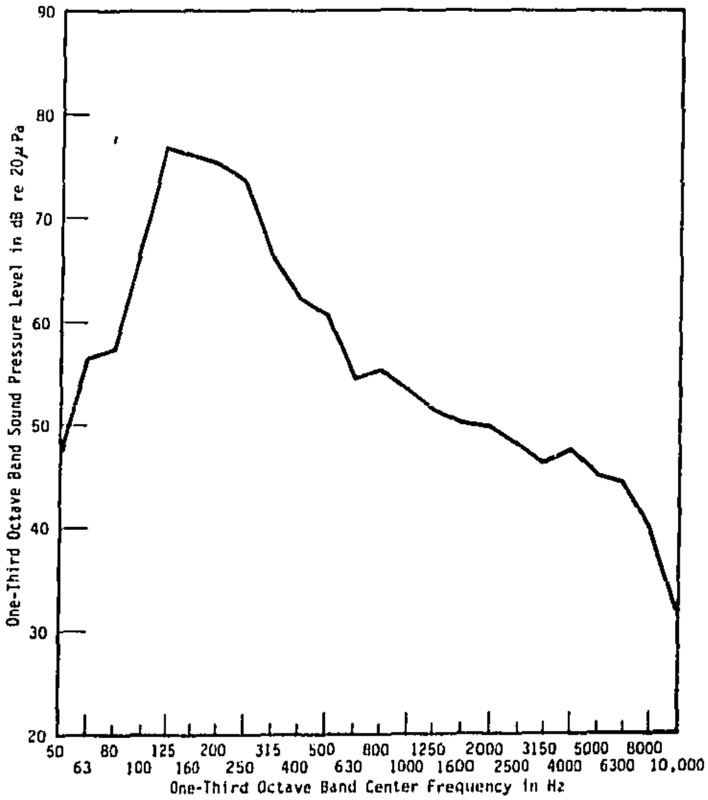

FIGURE B-21. SIGNAL B3 (FIRE PUMPER TRUCK, DOWNHILL, SERVICE BRAKE ONLY)

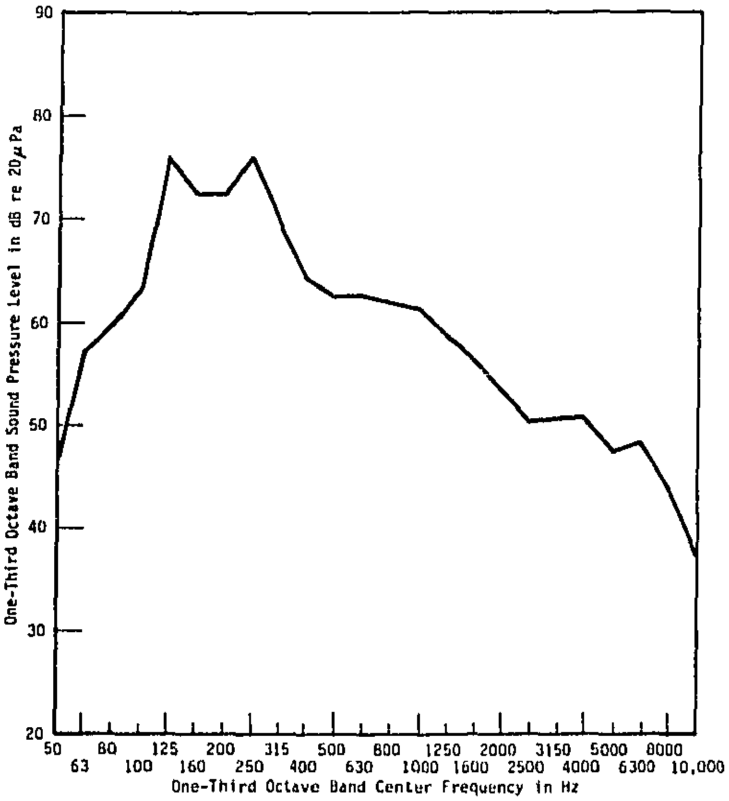

FIGURE B-22. SIGNAL B4 (FIRE PUMPER TRUCK, DOWNHILL, 6 CYLINDERS BRAKING)

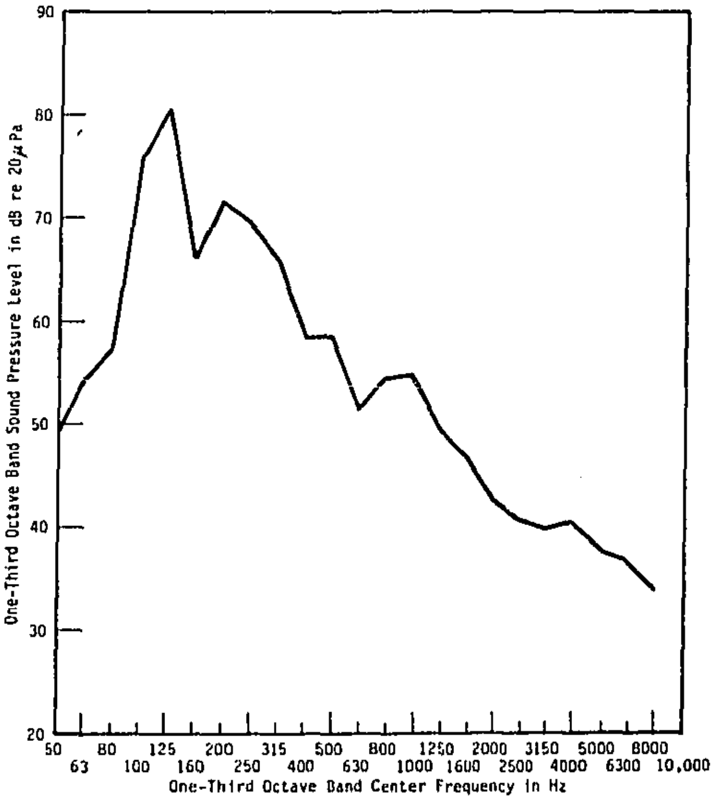

FIGURE B-23. SIGNAL B5 (FIRE PUMPER TRUCK, UPHILL)

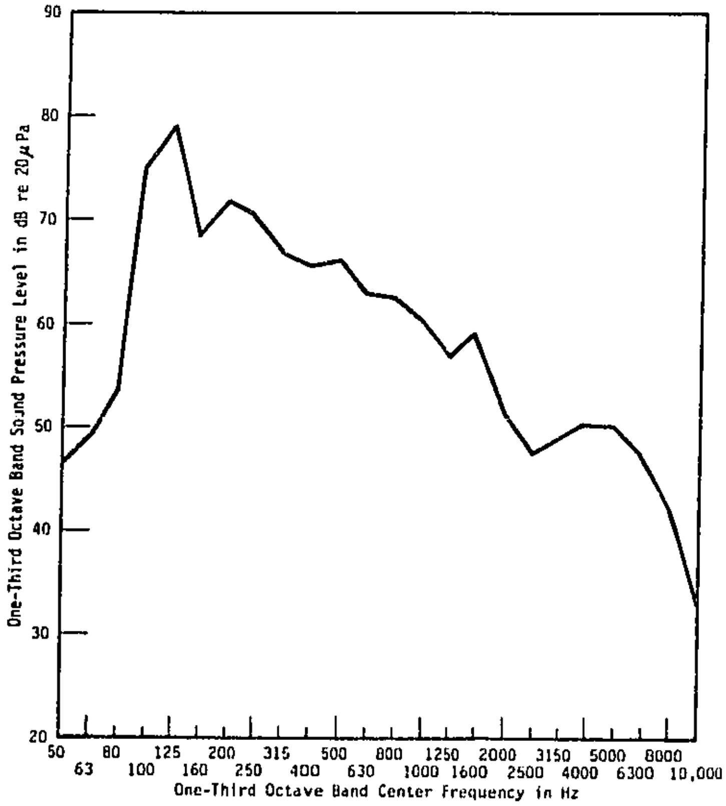

FIGURE B-24. SIGNAL B6 (FIRE PUMPER TRUCK, ACCELERATING)

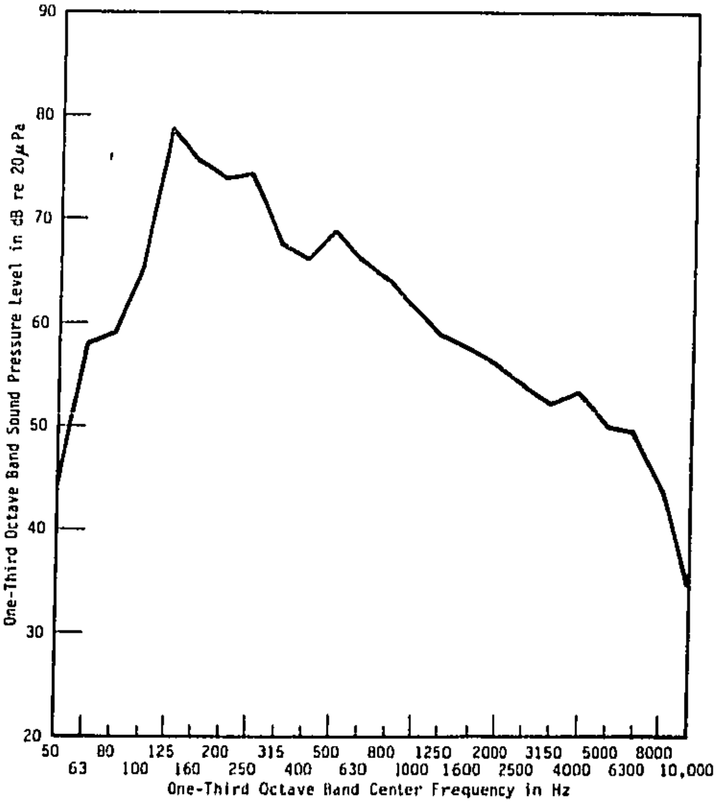

FIGURE B-25. SIGNAL B7 (FIRE PUMPER TRUCK, DECELERATING, 6 CYLINDERS BRAKING)

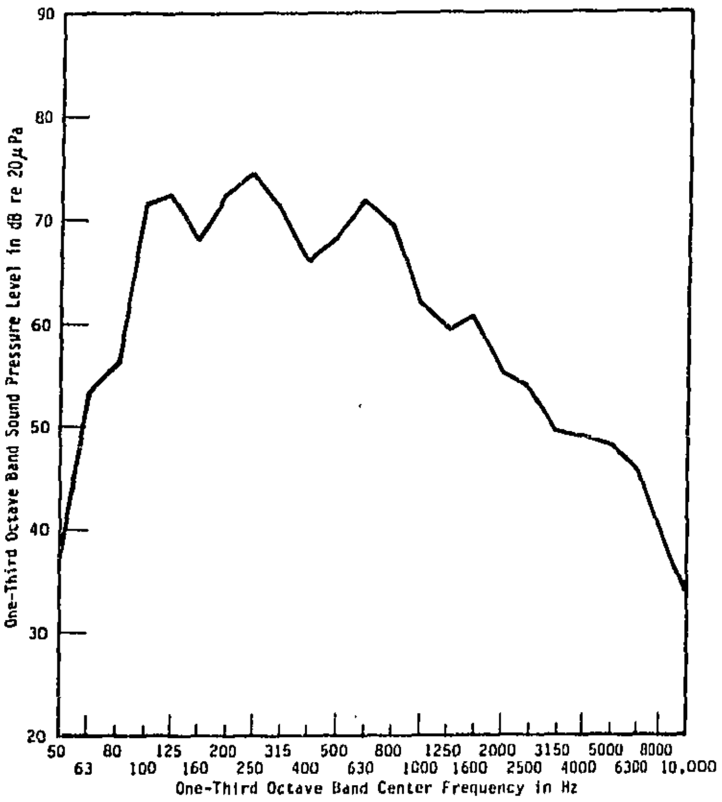

FIGURE B-26. SIGNAL B8 (DUMP TRUCK, DOWNHILL, WITH ENGINE BRAKE)

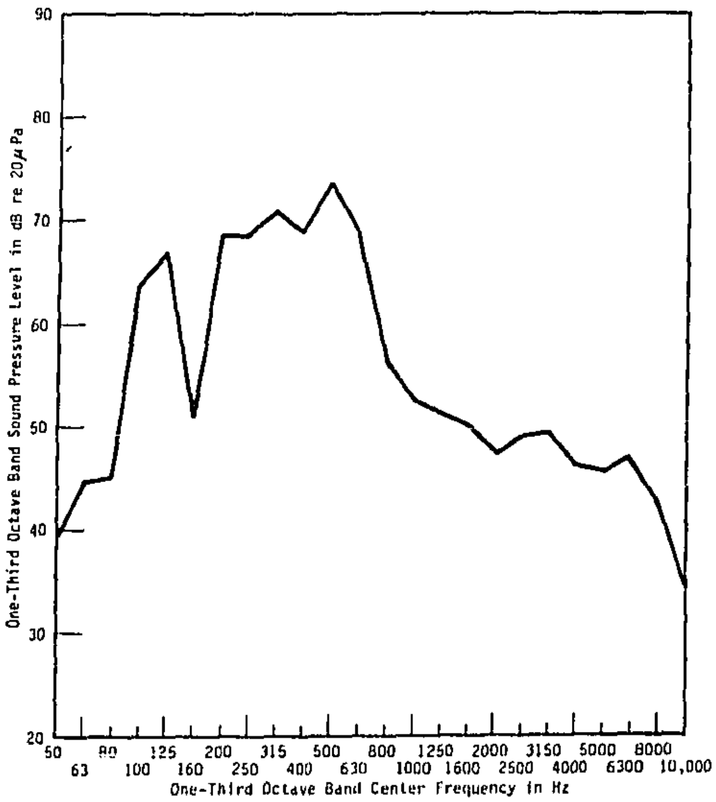

FIGURE B-27. SIGNAL B9 (MOTORCYCLE PASSBY)

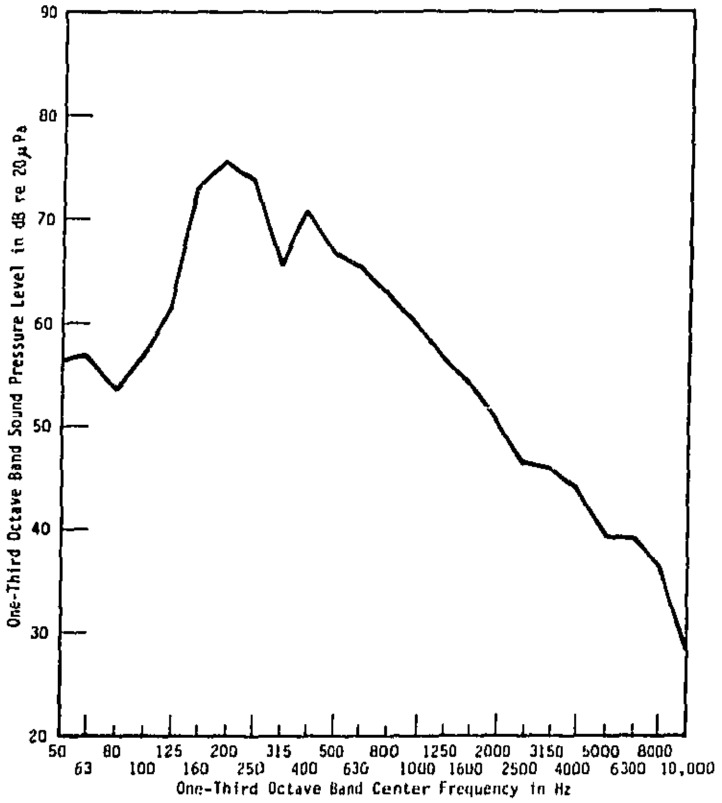

FIGURE B-28. SIGNAL B10 (HELICOPTER HOVER)

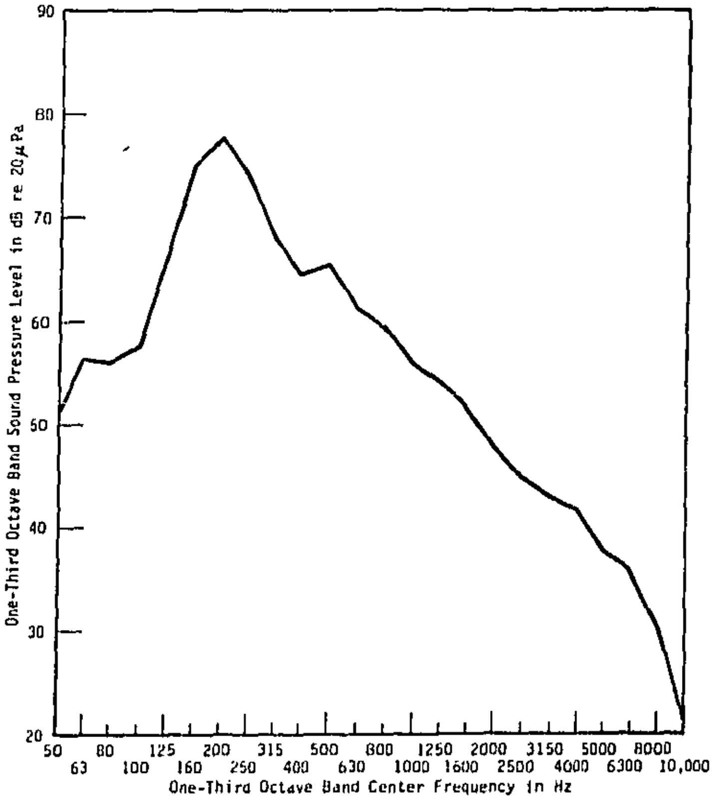

FIGURE B-29. SIGNAL B11 (AIRCRAFT FLYOVER)

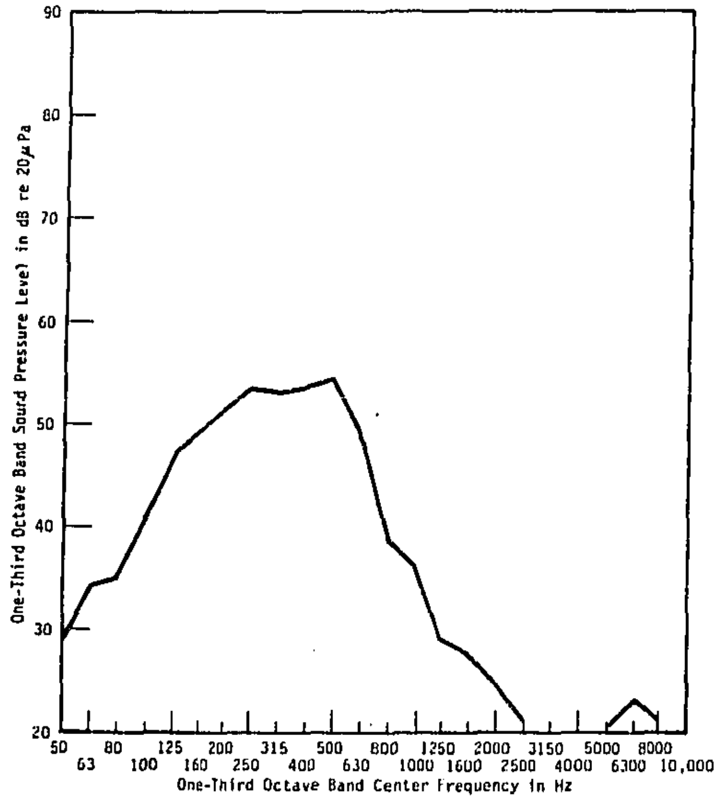

FIGURE B-30. SIGNAL B12 (IMPULSE WAVE TRAIN, 400 Hz SINUSOID, 5 Hz REPETITION RATE)

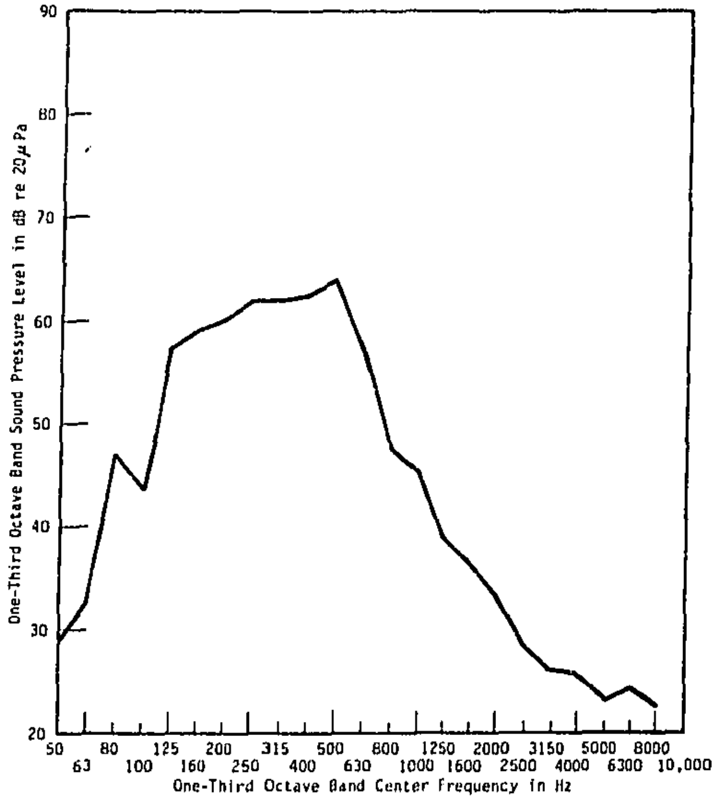

FIGURE B-31. SIGNAL B13 (IMPULSE WAVE TRAIN, 400 Hz SINUSOID, 40 Hz REPETITION RATE)

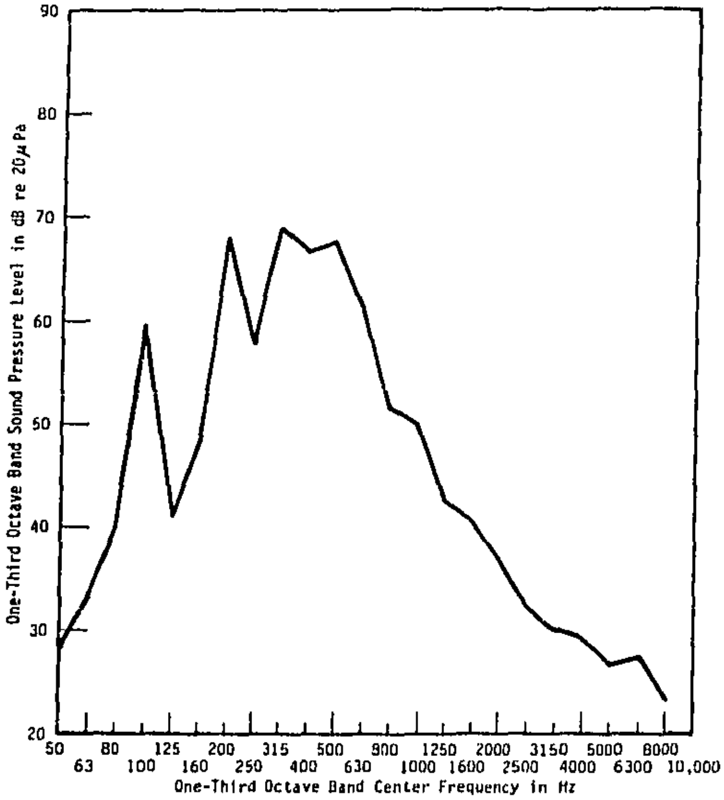

FIGURE B-32. SIGNAL B14 (IMPULSE WAVE TRAIN, 400 Hz SINUSOID, 100 Hz REPETITION RATE)

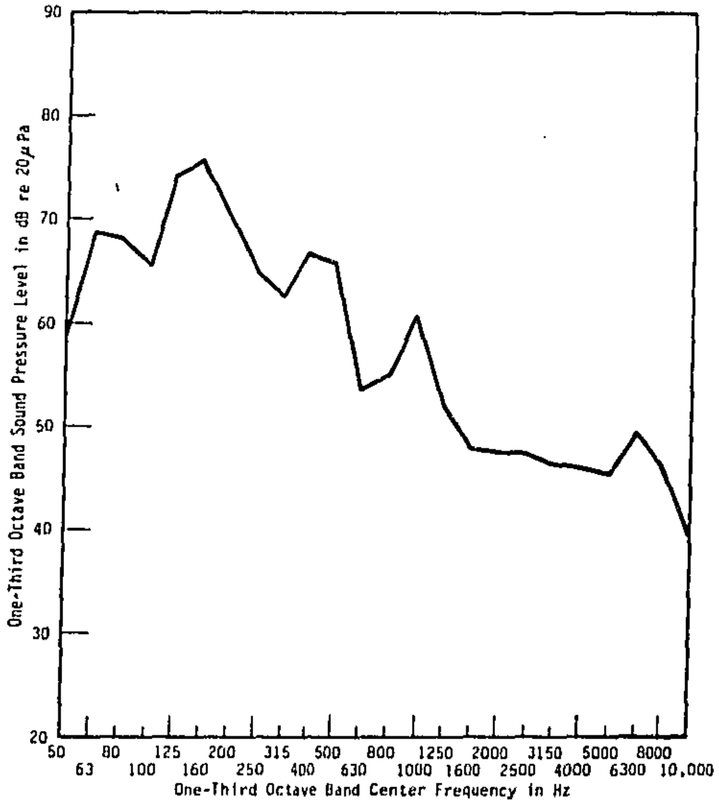

FIGURE B-33. SIGNAL B15 (GAUSSIAN NOISE SPECTRALLY SHAPED TO RESEMBLE TRUCK)

INSTRUCTIONS

During this experiment, you will hear a series of pairs of sounds. Your job will always be the same: to decide which sound of a pair is more annoying. The computer that presents the pairs of sounds to you will vary their length and loudness from time to time, based on which sounds you decide are more annoying.

In order for the computer to keep track of your decisions about which sound of a pair is more annoying, you will have to follow a certain trial procedure. A trial will start when the button marked "1" on your response box lights up. As long as Button 1 is lighted, you will be hearing the first sound of a pair. A short while after the light in Button 1 goes out, Button 2 will light up. As long as Button 2 is lighted, you will be hearing the second sound of a pair. As soon as the light in Button 2 goes out, you must press either Button 1 or Button 2 to indicate which sound you felt was more annoying. A short while later, the next trial will start.

The pairs of sounds you will hear will not be presented in any systematic pattern, but will be randomized by the computer. Since there is no "right" or "wrong" answer for a pair of sounds, and since there is no pattern to the order in which you will hear pairs of sounds, no "plan" or "scheme" can be used to help you make up your mind which sound of a pair is more annoying. All we ever want to know is which sound in the pair you have just heard is more annoying to you.

CONSENT FORM FOR TEST PARTICIPANTS

PART 1: BACKGROUND INFORMATION

This paper tells you about the conditions under which you may choose to participate in an experiment on the relative annoyance of various sounds. You will be asked to listen to many pairs of sounds, and to tell us which sound of each pair you think is more annoying. You will do this by pushing a button after hearing each pair of sounds. You will be seated in the anechoic chamber while making these judgments.

An Institutional Review Board has determined that there are no objective risks in this process. However, if you feel uncomfortable now or at any time during the test and wish to stop, you are free to do so. You may withdraw from the experiment at any time by so informing the person running the experiment and signing a form withdrawing your consent. If you do withdraw, you will receive payment for your participation up to the time you decide to stop.

The study is being conducted for the Environmental Protection Agency. As a participant, you will benefit by being paid a wage of $4.00 per hour. A summary of the results of the study will eventually be available as a government publication.

Please feel free to ask any questions you may have concerning the test procedure.

PART 2: AGREEMENT TO PARTICIPATE IN EXPERIMENT

I have read the above description of the experiment in which I will take part and I have discussed the nature of the study to my satisfaction. I have had the opportunity to ask, and have had answered, any questions I had about the test. I hereby consent to participate in the test. I am at least eighteen years old, and I have no physical or mental conditions that would render my participation more hazardous than to persons without such conditions.

If you have any questions concerning BBN's informed consent procedure, please contact Mr. Kenneth Jackson, Secretary of BBN's Institutional Review Board, at 617 - 497-3560.

Participant Signature:____________________

Witness Signature:____________________

Print Name:____________________

Print Name:____________________

Date:____________________

Date:____________________

PEST PROCEDURE EMPLOYED FOR SUBJECTIVE JUDGMENT TESTS

Parameter Estimation by Sequential Testing (PEST) is an adaptive psychophysical procedure that administers an iterative form of the standard paired comparison task. PEST is called an adaptive procedure because the sequence of signals heard by an observer is not fixed in advance, but rather is determined by his ongoing responses. PEST preserves many of the advantages of the paired comparison method, while gaining the speed and convenience of an adjustment method.

BBN's implementation of PEST is based on an interactive conversation between the experimenter and the computer software. The system acquires information needed for conduct of an experiment by inquiring of the experimenter the values of a series of parameters which determine the course of the PEST procedure. These include signal identification and the levels at which signals are initially presented for judgments.

The experimenter can also specify a standard operating procedure consisting of predetermined values of a dozen parameters such as the intersignal interval, intertrial interval, initial step size, maximum step size, degree of confidence in the observer's responses, anticipated direction of first step, and region of interest of the psychometric function.

In the current use, the program was set to determine the point of subjective equality, or the level at which observers judged each of the pair of signals equally annoying.

The trial procedure is a two-interval forced choice, in which one signal is invariant over trials, while the other signal may change in level. Approximately one second after START switch closure, the computer presents a pair of signals and waits for the observer to decide on his preference for the signal of the first or second interval. Upon receipt of the observer's response, the computer calculates the level at which the variable level signal will be presented on the next trial. After another pause of approximately one second, the computer initiates the next trial by presenting a modified signal pair.

PEST determines the increment in comparison signal level as follows (Taylor and Creelman, 1967):

1. On every reversal of step direction, halve the step size.

2. The second step in a given direction, if called for, is the same size as the first.

3. Whether a third successive step in a given direction is the same as or double the second depends on the sequence of steps leading to the most recent reversal. If the step immediately preceding that reversal resulted from a doubling, then the third step is not doubled; while if the step leading to the most recent reversal was not the result of a doubling, then this third step is double the second.

4. The fourth and subsequent steps in a given direction are each double their predecessor (except that large steps may be disturbing to a human observer and an upper limit on permissible step size of 16 dB is maintained).

A run, composed of a variable number of trials, is terminated when the system determines that sufficient information has been collected. The stopping criterion for a run is normally an anticipated change in level of the variable signal of 1 dB. When a run terminates, a line printer documents the details of the run (numbers of trials, several measures of signal levels, the time, etc.).