VERIFICATION OF MICNOISE COMPUTER PROGRAM FOR THE PREDICTION OF HIGHWAY NOISE

by

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March 12, 1974

IN REPLY PLEASE REFER TO FILE NO. 9-47.15

MEMORANDUM

TO : Mr. J. H. Dillard, Head, Virginia Highway Research Council

FROM : D. F. Noble

SUBJECT: Submittal of the report "Verification of MICNOISE Computer Program For The Prediction of Highway Noise"

The Virginia Department of Highways has acquired several different computer programs for the prediction of highway noise, and has adapted them for its use. The objectives of this study were to verify the computer program presently used by the Department to predict highway sound pressure levels, to determine whether the accuracy and usefulness of the program could be improved, and to make recommendations for future research.

Your attention is called to the following recommendations:

1. The revised MICNOISE computer program should be used essentially as is for the prediction of L_{10} levels within ± 2 dB of actual values, to 68% confidence limits.

2. Further changes to MICNOISE that would alter the predicted levels are not warranted.

3. An evaluation of the predictions for highway barriers should be made.

4. A new prediction program that would avoid the present limitations on MICNOISE should be developed.

In the course of the study, recommendations on changes to the MICNOISE computer program were made to the Environmental Quality Division by memorandum on December 13, 1974, as a preview of the final report.

This study was achieved through the cooperative efforts of the University of Virginia and the Virginia Highway Research Council.

Respectfully submitted,

David F. Noble
Highway Materials Research Analyst

DFN:jmv

Attachment

cc: Mr. J. E. Harwood
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Mr. H. G. Blundon
Mr. H. L. Kinnier
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Environmental Research Advisory Committee
Mr. F. E. Tracy
Mr. B. C. Pierce
Mr. J. W. Nicholson
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Virginia Highway Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways and the University of Virginia)

Charlottesville, Virginia

March 1974
VHRC 73-R37

The number of this report was changed post publication from 73-R37 to 73-R371 when it was discovered that 73-R37 was used for another report

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ABSTRACT

The objectives of this study were to verify the computer program used by the Virginia Department of Highways to predict highway sound pressure levels, to determine whether the accuracy and usefulness of the program could be improved, and to make recommendations for future research.

In the report,the recommendations of NCHRP Report 117 are described briefly because they are the core of the computer program used by the Department. Next, MICNOISE, the Virginia Department of Highways' version of the Michigan/117 computer program, is discussed. Instrumentation, measurement methodology, and analytical techniques are described in detail. On the basis of the evaluation of the predicted sound pressure levels (SPL) against the measured SPL the following conclusions are presented.

1. The revised MICNOISE 5 computer program predicts L_{10} levels within ± 2 dB of actual values, to 68% confidence limits.

2. Further changes in the MICNOISE program will not materially improve the results.

3. Various inherent limitations in the MICNOISE model dealing with final dB summing, the assumption of uniform vehicle separation, the use of the inverse $1\frac{1}{2}$ power law, the absence of a specification for confidence levels, and the lack of an accounting for separate sources of noise in the prediction of noise made by a vehicle are enumerated.

It is recommended that:

1. The revised MICNOISE computer program be used essentially as is for the prediction of L_{10} levels within the aforementioned confidence limits.

2. Further changes to MICNOISE that would alter the predicted levels are not warranted.

3. An evaluation of the predictions for highway barriers should be made.

4. A new prediction program that would avoid the present limitations on MICNOISE should be developed.

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1. INTRODUCTION

1.1 General

Public concern for the environment has led to requirements for governmental organizations to study the effects of their programs on the environment and to prepare environmental impact statements reporting these studies. The noise created by a line of vehicles is one of the environmental effects of building new highway facilities that has to be considered by the Virginia Department of Highways. In order that the many parameters that control highway noise could be adequately weighed, mathematical models to represent highway noise had to be developed. Since such undertakings were beyond the technical expertise of most state highway departments, this need was met by acoustical consultants and federal government sponsored groups such as the Transportation Systems Center located in Cambridge, Massachusetts. Among recent publications those of J. L. Beaton and L. Bourget of the California Division of Highways,[1] W. J. Galloway et al. of Bolt, Beranek and Newman,[2] the report by Serendipity, Inc.,[3] and the text by Bolt, Beranek and Newman,[4] focus attention on the problem of highway noise and on models for predicting sound levels.

The Virginia Highway Department first acquired a computerized version of the simulation model presented by W. J. Galloway et al.,[2] and slightly modified the model and computer program, calling it "NOISESIM". Inasmuch as the Federal Highway Administration had not approved "NOISESIM" for use in preparing environmental impact statements, the Highway Department obtained the FHWA approved Michigan/117, a computerized version of the model presented in NCHRP Report No. 117 by C. G. Gordon, et al. of Bolt, Beranek, and Newman.[5] The Virginia version is named MICNOISE. One of the problems with the available models is that they have not been thoroughly validated. Therefore, it seemed prudent that the validity of MICNOISE be investigated by directly evaluating its predictions against measurements of highway noise. This report presents the results of the evaluation of MICNOISE.

It was not the intent of this study to survey all the available highway noise simulation models. Nor was it the intent of this study to effect any major changes in the model presently used by the Department.

1.2 Purpose of MICNOISE Computer Program

The purpose of the MICNOISE computer program is to predict the L_{10} and L_{50} sound pressure levels; that is, the levels in A-weighted decibels, or dBA, exceeded 10% and 50% of the time, respectively. The L_{10} sound pressure level has been chosen by the Federal Highway Administration for the presentation of predicted noise levels near proposed highways, while both L_{10} and L_{50} are commonly given in environmental impact statements relating to new highways. MICNOISE predicts expected levels, so that the average prediction error should be zero and the confidence that the predicted level is not exceeded should be near 50%.

The use of L_{10} and L_{50} is not universally accepted, and it is sometimes suggested that any predictions should be based on L_{EQ}, which is the sound pressure level in A-weighted decibels based on a long-term average of the pressure squared. The advantage of this form is that combined effects from many sources are easy to calculate. MICNOISE does not predict L_{EQ}, but, in a sense, uses L_{50} in its place.

1.3 Objectives

The objectives of this investigation were as follows:

1. To compare the highway sound pressure levels predicted by the MICNOISE computer program with the highway sound pressure levels measured at the test sites from which the data input for the computer program was taken.

2. To determine whether minor changes to the program can be made which will improve its accuracy and usefulness, and to evaluate these.

3. To make recommendations for future research into highway noise prediction and control, if it appears to be appropriate.

2. CURRENT STATUS OF MICNOISE COMPUTER PROGRAM

The MICNOISE computer program is based on the recommendations of Report 117,[5] prepared under the National Cooperative Highway Research Program. In the main body of Report 117, the basic theory of highway noise prediction is presented, while a detailed method of calculation is given in the Appendix to that report.

The original Michigan/117 computer program was prepared by the Michigan Department of Highways and followed the method of calculation given in Report 117 very closely. However, some changes have been incorporated into the Virginia Department of Highways' version, known as MICNOISE (Version 2;8/1/72), as listed in Appendix B, for conversion from time-sharing to batch format on the IBM 360. During the final stages of the preparation of this report, a new version, Michigan/144, was received from Michigan. This version has also been converted to batch format on the IBM 360.

It was received too late for inclusion in this evaluation, but comments have been made in the present report wherever the new program differs significantly from the one that was evaluated. This new program is referred to as MICNOISE Version 5, 9/1/73. In the following discussion, Version 2 is simply referred to as MICNOISE, while the revised program is called MICNOISE 5. Later in this report reference is made to a modified MICNOISE program which was evaluated during the study. This program essentially anticipated changes incorporated into MICNOISE 5 and is therefore considered as adequate verification of the latter program.

In the next section, the recommendations of the main body of Report 117 are discussed. The discussion is followed by a description of and comments on the current MICNOISE and MICNOISE 5 programs.

2.1 Recommendations of NCHRP Report 117

2.1.1 Theoretical Traffic Model

Johnson and Saunders[6] derived a simple highway noise model based on a line of vehicles, equally spaced at a distance T apart, traveling at the same speed $\bar{S}$. (The units of $\bar{S}$ are assumed to be consistent with the distance from the road, D, and time, t.) If each vehicle causes a reference sound pressure level of L_{REF} dBA at a reference distance of D_{REF}, then the total sound pressure level in decibels (dB) at a distance D from the line would be a function of time, L(t), where

$$L(t) = L_{REF} + 10 \log_{10} \sum_{n=-\infty}^{\infty} \frac{D_{REF}^2}{D^2 + (\bar{S}t + n\,T)^2} \tag{1}$$

In the following discussion, the results presented in Report 117 are rederived, using a slightly different terminology.

First, the summation in Equation (1) is replaced, leading to

$$L(t) = L_{REF} + 10 \log_{10} \frac{\pi D_{REF}^2}{DT} \left[\frac{\sinh (2\pi\, D/T)}{\cosh (2\pi D/T) - \cos (2\pi\, \bar{S}t/T)} \right] \tag{2}$$

Equation (2) resembles a distorted sine wave. As the argument $2\pi\, D/T$ becomes large, the time variation decreases, and L (t) approaches the sound pressure level given by a continuous line source model, i.e.

$$L(t) \xrightarrow[D/T \to \infty]{} L_{CONT} = L_{REF} + 10 \log_{10} \left\{ \frac{\pi D^2_{REF}}{DT} \right\} \tag{3}$$

The L_{50} level is obtained by taking cos $(2 \pi \bar{S}t/T)$ as zero, thus

$$L_{50} = L_{CONT} + 10 \log_{10} \tanh \left\{ 2 \pi D/T \right\} \quad (4)$$

while the L_{10} level is obtained by taking the argument of the cosine term as 18^{o}, thus cos $(2 \pi \bar{S}t/T)$ is 0.951, and

$$L_{10} = L_{50} + 10 \log_{10} \left\{ \frac{\cosh (2 \pi D/T)}{\cosh (2 \pi D/T) - 0.951} \right\} \quad (5)$$

2.1.2 Calculation of L_{50} at 100 Feet

In the method recommended in Report 117 and incorporated into MICNOISE, the noise level of each line of automobiles and trucks is first calculated separately at 100 ft. Then corrections are incorporated for distance and attenuation, and the levels are combined.

If S_A is the automobile speed in mph, and V_A is the traffic volume in vehicles per hour, the sound level produced by a typical automobile at a distance D_{REF} may be expressed in the form

$$L_{REF}(\text{auto}) = K_A + 30 \log_{10} \left\{ S_A/S_{REF} \right\} \quad (6)$$

where S_{REF} is a reference speed in mph. Taking this speed as 60 mph. and D_{REF} as 100 ft., the value for the constant K_A consistent with Report 117 is 64.60 dBA. Then after substituting from Equations (3) and (6), Equation (4) can be written for automobiles at 100 ft. as

$$L_{50} (\text{auto}, 100') = 10 \log_{10} \left\{ V_A S_A^2 \tanh (0.119 V_A/S_A) \right\} -1 \quad (7)$$

Report 117 recommends that the sound level for trucks be taken independent of speed; therefore we obtain

$$L_{REF}(\text{truck}) = 77.26 \text{ dBA at } D_{REF} = 100 \text{ ft.} \quad (8)$$

Thus, from Equations (3), (4), and (8),

$$L_{50}(\text{truck}, 100') = 10 \log_{10} \left\{ V_T \tanh (0.119 V_T/S_T)/S_T \right\} +65 \quad (9)$$

Plots of Equations (8) and (9) are given in Report 117 as Figures 3 and 4, and again as Figures B-3 and B-4.

2.1.3 Distance Correction — DEL1

In Report 117, Figure B-5 gives the correction, DEL1, in dB for distances D other than 100 ft., or for cases where the number of lanes of traffic, P, is greater than one. The procedure is described as follows:

Given the near lane distance D_N, the far lane distance D_F is calculated from

$$\begin{aligned} D_F &= D_N + 12P - 12; \text{ for } P \leq 2 \\ &= D_N + 12.5P - 12; \text{ for } P > 2 \end{aligned} \qquad (10)$$

then the equivalent distance D_E is

$$D_E = \sqrt{D_N D_F} \qquad (11)$$

and the correction given is

$$\text{DEL1} = -15 \log_{10} \left\{ D_E/100 \right\} \qquad (12)$$

This expression for DEL1 is based on the assumption of an inverse $1\frac{1}{2}$ power law for distance, whereas the theoretical predictions of Equations (2) to (5) give more complex variations because D_E appears in the arguments of the hyperbolic functions within these equations.

2.1.4 Roadway Length Correction — DEL2

Report 117 recommends a correction, DEL2, for a segment of roadway which subtends an angle Θ to the observer which is less than 180° as though it were a uniform line source. Thus the correction is

$$\text{DEL2} = 10 \log_{10} \left\{ \Theta/180 \right\} \qquad (13)$$

Two plots are given for this purpose in Figures B-6 and B-7 of Report 117. The first gives the correction for a finite element, the second for a semi-infinite element. In the latter case, Θ appears in Figure B-7 as the symbol for the complement of the subtended angle.

2.1.5 Grade Correction — DEL3

A grade correction for trucks varying from 0 to 5 dB for grades from $\leq 2\%$ to $\geq 7\%$ is recommended in Report 117.

2.1.6 Vertical Correction — DEL4

Corrections for elevated and depressed roadways, are given for automobiles in Figure B-8 of Report 117. The correction for trucks is 5 dB less than for automobiles.

2.1.7 Roadway Surface Correction — DEL5

Corrections varying from -5 to +5 dB are recommended for conditions varying from very smooth pavement to very rough pavement, respectively.

2.1.8 Barrier Correction — DEL6

Corrections for infinite barriers are given for automobiles in Figure B-9 of Report 117. For finite barriers, further corrections are tabulated in terms of a parameter A, which is the ratio α/Θ, where α is the angle subtended by the barrier and Θ is the angle subtended by the road, as defined for DEL2. The correction for trucks is 5 dB less than for automobiles.

2.1.9 Structure Correction — DEL7

A correction of no more than -10 dB is suggested for the effects of intermediate buildings.

2.1.10 Calculation of L_{10}

The method recommended in Report 117 to calculate L_{10} is to find the difference, $L_{10} - L_{50}$, from Figure B-10 as a function of the parameter VD/S. This method yields larger values than Equation (4). When flow is interrupted, as at a traffic light, the report suggests that L_{10} be increased by 2 dB for automobiles, and by 4 dB for trucks to account for the additional sound caused by acceleration and deceleration.

2.1.11 Combination of Levels

The procedures described up to now lead to separate predictions of L_{50} and L_{10} levels for automobiles and trucks. Results may be further separated into different road elements or into finite length roadway sections.

The procedure recommended in Report 117 is that of "dB summing", whereby any two levels, say L_1 and L_2, are combined as follows

$$L = 10 \log_{10} \left\{ 10^{L_1/10} + 10^{L_2/10} \right\} \qquad (14)$$

2.2 Virginia Department of Highways' Version of MICNOISE

The following comments apply to the Virginia Department of Highways' MICNOISE, Version 2, except where specific reference is made to MICNOISE 5.

2.2.1 Table-Look-Up Functions

The MICNOISE computer program substitutes table-look-up and interpolation for graphs in the following cases:

(1) Distance correction, DEL1

(2) Roadway length correction DEL2

(3) Correction to L_{10}

2.2.2 Corrections Inserted By Program User

The following corrections are determined by the program user and are inserted with the other input data.

(1) Grade correction for trucks, DEL3

(2) Roadway surface correction, DEL5

(3) Structure correction, DEL7

(4) Option to use interrupted flow correction

2.2.3 Vertical and Barrier Corrections

The vertical and barrier corrections have been changed completely and are now based on the Fresnel method, as shown in Figure 8 of Report 117, with λ (wavelength of sound) presumably taken as 5 ft.

The method used is illustrated in Figure 1, which shows the vertical correction, DEL4, and the barrier correction (DEL6 if the barrier is infinite) in decibels as functions of the deficiency $\Delta = X + Y - Z$. For values of Δ less than .01 ft. the correction drops to zero. Also, for trucks it is reduced by 5 dB.

In calculating the distances X, Y and Z required for Δ, the distance from the observer to the roadway is taken as D_E, which is calculated from Equations (10) and (11). A further table-look-up replaces the finite barrier adjustment given in Figure B-9 of Report 117.

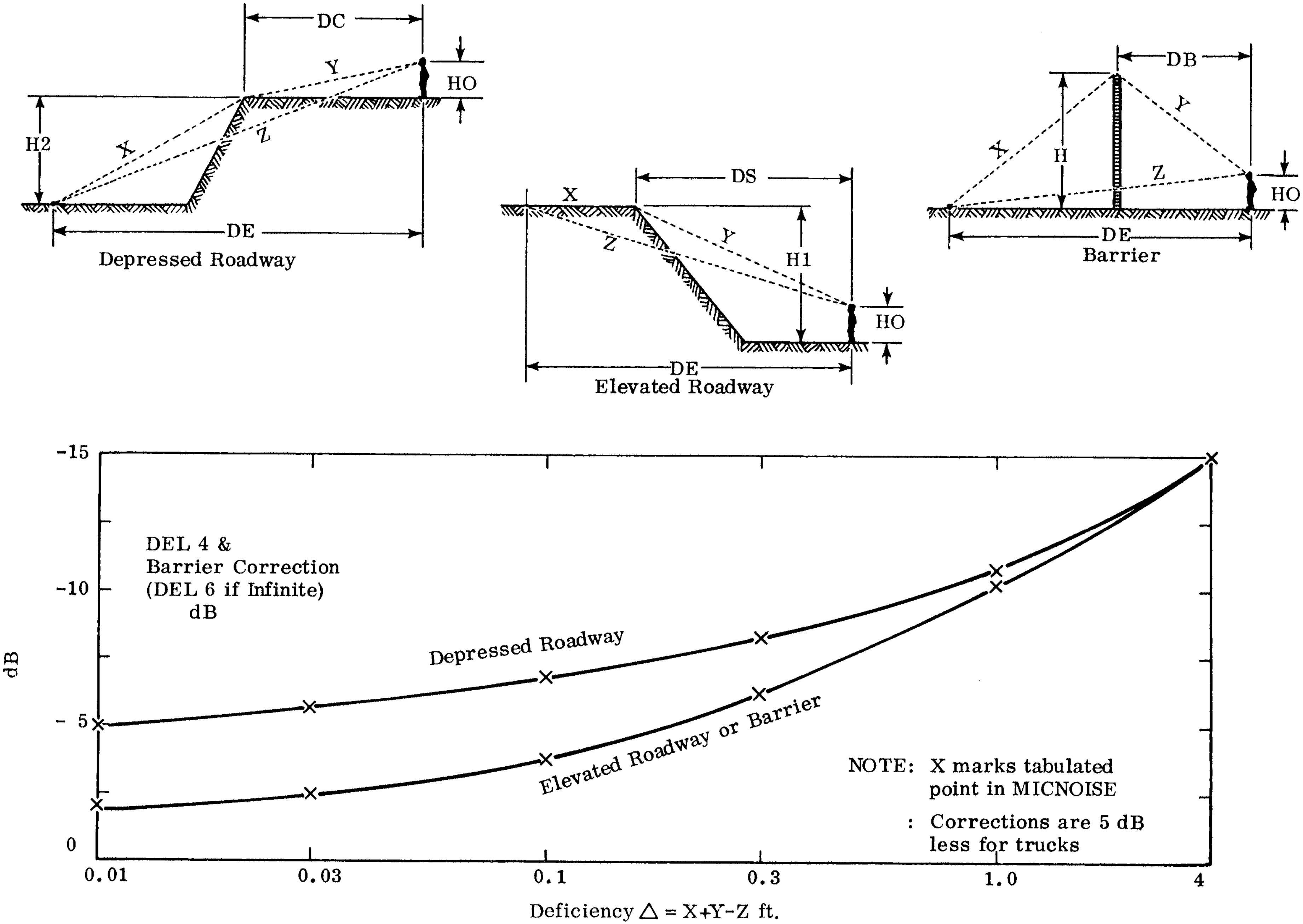

Figure 1. Vertical and barrier corrections in MICNOISE.

2.2.4 The "Twilight Zone"

When the L_{10} - L_{50} curve was tabulated in the current MICNOISE program the lowest value for the parameter VD/S supplied was 300 ft/mile. If truck traffic falls lower than this value, so that the corresponding L_{10} - L_{50} correction cannot be obtained, traffic is then said to be in the "twilight zone", where 15 automobiles are substituted for each truck, and the calculations are resumed. In MICNOISE 5, the L_{10} - L_{50} curve is tabulated down to 20 ft/mile, thereby eliminating the "twilight zone" procedure.

2.3 Comments on MICNOISE

During the present study, a number of problems in the use of MICNOISE were noted. These are discussed below. Specific recommendations are made elsewhere in this report.

2.3.1 Traffic Model

The traffic model in MICNOISE is not theoretically correct in the following respects:

(1) It replaces a random phenomenon with a precise model in which traffic moves at uniform speeds and is uniformly spaced.

(2) The dB-summing method of combining different lines of traffic and of combining automobile and truck noise is incorrect. In fact, it would be correct only if the lines of traffic so summed were to coincide.

If L_{EQ}, which is based on the time-averaged root mean squared (RMS) pressure, were calculated first, it could be obtained correctly by dB-summing the values of L_{CONT} obtained for the individual lines of traffic. Further it would be necessary to know only the average traffic during a given period to predict L_{CONT} correctly. Given a reliable basis in L_{EQ}, it might be possible to obtain good estimates for L_{50} and L_{10} based on overall traffic flows, and even to state the confidence limits on these estimates.

2.3.2 Line of Sight Errors

Presently, if a vertical or barrier correction is called for when the observer is, in fact, in line of sight of the road, an erroneous correction is calculated because a positive value is still obtained for the deficiency Δ shown in Figure 1. This has been corrected by a programmed test for line-of-sight in the revised MICNOISE 5 program.

2.3.3 Distance Correction

For reasons discussed in Report 117 and partly based on the results obtained by Galloway[2] on a simulation model, MICNOISE uses the inverse $1\frac{1}{2}$ power law for distance as in Equation (12) in place of the more complex variation given by Equations (4) and (5).

If Equations (7) and (9), which predict L_{50} levels for automobiles and trucks, were redefined in accordance with the theoretical model in Equation (4), we would have

$$L_{50}(\text{auto}) = 10 \log_{10} \left\{ \frac{100 V_A S_A{}^2}{D_E} \tanh\left(\frac{0.00119\ V_A D_E}{S_A} \right) \right\} - 1 \qquad (15)$$

$$L_{50}(\text{truck}) = 10 \log_{10} \left\{ \frac{100\ V_T}{D_E S_T} \tanh\left(\frac{0.00119 V_T D_E}{S_T} \right) \right\} + 65 \qquad (16)$$

In this approach, there would be no separate distance correction, DEL1. It is readily shown that the difference, ΔL, in decibels, between the inverse $1\frac{1}{2}$ power law used in MICNOISE and that given by Equations (15) and (16) is

$$\Delta L = 10 \log_{10} \left\{ \frac{\tanh\ (0.119\ V/S)}{\tanh\ (0.119\ D_E V/100S)} \right\} - 5 \log_{10} \left\{ \frac{D_E}{100} \right\} \qquad (17)$$

This difference, which is shown in Table 1 as a function of D_E in feet for several values of V/S (vehicles per mile), is the same for automobiles and for trucks. It will be seen that MICNOISE predicts sound levels which are lower (negative ΔL) than those predicted by theory as D_E increases beyond 100 ft.

The values in the last column of Table 1 are essentially the results of assuming the inverse $1\frac{1}{2}$ power law on a continuous model. It will be seen that ΔL is numerically larger as the traffic becomes more spaced out.

Table 1

Distance Correction Differential, Δ L, in dB

Distance D_E ft.	V/S = Vehicles Per Mile					
	0.6	2	6	20	60	200
30	7.84	7.77	7.25	4.66	2.73	2.61
100	0	0	0	0	0	0
300	- 7.10	- 6.58	- 4.39	- 2.46	- 2.39	- 2.39
1,000	-14.35	-11.24	- 7.12	- 5.07	- 5.00	- 5.00
3,000	-18.74	-13.70	- 9.51	- 7.46	- 7.39	- 7.39
10,000	-21.47	-16.32	-12.12	-10.07	-10.00	-10.00

2.3.4 Engine and Tire Noise

As noted in Sec. 2.1.2, automobile noise is assumed in Report 117 to increase as the cube of speed, whereas truck noise is held to be independent of speed. However, increasing evidence is being presented in the literature (see for example reference 7) that the different noise sources on trucks and automobiles obey different laws.

For example, because the surface correction is "straight through" at present, a negative smooth pavement correction for trucks is evidently unrealistic and should not be used. However, the reverse is reasonable, because it might well be valid to add 5 dB for a very rough road, in which case tire noise would dominate.

An obvious improvement would be to calculate engine, gear, exhaust, airflow and tire noises separately, and to apply corrections accordingly before combining.

2.3.5 Format for Terrain Data

The format in the current MICNOISE program allows for combinations of infinite, semi-infinite and finite road elements, which may be separately elevated or depressed. Barriers, either infinite, semi-infinite or finite, can be added. The height of the observer above a ground plane can be given.

In practice, the necessary information is confusing to obtain, and certain combinations, such as barriers on elevated highways, are difficult to put into the data format.

A method of supplying elevations of the roadway, highpoints, and observer height above the reference plane used in the highway layout would be preferable, because the data would be simpler to supply and more flexible, and would lead to a simpler computer program. The revised MICNOISE 5 program essentially meets these requirements.

2.3.6 Table-Look-Up

MICNOISE presently uses table-look-up interpolation on functions which can be computed readily. These are:

(1) Distance correction, DEL1: Equations (10), (11) and (12) could be used instead. In fact, D_E is already calculated from Equations (10) and (11) for the vertical correction, DEL4.

(2) Roadway length correction, DEL2: Equation (13) could be used instead.

2.3.7. Vertical and Barrier Corrections

The vertical and barrier corrections used at present may well be good compromises. However, the following points are made.

(1) The corrections are based on theoretical and experimental data (see Beranek[8] for further discussion) in which the dimensionless ratio λ /D (the Fresnel angle) is a parameter. It can be reduced to the form of Figure 1 only if a given spectral shape is assumed for all highway sounds.

(2) The theory predicts some correction even in line of sight, whereas there is no provision for this in MICNOISE.

(3) Some lanes may be in sight while others may be out of sight. Calculations are based on the center of the roadway, and also neglect the height of the vehicle above the roadway. (However, 5 dB is taken off for trucks, some of which may have high exhaust stacks.)

Some changes have been incorporated into the revised MICNOISE 5 program, which now uses one curve (the depressed roadway correction on Figure 1) for all cases. Also, an elevation of 8 ft. is added for all trucks, in place of the 5 dB reduction in attenuation.

2.3.8 The "Twilight Zone"

The present method of handling the "twilight zone" is acknowledged to be unsatisfactory. According to Report 117, the theoretical model for the $L_{10} - L_{50}$ correction, which can be written as

$$L_{10} - L_{50} = -10 \log_{10} \left\{1 - 0.951/\cosh\,(0.00119\ VD_E/S)\right\} \qquad (18)$$

should be adequate in the twilight zone, where the parameter VD/S is small.

In Figure 2 the values of the correction, as stored in MICNOISE, are plotted for comparison with a curve derived from Equation (18). It will be noted that the

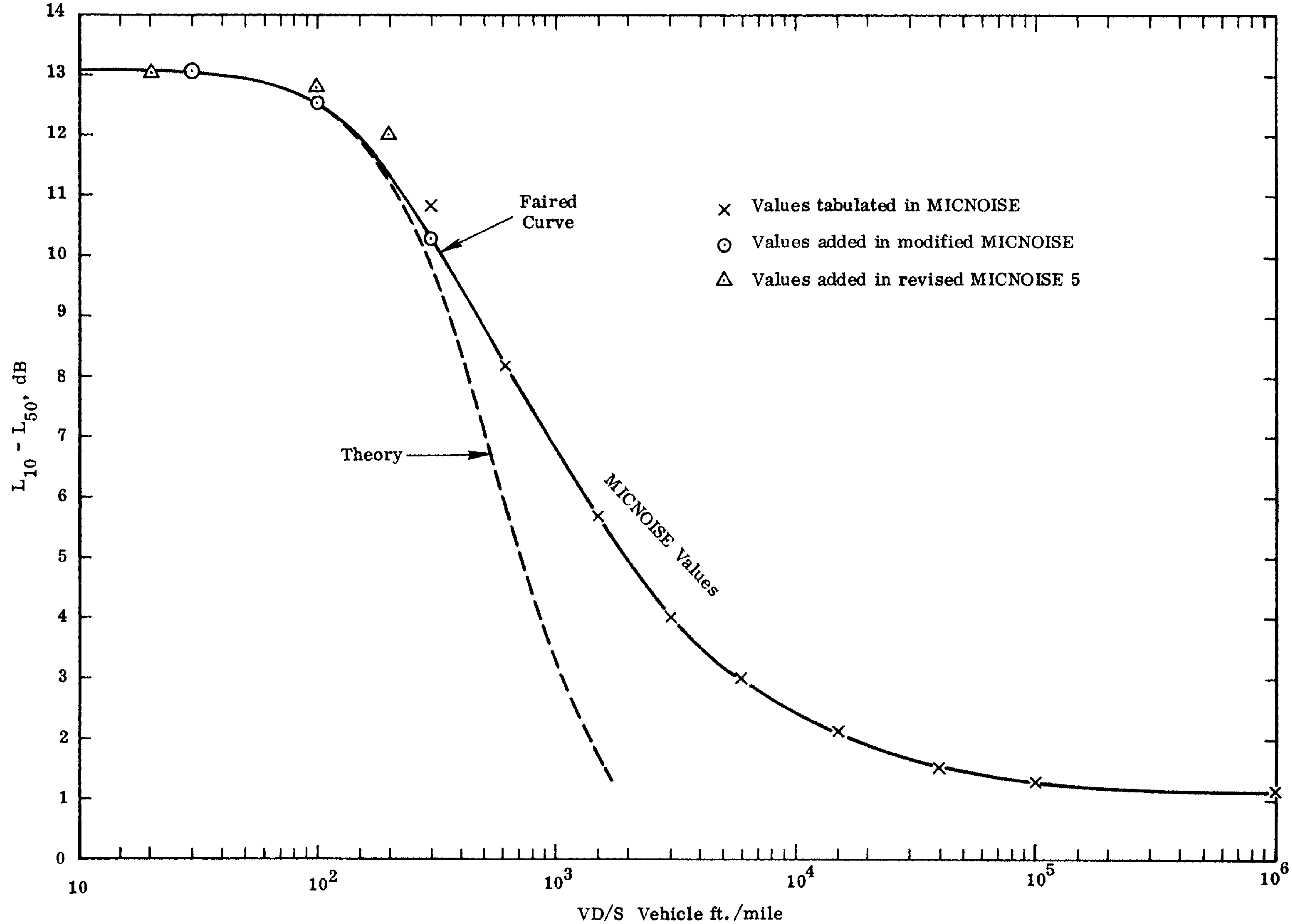

Figure 2. Values of $L_{10} - L_{50}$ vs. vehicle spacing.

theoretical maximum of 13.1 dB is derived from Equation (18) when VD/S is zero. At the edge of the twilight zone, with VD/S equal to 300, the MICNOISE program gives 10.87 dB whereas the theory gives 9.72, a difference of 1.15 dB. Evidently, a promising approach to correcting the "twilight zone" problem would be to develop a composite curve which would make a smooth transition from the present curve into the theoretical one, such as one of those shown in Figure 2. Of these, the lower points have been used for the modified MICNOISE program evaluated in the present report, while the upper points are incorporated into the revised MICNOISE 5 program.

3. PLANNING AND PROCEDURES

3.1 Site Selection

The model used in the computer program was studied to determine what parameters had the greatest effect on the predictions, so that as few variables as possible could be used to choose test sites and the total number of sites needed could be kept within bounds. It was decided that the criteria of traffic volume and roadway geometry were sufficient for choosing test sites. Other factors such as observer distance, road surface, and traffic mix, could either be varied within a site or restricted to the range available from sites selected by the above two criteria.

Considering traffic volume to vary from low (300 — 1,000 vehicles per hour) to medium (1,000 — 3,000 vph) to high (3,000 — 10,000 vph), and roadway geometry to be either depressed (cut), elevated (fill), or level, nine types of test sites can be identified. The designation of the appropriate traffic volumes as low, medium and high covers variations experienced in practice, and represents 5 dB intervals in predicted noise levels.

It was considered desirable to have free flowing traffic, which is a condition that most interstate roads satisfy. The urban centers of Northern Virginia, Richmond, and the Tidewater area have interstate highways and meet both the medium and high traffic volume criteria. The desired roadway geometry and low traffic volumes could be found within central Virginia.

3.1.1 Test Sites

Table 2 contains the locations and the criteria used to choose the test sites for this investigation. Detailed descriptions of these sites are to be found in Section 4 and in Tables A-1 through A-27 of Appendix A.

Table 2

Test Sites

No.	Route	Location	Geometry	Traffic Volume
1	I-495	Springfield	Depressed	Medium/High
2	I-495	Alexandria	Level	Medium/High
3	I-64	near Fishersville	Elevated	Low
4	U.S.-29	near Ruckersville	Depressed	Low
5	I-95	near Doswell	Elevated	Medium

3.2 Instrumentation

When dealing with a phenomenon such as sound, and in particular highway noise, which is essentially continuous though of fluctuating intensity and spectral makeup, it is necessary to have a data acquisition system which will accurately pick up, measure, and record the sound. In addition, considering the real life situation where people (i.e. sensors or receivers) are living at various distances from the roadway, it is desirable to take simultaneous measurements near and at some distance from the roadway. The reason for always taking a measurement close to the road is that a reference measurement is available, for comparison with those taken at other times.

To achieve the desired flexibility in the present study two B & K Model 2204 precision sound level meters with either one-inch B & K Model 4145 or half-inch B & K Model 4133 free-field condenser type microphones, two B & K Model 4230 calibrators, 400 ft. of coaxial cable, a portable two-channel, Nagra Model SD tape recorder and 3M No. 206 magnetic tape were used. Counting boards and two vehicular detection radar units were used to obtain data on vehicles per hour, number of trucks, and the average speed.

3.3 Test Procedures

A line, along which the microphones were located, was laid off approximately perpendicular to the roadway. The distances (50, 100, 200, and 300 ft.) at which the microphones were located from the roadway were measured horizontally. The equipment was arranged as shown in Figure 3. The main point to note about the arrangement was that the sound level meters, tape recorder, and technician were located off to the side of the measurement line as far as possible so that they would not interfere with the sound as it traveled to the microphones. Wind screens were used on the microphones and an umbrella was set over the sound level meters and tape recorder to shield them from direct sunlight and light rain.

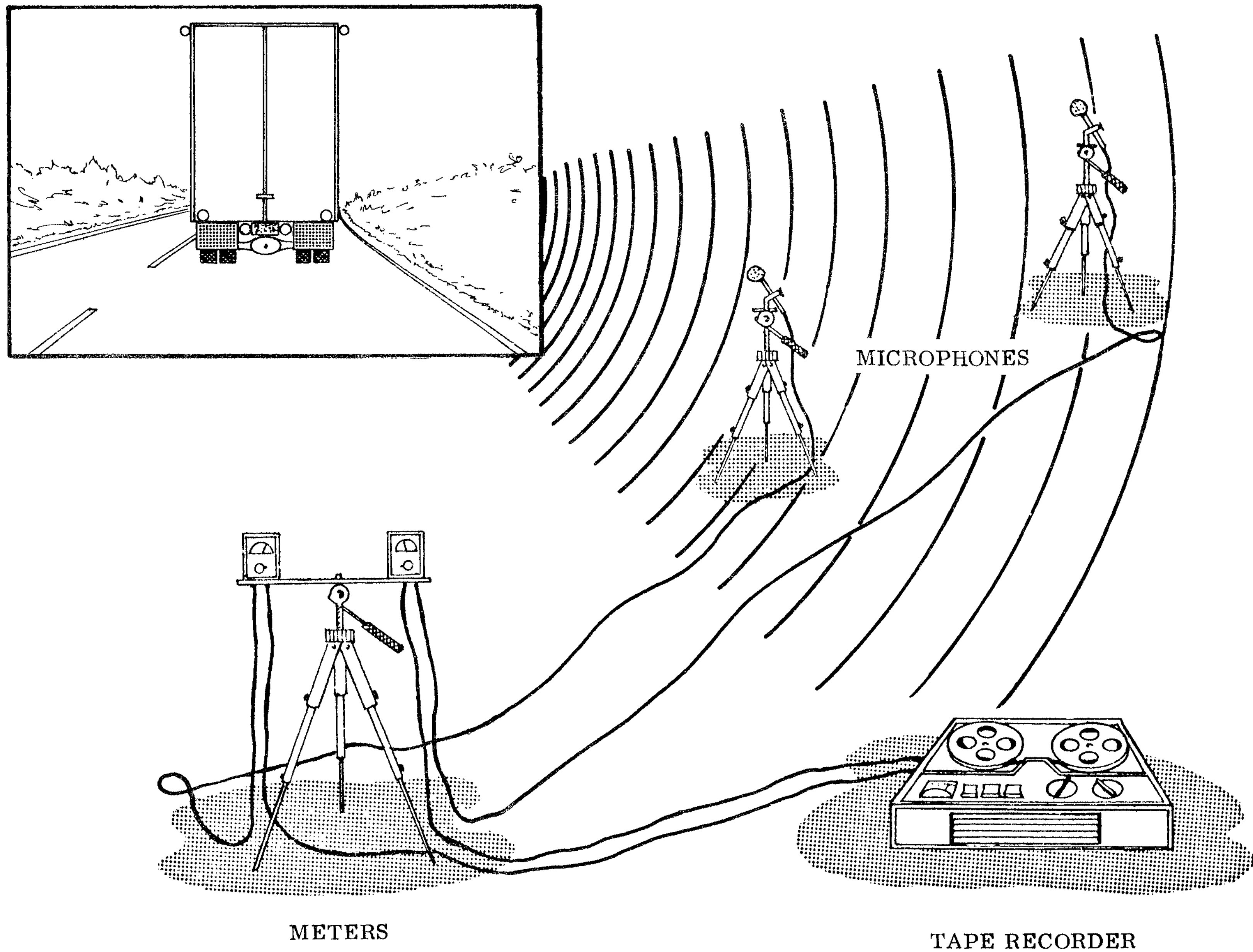

Figure 3. Schematic of measurement system.

The microphones were mounted vertically on tripods at an elevation of 5 ft. above ground. Signals were fed through as many as three 100-ft. lengths of microphone cable to the precision sound level meters. The AC outputs from the sound level meters, which were on the linear/record position, were fed into the two channels of the tape recorder.

The calibration of the sound level meters was checked at the beginning of each day. Before each trial, three 30-second calibrator recordings were made simultaneously on each microphone with the attenuators on the sound level meters set to 90, 100, and 110 dB in sequence. Thus the calibration signals were equivalent to the attenuator setting during recording, plus 3.6, -6.4, and -16.4 dB respectively on the one-inch microphones (3.8, -6.2, and -16.2 on the half-inch microphones). By covering a considerable proportion of the recording range with calibration signals in this manner, checks on the overall linearity of the system were provided.

Each trial had a duration of 10 to 15 minutes. The starting time for a test was usually chosen so that the test would be completed during the occurrence of a specific traffic density, but close enough to a density change that a second test could be run at a different traffic density without waiting for too long a time.

The test sites were located on either 4-lane or 6-lane divided highways. With fast moving medium to heavy traffic, the personnel who were counting traffic and monitoring the indicating meter for the radar were positioned so that they could observe all the lanes for traffic moving in one direction. Coordination of the start and the end of the measurement period among all the data collectors was difficult because of the high noise levels and because one of the traffic monitors was located on the opposite side of the highway at least 200 feet distant, and sometimes out of the line of sight. The radar sensor heads were located approximately 50 ft. downtraffic from the measurement site in the expectation that drivers would not radically change speed as they passed through the site.

3.4 Data Analysis

3.4.1 Laboratory Analysis

The laboratory setup is shown in Figure 4. Recordings were played back through either the original Nagra Model SD recorder on which they had been made or through a Nagra Model SJ recorder. For producing permanent records, and for quick checks on the data, they were first played through a B & K model 2113 Audio Frequency Spectrometer, set to A-weighting, and the AC output was fed into a B & K Model 2305 Level Recorder, with a 50 dB potentiometer, set to RMS. Strip chart recordings of the dB-A levels were thus made, preceded by three levels of calibration signal.

For the determination of cumulative exceedence levels the DC output of the Model 2113 was played into a Federal Scientific Model UC-202B Correlator, set to the cumulative distribution function. The DC output of the Model 2113 is a negative voltage proportional to RMS sound pressure and ranging from -2.43 volts at maximum pressure to -0.040 volts at minimum pressure, which represents an overall range of 35 dB, of which about 32 dB

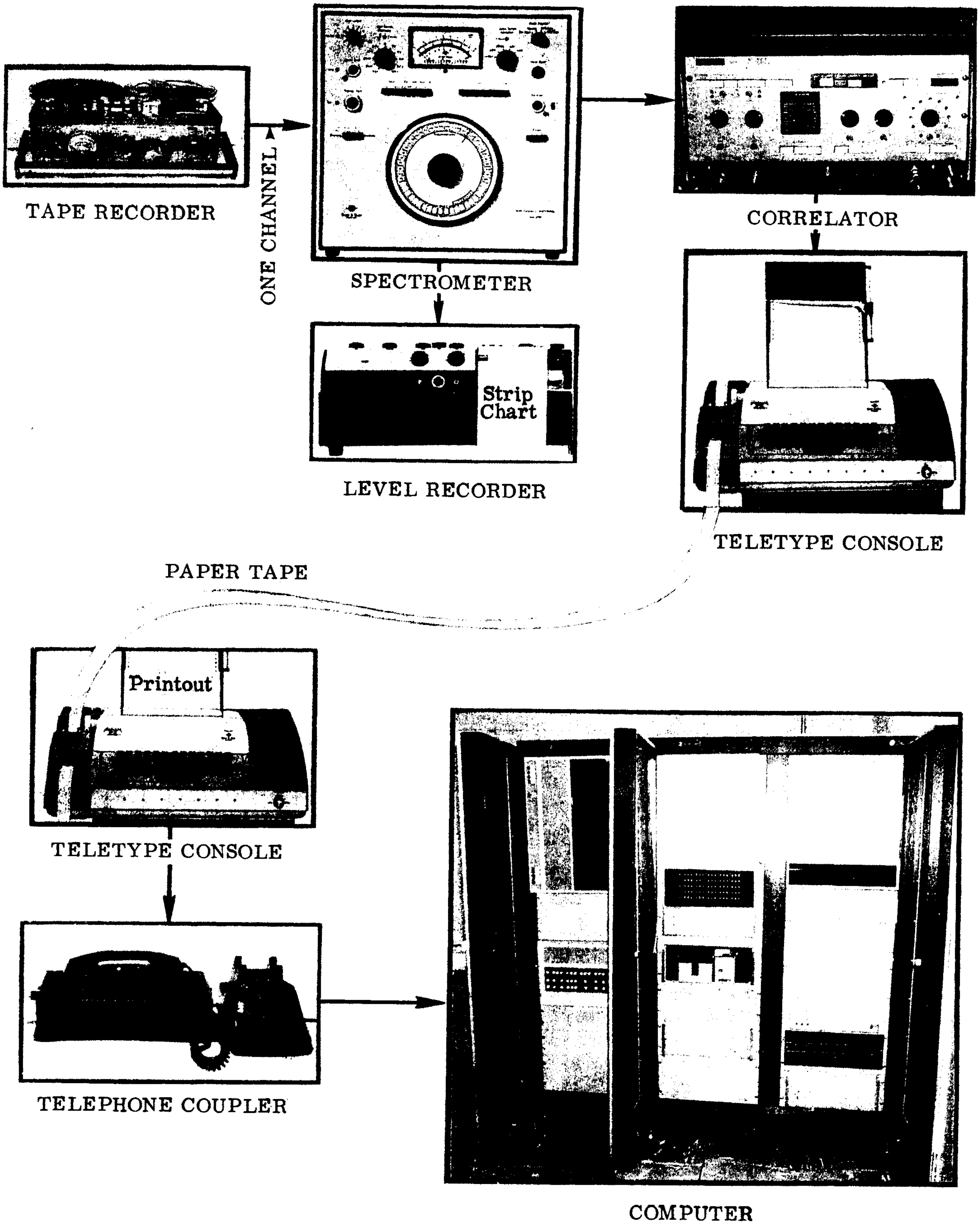

Figure 4. Schematic of analytical system.

is linear. In the correlator, a given peak-to-peak voltage range, centered on zero voltage, is divided equally into 512 values. The input voltage is sampled N times (with N as high as 1.3×10^6), the number of times the voltage is less than each of the 512 values is accumulated in storage, and shifted so that each register is full on a count of N. The stored data can be read out in any of three ways: in analog form for presentation on an oscilloscope, or on an X-Y plotter, or in digital form on paper tape. For the purpose of tabulating dB-A level exceedences, cumulative distributions were made of two of the three calibration signals and of an eight minute section of the recorded traffic noise, and these were recorded on paper tape.

The paper tapes were read into a Hewlett-Packard 2000 time-sharing computer, using a program which computes dB exceedence tables, dB distribution tables, and selected levels, such as L_1, L_{10}, L_{50}, L_{90}, and L_{99}.

The dB levels of the two calibration signals are supplied by the program user, and are used, together with the readings from the paper tapes, to obtain conversion factors. Thus exact conversion is obtained at the levels of the calibration signals, even if there should be nonlinearities in the system.

Using the procedures outlined above, dB-A exceedence tables and L_{10} and L_{50} values were obtained for all of the field measurements. Also for the comparison between one-inch and half-inch microphones, octave bands were analyzed.

3.4.2 Precision and Accuracy of Measurements

3.4.2.1 Overall System

Several instruments, all of which can contribute to errors, are involved in the overall processing system. An analysis of overall accuracy is made later in this report, but in this analysis no distinction can be made between errors introduced by measurement or data analysis and errors introduced because of uncertainties about vehicle noise levels. A detailed analysis of measurement errors was not made but several points were investigated and are noted below. The individual steps involved in data analysis were as follows:

A. Microphone pickup. Considerations in the selection of microphones are discussed below.

B. Microphone calibration. B & K Model 4230 Portable Acoustic Calibrators were used. These have an accuracy of ± 0.25 dB, according to the manufacturer's specifications. In comparisons with three of these calibrators differences have been found to be less than ± 0.2 dB.

C. Processing of microphone readings through preamplifier, and through amplifiers of Model 2204. The Model 2204 with microphone, preamplifier, cables, input attenuators, weighting filters, output attenuators, RMS rectifier, and dial meets the IEC 179 specification[9] for precision sound level meters, which requires an accuracy of ± 1.0 dB under certain conditions. Without weighting filter or rectifier, this requirement should be exceeded.

D. Tape recording of Model 2204 AC output on Nagra Model SD tape recorder. A test which reveals the dynamic range of the recorder is described below.

E. Tape playback from NAGRA Model SD used for recording or from NAGRA Model SJ. Two tests, one to investigate the effects of changing tape recorders and the other to determine cross-talk between channels, are described below.

F. Processing tape playback on Model 2113 through input and output amplifiers, A-weighting filter, and RMS rectification. This instrument also meets the IEC 179 specification.[9] Two tests which involve use of the Model 2113 are described below.

G. Processing DC output from the Model 2113 and on the Model UC-202B correlator to produce paper tape of cumulative voltage distribution.

H. Processing paper tape on computer to obtain final data.

3.4.2.2. Overall Calibration

By recording calibration signals at three levels ten dB apart, and by processing two of these right through the system, accuracy to within about ± 0.25 dB is ensured at two levels. Accuracy at other levels depends on the linearity of the system.

3.4.2.3 Microphone Selection

Because free-field microphones were used, it was originally thought that they should be directed at the roadway as, when pointed at the source, the one-inch microphone is accurate to within ± 1.0 dB up to about 18 kHz. However, there was some indication of directionality effects as traffic passed in earlier tests, and it was decided that the microphones should be mounted vertically to eliminate these effects. In this position, the one-inch microphone reads 3, 7, and 18 dB low at 4, 8, and 16 kHz respectively, while the half-inch microphone reads 1, 3, and 8 dB low at those frequencies. Because the one-inch microphones have the advantage of four times the sensitivity of the half-inch microphones, it was decided that initial measurements would be made with both types of microphone, until sufficient information was obtained about typical traffic spectra to make a final selection. During the field measurements, under test number 6, a one-inch and a half-inch microphone were placed close together at 60 ft. from a road (site number 2). Readings from each were processed in the normal way, except that each octave band was also analyzed. Values for L_{50} and L_{10} for the two microphones are shown in Figure 5 plotted against center frequencies of the octave bands.

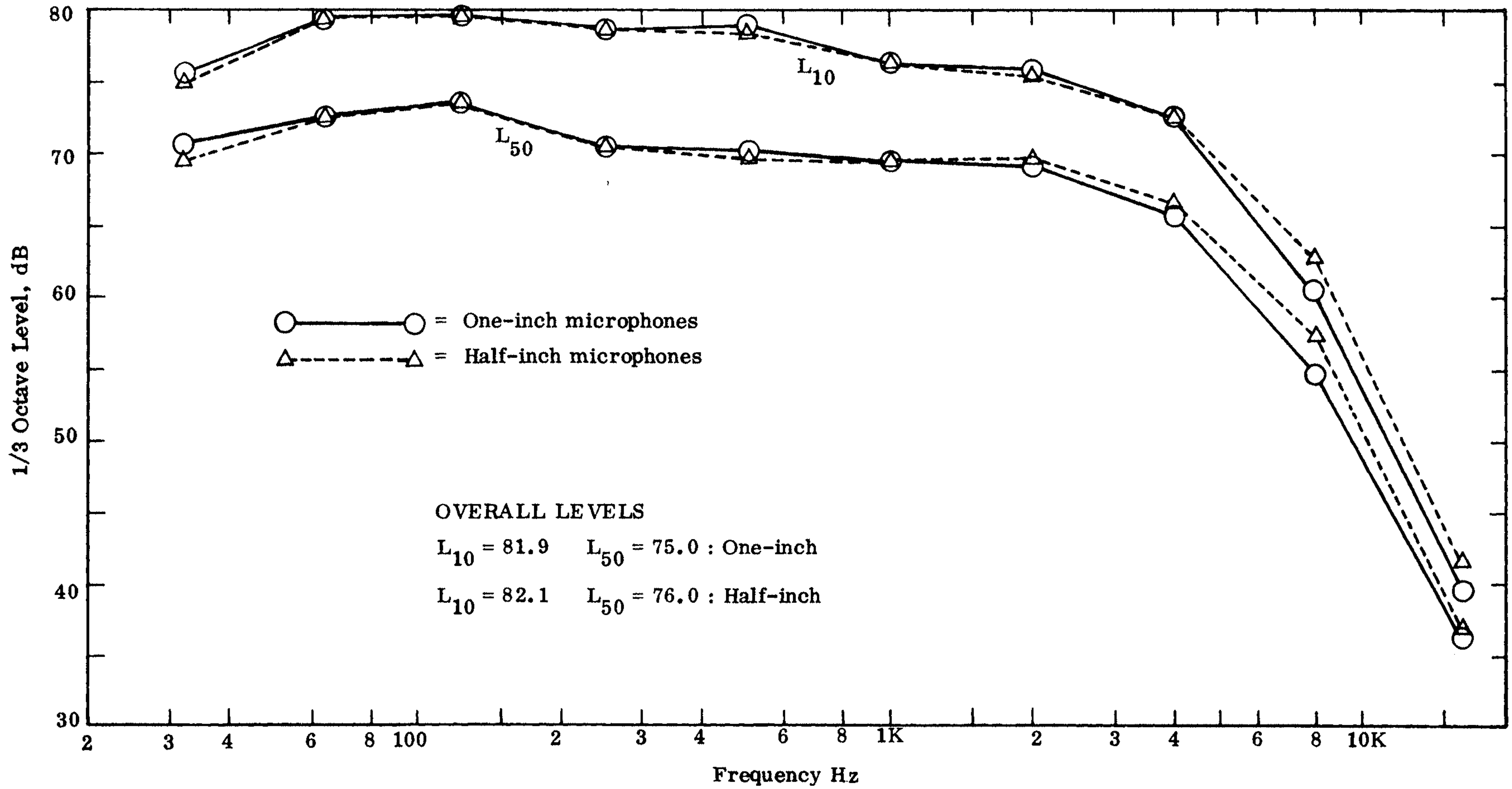

Figure 5. Spectra of L_{10} and L_{50} for one-inch and half-inch microphones.

Up to 4 kHz, agreement was good to within 0.5 dB, but a considerable drop-off in levels was found at 8 kHz, even on the half-inch microphone, which should have only a 3 dB correction.

The overall L_{10} and L_{50} levels are also shown in Figure 5. The L_{10} values differ by 0.2 dB, while the L_{50} values differ by 1.0 dB. The differences include effects of microphone accuracy, uncertainties about precise angles relative to microphone axes, possible errors in the overall data processing system, and small differences in location. Inasmuch as they fell within the expected 68% confidence range of error, only small differences in the spectra can be seen, and the spectral levels are off by 20 dB in the 8 kHz band (where the correction on one-inch microphones becomes significant), it was judged that adequate results would be obtained with one-inch microphones. The reader is cautioned against attempting to infer overall L_{10} or L_{50} levels from the spectra in Figure 5. The method of dB-summing spectral levels is not valid for exceedence levels.

3.4.2.4. System Linearity Check

Calibrator tone recordings were made from the Model 2204 sound level meter with the attenuator set in sequence to 80, 90, 100, 110, 120, and 130 dB. The input gain on the recorder was set so that it was just short of tape overload at the 80 dB setting. The tape was then played back through the Model 2113 and the dial readings were observed. Each time a 10 dB drop-off occurred, the attenuators were readjusted, so that an approximately constant dial reading was obtained. The readings are given in Table 3.

Table 3

System Linearity Check

Model 2204 Attenuator Setting, dB	Readings on Model 2113, dB	Linearity Error, dB
80	103.2	0.03
90	93.3	0.13
100	82.9	-0.27
110	72.8	-0.37
120	63.0	-0.17
130	53.8	0.63

The readings were not intended for making an error analysis. However, since they should drop off in 10 dB intervals if the system is functioning properly, a good indication of linearity is obtained by determining the mean error and subtracting from the actual readings to get the linearity error. The RMS value of this error is then a good indication of overall linearity over the range. For the full 50 dB range the RMS linearity error is 0.33 dB.

3.4.2.5 Model 2113 Output

As a check on the DC voltage output of the Model 2113, a calibrator signal was read through a microphone, amplifier, and preamplifier input (not used in analysis of measurements). The attenuators were set to various positions and the DC output was read, as given in Table 4.

Table 4

Model 2113 Output

Model 2113 Attenuator	D.C. Voltage Output, Volts	dB (re 1 Volt)
30	-2.43	7.71
40	-2.43	7.71
50	-2.43	7.71
60	-2.43	7.71
70	-2.26	7.08
80	-0.875	- 1.16
90	-0.202	-11.63
100	-0.087	-21.21
110	-0.045	-26.94
120	-0.040	-27.96
130	-0.040	-27.96

Converting the DC output to dB, it will be seen that there is a linear range of approximately 35 dB. The RMS linearity error, computed as before for annenuator settings ranging from 80 to 100, is 0.21 dB. The linear range is considerably less than the more than 50 dB of the tape recorder; however, this does not cause trouble when determining levels, since it merely distorts the upper and lower ranges. If the L_{10} level is affected in this way, it is readily noticed on the oscilloscope display attached to the correlator, and readjustments are easily made.

3.4.2.6 Match Between Two Tape Recorders

Since data were sometimes played back on a tape recorder different than the one on which they were recorded, it was important to check repeatability.

In the first check, a recording made on the NAGRA/SD was played into the Model 2305, and overlaid strip chart recordings were made, using both tape recorders in turn. Amplitudes were found to match within 0.2 dB, and the times within 1 sec. after ten minutes.

In the second check, channel alignments were checked by recording calibrator signals on the LH channels of both recorders, and then analyzing the differences between signal strengths of the RH and LH channels of the two recorders. The results, given in Table 5, indicate separations of better than 40 dB between the two channels of two recorders.

Table 5

Channel Cross-Talk (Strength on RH Channel, Minus LH Channel, With Signals on LH Channel)

Recorded On	Played Back on NAGRA SD	Played Back on NAGRA SJ
NAGRA SD	-46 dB	-42 dB
NAGRA SJ	-48	-53

A problem was encountered when either of the tape recorders was used. No equipment was available for placing timing marks on the tapes so that the same record would be analyzed each time. Therefore, analyses were not absolutely repeatable thus fluctuations in traffic flow could easily be missed.

4. EXPERIMENTAL DATA

Plan views of the five sites at which measurements were taken are given as Figures A1 through A5 of Appendix A, while dimensioned cross sections are given in Figures A6 to A10. Tables of input data for the MICNOISE computer program derived from survey measurements and traffic counts at the sites, and covering fifty-one microphone recordings taken in twenty-six trials, are given in Tables A1 to A22. One recording was missed because of difficulties with a sound level meter. In most cases, four 10-minute to 15-minute pairs of recordings were made on a tape, each recording being denoted by a trial number and each tape by a test number. Tests numbered 1 to 3 were made at site number 1, tests numbered 4 and 5 were made at site number 2, and tests numbered 7 to 9 were made at sites numbered 3 to 5 respectively. Test number 6 was also made at site number 2, but this was a comparison of one-inch and half-inch microphones which has already been reported on in the previous section. As a result of this test, it was found that there was not sufficient high frequency content in the recorded spectra to make any distinction between the readings of the two sizes of microphone. Pending the outcome of this analysis, half-inch microphones were used in tests numbered 2 and 5. These results were combined with the others for the purpose of making statistical evaluations of computer prediction accuracy in the remainder of this report.

The tables of input data are self-explanatory, particularly if reference is made to the listing of the MICNOISE computer program in Appendix B. Also included on these tables are the measured L_{50} and L_{10} values. Cumulative exceedence plots for the two microphones in Trial 1 of Test 1 are given in Figure 6. The shape of these plots lends some encouragement to the idea that it might be possible to represent cumulative exceedences by analytical functions, and thus to predict L_{10} and L_{50} from L_{EQ}.

A summary of the test results is given in Table 6, and discussions of the individual tests follow.

Table 6

Summary of Highway Test Program

Site #	Run #	Microphone Diameter	No. of Trials	No. of Recordings
1	1	1"	3	6
	2	½"	2	4
	3	1"	3	6
2	4	1"	3	6
	5	½"	3	6
	6	1" & ½"	(1)*	(2)*
3	7	1"	4	8
4	8	1"	4	7**
5	9	1"	4	8
			26	51

*Not counted in totals

**Failed sound level meter

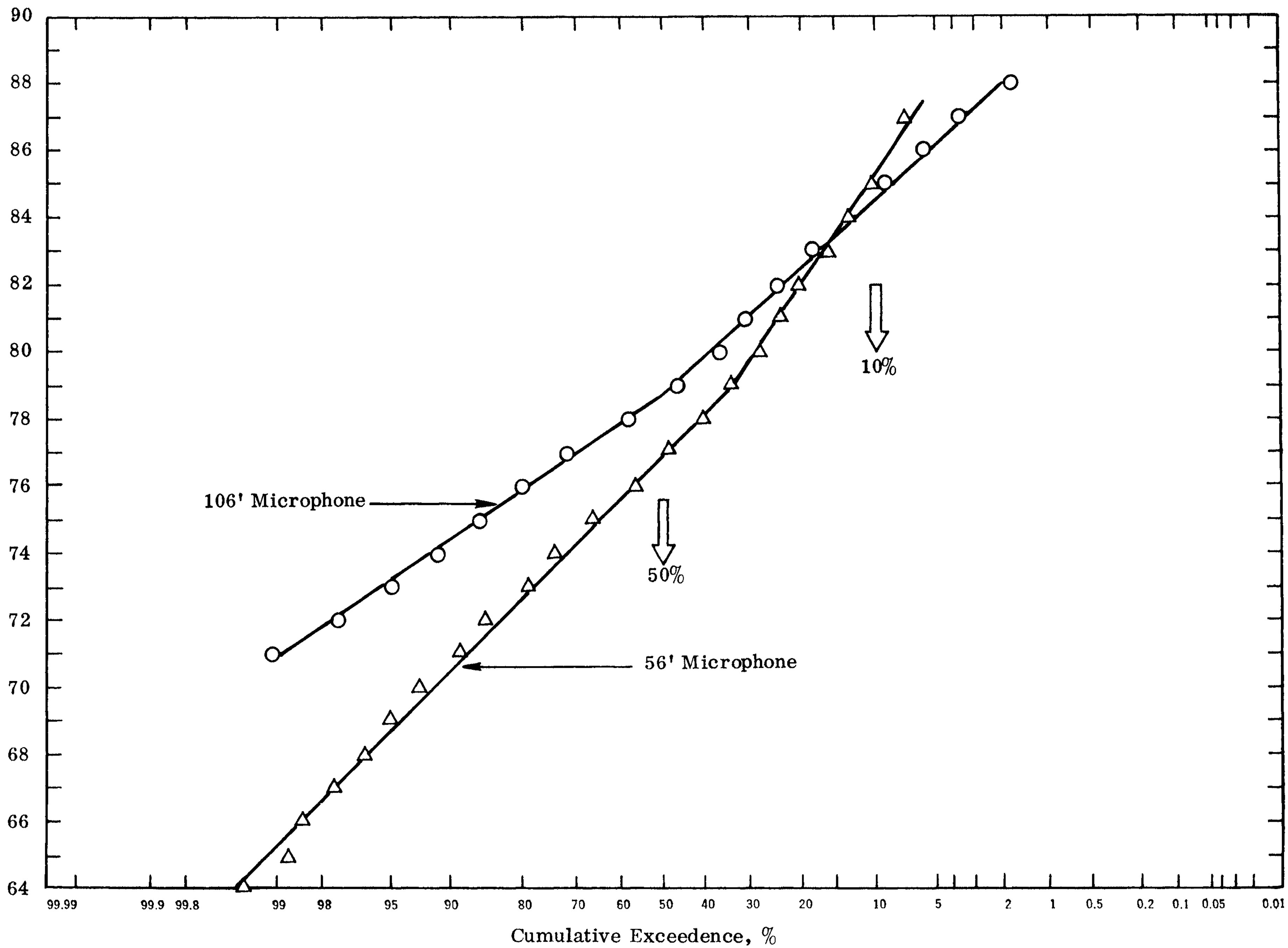

Figure 6. Cumulative exceedence for test 1, trial 1.

4.1 Site Descriptions

The sites are described in this section in terms of their geographic and route locations, their geometric relationship to the roadway and lane groups, the median, the ground cover, the grade, the type and texture of the pavement surface, anything that might have a special affect on the sound at the site, any cultural conditions that might affect traffic flow, and proximity to any other sources of noise such as railroads.

Test site number one was near Springfield on the south side of Route I-495 approximately 0.7 mile east of Route I-95. The roadway was depressed in respect to the land to the south with the three eastbound lanes and the three westbound lanes 35 ft. and 48 ft. below the top of the cut respectively, see Figures 7 and A6. The median widened near I-95 and was covered with 24-inch grass and pithy shrubs. The cut slope was covered with 24 to 30-inch grass, while the surface beyond the right-of-way was a sandy gravel with isolated patches of vegetation (grasses and 15-foot trees). The grade sloped slightly to the east. The pavement was portland cement concrete with $\frac{1}{2}$ to 1-inch crushed gravel aggregate that was exposed by the removal of the surficial paste. Light brushing with the fingertips indicated the surface had a relatively even texture. There was a railroad approximately 1,100 ft. north of the site and trail motorcycles were ridden within 300 ft. of the top of the cut.

Test site number two was near Alexandria on the north side of Route I-495 approximately 0.5 mile west of Telegraph Road . The site was level in that the roadway was at approximately the same elevation as the land to the north and south of the roadway, see Figures 8 and A7. The grassed (cut) median was depressed along its axis to accommodate drainage. The ground cover, along the test line, was 30-inch grass. The grade sloped slightly to the east. The pavement was portland cement concrete with $\frac{1}{4}$ to $1\frac{1}{4}$-inch crushed rock (appeared to be diabase) aggregate that was exposed in the two fast westbound lanes as it was in all three eastbound lanes. The fingertip test indicated these surfaces had a relatively even texture. The slow westbound lane started at Telegraph Road and carried traffic approaching via the entrance ramp. Because the slow lane did not carry as much traffic as the other lanes the aggregate was not yet exposed, however, the surface had developed a relatively even texture. There was a railroad approximately 1,300 ft. north of the site, but the field crew did not notice any sound from that source during the period of testing.

Test site number three was near Fishersville in Augusta County on the north side of Route I-64 approximately 0.4 mile west of Route 834. The roadway was elevated with respect to the land to the north and to the south, see Figures 9 and A8. The westbound lanes and the eastbound lanes were 23 ft. and 17 ft. respectively above the general elevation of the field that was north of the road. The median was depressed along its axis as a drainage measure and was covered by cut grass. The slope of the fill was covered with 18 to 24-inch grass while the pasture outside the right-of-way fence had short 3 to 4-inch grass. There was a slight grade sloping to the west. The pavement was bituminous concrete with $\frac{1}{2}$-inch crushed gravel or sandstone aggregate. The surface had a medium texture. The secondary road close to the test site did not carry enough traffic to affect the data materially.

Figure 7. Site number 1, depressed, I-495 near Springfield.

Figure 8. Site number 2, level, I-495 near Alexandria.

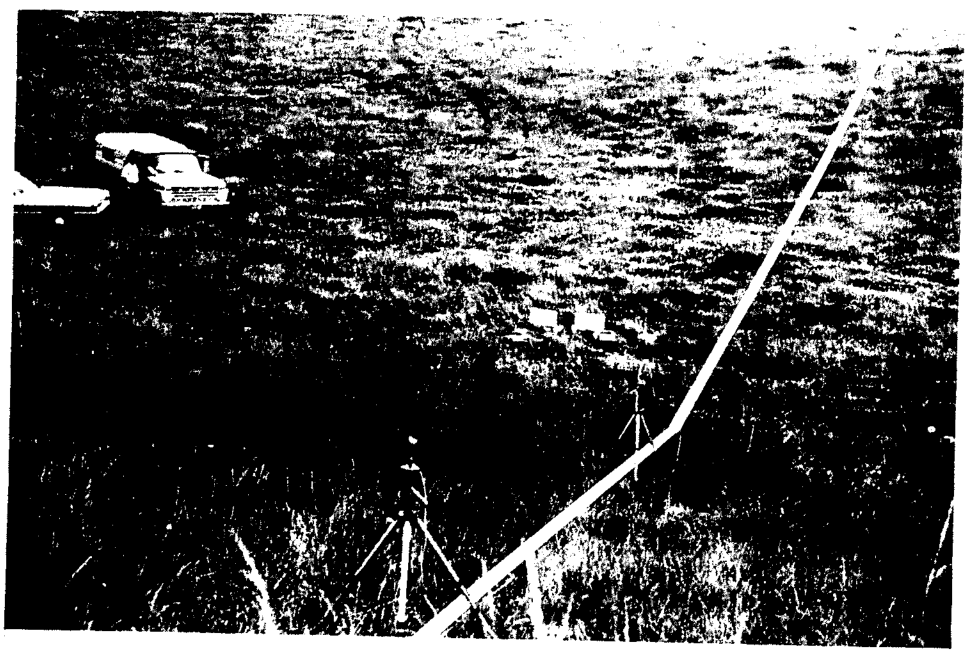

Figure 9. Site number 3, elevated, I-64 near Fishersville, from embankment, from roadway, respectively.

Test site number four was south of Ruckersville in Green County on the east side of Route 29 approximately 160 ft. south of Route 600 and 0.8 mile north of Route 607. The north- and southbound lanes (four) were depressed 14 ft. and 9 ft. respectively below the level of the field lying to the east of the road (see Figures 10 and A9). The median was grass covered. The cut slope was poorly vegetated with much soil exposed, and the field above was covered with 12-inch clover. The grade sloped moderately to the south. The pavement was bituminous concrete with a medium texture.

Test site number five was 0.3 mile east of Doswell, Hanover County, on the east side of Route I-95 approximately 0.15 mile north of the intersection of Routes 688 and 731. The roadway was 23 ft. above the land to the east of the roadway (see Figures 11 and A10). The median was depressed along its axis as a drainage measure, and was covered with 4 to 5-foot high shrubs. The slope of the fill was covered with shrubs and 6 to 7-foot high indigeneous trees. The field in which the 200-, 300-, and 400-foot positions fell was cultivated and planted in 18-inch soybeans. The grade, if any, was negligible. The pavement was bituminous concrete which had a relatively medium texture. From the intersection with Route 688, Route 731 parallels I-95 northward for 0.7 mile. Very light car and dump truck traffic runs on Route 731. For the first trial, it was necessary to lay the coaxial cable across Route 731. To prevent destruction of the cable, boards were positioned on each side of it and the traffic was slowed for the crossing. It was expected that the stop and go nature of the dump truck traffic would greatly increase the noise levels, however, they did not appear to be very noisy, nor did the microphone readings indicate that they were. Nevertheless, it was decided that for the next three trials, this situation should be avoided.

A large elevated billboard was located near the 200-foot station approximately parallel and 25 ft. off the line on which the microphones were located. Because the sign was at least 20 ft. above ground level, it was not judged to have a very great affect on the measurements. There was a wooded area several hundred feet north of the microphone line which was not considered to affect readings. A railroad parallels Route 688 approximately 750 ft. south of the microphone array line. It had very little effect on the trials.

4.2 Instrument Malfunction

Test 8 was to consist of four trials. However, it was observed that after being turned off for the purpose of changing microphone positions, one of the sound level meters was not receiving the calibration tone signal. By changing microphones, preamplifiers, and cables, it was determined that the malfunction must be in the body of the sound level meter and could not be corrected. Therefore, the fourth trial was made with one microphone only.

Figure 10. Site number 4, **depressed,** Route 29 near Ruckersville.

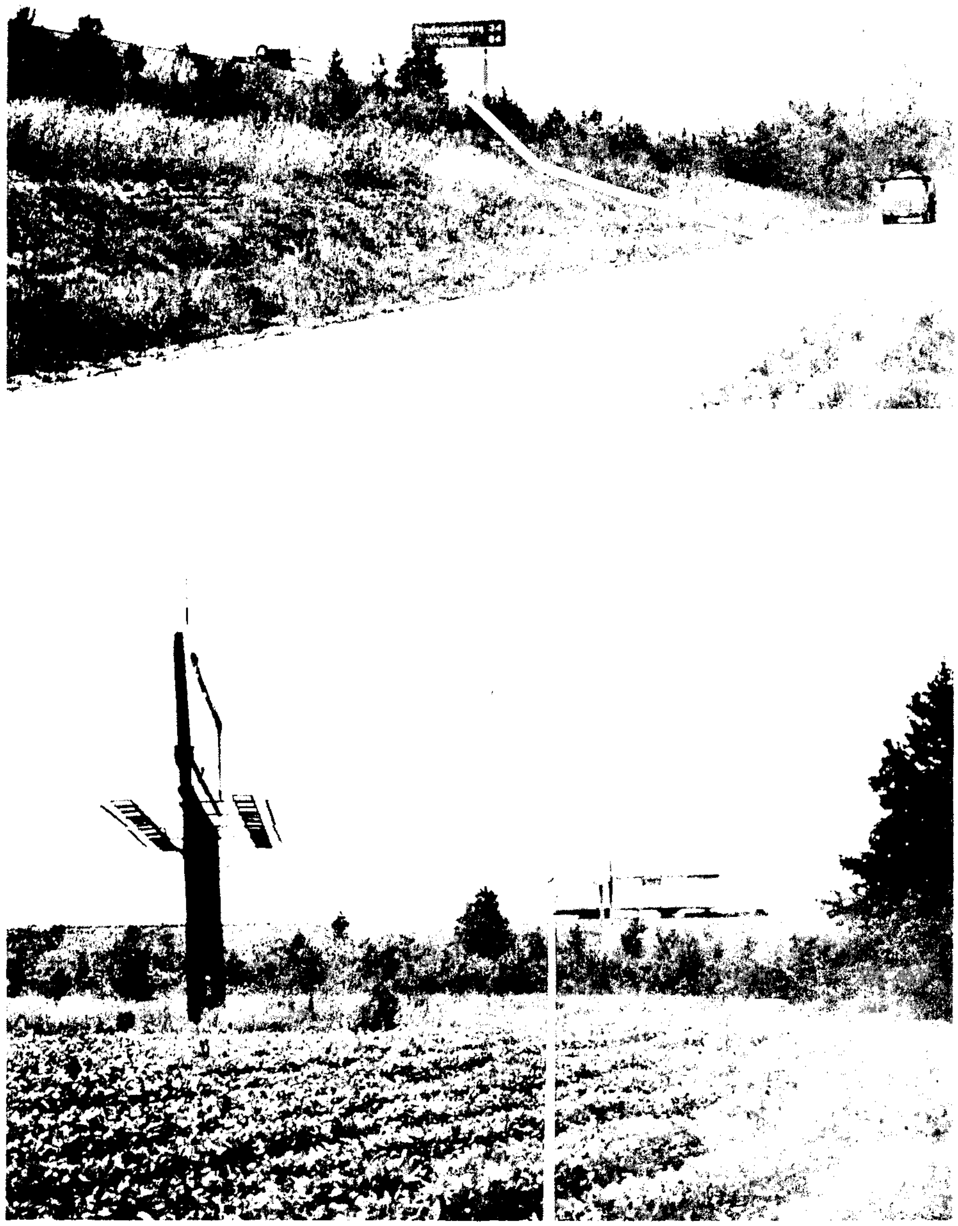

Figure 11. Site number 5, elevated, I-95 near Doswell.

5. EVALUATION OF MICNOISE COMPUTATIONS AGAINST EXPERIMENTAL RESULTS

5.1 Computer Programs

The version of MICNOISE which was to be evaluated had previously been programmed for the IBM 360 at the Computer Center of the Virginia Department of Highways. However, during the initial stages of this work the Hewlett-Packard HP-2000 time-sharing computer at the University of Virginia was programmed to perform the same calculations. Two programs were actually prepared: One, a close copy of MICNOISE, was named GOLNOY; the other, a more flexible program designed to investigate changes which might possibly be made to the original program, was called HAVNY1. Originally, all of the computations were made on GOLNOY, and these results were used as a check on the MICNOISE computations presented in this report.

During the later stages of this investigation, calculations were made with MICNOISE on the IBM 360. Also it became possible to experiment with a modified version of MICNOISE, and thus to try out possible changes in the program. The remainder of Section 5 is devoted to a presentation of the evaluation of these programs.

The calculated results using the MICNOISE computer program are given in Tables A23 through A27 of Appendix A, together with the experimental values which have taken from Tables A1 through A22. Data from these same tables were also used as input to MICNOISE in obtaining the results presented. The calculated results using the modified MICNOISE computer program are given in Tables A28 through A32 of Appendix A.

Copies of the revised MICNOISE 5 program were received too late to be included in the numerical evaluation. However, the revisions have generally been similar to those used in the modified program, and it has therefore been possible to draw conclusions about the accuracy of MICNOISE 5.

5.2 Experimental Accuracy

There would be little point in attempting to determine the accuracy of the analytical method used in MICNOISE without first determining how accurate the experimental data are. Use of precision sound level meters, the precaution taken to record three calibration tones at ten-decibel intervals, and the use of two of these tones for the reduction of the data would seem to be sufficient to ensure the accuracy of the results to within the ± 1.0 dB called for by specifications, [9, 10] if the measurements were carried out under ideal laboratory conditions. However, because measurements were made in the field and several stages of handling were required to reduce the data to its final form, random errors could have been introduced. Further, it was not possible to produce carefully controlled traffic noise to test the precision of the measurements.

At each site repeated measurements were made at the near microphone locations, so that it was possible to evaluate their precision by computing the variance of the errors between predicted and measured L_{50}, and L_{10} and $(L_{10} - L_{50})$ levels. Because these calculations were made for fixed locations, the only difference between successive sets of values was due to changes in the traffic volumes, but these should be matched by corresponding changes in measured levels so that the expected error should remain constant as traffic volumes change. Thus, any variance observed in the errors should be caused by a combination of (1) inherent instrument variances, of the order of ± 1.0 dB or less, (2) data handling, and (3) variances in sound level of vehicles assumed by MIC-NOISE to emit equal sound levels.

Variances for these fixed locations have been computed and have been tabulated in Table 7 in the form of standard deviations. Assuming samples of N measurements each, the items tabulated were derived as follows:

E = Error = Calculated Level - Experimental Level

$\bar{E}$ = Mean Error = $\frac{1}{N} \sum E$

E_{RMS} = RMS Error = $\sqrt{\frac{1}{N} \sum E^2}$

Standard Deviation = $\sqrt{\frac{1}{N-1} \sum (E - \bar{E})^2} = \sqrt{\frac{N}{N-1} (E_{RMS}^2 - \bar{E}^2)}$

Table 7

Analysis of Experimental Accuracy at Fixed Microphone Locations, in dBA

Site #	1	2	3	4	5
Microphone Locations	56 ft.	66 ft.	50 ft.	50 ft.	150 ft.
No. of Recordings	8	6	3	3	4
Mean Daily Traffic	5,733	4,318	713	486	2,304
L_{50} Mean Error	-0.10	-0.22	4.77	10.47	0.58
RMS Error	1.16	0.70	5.52	11.10	1.39
Standard Deviation	1.23	0.73	3.40	4.51	1.47
L_{10} Mean Error	-0.53	0.88	2.47	4.30	-0.73
RMS Error	1.00	1.05	2.99	4.65	1.48
Standard Deviation	0.97	0.64	2.06	2.16	1.49
L_{10} - L_{50} Mean Error	-0.43	1.10	-2.30	-6.17	-1.30
RMS Error	1.92	1.24	3.13	6.51	1.77
Standard Deviation	2.00	0.64	2.60	2.54	1.40

The standard deviation is derived in the conventional form of statistical analysis, and reduces small sample results to an approximately uniform level of confidence.

It will be noted that the smallest variances occurred at site number 2, which was flat and had a high traffic volume. At sites 1 and 5, which were respectively depressed and elevated, the variances were larger. The greatest variances occurred at the two low traffic volume sites 3 and 4, which were elevated and depressed, respectively. These findings would indicate that fluctuation in traffic noise level is the major contributor to the variances, and that stray echos present at the elevated or depressed sites may also be contributors. It had been thought that variances for the L_{10} levels would be significantly higher than for the L_{50} levels, because a few very noisy trucks would contribute to the former more than to the latter. However, no definite trend in this direction can be noted.

5.3 Analysis of Calculated Results

The errors between the calculated results, using MICNOISE, and the measured levels were analyzed, and the results are presented in Table 8 using the same definitions as have been used for Table 7, except that the 68% confidence ranges have been calculated by adding and then subtracting the predicted standard deviations from the mean errors. In averaging the errors to arrive at the tabulated values, three sets of values for the microphone at 106 ft. at site number 1 were omitted. It was noted that errors of the order of -5 dB were obtained here (see Table A23), and this was attributed to the situation of the microphone on a slope facing the highway. Such a location evidently cannot be handled by MICNOISE, and is not representative of any practical situation of interest.

The prediction errors for L_{50} and L_{10} fall within about 2 dB for the three sites at which high traffic levels were obtained, and fell more often on the conservative positive side. At the two low traffic level sites, numbers 3 and 4, errors were larger, but positive. In these cases, truck traffic frequently fell into the twilight zone.

Values for $(L_{10} - L_{50})$ errors were given mainly to provide comparisons for calculations carried out by other methods. The twilight-zone procedure used in MICNOISE leads to an underestimation of this quantity, as can readily be seen be examining the results for sites numbers 3 and 4, where the situation occurred frequently (see Tables A25 and A26, where this condition is indicated against computed results).

Table 8

Errors in Noise Levels Computed by MICNOISE.
All Microphone Locations, in dBA

Site		1	2	3	4	5
No. of Recordings		13*	12	8	7	8
L_{50} Mean Error		0.32	0	4.85	7.34	0.75
RMS Error		1.46	1.15	5.58	8.30	1.48
Standard Deviation		1.49	1.20	2.95	4.19	1.36
68% Confidence Range		-1.17	-1.20	1.90	3.15	- .61
		1.81	1.20	7.80	11.53	2.11
L_{10} Mean Error		0.19	0.54	1.68	4.63	-0.95
RMS Error		1.72	1.04	3.02	4.93	1.47
Standard Deviation		1.78	0.93	2.68	1.83	1.20
68% Confidence Range		-1.59	- .39	-1.00	2.80	-2.15
		1.97	1.47	4.36	6.46	.25
$L_{10} - L_{50}$ Mean Error		-0.13	0.54	-3.18	-2.71	-1.70
RMS Error		1.60	0.99	3.65	4.68	2.29
Standard Deviation		1.67	0.87	1.93	4.12	1.65
68% Confidence Range		-1.80	- .33	-5.11	-6.83	-3.35
		1.54	1.41	-1.25	1.41	- .05

*The 3 records taken at 106 ft. were not included.

5.4 Analysis of Distance Correction

In Section 2.3.3., the distance correction, DEL1, was discussed, and it was pointed out that the values used in MICNOISE were lower than the predicted values. In order to assess the accuracy of this correction more fully, the L_{50} errors for sites numbers 1 and 2 have been plotted against DEL1 for the nearest lane group in Figures 12 and 13.

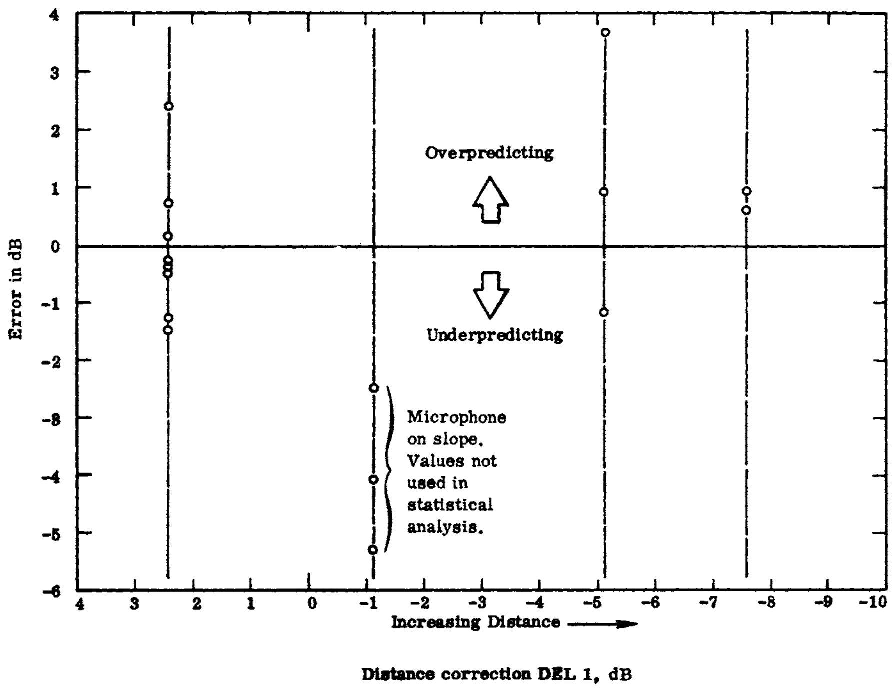

Figure 12. Errors in L_{50} (calculated minus measured) vs. distance correction DEL1 for near lane group, site 1.

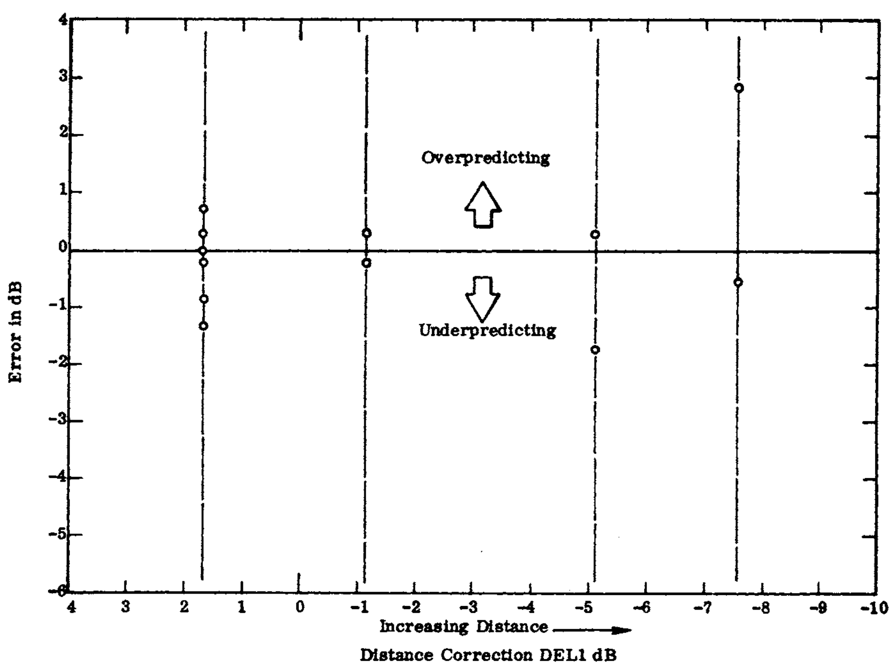

Figure 13. Errors in L_{50} (calculated minus measured) vs. distance correction DEL1. for near lane group, site 2.

If the corrections are exact the L_{50} error should be independent of DEL1. If there is any variation of the error with DEL1, this should indicate how the distance correction could be improved, because L_{50} is primarily affected by the traffic in the near lane group.

No severe trend of error vs. distance can be seen in the results plotted in the figures, beyond a tendency for MICNOISE to overpredict slightly at the greater distances. It will be recalled that the magnitude of DEL1 used in MICNOISE is greater (but negative and therefore algebraically less) than the theoretical values.

5.5 Modified MICNOISE Program

Analysis of the computed results from the MICNOISE program, and comparison with the experimental values, indicated that the only serious difficulty was with the handling of trucks in the twilight zone. Accordingly, a modified program was prepared to evaluate the alternative approach suggested in Section 2.3.8. At the same time, a few other minor changes, which did not have any affect on the results, were made for convenience. In summary, the modified program contains the following features:

(1) Twilight zone procedure eliminated. Table of $L_{10} - L_{50}$ values modified by adding three extra points, and changing another, to give the composite curve shown in Figure 2. A similar change, using slightly larger values, has already been incorporated in MICNOISE 5.

(2) Incorporation of tests for line-of-sight conditions in the computation of vertical and barrier corrections, DEL4 and DEL6. These eliminate the need for the user to test for these conditions in preparing input data, but had no affect on the data tabulated in Tables A1 through A22. A test for line-of-sight conditions has been incorporated into MICNOISE 5.

(3) Changes to permit automobile, truck or all traffic volume to be zero. These would not be so important in use, but were needed in this evaluation.

(4) Addition of output of all correction factors and of levels of automobile and truck noise in all lane groups.

(5) Elimination of table-look-up method for obtaining distance correction, DEL1, which was replaced by calculation from Equation (12) using the value of D_E calculated for the vertical and barrier corrections. This step was suggested in Section 2.3.6.

5.5.1 Analysis of Calculated Results from Modified Program

Using the computed results from this modified program, errors were evaluated statistically and the results are shown in Table 9, which can be compared directly with

Table 8. It was found that calculated levels for trial number 1 of test number 9 at site number 5 were excessive. In this case, there were slow moving gravel trucks on a side road, which had come into the twilight zone in MICNOISE and had therefore been essentially eliminated. However, in the modified program, their slow speed had led to very high predicted levels. To correct this situation, the traffic on the side road was ignored and predictions were based on the traffic on the highway, which led to computed results which were close to the measured value (see the first two lines of Table A32 in Appendix A).

Table 9

Errors in Noise Levels Computed by Modified MICNOISE, in dBA

Site #	1	2	3	4	5
No. of Recordings	13[1]	12	8	7	8[2]
L_{50} Mean Error	0.20	0	2.41	3.46	0.70
RMS Error	1.33	1.15	4.70	4.01	1.50
Standard Deviation	1.36	1.20	4.32	2.19	1.42
68% Confidence Range	-1.16	-1.20	-1.91	1.27	- .72
	1.55	1.20	6.73	5.65	2.12
L_{10} Mean Error	0.32	0.49	3.35	4.10	-0.35
RMS Error	1.60	1.00	5.98	4.91	1.68
Standard Deviation	1.62	0.91	5.29	2.90	1.75
68% Confidence Range	-1.3	- .42	-1.94	1.2	-2.10
	1.94	1.40	8.64	7.0	1.40
$L_{10} - L_{50}$ Mean Error	0.12	0.50	0.94	0.64	-1.05
RMS Error	0.78	0.92	1.54	3.54	1.91
Standard Deviation	0.80	0.82	1.30	3.76	1.71
68% Confidence Range	-0.68	- .32	- .36	-3.12	-2.76
	0.92	1.32	2.24	4.40	.66

[1] The three records taken at 106 ft. were not included.

[2] The predicted noise of trucks on the side road was deleted for trial #1.

In order to make the comparison between the results of the modified version and of the original MICNOISE program, Figure 14 was prepared to show the 68% confidence levels on L_{50}, $L_{10} - L_{50}$ at each site, which are tabulated in Tables 8 and 9. The difference in each case is due to the elimination of the twilight zone procedure and to the substitution of a new table of $(L_{10} - L_{50})$ values.

There is little difference at the three higher traffic density sites. At the two lower density sites, numbers 3 and 4, there is an increase in $(L_{10} - L_{50})$ values that results in decreased average errors, which indicates that the revised method of obtaining $L_{10} - L_{50}$ is an improvement over the original method.

The upper confidence levels on L_{50} are also reduced, indicating some improvement here, but the upper confidence levels on L_{10} are increased. Thus, although the calculation of $L_{10} - L_{50}$ is improved, L_{10}'s are high because L_{50}'s are high. Evidently the root of the problem is the overprediction of L_{50} levels, which is somewhat compensated in the basic MICNOISE program by underprediction of $(L_{10} - L_{50})$. The close results obtained at the other three sites indicate that the problem is not in the basic prediction method of MICNOISE. In point of fact, the method of obtaining basic traffic data is suspect in that vehicles, other than tractor and trailers, such as "step van" type of trucks and transcontinental busses, were counted along with tractor trailers as trucks. Because a large percentage of the trucks observed at sites 3 and 4 were light, and because very few if any really noisy tractor trailers passed, it is believed that the input data in these two cases were considerably exaggerated.

A particular case in point is the problem of determining 68% confidence levels at site number 3. Reference to Figure 14 indicates that although the mean error on L_{50} was improved with the modified program the standard deviation increased. However, there was an overall improvement in the prediction of $(L_{10} - L_{50})$, which indicates that the method is fundamentally improved by the modification. Referring to Table A30, it will be found that the errors on L_{50}, starting with trial number 1 at the near microphone, are 8.6, 9.2, 1.0, 2.3, -1.0, -1.8, 2.4, and -1.4 dB. If trial number 1 with the 8.9 and 9.2 errors were eliminated, the confidence limits could have been -1.64 to +2.14 dB, a considerable improvement over the values given in the figure, which are -1.91 to 6.73, based on all eight of the errors quoted above.

Examination of the records shows that early in the recording several trucks went by, which produced high sound levels. As a result, the decision was made to attenuate by 10 dB, after two minutes. Thus it was possible to analyze only the remaining eight minutes. However, truck traffic appears to have been markedly lower during this period, so that the predicted sound level, being based on a greater truck volume than the actual measurement, was high, which may have led to a relatively large error.

The conclusion to be drawn from Figure 14 is that the modified program predicts results which are within overall accuracy limits of measurement. Certainly procedures could be improved considerably with the experience gained to date, but it would be necessary to design and execute a new program of measurements to obtain a marked improvement.

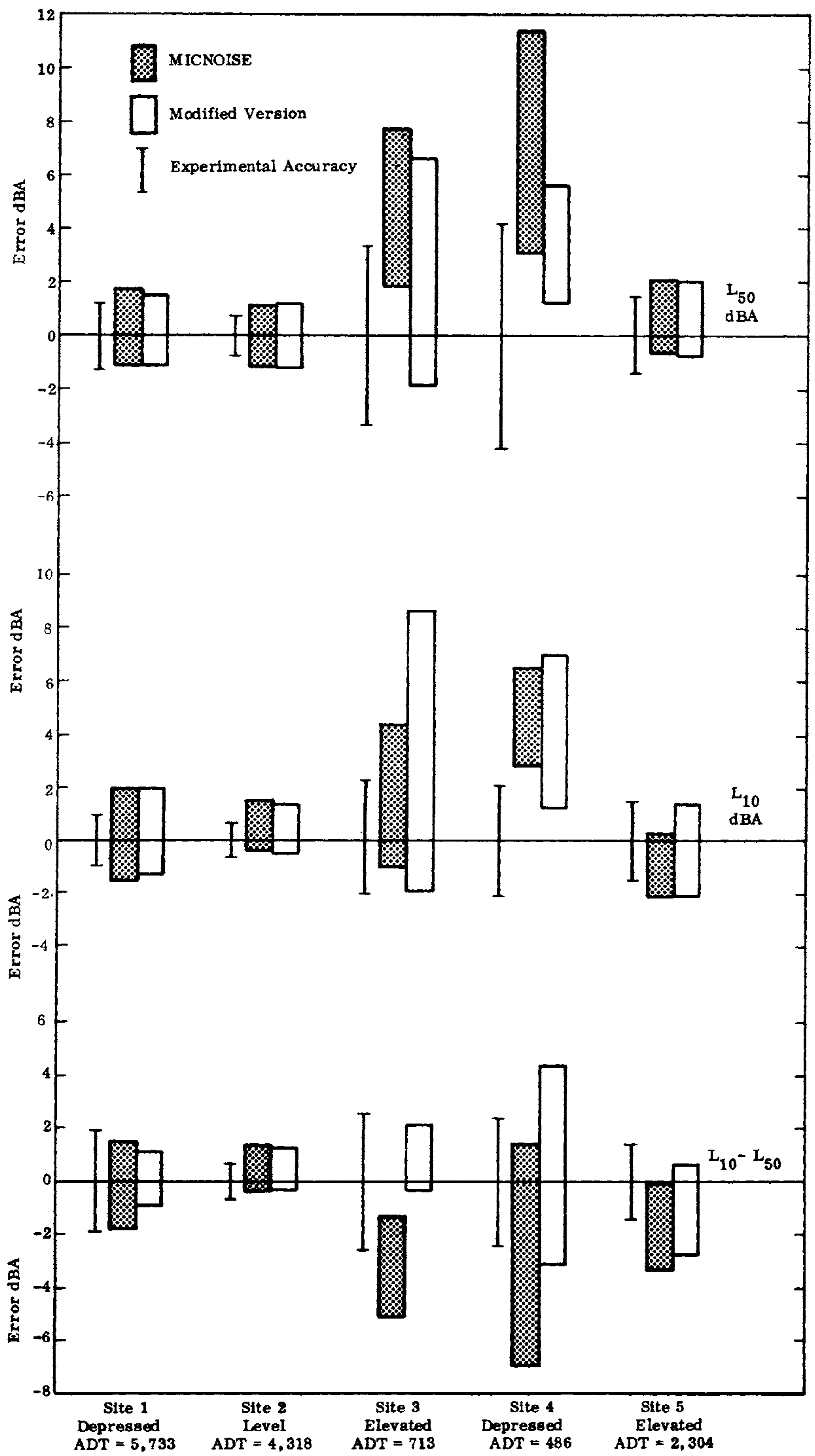

Figure 14. 68% confidence levels on errors (calculated minus measured) for MICNOISE and for the modified MICNOISE version.

5.5.2 Analysis of Vertical Corrections

The five groups of data obtained represent level, depressed, and elevated sites, and corrections were made to allow for attenuation in the last two cases. To gain an indication of the extent to which these corrections were applied, the computer output was searched for the highest attenuation applied to trucks in a near lane. This attenuation is very nearly an across-the-board value, since trucks in the near lane invariably predominate over the remaining traffic. The value was found to be -8.42 dB (13.42 dB for automobiles) for the microphones at 300 ft. at site number 1, which is depressed. The 68% confidence limits were within ± 2 dB at this site, which is a favorable confirmation of the method used in MICNOISE to correct for the shielding effects of cuts.

As a further evaluation of the method used for making vertical corrections in the MICNOISE program, Table 10 was prepared as a summary of all vertical corrections used in the analyses made with the modified MICNOISE program. The approach used in this case is to compare simultaneous levels at pairs of microphones, referred to as the "far" and "near" microphones. For reasons noted in the previous paragraph, the corrections used in the analysis for trucks in the near lane have been tabulated. Only two corrections were used, the distance correction already evaluated, and the vertical correction. These corrections are tabulated for the pairs of microphones.

Table 10

Summary of Vertical Correction Differences Between Far and Near Microphones in dB

Test No.	Trial No.	Site No.	* Type	Corrections used for trucks in near lane				Differences-far minus near microphone				
				Near micr.		Far micr.			L_{50}		L_{10}	
				DEL1	DEL4	DEL1	DEL4	EST.	MEAS.	CALC.	MEAS.	CALC.
1	2	1	D	2.55		-5.09	-6.61	-14.3	-13.8	-12.6	-18.4	-15.6
1	3	1	D	2.55		-7.55	-8.42	-18.6	-18.4	-17.6	-23.0	-21.2
2	1	1	D	2.55		-5.09	-6.61	-14.3	-13.8	-13.5	-16.4	-16.0
3	2	1	D	2.55		-5.09	-6.61	-14.3	-15.2	-12.2	-19.9	-15.3
3	3	1	D	2.55		-7.55	-8.42	-18.6	-15.5	-15.8	-18.5	-19.6
7	1	3	E	3.81	-5.51	-0.37	-2.94	- 1.6	- 2.1	- 1.5	- 3.6	- 2.8
7	2	3	E	3.81	-5.51	-4.71		- 3.0	- 2.0	- 0.7	- 3.0	- 3.0
7	3	3	E	3.81	-5.51	-7.28		- 5.6	- 2.2	- 3.0	- 3.6	- 6.3
7	4	3	E	-0.37	-2.94	-9.13		- 5.8	+ 0.6	- 3.2	- 0.7	- 6.2
8	1	4	D	3.81		-0.37	-4.32	- 8.5	- 4.3	- 6.3	-13.0	- 7.9
8	2	4	D	3.81		-4.71	-6.91	-15.4	-12.6	-13.1	-18.2	-14.5
8	3	4	D	3.81		-0.37	-4.32	- 8.5	- 7.3	- 8.5	-15.5	-10.0
9	1	5	E	0.63	-4.38	-2.89	-0.70	0.2	- 1.1	0.4	1.0	- 1.2
9	2	5	E	-2.89	-0.70	-4.71		- 1.1	- 0.8	- 0.8	- 3.1	- 2.0
9	3	5	E	-2.89	-0.70	-7.28		- 3.7	- 2.9	- 2.4	- 4.9	- 4.8
9	4	5	E	-2.89	-0.70	-9.13		- 5.5	- 4.3	- 3.9	- 6.7	- 6.9

*D = Depressed. E = Elevated.

Five values for the differences between the microphones are tabulated:

(1) The estimated (EST) differences based purely on the corrections noted in the preceding four columns of the table are given as an indication of what the calculated differences might be.

(2) The measured (MEAS) L_{50} differences.

(3) The calculated (CALC.) L_{50} differences from the modified MICNOISE program are for direct comparison with the column of measured values. The largest error is -3.8 dB, (calculated minus measured difference), while the mean error is +0.06 dB. These errors must be considered as combining the effects of distance and elevation corrections. Negative errors, are non-conservative.

(4) The measured L_{10} differences.

(5) The calculated L_{10} differences.

Comparing the calculated L_{10} levels with the measured levels, as for L_{50}, the largest error is +5.5 dB, while the mean error is +0.9 dB.

The results of this evaluation are summarized in Table 11, which gives the worst errors, average errors, standard deviations, and 68% confidence limits. Definitions are the same as used in previous tables.

Table 11

Summary of Vertical Correction Errors

	L_{50}	L_{10}
Max. Error	+3.0	+5.1
Min. Error	-3.8	-5.5
Mean Error	0.06	0.89
RMS Error	1.52	3.04
Standard Deviation	1.57	3.00
68% Confidence Range	-1.51	-2.11
	1.63	3.89

It will be noted that the 68% confidence limits are within ± 2 dB for L_{50}, but exceed these values for L_{10}, partly because of the inclusion of results from sites 3 and 4.

5.6 Detailed Conclusions

As a result of the evaluation of the MICNOISE computer program and the modified version, it is possible to draw conclusions about some of the points raised in Section 2.3, Comments on MICNOISE.

5.6.1 Traffic Model

The experimental accuracy evaluation and the overall error analysis tend to confirm the idea that the traffic noise, being largely random, should be treated statistically. This capability is beyond the scope of MICNOISE, or of any feasible modification, and must therefore be considered as an indication that ultimately a new program will be needed.

Serious errors do not appear to be generated by the dB-summing method, largely because trucks in the near lane predominate. In fact, they generally contribute within 1 dB of the overall predicted total.

5.6.2 Line-of-Sight Errors

If input is checked carefully, and if the level roadway code is used when line-of-sight conditions prevail, difficulties with the vertical corrections can be avoided. However, a test was put into the modified MICNOISE program with no difficulty and definitely seems to be desirable. A similar test is incorporated into the revised MICNOISE 5 program.

5.6.3 Distance Correction

An evaluation of the inverse $1\frac{1}{2}$ power law used in MICNOISE indicates that it gives good results and that it is an improvement over the basic theory. However, it might also be termed "nonphysical", and should therefore be avoided if a suitable alternative can be found.

5.6.4 Engine and Tire Noise

No further evaluation was made.

5.6.5 Format for Terrain Data

The revised MICNOISE 5 input format essentially meets the suggested requirements.

5.6.6 Table-Look-Up

Although calculation was substituted for table-look-up in obtaining the distance correction, DEL1, in the modified MICNOISE program, this was done because the limits of the tables were exceeded during the evaluation. The ultimate choice is one of programming style and program length.

5.6.7 Vertical and Barrier Corrections

It is considered that the results of the evaluation of the highway measurements, in which verticle and barrier corrections used in MICNOISE ranged to as much as 8.42 dB on trucks (13.42 dB on automobiles) are reasonable confirmations of the method used for elevated and depressed roads. By inference, the correction for barriers should be as good, but this does need further confirmation. As will be noted from Table 11, the L_{10} confidence limits for vertical corrections exceeded the overall values obtained in this study.

5.6.8 The Twilight Zone

The results of the overall evaluation, summed up in the bar charts of 68% confidence limits on (L_{10} - L_{50}) in Figure 14, support the proposed method of handling the (L_{10} - L_{50}) correction. The values used in the revised MICNOISE 5 program are sufficiently close (see Figure 2) that they are equally acceptable.

6. CONCLUSIONS

It is concluded that the revised MICNOISE 5 computer program predicts L_{10} levels that are within ± 2 dB of actual values, to 68% confidence limits; i.e. plus or minus one standard deviation. Since these confidence limits were observed to approximate the limits on experimental accuracy, it is conceivable that had more precise measurements been made the confidence limits might have been closer. Some improvement in experimental accuracy could be achieved by repeating the measurements and taking advantage of the experience gained. However, appreciable improvements could be made only by setting up carefully controlled tests at special sites with standardized vehicles.

It is the opinion of the authors that further changes in the program will not materially improve the results, even though they might simplify input, give more output, save computer storage and time, or otherwise result in a more elegant program.

It is believed that there are inherent limitations in the MICNOISE model, but that these will be overcome only by a fresh approach to the problem of highway noise prediction. To be more specific, these limitations include:

A. Calculation of L_{50} and L_{10} levels for separate rows of trucks and automobiles on different road groups, and final dB-summing.

B. Failure to recognize the random nature of vehicle separation and of individual vehicle noise.

C. Use of nonphysical effects such as the inverse $1\frac{1}{2}$ power law for distance, and use of a single frequency barrier correction.

D. Failure to provide for specification of confidence levels.

E. Failure to separate the sources of noise in a vehicle and their different speed-dependencies. For example, engine, gear, exhaust, intake, fan, and tire noise all behave in a different manner and should be computed independently.

7. RECOMMENDATIONS

It is recommended that the revised MICNOISE computer program, denoted by Program Version No. 5, 9/1/73, be used essentially as is for the prediction of L_{10} levels. The assumption should be made that the best estimate is predicted, and that 2 dB should be added to the prediction to obtain the 68% confidence level, and 4 dB should be added to obtain the 95% confidence level.

Further changes to MICNOISE which alter the predicted levels are not warranted and should not be made. This statement is not intended to prohibit changes which simplify input, provide more output, reduce time and storage, etc.

Consideration should be given to a parallel evaluation of highway barriers to confirm the predictions made by MICNOISE. Presently, accuracy of the barrier correction is inferred from the experimental verification obtained from vertical roadway corrections.

Work should be undertaken to develop a new prediction program which would avoid the present limitations on MICNOISE. Although it has not been an objective of the present study to investigate alternate methods, the following approach is tentatively suggested. Initially, the expected value of L_{EQ} (based on the time averaged square sound pressure) together with the predicted standard deviation should be computed. The value of L_{EQ} can be obtained quite accurately by combining values of L_{CONT}, the continuous line model estimates, and could take into account different noise sources and their variances. Final estimated values of L_{50}, L_{10} and any other quantity such as L_{NP} should be obtained by making overall corrections on the total levels at each point. These values should be given to preselected confidence levels.

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Analysis of the tape recordings was made in the Acoustic Laboratory at the School of Engineering and Applied Science of the University of Virginia. The computer program used to determine exceedence levels was developed by J. L. Schroeder, a graduate research assistant.

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APPENDIX A

PLAN VIEWS AND CROSS SECTIONS OF TEST SITES — TABLES OF MEASURED AND CALCULATED VALUES

APPENDIX B

LIST OF MICNOISE VERSION 2 COMPUTER PROGRAM

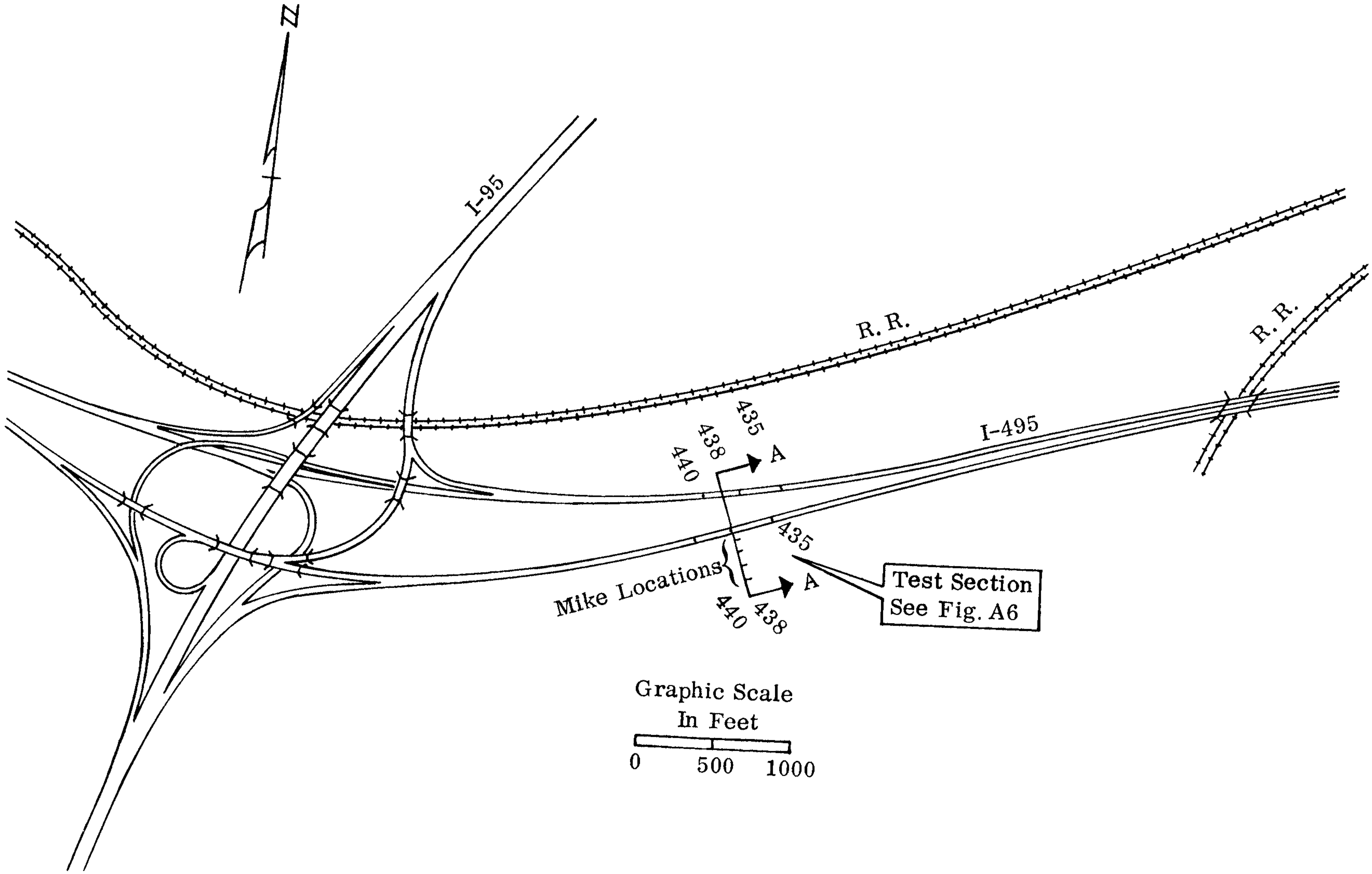

Figure A1. Plan of Site 1 on I-495 at Sta. 438 near Springfield, Virginia.

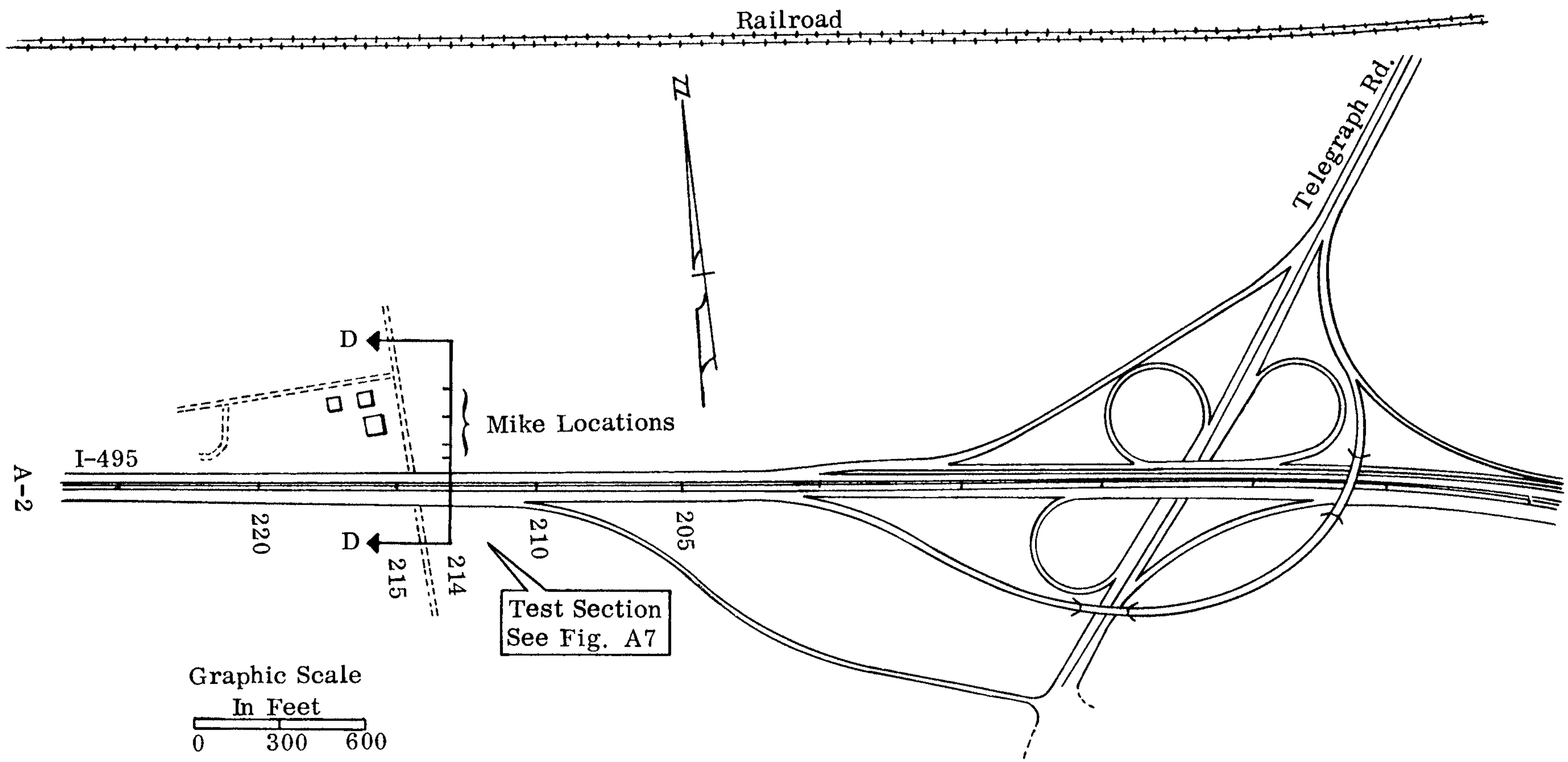

Figure A2. Plan of Site 2 on I-495 at Sta. 214, near Alexandria, Virginia.

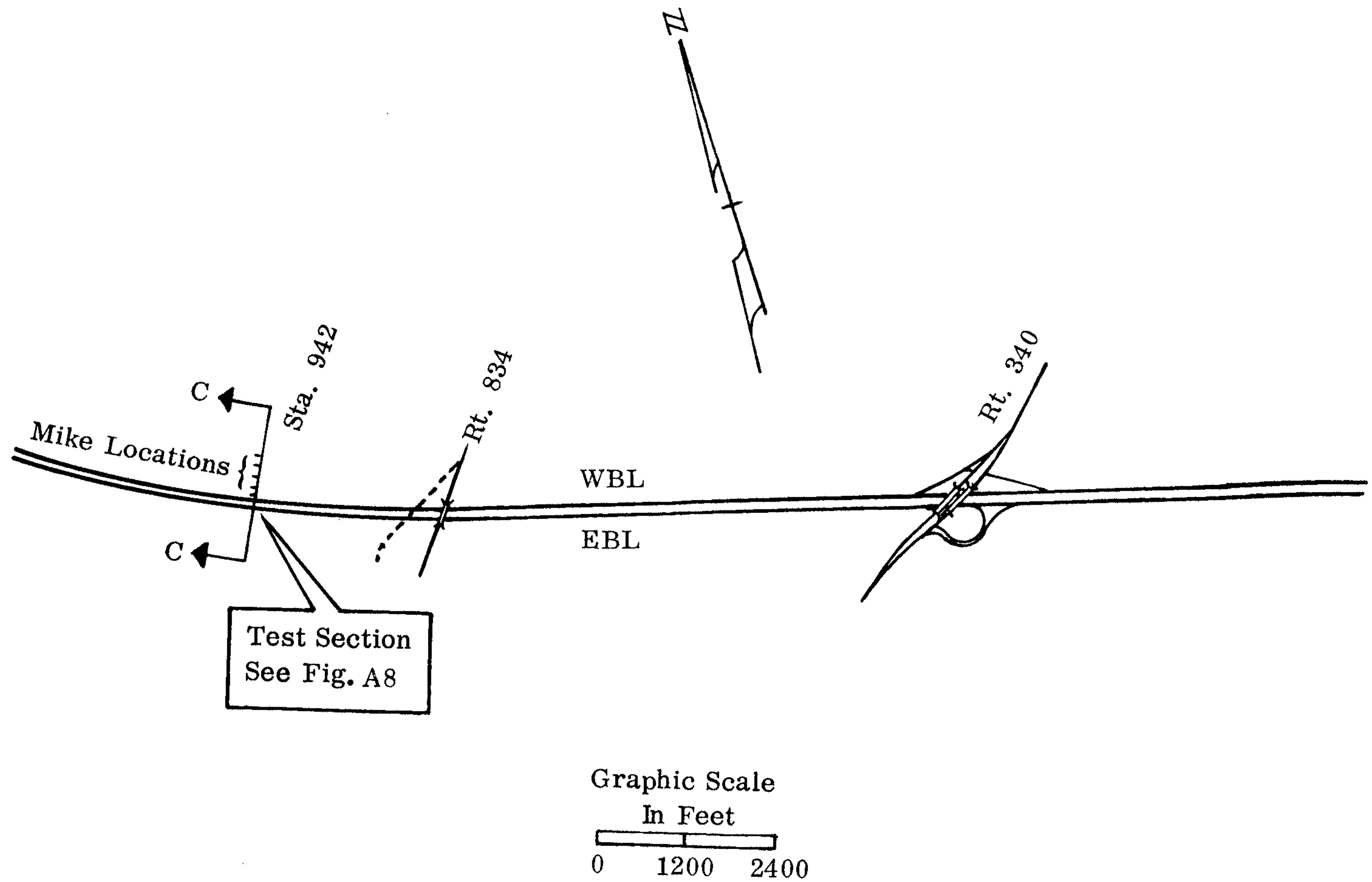

Figure A3. Plan of Site 3 on I-64 at Sta. 942, near Fishersville, Augusta County.

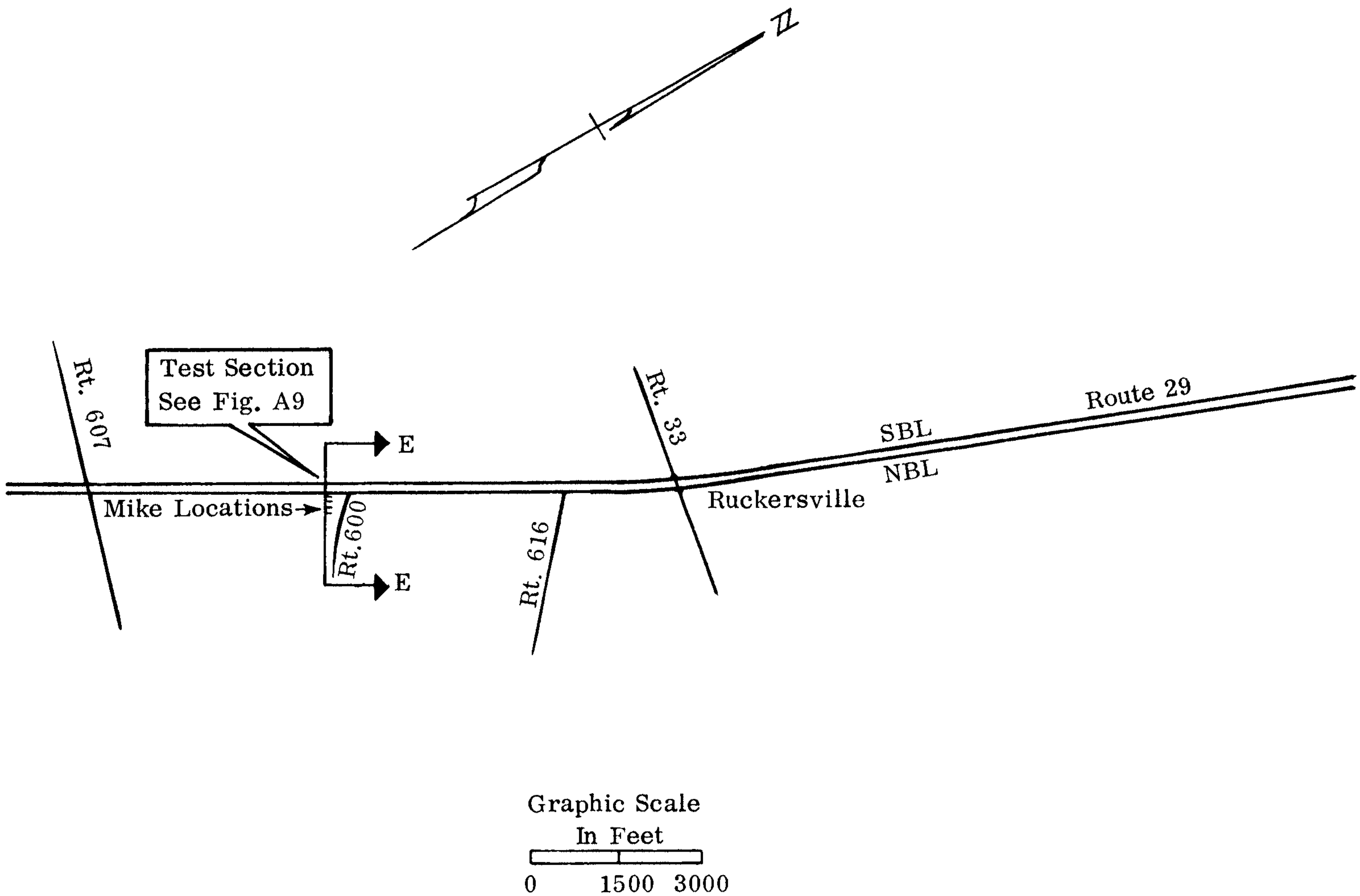

Figure A4. Plan of Site 4 on Rt. 29 at Sta. 750, south of Ruckersville, Virginia.

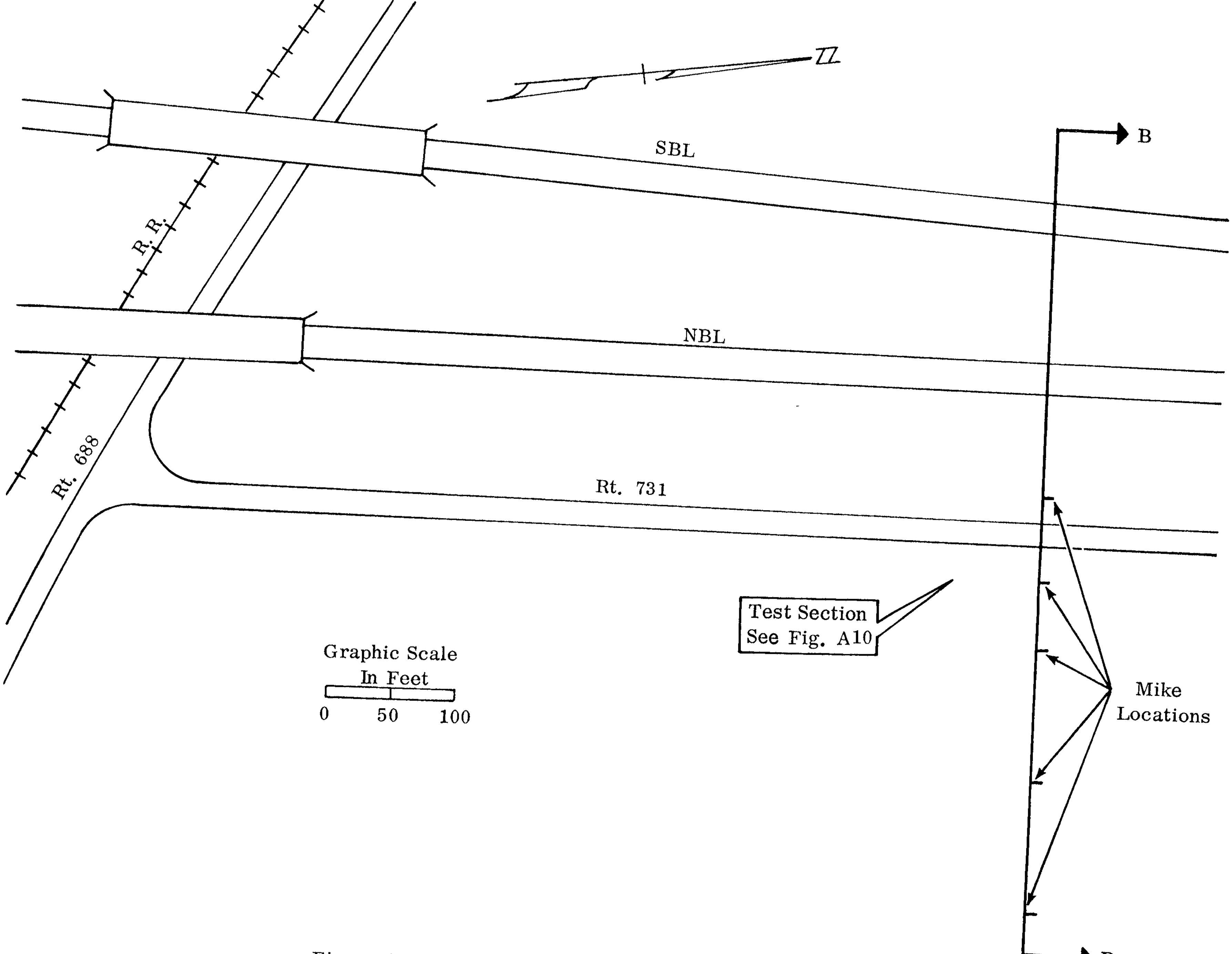

Figure A5. Plan of Site 5 on I-95 at Sta. 980, 0.3 mile east of Doswell, Hanover County, Virginia.

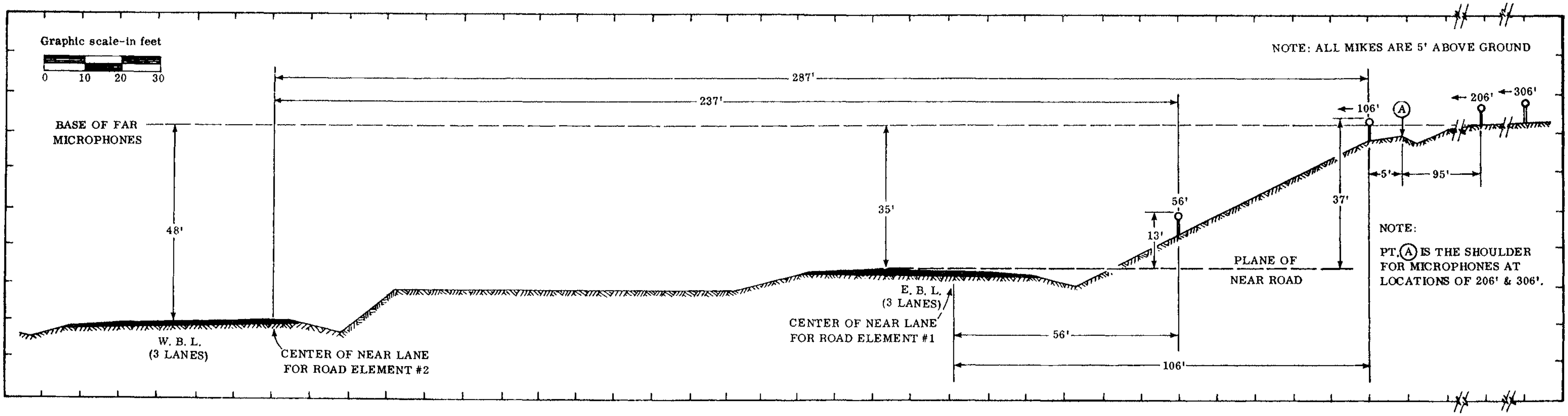

Figure A6. Cross section A-A from figure A1, Site 1 on I-495 at Sta. 438, near Springfield, Virginia.

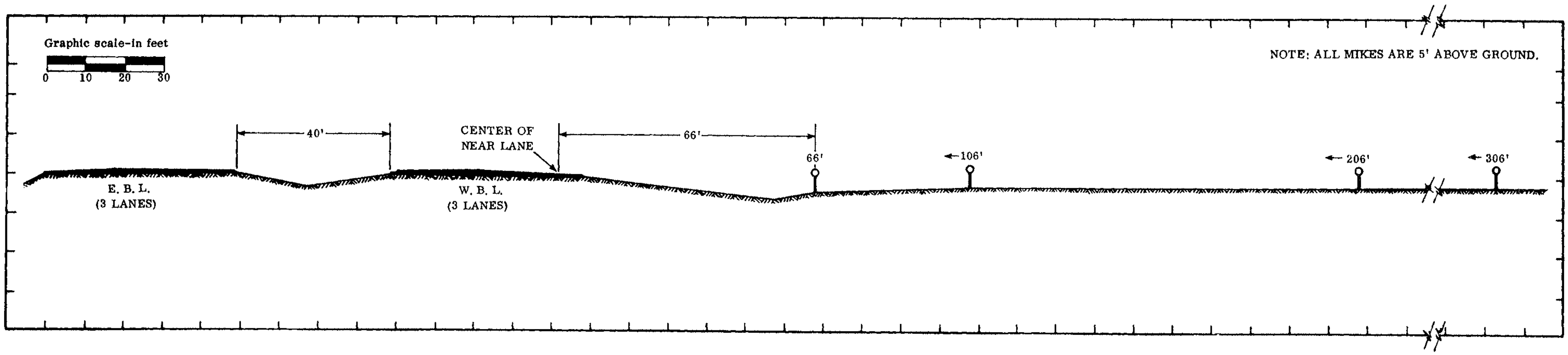

Figure A7. Cross section D-D from figure A2, Site 2, on I-495 at Sta. 214, near Alexandria, Virginia.

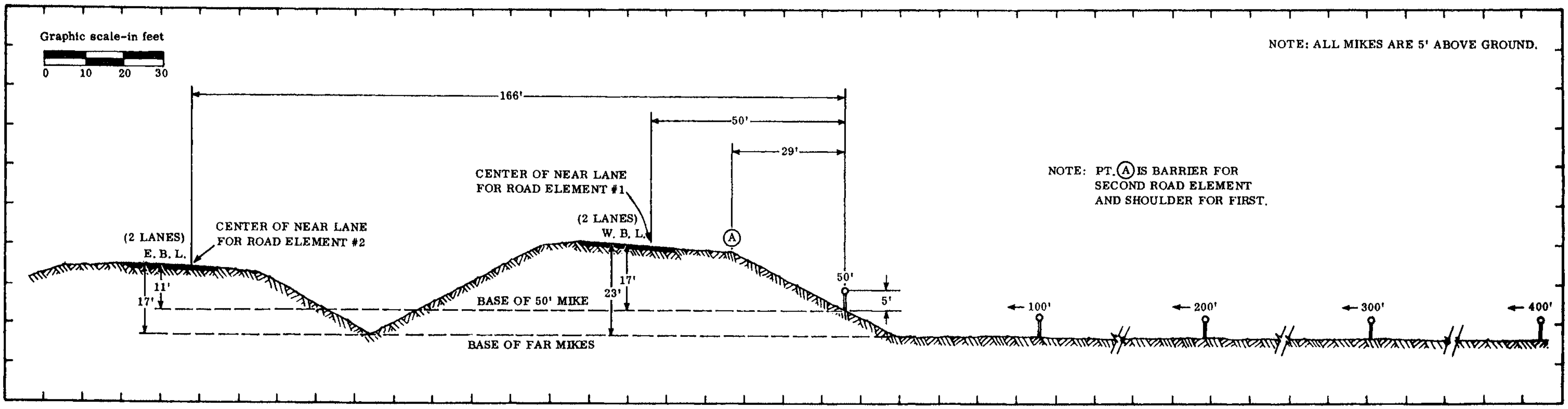

Figure A8. Cross section C-C from figure A3, Site 3 on I-64 at Sta. 942, near Fishersville, Augusta County, Virginia.

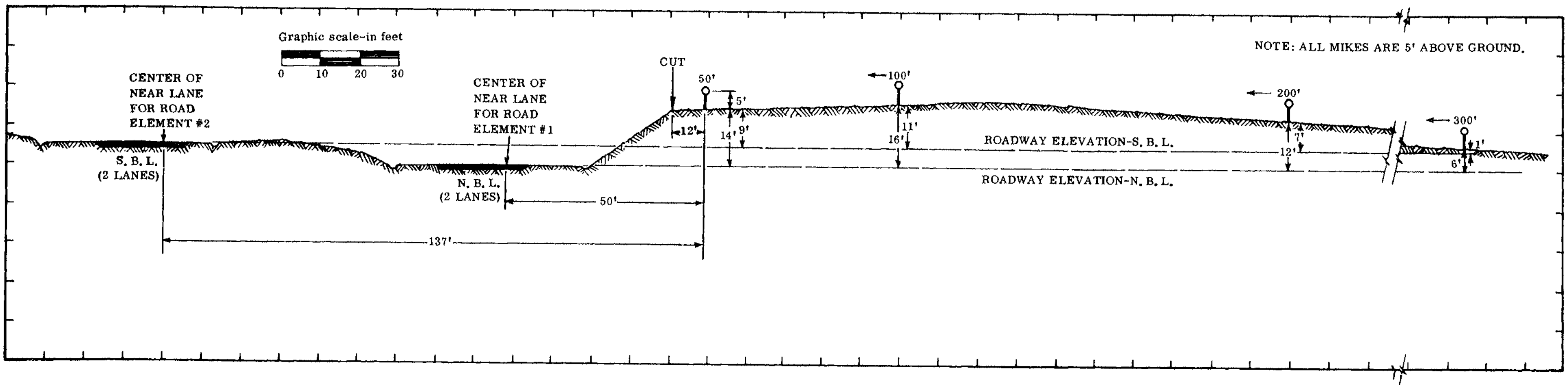

Figure A9. Cross section E-E from figure A4, Site 4 on Rt. 29 at Sta. 750, south of Ruckersville, Greene County, Virginia.

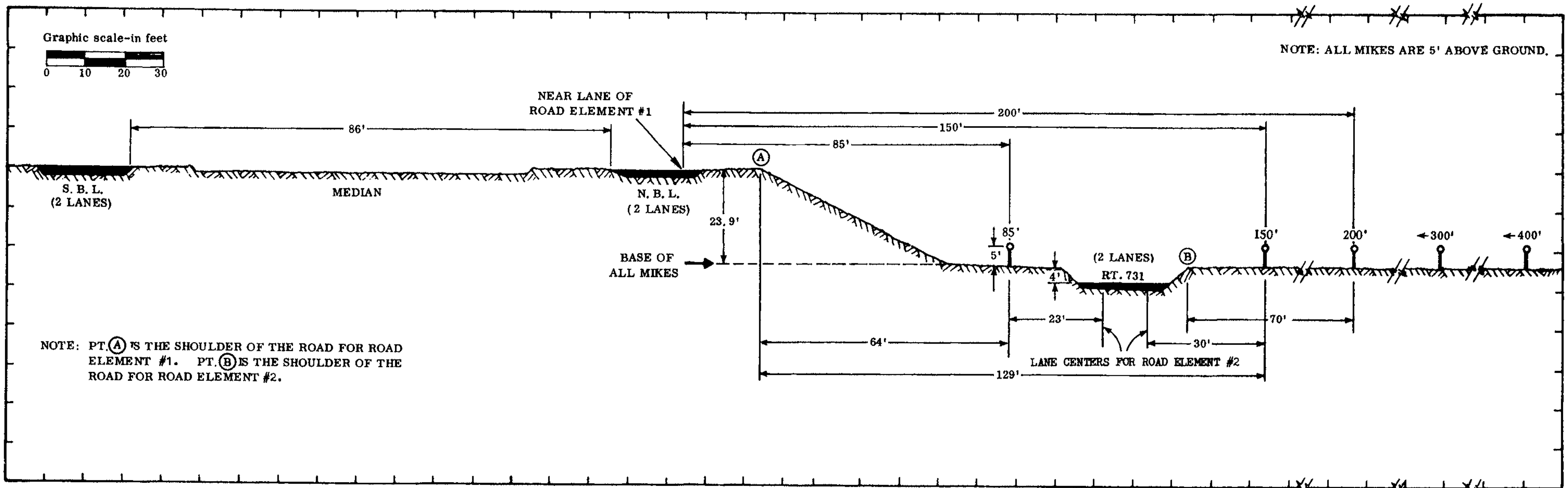

Figure A10. Cross section B-B from figure A5, Site 5 on I-95 at Sta. 980, 0.3 miles east of Doswell, Hanover County, Virginia.

TABLE A1 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 1, TRIAL 1, AT SITE 1 ON I-495 NEAR SPRINGFIELD

		Microphone Locn.	56		106	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	2011	2414	2011	2414
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	21	20	21	20
6	ST	Truck Sp. (mph)	58	59	58	59
7	SA	Auto Sp. (mph)	63	64	63	64
8	HD	Road Elev. Type	0	0	0	0
9	DN	Obs. to Road (ft)	56	237	106	287
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	3	3	3	3
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)				
22	DC	Obs. to Cut (ft)				
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	13	26	37	50
Notes (See Page ____)						
Measured Noise Levels		L50		76.9		78.7
		L10		85.0		84.8

TABLE A2 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS. TEST 1, TRIAL 2, AT SITE 1 ON I-495 NEAR SPRINGFIELD

		Microphone Locn.	56		206	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	2278	2414	2278	2414
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	19	20	19	20
6	ST	Truck Sp. (mph)	54	55	54	55
7	SA	Auto Sp. (mph)	63	64	63	64
8	HD	Road Elev. Type	0	0	1	1
9	DN	Obs. to Road (ft)	56	237	206	387
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	3	3	3	3
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)			35	48
22	DC	Obs. to Cut (ft)			95	95
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	13	26	5	5
Notes (See Page ____)						
Measured Noise Levels		L50		77.4		63.6
		L10		85.7		67.3

TABLE A3 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 1, TRIAL 3, AT SITE 1 ON I-495 NEAR SPRINGFIELD

		Microphone Locn.	56		306	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	2098	2589	2098	2589
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	20	13	20	13
6	ST	Truck Sp. (mph)	56	60	56	60
7	SA	Auto Sp. (mph)	62	66	62	66
8	HD	Road Elev. Type	0	0	1	1
9	DN	Obs. to Road (ft)	56	237	306	487
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	3	3	3	3
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress.(ft)			35	48
22	DC	Obs. to Cut (ft)			195	195
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	13	26	5	5
Notes (See Page ____)						
Measured Noise Levels		L50		76.4		58.0
		L10		85.2		62.2

TABLE A4 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 2, TRIAL 1, AT SITE 1 ON I-495 NEAR SPRINGFIELD

		Microphone Locn.	56		206	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	3434	2998	3434	2998
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	10	11	10	11
6	ST	Truck Sp. (mph)	55	52	55	52
7	SA	Auto Sp. (mph)	60	57	60	57
8	HD	Road Elev. Type	0	0	1	1
9	DN	Obs. to Road (ft)	56	237	206	387
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	3	3	3	3
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)			35	48
22	DC	Obs. to Cut (ft)			95	95
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	13	26	5	5
Notes (See Page ___)						
Measured Noise Levels		L50		77.9		64.1
		L10		84.7		68.3

TABLE A5 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 2, TRIAL 2, AT SITE 1 ON I-495 NEAR SPRINGFIELD

		Microphone Locn.	56		106	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	–	2	–
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	3052	3870	3052	3870
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	10	7	10	7
6	ST	Truck Sp. (mph)	55	50	55	50
7	SA	Auto Sp. (mph)	64	58	64	58
8	HD	Road Elev. Type	0	0	0	0
9	DN	Obs. to Road (ft)	56	237	106	287
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	3	3	3	3
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)				
22	DC	Obs. to Cut (ft)				
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	13	26	37	50
Notes (See Page ____)						
Measured Noise Levels		L50		77.3		76.9
		L10		83.5		81.5

TABLE A6 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 3, TRIAL 1, AT SITE 1 ON I-495 NEAR SPRINGFIELD

		Microphone Locn.	56		106	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	2943	3815	2943	3815
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	10	8	10	8
6	ST	Truck Sp. (mph)	54	34	54	34
7	SA	Auto Sp. (mph)	61	38	61	38
8	HD	Road Elev. Type	0	0	0	0
9	DN	Obs. to Road (ft)	56	237	106	287
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	3	3	3	3
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)				
22	DC	Obs. to Cut (ft)				
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	13	26	37	50
Notes (See Page ____)						
Measured Noise Levels		L50		76.4		75.4
		L10		83.3		81.3

TABLE A7 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 3, TRIAL 2, AT SITE 1 ON I-495 NEAR SPRINGFIELD

		Microphone Locn.	56		206	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	–	2	–
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	2616	4033	2616	4033
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	14	8	14	8
6	ST	Truck Sp. (mph)	54	32	54	32
7	SA	Auto Sp. (mph)	62	36	62	36
8	HD	Road Elev. Type	0	0	1	1
9	DN	Obs. to Road (ft)	56	237	206	387
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	3	3	3	3
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)			35	48
22	DC	Obs. to Cut (ft)			95	95
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	13	26	5	5
Notes (See Page ____)						
Measured Noise Levels		L50		75.9		60.7
		L10		83.7		63.8

TABLE A8 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 3, TRIAL 3, AT SITE 1 ON I-495 NEAR SPRINGFIELD

		Microphone Locn.	56		306	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	1962	3325	1962	3325
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	13	10	13	10
6	ST	Truck Sp. (mph)	59	43	59	43
7	SA	Auto Sp. (mph)	64	48	64	48
8	HD	Road Elev. Type	0	0	1	1
9	DN	Obs. to Road (ft)	56	237	306	487
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	3	3	3	3
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)			35	48
22	DC	Obs. to Cut (ft)			195	195
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	13	26	5	5
Notes (See Page ____)						
Measured Noise Levels		L50		73.5		58.0
		L10		81.7		63.2

TABLE A9 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 4 AT SITE 2 ON I-495 NEAR ALEXANDRIA

		TRIAL NO.	1	1	2	2	3	3
		Microphone Locn.	66	106	66	206	66	306
		Road Element No.	1	1	1	1	1	1
Seq No.	Symb.	Item						
1	REN	No. of Road Els.	1	1	1	1	1	1
2	NLG	No. of Lane Grps.	2	2	2	2	2	2
3	ADT.	Avg. Daily Tr.	2136	2136	2017	2017	2092	2092
4	PCADT	% ADT. per hr.	100	100	100	100	100	100
5	TMIX	% Trucks	19	19	18	18	15	15
6	ST	Truck Sp. (mph)	57	57	55	55	54	54
7	SA	Auto Sp. (mph)	62	62	62	62	62	62
8	HD	Road Elev. Type	0	0	0	0	0	0
9	DN	Obs. to Road (ft)	66	106	66	206	66	306
10	RL	Road Length Type	1	1	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1	1	1
13	P	No. of Lanes	3	3	3	3	3	3
14	DEL3	Grade Corr.						
15	DEL5	Road Surf. Corr.						
16	DEL7	Struc. Corr.						
17	MED	Median Width (ft)	40	40	40	40	40	40
18	THETA	Road Incl. Angle						
19	H1	Road Elev. (ft)						
20	DS	Obs. Shoulder (ft)						
21	H2	Road Depress. (ft)						
22	DC	Obs. to Cut (ft)						
23	H	Barrier Ht. (ft)						
24	DB	Obs. to Barr. (ft)						
25	ALPHA	Barr. Incl. Angle						
26	HO	Obs. Ht. (ft)	5	5	5	5	5	5
Notes (See Page ____)								
Measured Noise Levels		L50	75.9	74.1	77.0	71.8	75.9	67.9
		L10	82.2	79.8	83.0	76.4	82.3	71.7

TABLE A10 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 5 AT SITE 2 ON I-495 NEAR ALEXANDRIA

		TRIAL NO.	1	1	2	2	3	3
		Microphone Locn.	66	306	66	206	66	106
		Road Element No.	1	1	1	1	1	1
Seq No.	Symb.	Item						
1	REN	No. of Road Els.	1	1	1	1	1	1
2	NLG	No. of Lane Grps.	2	2	2	2	2	2
3	ADT.	Avg. Daily Tr.	2276	2276	2227	2227	2206	2206
4	PCADT	% ADT. per hr.	100	100	100	100	100	100
5	TMIX	% Trucks	16	16	17	17	14	14
6	ST	Truck Sp. (mph)	53	53	51	51	52	52
7	SA	Auto Sp. (mph)	64	64	60	60	62	62
8	HD	Road Elev. Type	0	0	0	0	0	0
9	DN	Obs. to Road (ft)	66	306	66	206	66	106
10	RL	Road Length Type	1	1	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1	1	1
13	P	No. of Lanes	3	3	3	3	3	3
14	DEL3	Grade Corr.						
15	DEL5	Road Surf. Corr.						
16	DEL7	Struc. Corr.						
17	MED	Median Width (ft)	40	40	40	40	40	40
18	THETA	Road Incl. Angle						
19	H1	Road Elev. (ft)						
20	DS	Obs. Shoulder (ft)						
21	H2	Road Depress. (ft)						
22	DC	Obs. to Cut (ft)						
23	H	Barrier Ht. (ft)						
24	DB	Obs. to Barr. (ft)						
25	ALPHA	Barr. Incl. Angle						
26	HO	Obs. Ht. (ft)	5	5	5	5	5	5
Notes (See Page ____)								
Measured Noise Levels		L50	75.5	65.3	76.4	70.5	75.5	72.8
		L10	82.1	70.5	83.5	75.8	81.4	78.6

TABLE A11 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 7, TRIAL 1, AT SITE 3 ON I-64 NEAR FISHERSVILLE

		Microphone Locn.	50		100	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	402	354	402	354
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	37	11	37	11
6	ST	Truck Sp. (mph)	56	52	56	52
7	SA	Auto Sp. (mph)	66	66	66	66
8	HD	Road Elev. Type	-1	0	-1	0
9	DN	Obs. to Road (ft)	50	166	100	216
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	1	0	1
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)	17		23	
20	DS	Obs. Shoulder (ft)	29		79	
21	H2	Road Depress. (ft)				
22	DC	Obs. to Cut (ft)				
23	H	Barrier Ht. (ft)		6		6
24	DB	Obs. to Barr. (ft)		29		79
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	-6	5	-12
Notes (See Page ____)						
Measured Noise Levels		L50		53.8		51.7
		L10		63.4		59.8

TABLE A12 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 7, TRIAL 2, AT SITE 3 ON I-64 NEAR FISHERSVILLE

		Microphone Locn.	50		200	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	348	336	348	336
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	9	60	9	60
6	ST	Truck Sp. (mph)	59	54	59	54
7	SA	Auto Sp. (mph)	66	66	66	66
8	HD	Road Elev. Type	-1	0	-1	0
9	DN	Obs. to Road (ft)	50	166	200	316
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	1	0	1
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)	17		23	
20	DS	Obs. Shoulder (ft)	29		179	
21	H2	Road Depress. (ft)				
22	DC	Obs. to Cut (ft)				
23	H	Barrier Ht. (ft)		6		6
24	DB	Obs. to Barr. (ft)		29		179
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	-6	5	-12
Notes (See Page ____)						
Measured Noise Levels		L50		56.1		54.1
		L10		63.7		60.7

TABLE A13 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 7, TRIAL 3, AT SITE 3 ON I-64 NEAR FISHERSVILLE

		Microphone Locn.	50		300	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	372	354	372	354
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	9	18	9	18
6	ST	Truck Sp. (mph)	54	49	54	49
7	SA	Auto Sp. (mph)	67	67	67	67
8	HD	Road Elev. Type	-1	0	-1	0
9	DN	Obs. to Road (ft)	50	166	300	416
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	1	0	1
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)	17		23	
20	DS	Obs. Shoulder (ft)	29		279	
21	H2	Road Depress. (ft)				
22	DC	Obs. to Cut (ft)				
23	H	Barrier Ht. (ft)		6		6
24	DB	Obs. to Barr. (ft)		29		279
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	-6	5	-12
Notes (See Page ___)						
Measured Noise Levels		L50		55.4		53.2
		L10		65.3		61.7

TABLE A14 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 7, TRIAL 4, AT SITE 3 ON I-64 NEAR FISHERSVILLE

		Microphone Locn.	100		400	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	–	2	–
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	327	360	327	360
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	9	9	9	9
6	ST	Truck Sp. (mph)	55	50	55	50
7	SA	Auto Sp. (mph)	66	66	66	66
8	HD	Road Elev. Type	-1	0	-1	0
9	DN	Obs. to Road (ft)	100	216	400	516
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	1	0	1
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)	23		23	
20	DS	Obs. Shoulder (ft)	79		379	
21	H2	Road Depress. (ft)				
22	DC	Obs. to Cut (ft)				
23	H	Barrier Ht. (ft)		6		6
24	DB	Obs. to Barr. (ft)		79		379
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	-12	5	-12
Notes (See Page ____)						
Measured Noise Levels		L50		49.1		49.7
		L10		59.4		58.7

TABLE A15 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.
TEST 8, TRIAL 1, AT SITE 4 ON U.S. Rte. 29 NEAR RUCKERSVILLE

		Microphone Locn.	50		100	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	138	216	138	216
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	27.8	5.9	27.8	5.9
6	ST	Truck Sp. (mph)	53.7	53.7	53.7	53.7
7	SA	Auto Sp. (mph)	64.3	64.3	64.3	64.3
8	HD	Road Elev. Type	0	0	1	1
9	DN	Obs. to Road (ft)	50	137	100	187
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)			14	9
22	DC	Obs. to Cut (ft)			62	62
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	5	7	7
Notes (See Page ____)						
Measured Noise Levels		L50		51.2		46.9
		L10		68.5		55.5

TABLE A16 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 8, TRIAL 2, AT SITE 4 ON U.S. Rte. 29 NEAR RUCKERSVILLE

		Microphone Locn.	50		200	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	–	2	–
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	270	252	270	252
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	15.4	20.0	15.4	20.0
6	ST	Truck Sp. (mph)	58.1	58.1	58.1	58.1
7	SA	Auto Sp. (mph)	66.7	66.7	66.7	66.7
8	HD	Road Elev. Type	0	0	1	1
9	DN	Obs. to Road (ft)	50	137	200	287
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)			14	9
22	DC	Obs. to Cut (ft)			162	162
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	5	3	3
Notes (See Page ____)						
Measured Noise Levels		L50		59.8		47.2
		L10		71.8		53.6

TABLE A17 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 8, TRIAL 3, AT SITE 4 ON U.S. Rte. 29 NEAR RUCKERSVILLE

		Microphone Locn.	50		100	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	–	2	–
2	NLG	No. of Lane Grps.	1	1	1	1
3	ADT.	Avg. Daily Tr.	270	222	270	222
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	2.3	8.8	2.3	8.8
6	ST	Truck Sp. (mph)	57.2	57.2	57.2	57.2
7	SA	Auto Sp. (mph)	62.1	62.1	62.1	62.1
8	HD	Road Elev. Type	0	0	1	1
9	DN	Obs. to Road (ft)	50	137	100	187
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)			14	9
22	DC	Obs. to Cut (ft)			62	62
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	5	7	7
Notes (See Page ____)						
Measured Noise Levels		L50		56.6		49.3
		L10		70.9		55.4

TABLE A18 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 8, TRIAL 4, AT SITE 4 ON U.S. Rte. 29 NEAR RUCKERSVILLE

		Microphone Locn.	300			
		Road Element No.	1	2		
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—		
2	NLG	No. of Lane Grps.	1	1		
3	ADT.	Avg. Daily Tr.	258	318		
4	PCADT	% ADT. per hr.	100	100		
5	TMIX	% Trucks	7.5	15.2		
6	ST	Truck Sp. (mph)	56.3	56.3		
7	SA	Auto Sp. (mph)	65.3	65.3		
8	HD	Road Elev. Type	1	1		
9	DN	Obs. to Road (ft)	300	387		
10	RL	Road Length Type	1	1		
11	BL	Barr. Length Type	0	0		
12	FLO	Traffic Flow	1	1		
13	P	No. of Lanes	2	2		
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)				
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)				
20	DS	Obs. Shoulder (ft)				
21	H2	Road Depress. (ft)	14	9		
22	DC	Obs. to Cut (ft)	262	262		
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	-3	-3		
Notes (See Page ____)						
Measured Noise Levels		L50		42.5		
		L10		46.9		

TABLE A19 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 9, TRIAL 1, AT SITE 5 ON I-95 NEAR DOSWELL

		Microphone Locn.	85		150	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	2	1	2	1
3	ADT.	Avg. Daily Tr.	1113	24	1113	24
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	15.9	100	15.9	100
6	ST	Truck Sp. (mph)	55.4	10	55.4	10
7	SA	Auto Sp. (mph)	65.3	10	65.3	10
8	HD	Road Elev. Type	-1	0	-1	0
9	DN	Obs. to Road (ft)	85	23	150	30
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	0	1	0
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)	86		86	
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)	23.9		23.9	
20	DS	Obs. Shoulder (ft)	64		129	
21	H2	Road Depress. (ft)				
22	DC	Obs. to Cut (ft)				
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	9	5	9
Notes (See Page ____)						
Measured Noise Levels		L50		61.5		62.6
		L10		69.8		70.8

TABLE A20 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 9, TRIAL 2, AT SITE 5 ON I-95 NEAR DOSWELL

		Microphone Locn.	150		200	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	–	2	–
2	NLG	No. of Lane Grps.	2	1	2	1
3	ADT.	Avg. Daily Tr.	1188	18	1188	18
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	16.2	33	16.2	33
6	ST	Truck Sp. (mph)	58.1	25	58.1	25
7	SA	Auto Sp. (mph)	66.7	25	66.7	25
8	HD	Road Elev. Type	-1	0	-1	1
9	DN	Obs. to Road (ft)	150	30	200	80
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)	86		86	
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)	23.9		23.9	
20	DS	Obs. Shoulder (ft)	129		179	
21	H2	Road Depress. (ft)				4
22	DC	Obs. to Cut (ft)				70
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	9	5	5
Notes (See Page ____)						
Measured Noise Levels		L50		64.7		63.9
		L10		73.5		70.4

TABLE A21 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 9, TRIAL 3, AT SITE 5 ON I-95 NEAR DOSWELL

		Microphone Locn.	150		300	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	2	1	2	1
3	ADT.	Avg. Daily Tr.	1185	18	1185	18
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	15.2	33	15.2	33
6	ST	Truck Sp. (mph)	57.2	25	57.2	25
7	SA	Auto Sp. (mph)	62.1	25	62.1	33
8	HD	Road Elev. Type	-1	0	-1	1
9	DN	Obs. to Road (ft)	150	30	300	180
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)	86		86	
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)	23.9		23.9	
20	DS	Obs. Shoulder (ft)	129		279	
21	H2	Road Depress. (ft)				4
22	DC	Obs. to Cut (ft)				170
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	9	5	5
Notes (See Page ____)						
Measured Noise Levels		L50		65.0		62.1
		L10		74.3		69.4

TABLE A22 EXPERIMENTAL PARAMETERS AND MEASURED LEVELS.

TEST 9, Trial 4, AT SITE 5 ON I-95 NEAR DOSWELL

		Microphone Locn.	150		400	
		Road Element No.	1	2	1	2
Seq No.	Symb.	Item				
1	REN	No. of Road Els.	2	—	2	—
2	NLG	No. of Lane Grps.	2	1	2	1
3	ADT.	Avg. Daily Tr.	1044	18	1044	18
4	PCADT	% ADT. per hr.	100	100	100	100
5	TMIX	% Trucks	19.3	33	19.3	33
6	ST	Truck Sp. (mph)	56.3	25	56.3	25
7	SA	Auto Sp. (mph)	65.3	25	65.3	25
8	HD	Road Elev. Type	-1	0	-1	1
9	DN	Obs. to Road (ft)	150	30	400	280
10	RL	Road Length Type	1	1	1	1
11	BL	Barr. Length Type	0	0	0	0
12	FLO	Traffic Flow	1	1	1	1
13	P	No. of Lanes	2	2	2	2
14	DEL3	Grade Corr.				
15	DEL5	Road Surf. Corr.				
16	DEL7	Struc. Corr.				
17	MED	Median Width (ft)	86		86	
18	THETA	Road Incl. Angle				
19	H1	Road Elev. (ft)	23.9		23.9	
20	DS	Obs. Shoulder (ft)	129		379	
21	H2	Road Depress. (ft)				4
22	DC	Obs. to Cut (ft)				270
23	H	Barrier Ht. (ft)				
24	DB	Obs. to Barr. (ft)				
25	ALPHA	Barr. Incl. Angle				
26	HO	Obs. Ht. (ft)	5	9	5	5
Notes (See Page ____)						
Measured Noise Levels		L50		62.6		58.3
		L10		73.9		67.2

TABLE A23 COMPARISON OF LEVELS CALCULATED BY MICNOISE WITH MEASURED LEVELS AT SITE 1 ON I-495 NEAR SPRINGFIELD

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
1	1	56 N	76.9	76.5	85.0	84.4
1	1 *	106 F	78.7	73.4	84.8	79.6
1	2	56 N	77.4	77.1	85.7	84.7
1	2	206 F	63.6	64.5	67.3	69.0
1	3	56 N	76.4	76.5	85.2	84.4
1	3	306 F	58.0	58.9	62.2	63.1
2	1	56 N	77.9	76.4	84.7	84.1
2	1	206 F	64.1	62.9	68.3	67.8
2	2	56 N	77.3	76.0	83.5	83.8
2	2 *	106 F	76.9	72.8	81.5	78.8
3	1	56 N	76.4	75.9	83.3	83.7
3	1 *	106 F	75.4	72.9	81.3	78.8
3	2	56 N	75.9	76.6	83.7	84.3
3	2	206 F	60.7	64.4	63.8	68.8
3	3	56 N	73.5	75.9 T	81.7	79.2
3	3	306 F	58.0	58.6	63.2	62.8

These values not included in statistical analysis.

Twilight zone, near lane

TABLE A24 COMPARISON OF LEVELS CALCULATED BY MICNOISE WITH MEASURED LEVELS AT SITE 2 ON I-495 NEAR ALEXANDRIA

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
4	1	66 N	75.9	76.2	82.2	83.5
4	1	106 F	74.1	73.9	79.8	80.1
4	2	66 N	77.0	75.7	83.0	83.3
4	2	206 F	71.8	70.1	76.4	75.0
4	3	66 N	75.9	75.1	82.3	82.9
4	3	306 F	67.9	67.4	71.7	71.6
5	1	66 N	75.5	76.2	82.1	83.5
5	1	306 F	65.3	68.4	70.5	72.4
5	2	66 N	76.4	76.4	83.5	83.6
5	2	206 F	70.5	70.8	75.8	75.5
5	3	66 N	75.5	75.3	81.4	83.0
5	3	106 F	72.8	73.1	78.6	79.4

TABLE A25 COMPARISON OF LEVELS CALCULATED BY MICNOISE WITH MEASURED LEVELS AT SITE 3 ON I-64 NEAR FISHERSVILLE

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
7	1	50 N	53.8	62.5 TT	63.4	67.3
7	1	100 F	51.7	61.1 TT	59.8	64.7
7	2	50 N	56.1	59.1 T	63.7	67.1
7	2	200 F	54.1	58.1 T	60.7	63.6
7	3	50 N	55.4	58.0 TT	65.3	65.4
7	3	300 F	53.2	55.0 T	61.7	59.6
7	4	100 N	49.1	55.6 TT	59.4	61.7
7	4	400 F	49.7	52.5 T	58.7	56.7

T - Twilight zone, near lane

TT- Twilight zone, both lanes

TABLE A26 COMPARISON OF LEVELS CALCULATED BY MICNOISE WITH MEASURED LEVELS AT SITE 4 ON U.S. 29 NEAR RUCKERSVILLE

TEST #	TRIAL #	MICR. LOCN.	L50		L 10	
			MEAS.	CALC.	MEAS.	CALC.
8	1	50 N	51.2	66.7 TT	68.5	74.9
8	1	100 F	46.9	54.4 TT	55.5	60.8
8	2	50 N	59.8	69.0 TT	71.8	76.2
8	2	200 F	47.2	53.1 TT	53.6	56.8
8	3	50 N	56.6	63.3 TT	70.9	73.0
8	3	100 F	49.3	52.3 TT	55.4	59.1
8	4	300 F	42.5	46.1 T	46.9	54.2

T - Twilight zone, near lane.
TT- Twilight zone, both lanes.

TABLE A27 COMPARISON OF LEVELS CALCULATED BY MICNOISE WITH MEASURED LEVELS AT SITE 5 ON I-95 NEAR DOSWELL

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
9	1	85 N	61.5	63.0 T	69.8	67.7
9	1	150 F	62.6	64.1 T	70.8	72.2
9	2	150 N	64.7	64.4 T	73.5	72.5
9	2	200 F	63.9	63.7 T	70.4	70.6
9	3	150 N	65.0	64.0 T	74.3	72.2
9	3	300 F	62.1	61.8	69.4	67.7
9	4	150 N	62.6	64.7 T	73.9	72.7
9	4	400 F	58.3	61.0 T	67.2	66.1

T = Twilight zone on side road.

TABLE A28 COMPARISON OF LEVELS CALCULATED BY MODIFIED MICNOISE WITH MEASURED LEVELS AT SITE 1 ON I-495 NEAR SPRINGFIELD

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
1	1	56 N	76.9	76.5	85.0	84.3
1	1 *	106 F	78.7	73.4	84.8	79.6
1	2	56 N	77.4	77.1	85.7	84.6
1	2	206 F	63.6	64.5	67.3	69.0
1	3	56 N	76.4	76.5	85.2	84.3
1	3	306 F	58.0	58.9	62.2	63.1
2	1	56 N	77.9	76.4	84.7	83.8
2	1	206 F	64.1	62.9	68.3	67.8
2	2	56 N	77.3	76.0	83.5	83.4
2	2 *	106 F	76.9	72.8	81.5	78.8
3	1	56 N	76.4	75.9	83.3	83.4
3	1 *	106 F	75.4	72.9	81.3	78.8
3	2	56 N	75.9	76.6	83.7	84.1
3	2	206 F	60.7	64.4	63.8	68.8
3	3	56 N	73.5	74.4	81.7	82.4
3	3	306 F	58.0	58.6	63.2	62.8

* These values not included in statistical analysis.

TABLE A29 COMPARISON OF LEVELS CALCULATED BY MODIFIED MICNOISE WITH MEASURED LEVELS AT SITE 2 ON I-495 NEAR ALEXANDRIA

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
4	1	66 N	75.9	76.2	82.2	83.5
4	1	106 F	74.1	73.9	79.8	80.1
4	2	66 N	77.0	75.7	83.0	83.2
4	2	206 F	71.8	70.1	76.4	75.0
4	3	66 N	75.9	75.1	82.3	82.7
4	3	306 F	67.9	67.4	71.7	71.6
5	1	66 N	75.5	76.2	82.1	83.4
5	1	306 F	65.3	68.4	70.5	72.4
5	2	66 N	76.4	76.4	83.5	83.6
5	2	206 F	70.5	70.8	75.8	75.5
5	3	66 N	75.5	75.3	81.4	82.8
5	3	106 F	72.8	73.1	78.6	79.4

TABLE A30 COMPARISON OF LEVELS CALCULATED BY MODIFIED MICNOISE WITH MEASURED LEVELS AT SITE 3 ON I-64 NEAR FISHERSVILLE

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
7	1	50 N	53.8	62.4	63.4	74.1
7	1	100 F	51.7	60.9	59.8	71.3
7	2	50 N	56.1	57.1	63.7	66.8
7	2	200 F	54.1	56.4	60.7	63.8
7	3	50 N	55.4	54.4	65.3	65.8
7	3	300 F	53.2	51.4	61.7	59.5
7	4		49.1	51.5	59.4	62.2
7	4	400 F	49.7	48.3	58.7	56.0

TABLE A31 COMPARISON OF LEVELS CALCULATED BY MODIFIED MICNOISE WITH MEASURED LEVELS AT SITE 4 ON U.S. 29 NEAR RUCKERSVILLE

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
8	1	50 N	51.2	58.6	68.5	70.9
8	1	100 F	46.9	52.3	55.5	63.0
8	2	50 N	59.8	61.6	71.8	73.3
8	2	200 F	47.2	48.5	53.6	58.8
8	3	50 N	56.6	60.1	70.9	70.7
8	3	100 F	49.3	51.6	55.4	60.7
8	4	300 F	42.5	45.0	46.9	53.9

TABLE A32 COMPARISON OF LEVELS CALCULATED BY MODIFIED MICNOISE WITH MEASURED LEVELS AT SITE 5 ON I-95 NEAR DOSWELL

TEST #	TRIAL #	MICR. LOCN.	L50		L10	
			MEAS.	CALC.	MEAS.	CALC.
9	1	85 N	61.5	63.5*	69.8	73.0*
9	1	150 F	62.6	63.9*	70.8	71.8*
9	2	150 N	64.7	64.4	73.5	72.6
9	2	200 F	63.9	63.6	70.4	70.6
9	3	150 N	65.0	63.9	74.3	72.3
9	3	300 F	62.1	61.5	69.4	67.5
9	4	150 N	62.6	64.7	73.9	72.8
9	4	400 F	58.3	60.8	67.2	65.9

* Trucks on side road ignored in these calculations.

```
C***********************************************************************C
C*                                                                     *C
C*                                                                     *C
C*   MM     MM  III    CCCC   N     N    0000    III   SSS   EEEEEE    *C
C*   M M   M M   I    C    C  NN    N   0    0    I   S   S  E         *C
C*   M  M M  M   I    C       N N   N  0      0   I   S      E         *C
C*   M   M   M   I    C       N  N  N  0      0   I    S     EEEEE     *C
C*   M       M   I    C       N   N N  0      0   I     S    E         *C
C*   M       M   I    C    C  N    NN   0    0    I   S   S  E         *C
C*   M       M  III    CCCC   N     N    0000    III   SSS   EEEEEE    *C
C*                                                                     *C
C*                                                                     *C
C***********************************************************************C
C
C
C      INPUT VARIABLES
C
C      JOB = JOB NUMBER
C      ID = IDENTIFICATION NO.
C      NC = CARD IDENTIFICATION NUMBER
C      NRE = NUMBER OF ROADWAY ELEMENTS
C      N = NUMBER OF LANE GROUPS
C      ADT = AVER. ANNUAL DAILY TRAFFIC (VEH/DAY)
C      PCAUT = PERCENT ADT DURING SELECTED TIME INTERVAL
C      TMIX = PERCENT TRUCK MIX
C      ST = TRUCK SPEED (MPH)
C      SA = AUTO SPEED (MPH)
C      HD = ROADWAY ELEVATION TYPE
C           1 = DEPRESSED, 0 = AT GRADE, -1 = ELEVATED
C      DN = OBSERVER TO CENTER OF NEAR LANE (FEET)
C      RL = ROADWAY LENGTH TYPE
C           1 = INFINITE, 2 = SEMI-INFINITE, 3 = FINITE
C      BL = BARRIER LENGTH
C           0 = NONE, 1 = INFINITE, 2 = FINITE
C      FLO = TRAFFIC FLOW (0 = INTERRUPTED, 1 = FREE FLOW)
C      P = NUMBER OF LANES PER LANE GROUP
C      DEL3 = GRADE CORRECTION
C            0,+2,+3,+5 DB FOR .LE. 2, 3-4, 5-6, .GE. 7%)
C      DEL5 = ROADWAY SURFACE CORRECTION
C            -5, 0, +5 DB FOR SMOOTH, NORMAL, ROUGH
C      DEL7 = STRUCTURE CORRECTION (3-5 DB/ROW OF HOUSES, 10 DB MAX.)
C      MED = MEDIAN WIDTH FOR DIVIDED HIGHWAYS (FEET) WHEN N .GT. 1
C      THETA = ROADWAY INCLUDED ANGLE (DEGREES) WHEN RL .GE. 2
C      H1 = ELEVATED HEIGHT (FEET) WHEN HD = -1
C      DS = OBSERVER TO SHOULDER (FEET) WHEN HD = -1
C      H2 = DEPRESSED HEIGHT (FEET) WHEN HD = 1
C      DC = OBSERVER TO CUT (FEET) WHEN HD = 1
C      H = BARRIER HEIGHT (FEET) WHEN BL = 1 OR 2
C      DB = OBSERVER TO BARRIER (FEET) WHEN BL = 1 OR 2
C      ALPHA = BARRIER INCLUDED ANGLE (DEGREES) WHEN BL .GE. 2
C      HO = OBSERVER HEIGHT REL. TO REF. PLANE (FEET); +ABOVE, - BELOW
C      ICON = END OF DATA INDICATOR
C            -1 STOP PROGRAM, 0 NEW DATA, 1 CHANGE OBSERVER'S POSITION
C
C
C***********************************************************************C
C*     CAUTION, METHOD NOT VALIDATED. READ REPORT NCHNP 117,           *C
C*              PROGRAM VERSION NO. 2, 8/1/72.                          *C
C*                                                                     *C
C*     ADDITIONAL REVISIONS HAVE BEEN MADED TO THIS PROGRAM            *C
C*     BY RONALD HEISLER OF THE VIRGINIA DEPARTMENT OF HIGHWAYS        *C
C*     TO OBTAIN RESULTS WITHOUT THE USE OF TELECOMMUNICATIONS         *C
C***********************************************************************C
```

```
C
C
C
      REAL MED
      REAL     VAL(9)/10.87,8.19,5.63,4.0,3.0,2.13,1.50,1.26,1.13/
      REAL     ARG(9)/300.,600.,1500.,3000.,6000.,15000.,40000.,100000.,
     1800000./
      REAL     A1(5)/30.,100.,300.,1000.,3000./
      REAL     A2(10)/.1,.2,.3,.4,.5,.6,.7,.8,.9,1./
      REAL     A5(7)/-60.,-20.,20.,40.,60.,70.,80./
      REAL     A6(7)/0.,10.,20.,40.,60.,100.,160./
      REAL     D1(7)/-2.,-2.5,-3.75,-6.25,-10.16,-15.,-15./
      REAL     D2(7)/-5.,-5.63,-6.88,-8.28,-10.62,-15.,-15./
      REAL     DEL(7)/.01,.03,.1,.3,1.,4.,30./
      REAL     V5(7)/-.78,-2.03,-4.06,-5.62,-7.82,-9.55,-12.66/
      REAL     V6(7)/-16.25,-12.34,-9.68,-6.56,-4.68,-2.34,-.31/
      REAL     V11(5)/8.,0.,-7.,-15.,-22./
      REAL     V12(5)/6.5,-.5,-7.,-15.,-22./
      REAL     V13(5)/6.,-.7,-7.,-15.,-22./
      REAL     V14(5)/5.5,-1.,-7.,-15.,-22./
      REAL     V16(5)/4.,-1.5,-7.,-15.,-22./
      REAL     V18(5)/2.5,-2.,-7.5,-15.,-22./
      REAL     V25(10)/0.,3*-1.,2*-2.,-3.,2*-4.,-5./
      REAL     V210(10)/0.,2*-1.,-2.,2*-3.,-4.,-6.,-7.,-10./
      REAL     V215(10)/0.,-1.,2*-2.,-3.,-4.,-5.,-7.,-10.,-15./
   29 INRE = 1
      READ(1,444) JOB,ID,NC,NRE
  444 FORMAT(2A3,I1,I8)
      IF(NC .NE. 0) GO TO 800
   93 J = 1
      READ(1,444) JOB,ID,NC,N
      IF(NC .NE. 1) GO TO 800
      WRITE (2,400) JOB
  400 FORMAT('1',15X.'THE MICHIGAN NOISE PREDICTOR PROGRAM',15X,'COMPUTE
     1R JOB NO. ',A3/)
   70 CONTINUE
      WRITE(2,450) ID,INRE,NRE,N
  450 FORMAT('-',30X,'RUN = ',A3,'  --  ROAD ELEMENT NO.',I2//' TOTAL RO
     1AD ELEMENTS =',I2/'0NO. OF LANE GROUPS =',I2)
      READ(1,555) JOB,ID,NC,ADT,PCADT,TMIX,ST,SA,HD,DN,RL,BL,FLO,P,
     1DEL3,DEL5,DEL7
  555 FORMAT(2A3,I1,F8.0,13F5.0)
      IF(NC .NE. 2) GO TO 800
      READ(1,555) JOB,ID,NC,MED,THETA,H1,DS,H2,DC,H,DB,ALPHA,HO
      IF(NC .NE. 3) GO TO 800
C
C               PRINT INPUT VARIABLES
      WRITE(2,560) ADT,MED,PCADT,THETA,TMIX,H1,ST,DS,SA,H2
  560 FORMAT('0ADT =', F8.0,' VEH/DAY',T61,'MEDIAN WIDTH =',F4.0,' FEET'
     1/'0% ADT =',F4.0,T61,'ROAD INCLUDED ANGLE =',F5.0,' DEGREES'/'0% T
     2RUCK MIX =',F4.0,T61,'ELEV. HT. =',F4.0,' FEET'/'0TRUCK SPEED =',F
     34.0,' MPH',T61,'OBS. TO SHOULDER =',F5.0,' FEET'/'0CAR SPEED =',F5
     4.0,' MPH',T61,'DEPRESSED HEIGHT =',F4.0,' FEET')
      WRITE(2,570) HD,DC,DN,H,RL,DB,BL,ALPHA,FLO,HO
  570 FORMAT('0ROAD ELEV. TYPE =',F3.0,T61,'OBS. TO CUT =',F5.0,' FEET'/
     1'0OBS. TO ROAD =',F5.0,' FEET',T61,'BARRIER HT. =',F4.0,' FEET'/'0
     2ROAD LENG. TYPE =',F3.0,T61,'OBS. TO BARRIER =',F5.0,' FEET'/'0BAR
     3RIER LENG. =',F3.0,T61,'BARRIER INCLUDED ANGLE =',F5.0,' DEGREES'/
     4'0TRAFFIC FLOW =',F3.0,T61,'OBS. HT. =',F5.0,' FEET')
      WRITE(2,580) P,DEL3,DEL5,DEL7
  580 FORMAT('0NO. OF LANES PER LANE GROUP =',F3.0/'0GRADE CORRECTION ='
     1,F3.0,' DB'/'0ROAD SURFACE CORRECTION =',F4.0,' DB'/'0STRUCTURE CO
     2RRECTION =',F3.0,' DB'////)
```

```
C
C     CALCULATE VEHICLE VOLUMES
      V = ADT*PCADT*.01
      VT = TMIX*V*.01
      VA = V - VT
C
C     CHECK FOR INPUT ERRORS
C
      IF(HD)100,102,101
  100 IF(H1 .GT. 0. .AND. DS .GT. 0.) GO TO 103
      WRITE(2,200)
  200 FORMAT(' ** INCORRECT VALUES FOR ELEV. HT. OR OBS. TO SHOULDER')
      GO TO 900
  101 IF(H2 .GT. 0. .AND. DC .GT. 0.) GO TO 103
      WRITE(2,205)
  205 FORMAT(' ** INCORRECT VALUE FOR DEPRESSED HT. OR OBS. TO CUT')
      GO TO 900
  102 IF(H1.EQ.0. .AND. DS.EQ.0. .AND. H2.EQ.0. .AND. DC.EQ.0.)GO TO 103
      WRITE(2,210)
  210 FORMAT(' ** ERROR IN ROAD ELEV. TYPE - ELEV. OR DEP. ROAD FIELD(S)
     1 ARE CODED')
      GO TO 900
  103 IF(RL .GE. 2.) GO TO 104
      IF(THETA .EQ. 0.) GO TO 105
      WRITE(2,215)
  215 FORMAT(' ** INFINITE ROAD TYPE HAS ROAD INCLUDED ANGLE')
      GO TO 900
  104 IF(THETA .NE. 0.) GO TO 105
      WRITE(2,220)
  220 FORMAT(' ** SEMI-INF. OR FINITE ROAD TYPE WITH ZERO ROAD ANGLE')
      GO TO 900
  105 IF(BL - 1.)106,108,107
  106 IF(H .EQ. 0. .AND. DB .EQ. 0.) GO TO 109
      WRITE(2,225)
  225 FORMAT(' ** BARRIER HT. AND/OR OBS. TO BARRIER FIELD ARE CODED WIT
     1H NO EXISTING BARRIER')
      GO TO 900
  107 IF(ALPHA .NE. 0.) GO TO 108
      WRITE(2,230)
  230 FORMAT(' ** FINITE BARRIER LENG. WITH INCLUDED ANGLE ZERO')
      GO TO 900
  108 IF(H .GT. 0. .AND. DB .GT. 0.) GO TO 109
      WRITE(2,235)
  235 FORMAT(' ** BARRIER LENG. IS FINITE OR INFINITE AND BARRIER HT. OR
     1 OBS. TO BARRIER IS EQUAL/LESS THAN ZERO')
      GO TO 900
  109 IF(FLO .EQ. 0. .OR. FLO .EQ. 1.) GO TO 110
      WRITE(2,240)
  240 FORMAT(' ** FLOW DOES NOT EQUAL ZERO OR ONE')
      GO TO 900
  110 IF(N .GT. 1) GO TO 111
      IF(MED .EQ. 0.) GO TO 112
      WRITE(2,245)
  245 FORMAT(' ** MEDIAN WIDTH FOR ONE LANE GROUP')
      GO TO 900
  111 IF(MED .GE. 0.) GO TO 112
      WRITE(2,250)
  250 FORMAT(' ** MEDIAN WIDTH IS NEGATIVE')
      GO TO 900
  112 IF(DEL3 .GE. 0. .AND. DEL3 .LE. 5.) GO TO 113
      WRITE(2,255)
  255 FORMAT(' ** GRADE CORRECTION NOT IN 0 - +5 RANGE')
      GO TO 900
  113 IF(DEL5 .GE. -5. .AND. DEL5 .LE. 5.) GO TO 114
```

```
      WRITE(2,260)
  260 FORMAT(' ** ROAD SURFACE CORR. NOT -5,0,OR +5')
      GO TO 900
  114 IF(DEL7 .GE. 0. .AND. DEL7 .LE. 10.) GO TO 82
      WRITE(2,265)
  265 FORMAT(' ** STRUCTURE CORRECTION NOT 0 - 10 DB')
      GO TO 900
C
C     DEL2   -   ELEMENT CORRECTION
   82 IF(RL - 2.) 39,40,41
   39 DEL2 = 0.
      GO TO 42
   40 DEL2 = FIGB10(V5,A5,THETA,7,1)
      GO TO 42
   41 DEL2 = FIGB10(V6,A6,THETA,7,1)
   42 IF(P.GT.2.) GO TO 63
C     DE   -   EQUIVALENT LAND DISTANCE CALCULATION
      DF = DN + 12.*P -12.
      GO TO 64
   63 DF = DN + 12.5*P - 12.
   64 DE = SQRT(DN*DF)
C     DEL1  -  DISTANCE CORRECTION
      IF(P - 2.) 190,191,192
  190 DEL1 = FIGB10(V11,A1,DN,5,0)
      GO TO 61
  191 DEL1 = FIGB10(V12,A1,DN,5,0)
      GO TO 61
  192 IF(P - 4.) 193,194,195
  193 DEL1 = FIGB10(V13,A1,DN,5,0)
      GO TO 61
  194 DEL1 = FIGB10(V14,A1,DN,5,0)
      GO TO 61
  195 IF(P .GT. 6) GO TO 196
      DEL1 = FIGB10(V16,A1,DN,5,0)
      GO TO 61
  196 DEL1 = FIGB10(V18,A1,DN,5,0)
C     DEL4   -   VERTICAL CORRECTION
   61 IF(HD)53,43,44
   53 HH = (H1 - H0) * (H1 - H0)
      DL = DE - DS + SQRT(HH+DS*DS) - SQRT(HH+DE*DE)
      IF(DL .LT. .01) GO TO 43
      DEL4 = FIGB10(D1,DEL,DL,7,0)
      GO TO 47
   44 A = SQRT(H2 * H2 + (DE-DC) * (DE-DC))
      B = SQRT(H0 * H0 + DC * DC)
      D = SQRT((H2 + H0) * (H2 + H0) + DE * DE)
      DL = A + B - D
      IF(DL .LT. .01) GO TO 43
      DEL4 = FIGB10(D2,DEL,DL,7,0)
   47 DL4 = AMIN1(DEL4+5.,0.)
      GO TO 48
   43 DEL4 = 0.
      DL4 = 0.
C  DEL6 - BARRIER CORRECTION
   48 DEL6 = 0.
      DL6 = 0.
      IF(BL .EQ. 0) GO TO 33
      A = SQRT(H * H + (DE - DB) * (DE - DB))
      B = SQRT((H - H0) * (H - H0) + DB * DB)
      D = SQRT(H0 * H0 + DE * DE)
      DL = A + B - D
```

```
      IF(DL .LT. .01) GO TO 33
   34 DEL6 = FIGB10(D1,DEL,DL,7,0)
      DL6 = AMIN1(DEL6+5.,0.)
   37 IF(BL-2.)33,38,38
   38 IF(RL-2.)74,75,76
   74 A = ALPHA/180.
      GO TO 77
   75 A = ALPHA/(90.-THETA)
      GO TO 77
   76 A = ALPHA/THETA
   77 IF(A .LE. .1) GO TO 89
      IF(DEL6 .GT. -5.) GO TO 86
      IF(DEL6 .GT. -10.) GO TO 87
      VU = FIGB10(V210,A2,A,10,1)
      VL = FIGB10(V215,A2,A,10,1)
      GO TO 88
   89 DEL6 = 0.
      DL6 = 0.
      GO TO 33
   86 VU = 0.
      VL = FIGB10(V25,A2,A,10,1)
      GO TO 88
   87 VU = FIGB10(V25,A2,A,10,1)
      VL = FIGB10(V210,A2,A,10,1)
   88 AL = .1 * AINT(10. * A)
      AU = AL + .1
      DEL6 = (A-AL) * (VL-VU) / .1 + VU
      DL6 = AMIN1(DEL6+5.,0.)
   33 CONTINUE
C
C     CALCULATE   L50  AND  L10
C
      S = DEL1 + DEL2 + DEL5 + DEL7
      SDEL = S + AMAX1(DEL4+DEL6,-15.)
      SDELT = S + DEL3 + AMAX1(DL4+DL6,-15.)
      AT = VT*DE/ST
      IF(AT.LT.300.) GO TO 49
      AA = VA*DE/SA
      AL10A = FIGB10(VAL,ARG,AA,9,0)
      AL10T = FIGB10(VAL,ARG,AT,9,0)
      YA = 0.119*VA/SA
      UA = VA*SA*SA*TANH(YA)
      AL50A = 10.*ALOG10(UA)-1.
      YT = .119*VT/ST
      UT = VT*TANH(YT)/ST
      AL50T = 10.*ALOG10(UT) + 65.
      OL50A = AL50A + SDEL
      OL50T = AL50T + SDELT
      OL10A = OL50A + AL10A
      OL10T = OL50T + AL10T
      IF(FLO.GT.0.) GO TO 51
      OL10A = OL10A + 2.
      OL10T = OL10T + 4.
   51 AL50 = DBSUM(OL50A,OL50T)
      AL10 = DBSUM(OL10A,OL10T)
      GO TO 52
   49 V = VA + 15.*VT
      AAT=V*DE/SA
      WRITE(2,90)
   90 FORMAT(/' ** TWILIGHT ZONE - ALL VEHICLES NOW CARS **')
      AL10V = FIGB10(VAL,ARG,AAT,9,0)
```

```
      YA=.119*V/SA
      UA=V*SA*SA*TANH(YA)
      AL50V = 10.*ALOG10(UA) - 1.
      AL50 = AL50V + SDEL
      AL10 = AL50 + AL10V
      IF(FLO.GT.0.) GO TO 52
      AL10 = AL10 + 2.
   52 CONTINUE
      IF(N.EQ.1) GO TO 72
      IF(J.EQ.1) GO TO 65
      AL50 = DBSUM(AL50,XX)
      AL10 = DBSUM(AL10,YY)
C     CHECK IF ANY MORE LANE GROUPS
      IF(J.EQ.N) GO TO 72
   65 XX = AL50
      YY = AL10
      J = J + 1
      DN = DN + MED + 12.*P
      GO TO 42
C     CHECK IF ANY MORE ROADWAY ELEMENTS
   72 IF(NRE.EQ.1) GO TO 92
      IF(INRE.EQ.1) GO TO 67
      AL50 = DBSUM(AL50,RODL5)
      AL10 = DBSUM(AL10,RODL1)
      IF(INRE.EQ.NRE) GO TO 92
   67 RODL5 = AL50
      RODL1 = AL10
      INRE = INRE + 1
      GO TO 93
C     OUTPUT RESULTING L50 AND L10 VALUES
   92 CONTINUE
      WRITE(2,23) ID,AL50,AL10
   23 FORMAT(//' RUN = ',A3,'  L50 = ',F5.1,'    L10 = ',F5.1/)
C     CHECK IF ANY MORE PROBLEMS TO BE SOLVED
      READ(1,444) JOB,ID,NC,ICON
      IF(NC .NE. 4) GO TO 800
  115 CONTINUE
      IF(ICON)28,29,30
   30 CONTINUE
      READ(1,555) JOB,ID,NC,DUM,DUM,DUM,DUM,DUM,DUM,DN
      IF(NC .NE. 2) GO TO 800
      WRITE (2,400) JOB
      WRITE(2,450) ID,INRE,NRE,N
      WRITE(2,560) ADT,MED,PCADT,THETA,TMIX,H1,ST,DS,SA,H2
      WRITE(2,570) HD,DC,DN,H,RL,DB,BL,ALPHA,FLO,HO
      WRITE(2,580) P,DEL3,DEL5,DEL7
      J = 1
      INRE = 1
      GO TO 82
  800 WRITE(2,305) NC
  305 FORMAT('0DATA CARD HAS WRONG CARD NO., PROBABLE ERROR IS TOO MANY
     1OR TOO FEW CARDS',5X,'WRONG NO. IS',I2)
  900 WRITE(2,300)
  300 FORMAT('0INPUT ERROR -- CALCULATIONS WERE NOT PERFORMED  --  READ
     1NEXT SET OF DATA')
  116 READ(1,444) JOB,ID,NC,ICON
      IF(NC .EQ. 4) GO TO 115
      GO TO 116
   28 STOP 0001
      END
```

```
      FUNCTION FIGB10(VAL,ARG,DY,K,J)
      DIMENSION VAL(1), ARG(1)
C     INTERPOLATES ON EITHER A LINEAR OR SEMILOG GRID
C     IN THE CALL, SET J = 1 FOR LINEAR, = 0 FOR SEMILOG
      D = AMAX1(AMIN1(DY,ARG(K)),ARG(1))
      IF(DY.GT.ARG(1)) GO TO 7
      WRITE(2,20) DY,ARG(1),ARG(K)
   20 FORMAT(' ** ARGUMENT LIMITED AT LOW END **     DY=',F8.2,' ARG(1)='
     1,F8.2,' ARG(K)=',F8.2/)
      GO TO 8
    7 IF(DY.LT.ARG(K)) GO TO 8
      WRITE(2,21) DY,ARG(1),ARG(K)
   21 FORMAT(' ** ARGUMENT LIMITED AT HIGH END **     DY=',F8.2,' ARG(1)=
     1',F8.2,' ARG(K)=',F8.2/)
    8 DO 1 I = 2,K
      IF(D.GT.ARG(I)) GO TO 1
      IF(J.EQ.1) GO TO 9
      FIGB10 = ALOG10(D) -ALOG10(ARG(I-1))
      F = ALOG10(ARG(I)) - ALOG10(ARG(I-1))
    6 FIGB10 = FIGB10*(VAL(I)-VAL(I-1))/F + VAL(I-1)
      RETURN
    9 FIGB10 = D - ARG(I-1)
      F = ARG(I) - ARG(I-1)
      GO TO 6
    1 CONTINUE
      RETURN
      END


      FUNCTION DBSUM(A,B)
C     CALCULATES THE DB SUM OF A AND B
      DBSUM = B
      IF(A.LE.0.01) RETURN
      DBSUM = A
      IF(B.LE.0.01) RETURN
      DBSUM = 10.*ALOG10(10.**(0.1*A) + 10.**(0.1*B))
      RETURN
      END
```