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USER'S MANUAL FOR THE COMPUTER PROGRAM FOR THE PREDICTION OF ROAD TRAFFIC NOISE

U.J. Kurze
W.H. Levison
S. Serben

November 1971

Contract No. DOT-TSC-315

Submitted to:

Transportation Systems Center
55 Broadway
Cambridge, Massachusetts 02142

CAMBRIDGE NEW YORK CHICAGO LOS ANGELES SAN FRANCISCO

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ABSTRACT

This manual is a guide for using a computer program for prediction of noise from freely flowing road traffic. The program is written in Fortran IV for use on the DDP-516/H-832 computer complex under the control of the Computer Technology Division of the Technology Directorate at TSC.

The manual consists of four parts. In the introduction, we describe the limitations of the computer model. In the second part, acoustical properties of the traffic and sound propagation model developed are presented and the analytical expressions used in the computer program are described. The third part contains a description of the structure of the computer program and of detailed calculation procedures. The fourth part gives practical guidelines for use of the computer program.

ACKNOWLEDGMENT

The program described herein was developed under Contract DOT-TSC-315 with the Transportation Systems Center in order to streamline and improve the motor vehicle/highway noise model developed by Serendipity, Inc., Arlington, Virginia. Captain John E. Wessler of the Transportation Systems Center was the technical monitor. His profound understanding of advanced concepts for the prediction of road traffic noise was extremely helpful in modifying the original program to meet the current and future needs of TSC. Special thanks go to Mr. Jim Steinberg of the Computer Technology Division for his assistance in adapting the new program to the computer complex at TSC.

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1. INTRODUCTION

The relationship between road traffic characteristics and the effective noise level at a given receiver location is extremely complex. The characteristics of the sound emanating from a particular roadway depend on parameters related to the vehicles on the road, such as vehicle type, density, speed, acceleration, and directivity of radiation. The characteristics of this sound as perceived at the receiver are affected by topological considerations such as location, orientation, shape, and reflectivity characteristics of obstacles; by atmospheric and ground absorption; by micrometeorological considerations; by the formation of shadow zones; by interference; and by other effects specific to the particular receiver location. Finally, the predicted annoyance level depends on the rating scheme applied to fluctuations in the sound intensity. Accordingly, complex models for noise sources, sound propagation paths, and human psychology are required if accurate predictions are to be obtained.

Accounting for as many of these factors as possible should be the ultimate goal in modelling road traffic noise. Nevertheless, in order to keep the problem tractable without unduly sacrificing predictive accuracy, the following major limitations have been incorporated in the current implementation of the computer model:

a. The computer model handles only freely flowing road traffic. Stop-and-go traffic with a time-dependent number of vehicles per length of roadway and effects of acceleration on the radiated sound power are not included.

b. The computer model assumes a uniform atmosphere. Effects of refraction and shadow zones are neglected. Since the sound pressure level at a distance of more than a thousand feet from a source can be strongly affected by micrometeorological conditions of the atmosphere, a considerable spread of actual data must be expected around the predicted values at distances of more than a thousand feet.

c. The computer model regards all the contributions to the sound intensity at a receiver as incoherent and adds the intensities without consideration of possible phase relations. This simplification can result in major errors for the sound pressure level close to absorbing or reflecting surfaces.

d. In its present form, the computer program calculates only the mean energy level, which is the quantity that would be measured by a special sound level meter with a very slow response. The calculation of noise data corresponding to different rating scales for fluctuating noise is subject to future improvements of the program.

Secondary limitations include:

a. Simplified assumptions for the orientation and shape of obstacles in the sound propagation path,

b. first-order approximations for the effect of ground cover on the attenuation of sound, and

c. consideration of single reflections only.

Despite these limitations, the computer program has yielded predictions of A-weighted noise levels that are generally within ±3 dB of those measured in the field. Thus, the approach used in deriving the mathematical models for highway noise appears to be valid, and one might justifiably expect reasonably accurate predictions over a range of highway and topographical conditions.

2. MODEL OF NOISE FROM FREELY FLOWING ROAD TRAFFIC

2.1 Energy Mean Level

To give the user an overview of the calculations, we derive briefly the mathematical formulation for the energy mean level.

We first consider the sound emanating from a single vehicle located at a point x on a road segment extending from x_1 to x_2. The sound intensity I at a receiver located a distance d from the road (see Fig. 1) is given as

$$I = \frac{I_{ref} r_0^2}{x^2+d^2} \; 10^{-D/10} \quad , \tag{1}$$

where I_{ref} is the reference value of the intensity at a short distance r_0 (typically 50 ft) from a single vehicle on an unobstructed roadway site, and D is the uniform attenuation in dB of sound from all points of the road segment considered. Equation (1) is based on the assumption of hemispherical radiation from a point source, for which the intensity in the diverging field decreases with the inverse square of the distance.

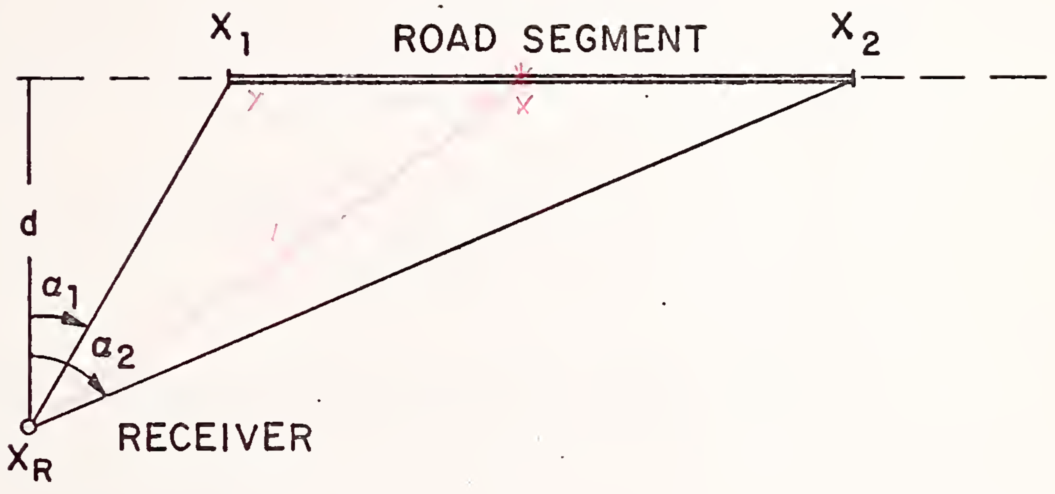


FIG.1 DEFINITION OF PARAMETERS DESCRIBING A ROAD SEGMENT AND A RECEIVER LOCATION

Let us now consider the situation in which the road segment x_1, x_2 contains a stationary flow of vehicles having identical noise characteristics and moving at essentially the same speed. The mean vehicle concentration λ in vehicles/foot, is given as

$$\lambda = \frac{(\text{vehicles}/\overset{\text{hour}}{\cancel{\text{mile)}}}}{V \cdot 5280} \quad , \tag{2}$$

where V is vehicle speed in miles/hour. The mean sound intensity at the receiver due to all the vehicles on the road segment is then

$$I = I_{ref} r_0^2 \cdot 10^{-D/10} \int_{x_1}^{x_2} \frac{\lambda}{x^2+d^2}\, dx \quad . \tag{3}$$

We define the angle at the observer (Fig. 1) as

$$\alpha = \tan^{-1} \frac{x}{d} \quad ,$$

so that Eq. (3) is evaluated as

$$I = I_{ref} r_0^2 \frac{\lambda}{d} \Delta\alpha \; 10^{-D/10} \quad ; \tag{4}$$

where $\Delta\alpha$ is the angle subtended at the receiver by the road end points x_1 and x_2.

For T different groups of vehicles, with each group having an intensity $I_{ref,t}$ and an average vehicle concentration λ_t, we obtain the mean intensity

$$I = \frac{r_0^2}{d} \Delta\alpha 10^{-D/10} \sum_{t=1}^{T} \lambda_t I_{ref,t} \quad . \tag{5}$$

Field experience has shown that the reference level $L_{ref,t}$, defined as $L_{ref,t} = 10 \log I_{ref,t}$ dB, has approximately a normal distribution for certain large groups of vehicles (such as passenger cars or heavy trucks travelling at roughly the same speed). Therefore, rather than considering a large number T of small groups for all kinds of different vehicles or for slightly different speeds, we consider a smaller number S of broader groupings. Accordingly, we replace the summation shown in Eq. (5) as follows:

$$\sum_{t=1}^{T} \lambda_t \, 10^{L_{ref,t}/10} \approx \sum_{s=1}^{S} \frac{\lambda_s}{\sigma_{ref,s}\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-\frac{1}{2}\left(\frac{L-L_{ref,s}}{\sigma_{ref,s}}\right)^2} 10^{L/10} \, dL, \tag{6}$$

where λ_s is the average concentration of all vehicles of group s, $L_{ref,s}$ is the mean, and $\sigma_{ref,s}$ is the standard deviation of a normal distribution of reference levels. The expression for the mean intensity from traffic with S groups of vehicles is then

$$I = \frac{r_0^2}{d} \Delta\alpha \, 10^{-D/10} \sum_{s=1}^{S} \lambda_s 10^{L_{ref,s}/10} \, e^{\frac{1}{2}(\sigma_{ref,s}/4.35)^2} . \tag{7}$$

In general, multiple road segments of a complex highway configuration differ in the distance d from the receiver perpendicular to the road, in the angle $\Delta\alpha$ enclosed at the receiver by two lines towards the ends of the road segments, and in attenuation D of sound from the road segments. Thus, the mean intensity of sound from complex road traffic is given

by the following double summation:

$$I = \sum_{\substack{\text{road}\\ \text{segments}}} \left[\frac{r_0^2}{d} \Delta\alpha \sum_{\substack{\text{vehicle}\\ \text{groups}}} \lambda \, 10^{-D/10} 10^{L_{ref}/10} \, e^{\frac{1}{2}(\sigma_{ref}/4.35)^2} \right] . \tag{8}$$

The energy mean level, in dB, is then defined as

$$L_e = 10 \log I \quad . \tag{9}$$

In the remainder of this section, we describe the calculation of the quantities employed in Eq. (8) and discuss the data used in the computer program for the numerical evaluation of the energy mean level.

2.2 Reference Levels

The parameters $L_{ref,s}$ and $\sigma_{ref,s}$ defining the normal distribution of levels at a distance r_0 from single vehicles of group s generally depend on the velocity of the vehicles and on the frequency band considered.

There is no theoretical limit to the number of vehicle types that may be considered by the program. However, the current implementation provides data blocks for only two types: cars (Type 1) and trucks (Type 2).

Reference levels for cars ($L_{ref,1}$) are stored in the computer program and are shown in Fig. 2. A-weighted octave band levels as well as A-weighted overall levels are given for vehicle speeds of 30 and 70 mph. The data are based on measurements

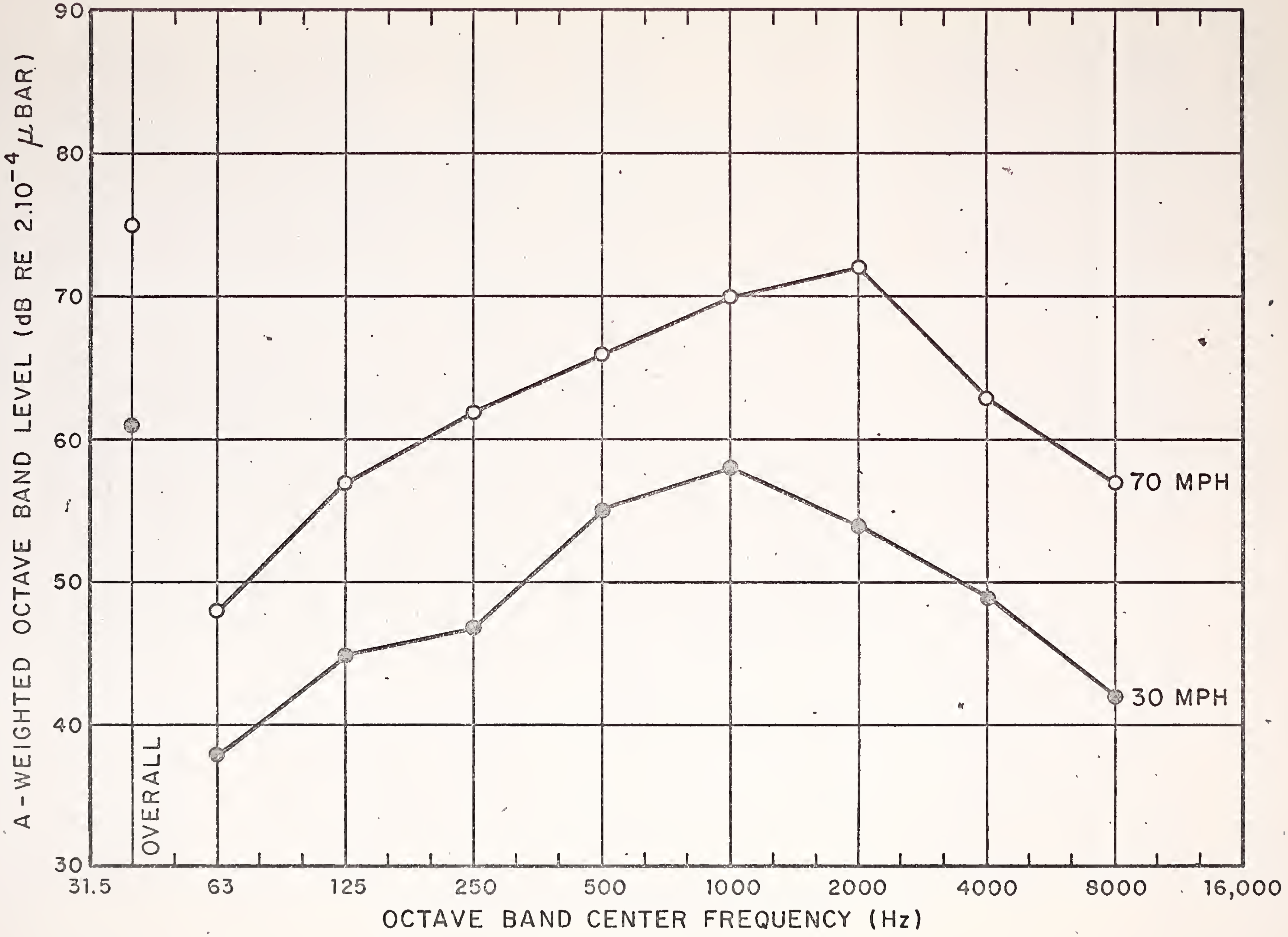


FIG.2 PASSENGER CARS AT r_o = 50 FT

made by N. Olson [*1*]. They show the predominant influence of tire noise with maximum levels at 1000 Hz for 30 mph and at 2000 Hz for 70 mph. An increase of the A-weighted overall level by 14 dB for an increase of the velocity V from 30 to 70 mph corresponds closely with the frequently observed speed dependence of 40 log V. For velocities different from the stored data, the computer program interpolates, using the formula

$$L_{ref,1}(V) = L_{ref,1}(30\text{ mph}) + \frac{10 \log \frac{V}{30}}{10 \log \frac{70}{30}} [L_{ref,1}(70\text{ mph}) - L_{ref,1}(30\text{ mph})] \quad . \qquad (10)$$

Below 1000 Hz, the octave band levels at 50 mph are about the same as those found by Galloway *et al* [*2*]. Above 1000 Hz, Galloway's data are lower by 5 to 10 dB.

In contrast to our speed dependence with 38 log V for the A-weighted overall level, Galloway found only 30 log V. However, the differences are only 1.2 dB at 70 mph and 1.8 dB at 30 mph.

The standard deviation $\sigma_{ref,1}$ was based on Olson's data. Although there is some dependence on frequency and velocity, we propose to use the single number $\sigma_{ref,1} = 2.5$ dB. This number is consistent with findings in the USA [*2*] and in England [*3*]. Note that any number smaller than 3 dB increases the energy mean level by less than 1 dB.

Reference levels for trucks ($L_{ref,2}$) are plotted in Fig. 3. The data are based on measurements made by Olson [*1*] and on recent measurements at the New Jersey Turnpike. We ignore

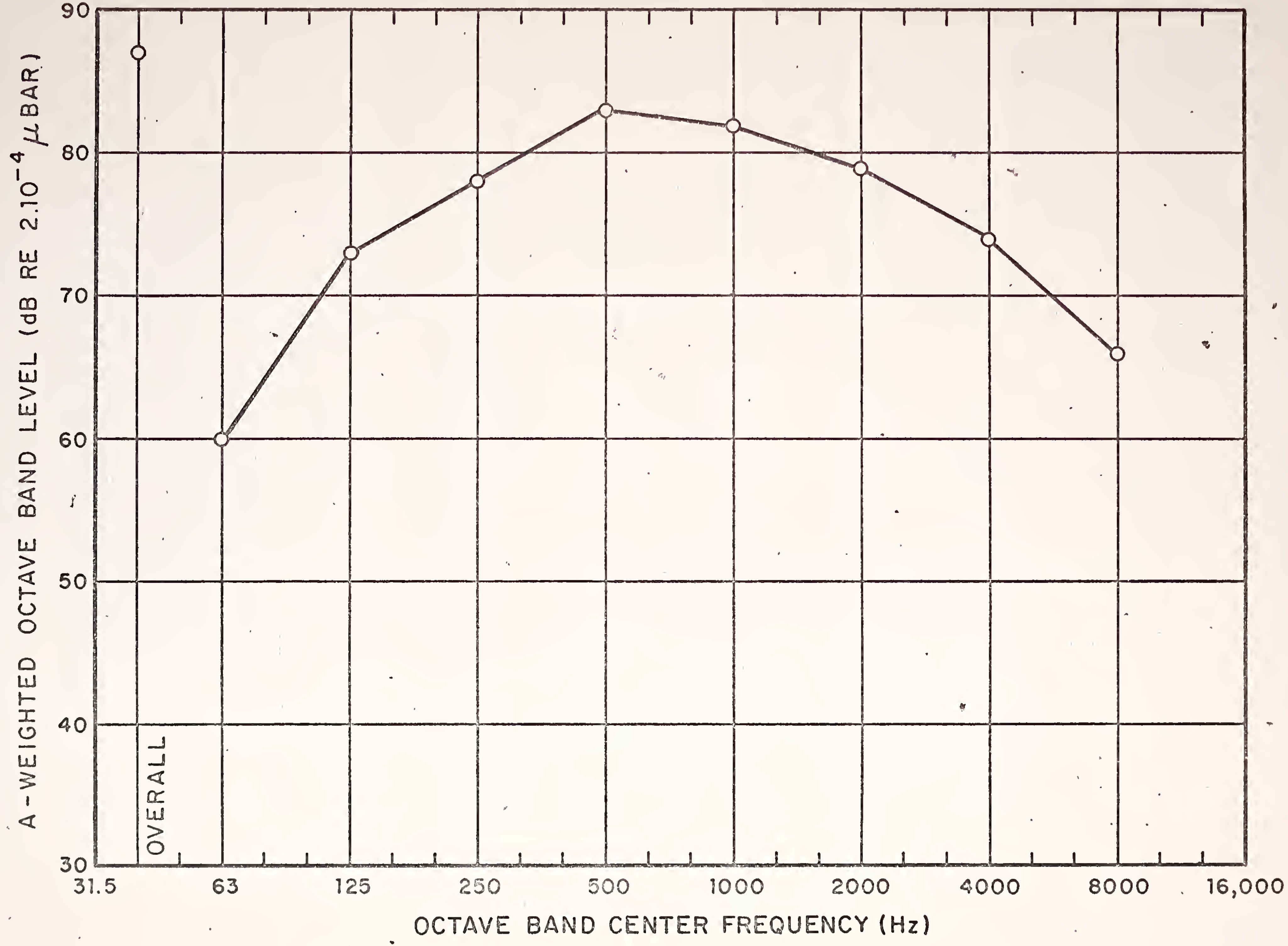


FIG.3 TRUCKS AT r_o = 50 FT

TOLERANCES EQ (17) AT 500 H

the speed dependence observed in the higher frequency bands for trucks with cross-bar tires, and we account for engine, fan, and exhaust noise exclusively with speed-independent levels.

The A-weighted overall level is higher by 6 dB than data reported by Galloway [2]. We found out that Galloway's data are referred to trucks with good mufflers, but that our data are more representative for actual truck noise. The influence of mufflers on the A-level indicates that most of the truck noise is radiated from the exhaust. The effective source height of trucks should therefore be chosen about 8 ft higher than the source height of passenger cars.

A value of 3.5 dB for the standard deviation $\sigma_{ref,2}$ is consistent with data from Galloway [2], except for steep gradients of the road where considerably higher numbers, up to 6.8 dB, have been measured.

2.3 Attenuation

2.3.1 Atmospheric absorption

For outdoor sound propagation, the attenuation by atmospheric absorption at a temperature of 68°F can be reasonably well approximated by [4]

$$D_A = 7.4 \frac{f^2 r}{\phi} 10^{-8} \text{ dB} \quad , \qquad (11)$$

where f = geometric-mean frequency of band, Hz
ϕ = relative humidity of the air, %
r = distance between source and receiver, m.

The computer program uses a relative humidity of 55% and octave bands with the numbers n = 2,...,9 for mid-frequencies from 62.5 Hz to 8000 Hz. Distances are given in feet. Thus, Eq. 11 becomes

$$D_A = 7.4 \left(2^n \frac{1000}{26}\right)^2 \left(\frac{10^{-8}}{55}\right) \frac{r'}{3.28} \approx 10^{-7}\, 4^n\, r' \quad , \qquad (12)$$

where r' is taken by the computer program as the minimum distance, in feet, between the receiver and a road segment. At a frequency of 500 Hz, where n = 5, the attenuation is less than 1 dB up to distances of 10,000 ft. Since the attenuation of traffic noise is typically characterized by the attenuation in the 500-Hz octave band, atmospheric attenuation has hardly any influence in all practical cases of noise prediction within a distance of a few thousand feet from a road. Consequently, no checks are made in the computer program for small differences in attenuation by atmospheric absorption of sound from different locations on a road segment; it is assumed that the attenuation from the nearest point on the road is representative for the entire road segment.

Note that the attenuation predicted by Eq. (12) will be too low if the actual humidity of the air is considerably less than 55% or if the actual temperature is between 20 and 30°F. Conversely, the predicted D_A will be too high for relative humidities much greater than 55% [4].

2.3.2 Diffraction

Diffraction of sound is caused by obstacles in the direct or reflected propagation paths from the roadway to the receiver. Such obstacles can be artificial barriers, earth berms, hills,

buildings, etc. For the calculation of attenuation by diffraction, we assume that the obstacle can be modeled by a rigid, impervious screen oriented perpendicular to the ground plane and that sound is diffracted over the top edge of the screen exclusively. We neglect the shape of hills and the thickness of barriers because of the lack of available knowledge. The sound absorption and transmission properties of barriers are not considered because they play a minor rôle in most practical cases. We expect that the neglect of diffraction around the ends of barriers will introduce no significant errors, and it simplifies considerably the computational procedures. Furthermore, a diffracting barrier is now completely specified by the coordinates of the two end points of the top line.

The attenuation of sound by barriers is determined primarily by the difference δ between the path length of the shortest ray from the source over the top edge of the barrier to the receiver and the path length of the direct ray from the source to the receiver in the absence of the barrier (see Fig. 4).

For large path length differences, the attenuation in the acoustical shadow zone of a barrier is limited by effects of refraction and scattering of sound in the atmosphere. Based on data from Rathé [5], the computer program has a built-in maximum attenuation of 24 dB.

The attenuation is not zero for zero path length difference (i.e., for a ray grazing over the barrier). For this situation, the theory of Fresnel diffraction yields an attenuation of about 5 dB. The attenuation becomes negligible when a direct sound ray travelling from the source to the receiver passes far over the top edge of the barrier. To simplify computations,

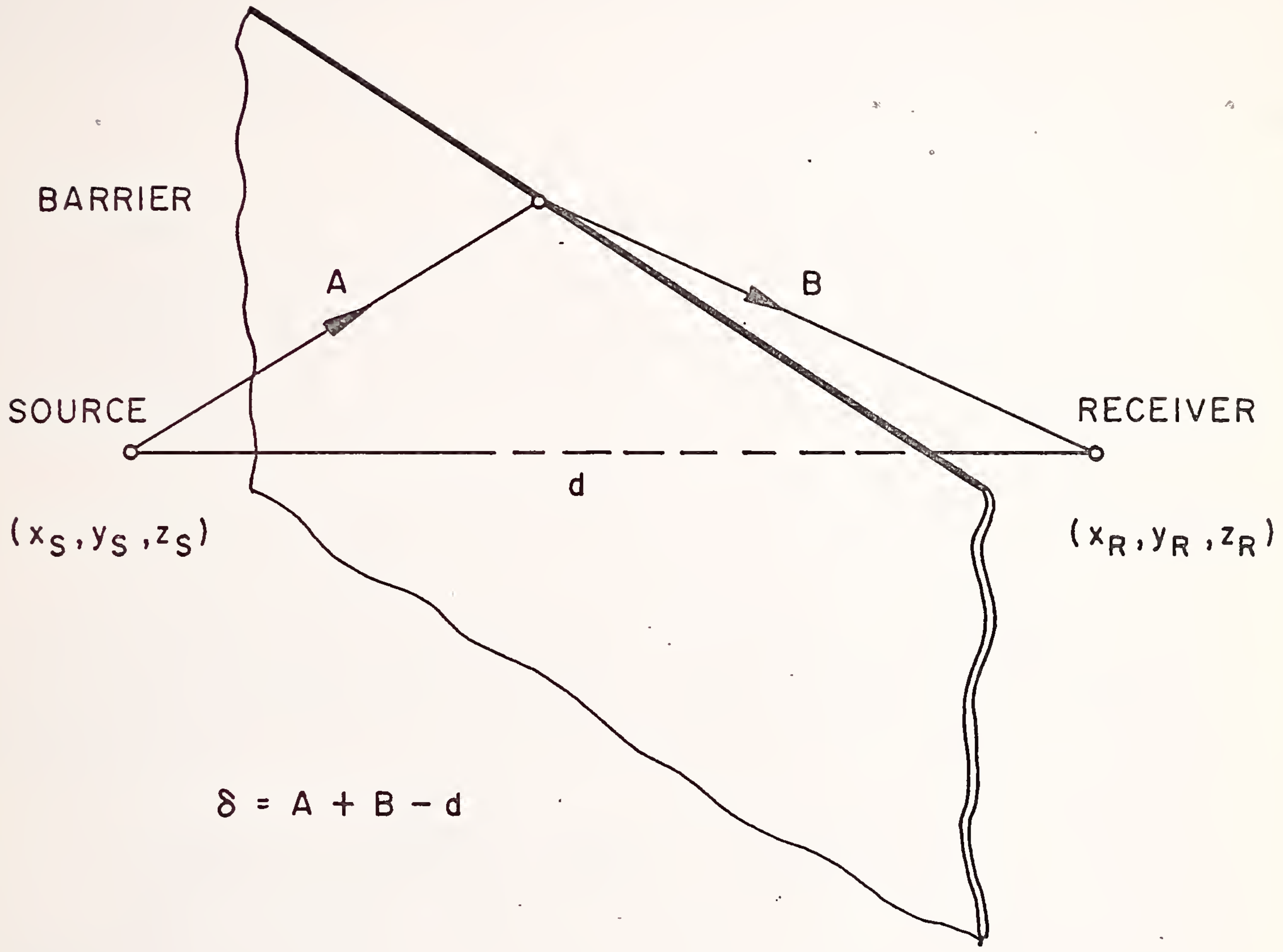


FIG.4 DEFINITION OF THE PATH LENGTH DIFFERENCE δ FOR SOUND DIFFRACTION BY A BARRIER

we neglect diffraction effects when the height difference between the direct ray and the top of the barrier is greater than 20 feet.

For height differences of 20 feet or less, we calculate the Fresnel number

$$N = \frac{2\delta}{\lambda} \quad , \tag{13}$$

where δ is the path length difference and λ is the wavelength corresponding to the center frequency of an octave band. We assume normal atmospheric conditions, with a speed of sound c of 1120 ft/sec. Thus, for a center frequency f, the Fresnel number is taken to be

$$N = \frac{2f}{c}\,\delta \quad . \tag{14}$$

We employ the Fresnel number and an analytic approximation to measured data from Maekawa for the calculation of the barrier attenuation [4]

$$D_B = \begin{cases} \left(20 \log \dfrac{\sqrt{2\pi N}}{\tanh \sqrt{2\pi N}} + 5\right) \text{dB} & \text{for } N \geq -0.2 \\ \\ 0 & \text{otherwise} \quad . \end{cases} \tag{15}$$

The formula Eq. (15) is applicable to both positive and negative values of N. However, for the actual computation we separate:

$$D_B = \begin{cases} 0 & \text{for } N \leq -0.2 \\ \left(20 \log \dfrac{\sqrt{2\pi|N|}}{\tan\sqrt{2\pi|N|}} + 5\right) \text{dB} & \text{for } -0.2 < N \leq 0 \\ \left(20 \log \dfrac{\sqrt{2\pi N}}{\tanh \sqrt{2\pi N}} + 5\right) \text{dB} & \text{for } 0 < N \leq 12.5 \\ 24 \text{ dB} & \text{for } N > 12.5 \end{cases} \qquad (16)$$

The last line in Eq. (16) accounts for the above-mentioned upper limit to barrier attenuation.

As shown in Fig. 5, the attenuation of the A-weighted sound pressure level of typical passenger car noise (see Fig. 2) is almost identical with the sound attenuation in the 500 Hz band. Hence, the only number important for the attenuation of road traffic noise is the path length difference.

The path length difference accounts for heights and distances of a point source, a receiver, and the top edge of a barrier. Furthermore, it allows us to account for the reduced attenuation of rays oblique to the top edge of the barrier [6].

For noise from a road segment and for a barrier at oblique angle to the road, the computer program finds the path length difference δ_N for sound from the nearest point on the road. Then, by assuming a monotonic variation of the path length difference from other points on the road, the extreme ends of the road segment are considered. If the path length differences δ_1 and δ_2 for these end points differ from δ_N by more than a number that results in an attenuation difference of about 1 dB, the road segment between the near point

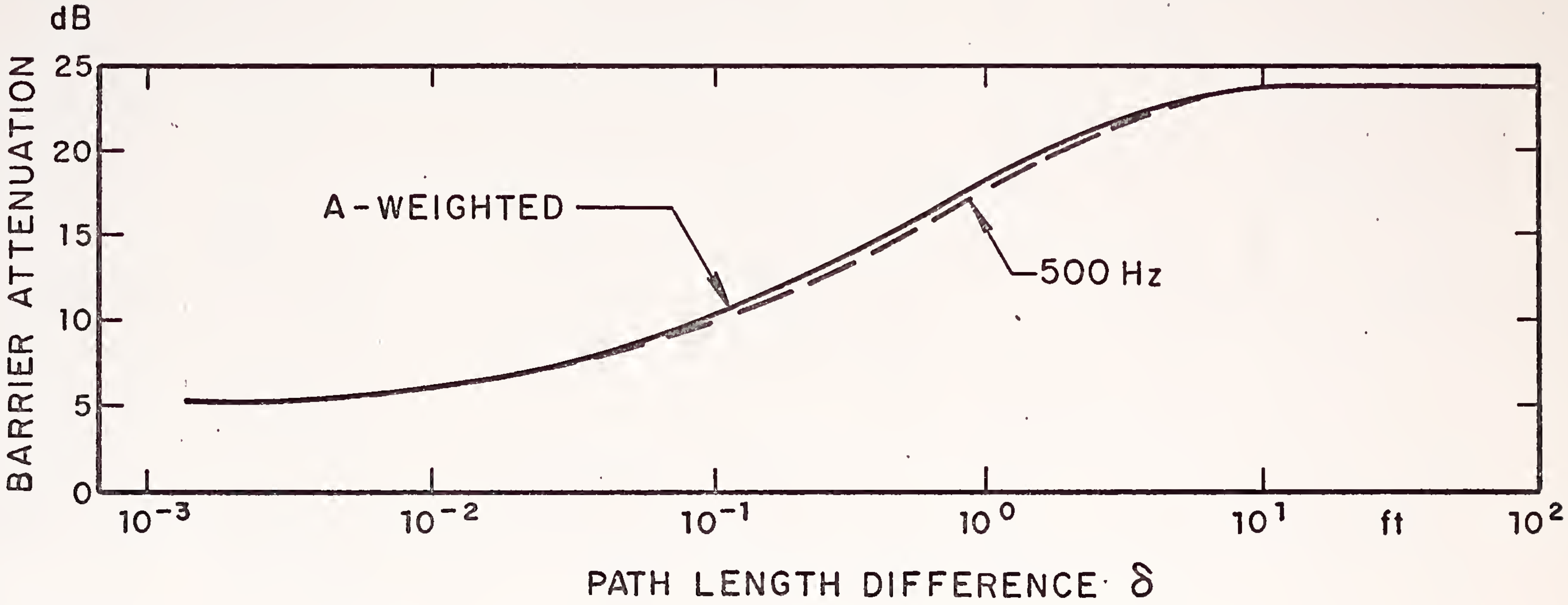


FIG.5 BARRIER ATTENUATION AS A FUNCTION OF THE PATH LENGTH DIFFERENCE δ FOR A FREQUENCY OF 500 Hz AND FOR A-WEIGHTED LEVEL OF TYPICAL PASSENGER CAR NOISE

N and the point 1 or the point 2, respectively, is cut in half. New path length differences are calculated for the new end points of the road segment, and the procedure of reducing the length of the road segment is repeated until the attenuation by diffraction is approximately constant.

The criterion used for the acceptance of a sufficiently small difference in path length differences is:

$$|\delta_2-\delta_1| - \frac{\delta_1+\delta_2}{100}\left(1 + \frac{\delta_1+\delta_2}{2}\right) \leq 0.1 \qquad (17)$$

The numbers are based on a frequency of 500 Hz, for which the effect of Eq. (17) on the attenuation is plotted in Fig. 6.

In case of multiple diffraction by several barriers in parallel, we account for the strongest diffraction exclusively. This is a conservative procedure resulting in attenuations that are somewhat too small, but it seems to be the most reasonable way to bypass the very complicated and not yet fully understood problem of multiple diffraction.

2.3.3 Ground absorption

Ground attenuation is a function of the structure and the covering of the ground, both of which influence its acoustic properties, and of the heights of the source and receiver above the ground.

In the computer program, we consider in a very simple approximation rectangular ground strips, which are defined by two end points of a center line and by a width, and which have either a low cover, such as shrubbery and thick grass, or a high cover, such as trees.

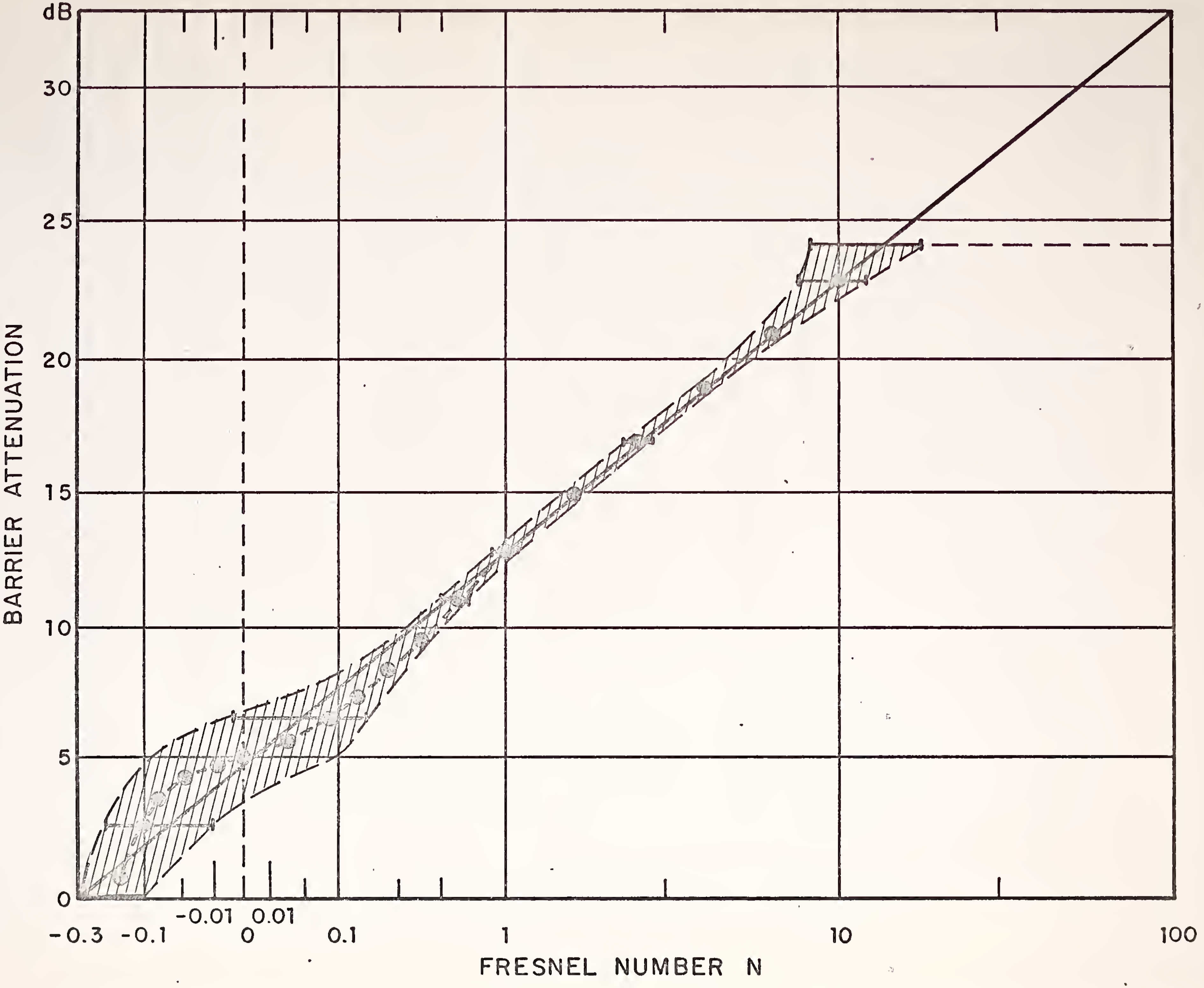


FIG.6 BARRIER ATTENUATION AS A FUNCTION OF THE FRESNEL NUMBER OF DIFRACTIONS. ——— RESULTS OF MAEKAWA'S MEASUREMENTS, ▨●▨●▨ EQ.(16) WITH TOLERANCES EQ.(17) AT 500 Hz

The height of a sound ray travelling from the source to the receiver over the ground strip is checked only with respect to the center line of the strip. Thus, it is assumed that the plane of the ground strip is approximately parallel to a plane defined by a road segment and a receiver. If the height of the direct sound ray from the source to the receiver is more than 10 ft above a ground strip with a low cover or more than 30 ft above a ground strip with high cover, any sound attenuation due to ground absorption is neglected. The heights of 10 and 30 ft are based on rough estimates rather than on field experience and might be revised if found necessary.

In general, the amount of ground attenuation cannot be stated in terms of excess attenuation per unit of distance. To a first approximation, however, such behavior can be assumed in the range of distances of 200 to 2000 ft unless the total attenuation exceeds 30 dB.

No attempt has been made to calculate accurate distances over a ground strip with the computer program. Instead, mean path lengths r over ground strips are calculated with the formula

$$r = \frac{\pi/2}{\frac{1}{w} + \frac{1}{\ell}} \quad , \tag{18}$$

where w is the width of the strip and ℓ the length of the center line.

The following analytical approximations to average values of measured data [4] are used to calculate the attenuation of sound propagating

a. through shrubbery and over thick grass

$$D_G = [0.18 \log (f) - 0.31] \frac{r}{3.28} \text{ dB} \quad , \tag{19}$$

(see Fig. 7)

b. through tree zones

$$D_G = 0.01 (f)^{1/3} \frac{r}{3.28} \text{ dB} \tag{20}$$

(see Fig. 8), where r is given in feet and f in Hz.

For the computer program, we calculate the following attenuations with r in feet and with octave band numbers n, where n = 5 for the octave band center frequency f = 500 Hz:

a. for shrubbery and thick grass

$$D_G = \begin{cases} (0.016n - 0.028)r \text{ dB} & \text{if } D_G \leq 30 \text{ dB} \\ 30 \text{ dB} & \text{if } D_G > 30 \text{ dB} \end{cases} \tag{21}$$

b. for tree zones

$$D_G = \begin{cases} \dfrac{2^{n/3}}{1{,}310} r \text{ dB} & \text{if } D_G \leq 30 \text{ dB} \\ 30 \text{ dB} & \text{if } D_G > 30 \text{ dB} \quad . \end{cases} \tag{22}$$

The notation in the second lines of Eqs. (21) and (22) means that the attenuation is limited to 30 dB.

Consistent with the assumption that the ground attenuation is proportional to the mean path length of the sound over the ground strip, the computer program accumulates attenuations

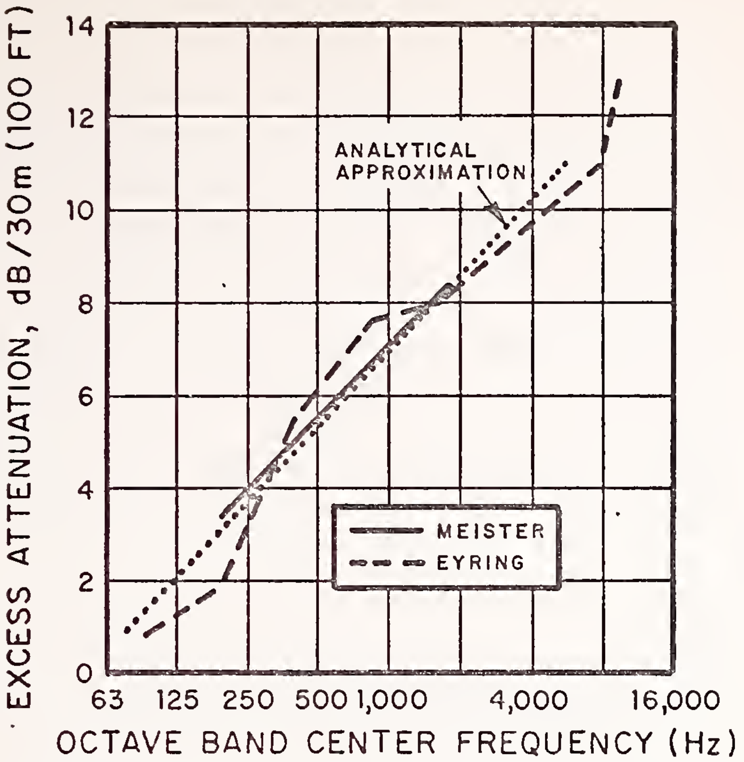


FIG.7 ATTENUATION FOR SOUND PROPAGATION THROUGH SHRUBBERY AND OVER THICK GRASS, MEASURED DATA AND ANALYTICAL APPROXIMATION

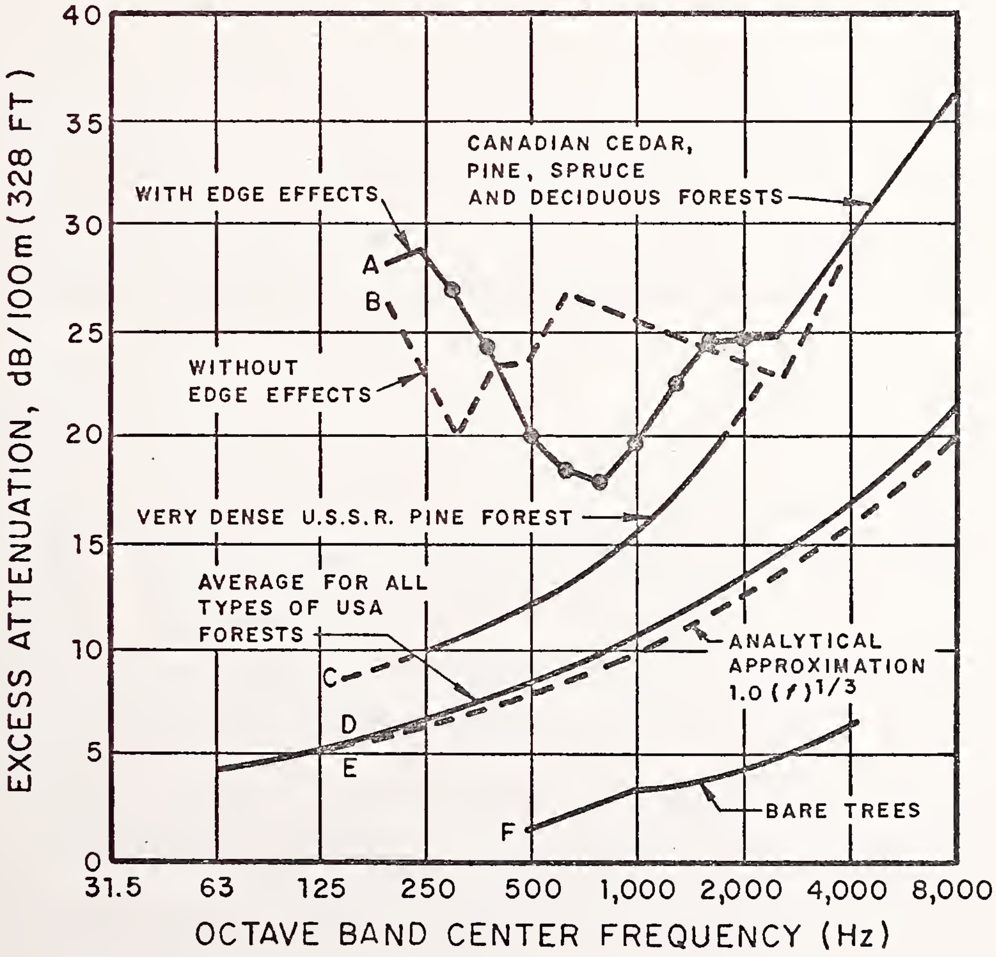


FIG.8 ATTENUATION FOR SOUND PROPAGATION IN TREE ZONES, MEASURED DATA AND ANALYTICAL APPROXIMATION FOR AVERAGE U.S.A. FORESTS

of various ground strips in series. However, since the path length considered represents a statistical average for rays propagating in all directions over the strip, the path length over two equal, parallel strips is not just twice the path length over a single strip of twice the width but is generally shorter. Consequently, the attenuation calculated for one strip will be smaller than the attenuation calculated for two strips in parallel each having half the width.

The purpose of using the statistical formulation for path length given by Eq. (18) is to obtain reasonable predictions for the effects of ground absorption on the average. There exist, however, particular cases where the model will not be very accurate. For example, the attenuation of sound from a short road segment by long, narrow absorbing strips is overestimated, whereas the attenuation by a wide strip oriented perpendicularly to the road is underestimated. To some extent, we expect these modeling errors to compensate for one another in most practical situations. In general, inaccuracies are inherent to the entire problem of ground absorption.

2.4 Reflection

The sound field at a receiver results from contributions of direct (or diffracted) and reflected rays. In many practical cases of sound propagation from a highway, corrections applied for reflections are small compared to the inaccuracies involved in the prediction of ground attenuation and in uncertainties with acoustical shadow zones owing to wind and temperature gradients in the atmosphere. Therefore, the computer program has been designed to account for reflections with a first-order approximation.

In the computer program, we disregard phase relations between the various contributions and consider incoherent waves for which the total sound intensity is made up by the sum of the intensities of the individual contributions.

There are always reflections from the road surface. However, the contributions from these reflections are already accounted for in reference levels at a short distance from individual vehicles on the road. They don't enter again into the calculations.

Reflections at the ground plane further out from the roadway are disregarded because they generally result in a complex interference pattern with the direct ray. Consideration of these effects is beyond the scope of a first-order approximation.

Reflections at any inclined plane result in rays directed either towards the ground, and thus being neglected, or towards the sky, and thus not contributing to the sound intensity at a normal receiver location close to the ground. Therefore, we consider only reflections on planes that are perpendicular to the ground plane.

Within the first-order approximation, we further neglect the actual frequency-dependent magnitude of reflection coefficients and distinguish only between reflection coefficients 0 and 1 of reflecting surfaces.

In order to determine whether a reflective barrier is high enough to be effective, we consider the possibly reflected ray that travels a minimum distance from the road segment to the receiver. A reflective plane perpendicular to the ground is considered high enough if the ray strikes the

barrier at least two feet below the top edge of the barrier. For reflection points within two feet of the top edge, diffraction effects are considered to be strong enough for all frequencies so that the reflected ray is sufficiently reduced in amplitude to be negligible.

Also neglected are reflections from planes that are either very short or very remote so that the contribution to the sound intensity at the receiver is less than 10% of the intensity received via direct (or diffracted) rays from the road segment under consideration. The analytical formulation for this criterion is

$$\frac{d\Delta\alpha'}{d'\Delta\alpha} \; 10^{-D_B/10} < 0.1 \quad , \tag{23}$$

where d = distance from the receiver to the road segment,

$\Delta\alpha$ = aspect angle of the road segment at the receiver,

d' = distance from the road segment to a receiver location imaged about the reflector.

$\Delta\alpha'$ = aspect angle of the barrier at the image receiver,

D_B = attenuation in dB by diffraction of the direct ray due to a possible barrier (referred to a frequency of 500 Hz).

Single reflections are considered exclusively; contributions from rays that strike two or more reflectors are ignored. It is essential for the future calculation of higher order statistical parameters of road traffic noise that the reflections of sound from a certain road segment be treated as amplifications of the direct (or diffracted) rays and not as uncorrelated contributions from independent road segments. The factor F

multiplying the intensity of the direct sound from a road segment is calculated using

$$F = 10^{-D_B/10} + \sum_{i=1}^{N} \frac{\Delta\alpha_i' d}{\Delta\alpha d_i'} 10^{-D_i/10} \quad , \qquad (24)$$

where the subscript i indicates reflections at N different surfaces, each of which might be diffracted by a barrier before or after reflection and therefore might have an attenuation D_i. The factor F is calculated as a function of frequency. The notation in Eq. (24) is the same as in Eq. (23) except for the angle $\Delta\alpha'$ which denotes the aspect angle of the road segment at the image receiver (see Fig. 9).

2.5 Combination of Attenuation and Reflection

2.5.1 Atmospheric absorption

The computer program accounts for atmospheric absorption in combination with barrier diffraction, ground absorption and reflections. The path length used for calculating the atmospheric absorption is the direct distance from the source to the receiver and is not corrected for the path length difference δ of diffracted rays nor for the increased path length of reflected rays. The factor F, defined by Eq. (24), is multiplied by $10^{-D_A/10}$, where D_A is defined by Eq. (13), in order to calculate for each individual road segment s the factor

$$10^{-D_s/10} = F \, 10^{-D_A/10} \, 10^{-D_G/10} \quad , \qquad (25)$$

which is employed for the calculation of the energy mean level in Eqs. (8) and (9).

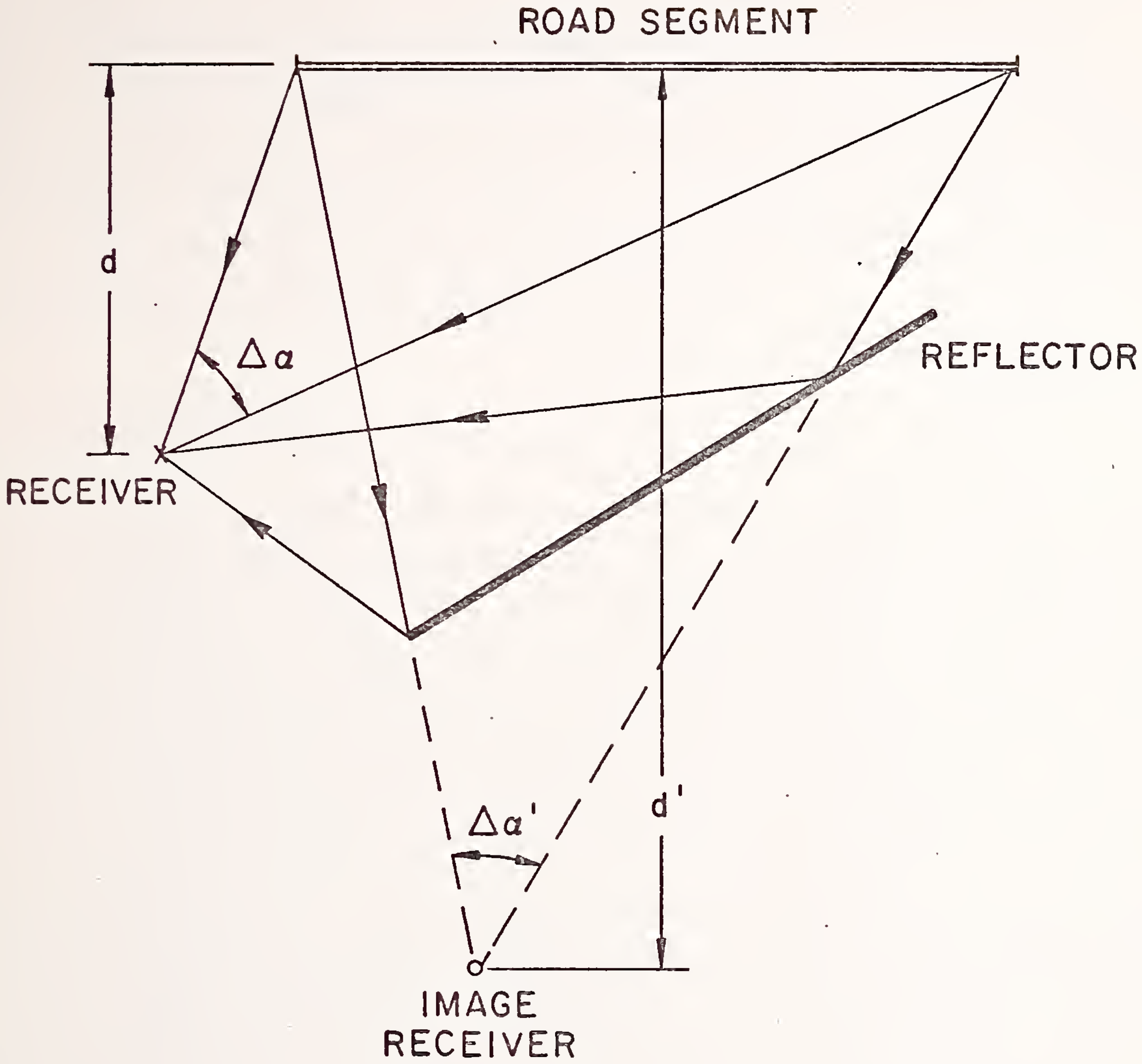


FIG.9 EXAMPLE FOR RAY TRACES FROM A REFLECTOR, INDICATING THE CONSTRUCTION BY MEANS OF AN IMAGE RECEIVER

2.5.2 Ground absorption

The computer program accounts for ground absorption only if the rays travelling over the ground are not diffracted by a barrier. This concept is based on field experience with low ground cover [7,8]. For high ground cover, it might be necessary to reconsider the approach taken. As shown with the formula Eq. (25), the same ground absorption is assumed for the direct rays and for all reflections.

2.5.3 Reflection

The computer program accounts for reflections in combination with diffraction provided that there is only a single diffraction before or after the reflection and that the path length increase due to diffraction is less than 12.5 ft. Doubly diffracted reflections are neglected as well as very weak single reflections that suffer, in the 500 Hz band, the maximum attenuation of 24 dB assumed for barrier diffraction.

The attenuation of reflected rays by diffraction is calculated for one location on the road segment only: the point nearest to the image receiver. No attempt has been made to refine this calculation by checking for the attenuation from other points on the road segment, since the contribution of diffracted reflections will be generally small and, hence, inaccuracies of the calculation will be negligible.

3. DESCRIPTION OF THE COMPUTER PROGRAM

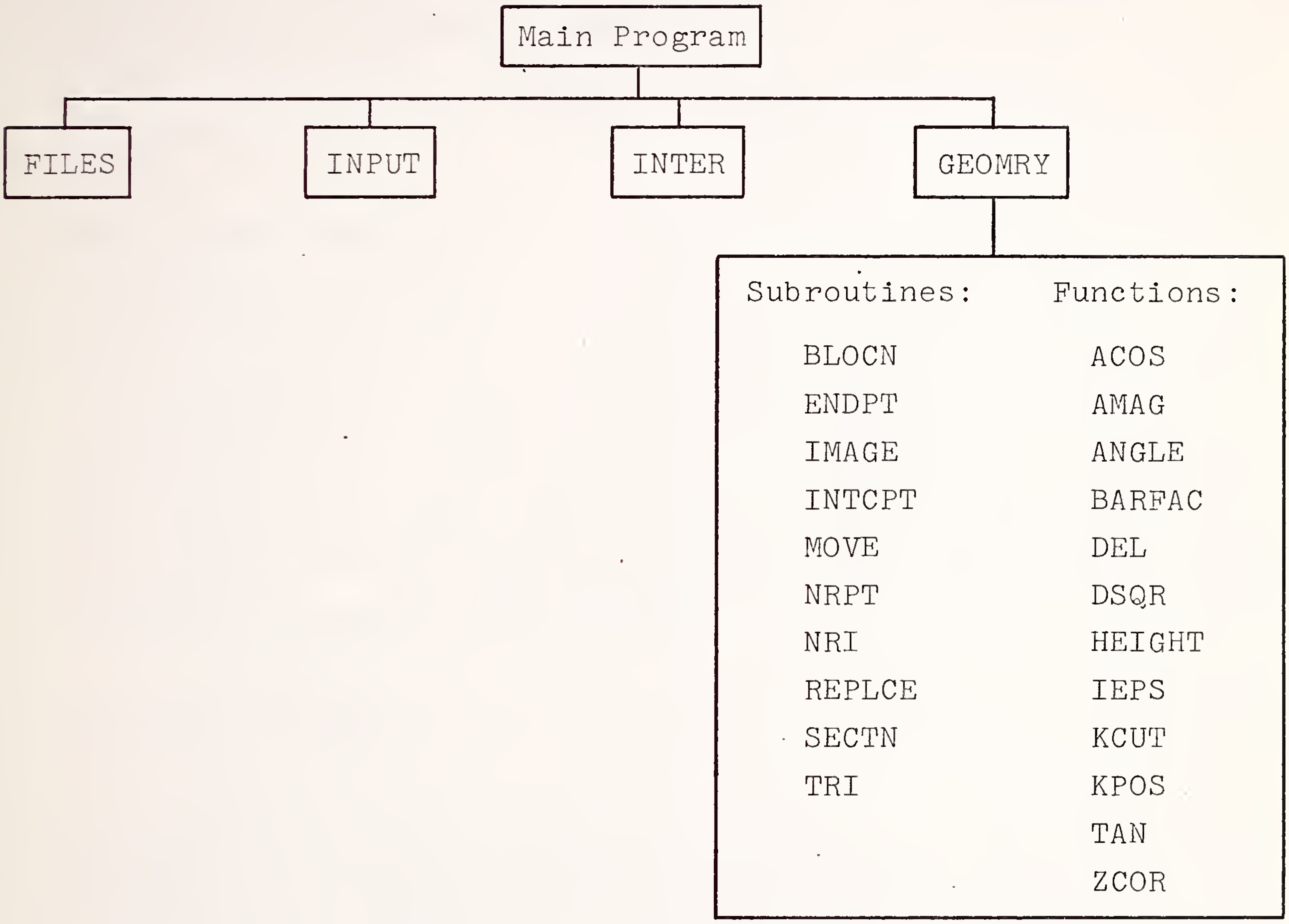
3.1 Introduction

The computer program is designed to run on the DDP-516/H-832 computer complex which is currently installed in the Computer Technology Division at TSC. The program is written in FORTRAN-IV and is designed to run in batch mode. Because of the modular organization of the program, only a modest level of effort should be required to modify it for an interactive mode of operation. As currently implemented, inputs are provided via punched cards and outputs are provided on the user teletype.

To meet the constraints on core storage imposed by the PDP-516, the disk is used whenever feasible for storing large temporary arrays and input data. Should the program be implemented on a computer which has a larger core memory, computation time will be significantly reduced by using core memory for storing certain arrays now stored on the disk.

The organizational scheme of the program is shown in the following flow diagram. The major blocks of code are contained in the main program and in the subroutines INPUT and GEOMRY. The subroutine INPUT reads input data provided on cards, stores this information on disk files, and outputs it on the user's teletype. The subroutine GEOMRY provides the bulk of the calculations performed by the computer program and uses a number of additional subroutines and functions in the process. Additional subroutines called by the main program are FILES, which assigns device numbers to the various I/O devices and files used by the program, and INTER, which computes reference intensities for the various vehicle groups specified by the user.

ORGANIZATIONAL SCHEME OF COMPUTER PROGRAM



The main program and the subroutines INPUT and GEOMRY are discussed individually in some detail in the remainder of this section and the remaining subroutines and functions are described very briefly. Listings for the entire computer program are given in Sec. 3.6. Details on program usage are provided in Sec. 4.

The following definitions are used throughout the remainder of this manual. A "road" or "roadway" is defined as a set of connected straight "road sections" for which the traffic conditions are uniform. That is, the number of vehicle groups and the concentration and mean vehicle speed associated with each group are the same for all sections of a given road. Barriers are treated similarly. Thus, a "barrier" is defined as a set of connected straight "barrier sections" for which the absorptive/reflective properties are the same.

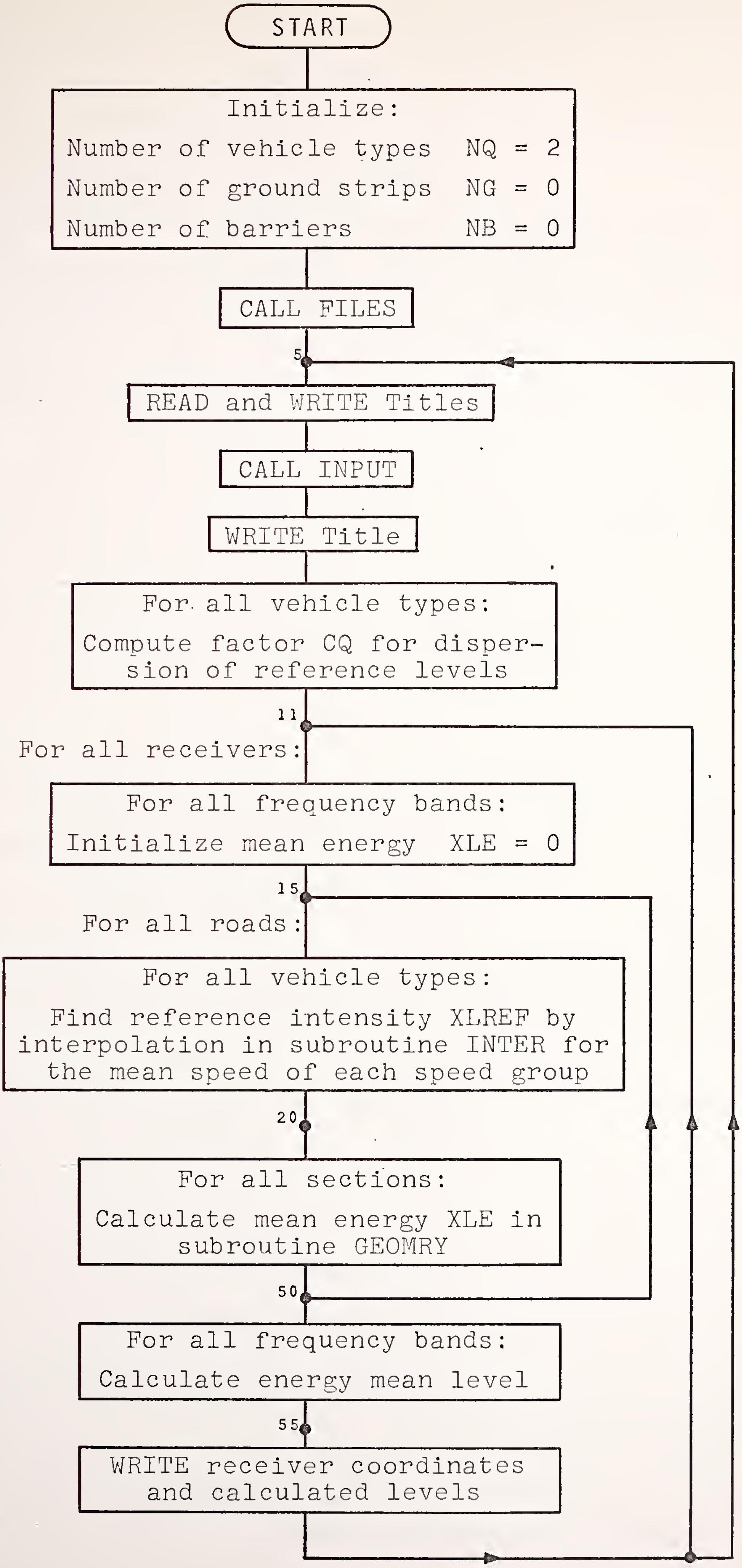
3.2 Main Program

3.2.1 Overview

The primary function of the main program is to control the flow of operations. Various subroutines are called upon to perform the bulk of the input-output operations and the analysis. In addition, certain variables are initialized in the main program and the final computation of energy mean levels is made.

A flow diagram of the main program is given below. This diagram is self-explanatory. Whenever possible, statement numbers are shown so that reference may be made to the corresponding block of code in the program listing.

Main Program



3.2.2 List of variables for main program

Variables appearing in the main program are listed below. Array variables are not generally identified as such; the dimensionality of the variables can be determined from the program listing in Sec. 3.6. The variables XR1 and XR2 listed below are vector quantities which indicate the coordinates of road end points. The first element of the vector indicates the x-coordinate, the second element the y-coordinate, and the third element the z-coordinate. This format is used widely throughout the remainder of the entire computer program to denote coordinates.

CO	Factor accounting for standard deviation of reference level
I	Index
IBAR	Barrier number
IBR	Barrier file device number
IDF	Barrier subfile device number
IERR	Error index
IGA	File device number for absorptive ground strips
IGRA	Ground strip number
IGTA	Subfile device number for absorptive ground strips
II	Index
IQ	Index
IRD	Roadway file device number
IREF	Reflector file device number
IRFDF	Barrier subfile device number

ISEG	Barrier section number
J	Index
M	Roadway number
N	Road section number
NB	Number of barriers
NF	Number of frequency bands
NG	Number of absorptive ground strips
NQ	Number of vehicle types
NQQ	Number of groups within one vehicle type
NQS	Vector notation for number of vehicle groups
NR	Number of roadways
NRC	Number of receivers
NRSEC	Number of sections for one roadway
RDIN	Vector notation for initialization parameters
SIG	Standard deviation of reference level
VEXPH	Vehicles per foot
XLA	A-weighted overall intensity and level
XLE	A-weighted intensity and level in frequency bands
XMPH	Vehicle speed in mph
XR1	Road section initial point
XR2	Road section end point
XRC	x-coordinate of receiver
YRC	y-coordinate of receiver
ZRC	z-coordinate of receiver

3.3 Subroutine INPUT

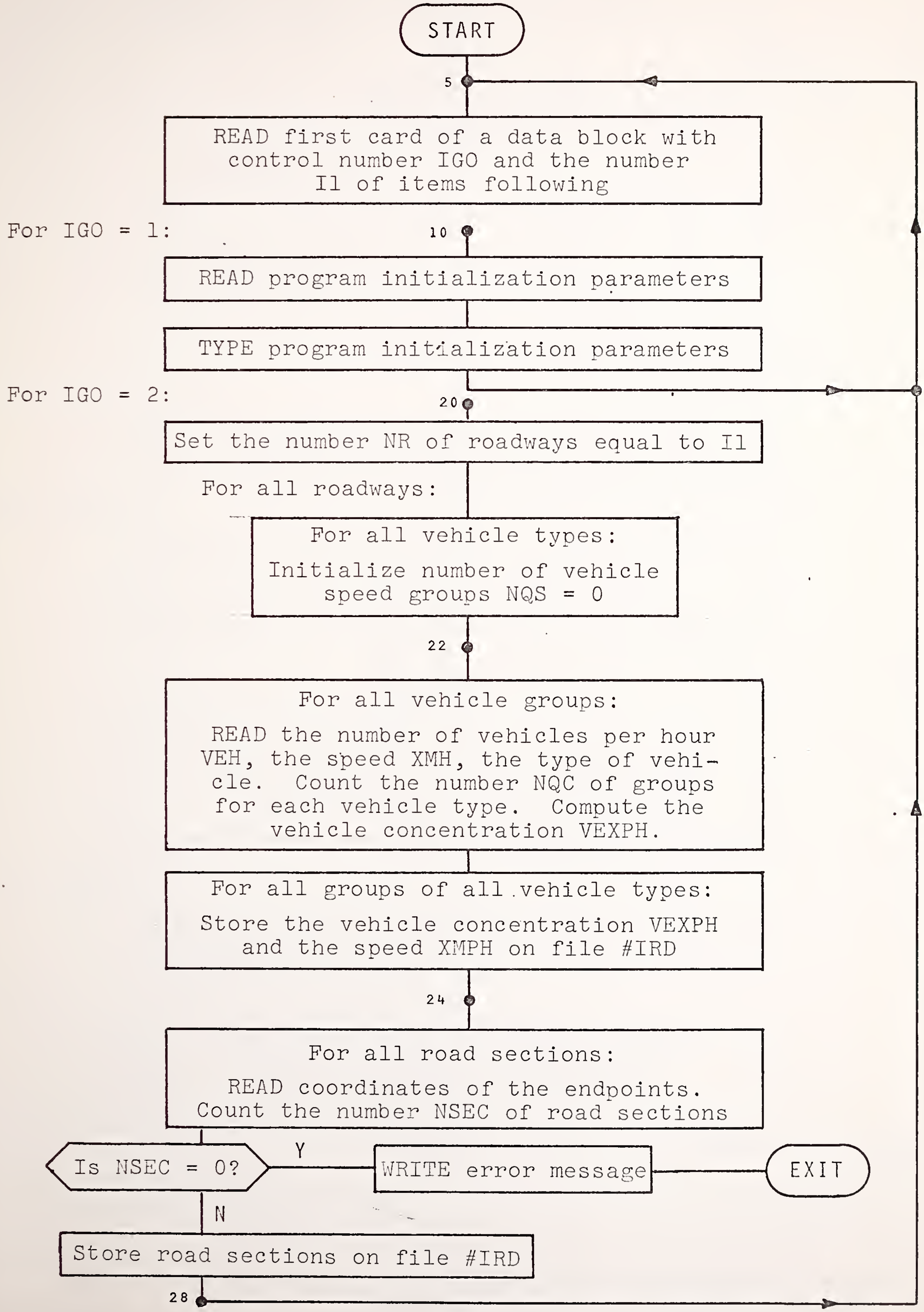
3.3.1 Overview

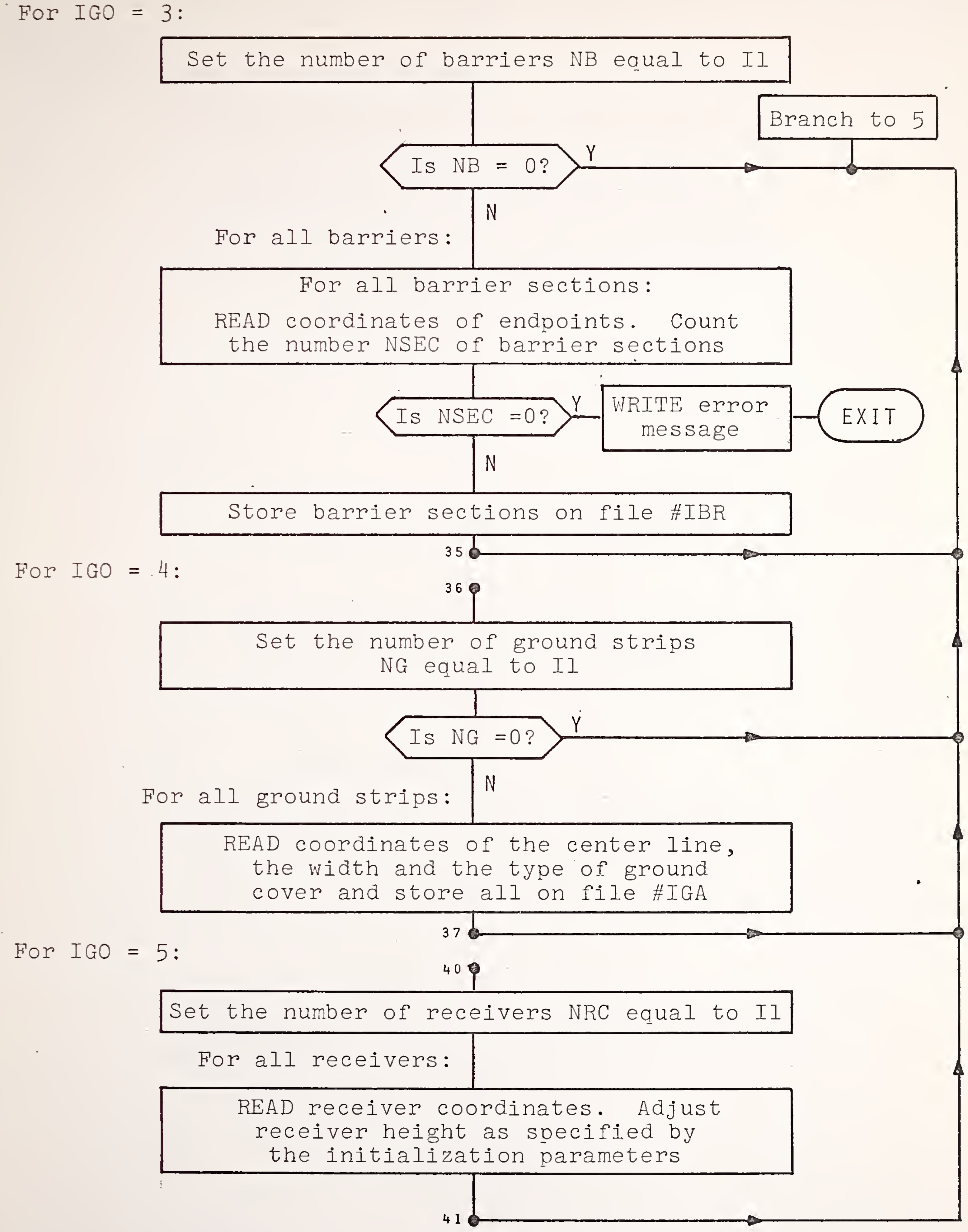
This subroutine reads the input data provided by the user on punched cards, stores this data on disk files in a format suitable for use in the remainder of the computer program, and outputs the data on the user teletype so that a permanent record is created.

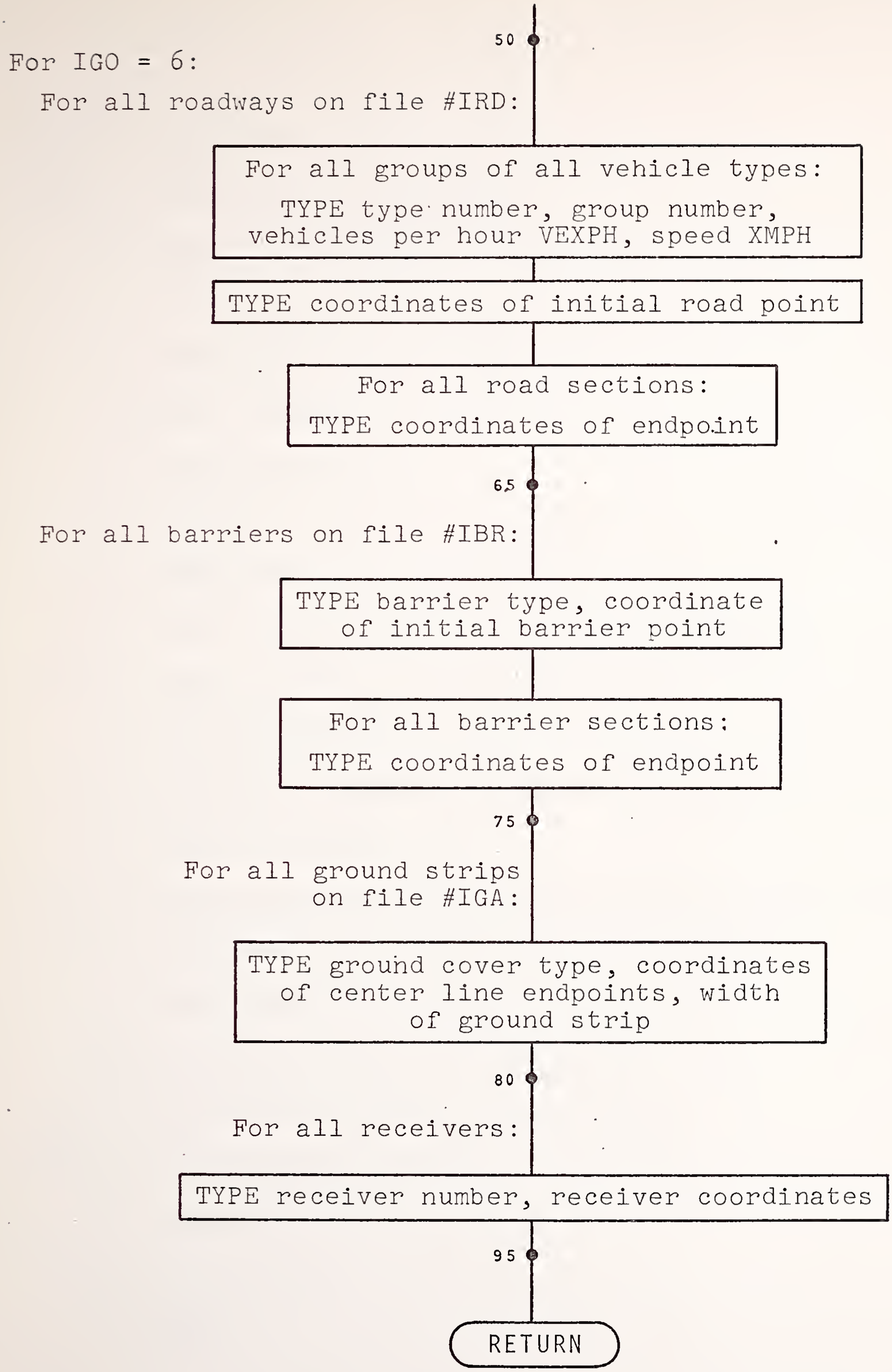
The computer program is organized in such a way that the user need not redefine the entire situation each time a new case is analyzed. Instead, it is necessary to specify only those aspects of the problem that are different from the previous case. Accordingly, each block of input data is preceded by a control card that indicates the type of data (e.g., barrier specifications) and the number of items (e.g., number of barriers) to follow. After a special control character has signified the end of data input, the entire set of input variables is typed out and control returns to the main program.

A flow diagram of this subroutine is given below, followed by a list of variables.

Subroutine Input




For IGO = 3:
Set the number of barriers NB equal to I1
Branch to 5
Is NB = 0?
Y
N
For all barriers:
For all barrier sections:
READ coordinates of endpoints. Count the number NSEC of barrier sections
Is NSEC =0?
Y
WRITE error message
EXIT
N
Store barrier sections on file #IBR
35
For IGO = 4:
36
Set the number of ground strips NG equal to I1
Is NG =0?
Y
N
For all ground strips:
READ coordinates of the center line, the width and the type of ground cover and store all on file #IGA
37
For IGO = 5:
40
Set the number of receivers NRC equal to I1
For all receivers:
READ receiver coordinates. Adjust receiver height as specified by the initialization parameters
41


50
For IGO = 6:
For all roadways on file #IRD:
For all groups of all vehicle types:
TYPE type number, group number, vehicles per hour VEXPH, speed XMPH
TYPE coordinates of initial road point
For all road sections:
TYPE coordinates of endpoint
65
For all barriers on file #IBR:
TYPE barrier type, coordinate of initial barrier point
For all barrier sections:
TYPE coordinates of endpoint
75
For all ground strips on file #IGA:
TYPE ground cover type, coordinates of center line endpoints, width of ground strip
80
For all receivers:
TYPE receiver number, receiver coordinates
95
RETURN

3.3.2 List of variables for subroutine INPUT

ALPHA	Alphanumeric information
BG	Width of absorptive ground strip
I	Index
II	Number of items in data block
I2	Dummy variable
IA	Alphanumeric "A"
IBR	File device number for barriers
IDF	Subfile device number for barriers
IDN	Index for program initialization parameter
IDUM	Index for type of absorptive ground cover
IG	Alphanumeric "G"
IGA	File device number for absorptive ground strips
IGO	Index for data blocks
IGTA	Subfile device number for absorptive ground strips
ILAST	Alphanumeric indicator for last section
IR	Alphanumeric "R"
IRD	File device number for roadways
IREF	File device number for reflectors
IRFDF	Subfile device number for barriers
IT	Alphanumeric "T"
ITY	Vehicle type
J	Index

K	Index
LAST	Alphanumeric "L"
NB	Number of barriers
NG	Number of absorptive ground strips
NQ	Number of vehicle types
NQC	Number of groups within one vehicle type
NQS	Vector notation for number of vehicle groups
NR	Number of roadways
NRC	Number of receivers
NSEC	Section number
NSM1	NSEC-1
RDIN	Vector notation for initialization parameters
VALUE	Initialization parameter
VEH	Vehicles per hour
VEXPH	Vehicles per foot, vehicles per hour
X	Coordinate
XG1	X-coordinate for end point of ground strip center line
XMH	Speed in mph for one group of vehicles
XMPH	Vector notation for vehicle speed
XNIGHT	Height adjustment for receiver coordinate
XRC	X-coordinate of receiver
XT	X-coordinate for end point of road section
Y	Coordinate

YG1	Y-coordinate for end point of ground strip center line
YRC	Y-coordinate of receiver
YT	Y-coordinate for end point of road section
Z	Coordinate
ZG1	Z-coordinate for end point of ground strip center line
ZRC	Z-coordinate of receiver
ZT	Z-coordinate for end point of road section

3.4 Subroutine GEOMRY

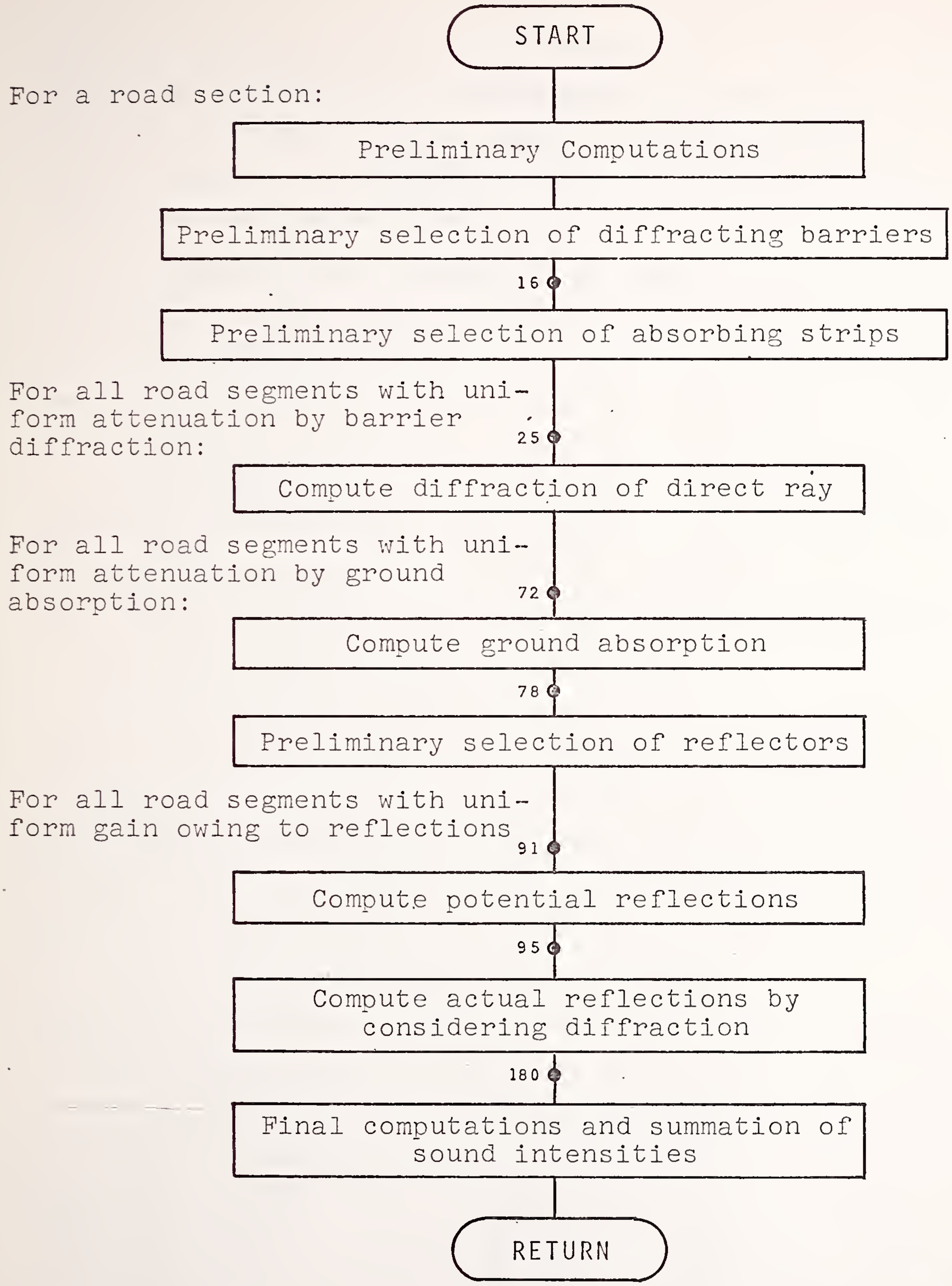
3.4.1 Overview

The bulk of the computational effort of this subroutine is devoted to finding segments of a straight road section for which sound from all points along the segment reaching a particular receiver is nearly equally attenuated by barrier diffraction or ground absorption or is equally amplified by reflections.

Because of the complexity of this subroutine, a detailed description with a series of flow diagrams is presented in Sec. 3.4.2. Before reviewing these diagrams, however, the reader should become familiarized with the basic philosophy of the computational scheme outlined below.

As shown in the following diagram giving an overview of subroutine GEOMRY, checks are performed on two different levels — first on all the barriers, then on all the absorptive ground strips, and finally on all the reflectors. On the lower level, preliminary checks are made mostly in the two dimensions of the x-y plane to determine whether a barrier, a ground strip,

AN OVERVIEW OF SUBROUTINE GEOMRY



or a reflector can be at all effective for the road segment and the receiver under consideration. During these checks, subfiles are created for a smaller number of barriers, ground strips, and reflectors that need to be investigated more closely at the higher level.

At this higher level, break points between road segments possibly affected and unaffected by barriers, ground strips, or reflectors are determined from checks first made in the two dimensions of the x-y plane. If the road segment between the initial point and the break point is unaffected, then no further checks in three dimensions are made on the actual effect of the remaining road segment, but the break point is considered as the new end point of the road segment. The remaining road segment is investigated after the calculations for the first road segment are finished.

If the road segment between the initial point and the break point is possibly affected by a barrier, a ground strip, or a reflector, the break point is taken as a preliminary end point until the subsequent analysis in three dimension shows whether there is an actual effect that makes it necessary to keep the break point as an end point or whether there is no effect and the break point can be dropped.

Since all the checks are performed first for diffraction, then for absorptive ground strips, and finally for reflections, the initial road section may be reduced several times by each group of elements. The procedure of subdividing a road section is diagrammed in Fig. 10. The final reduction in each group is stored in terms of end points XR2D for barriers, XR2G for absorptive ground strips, and XR2 for reflectors. By this means, duplicate calculations are avoided. After the noise

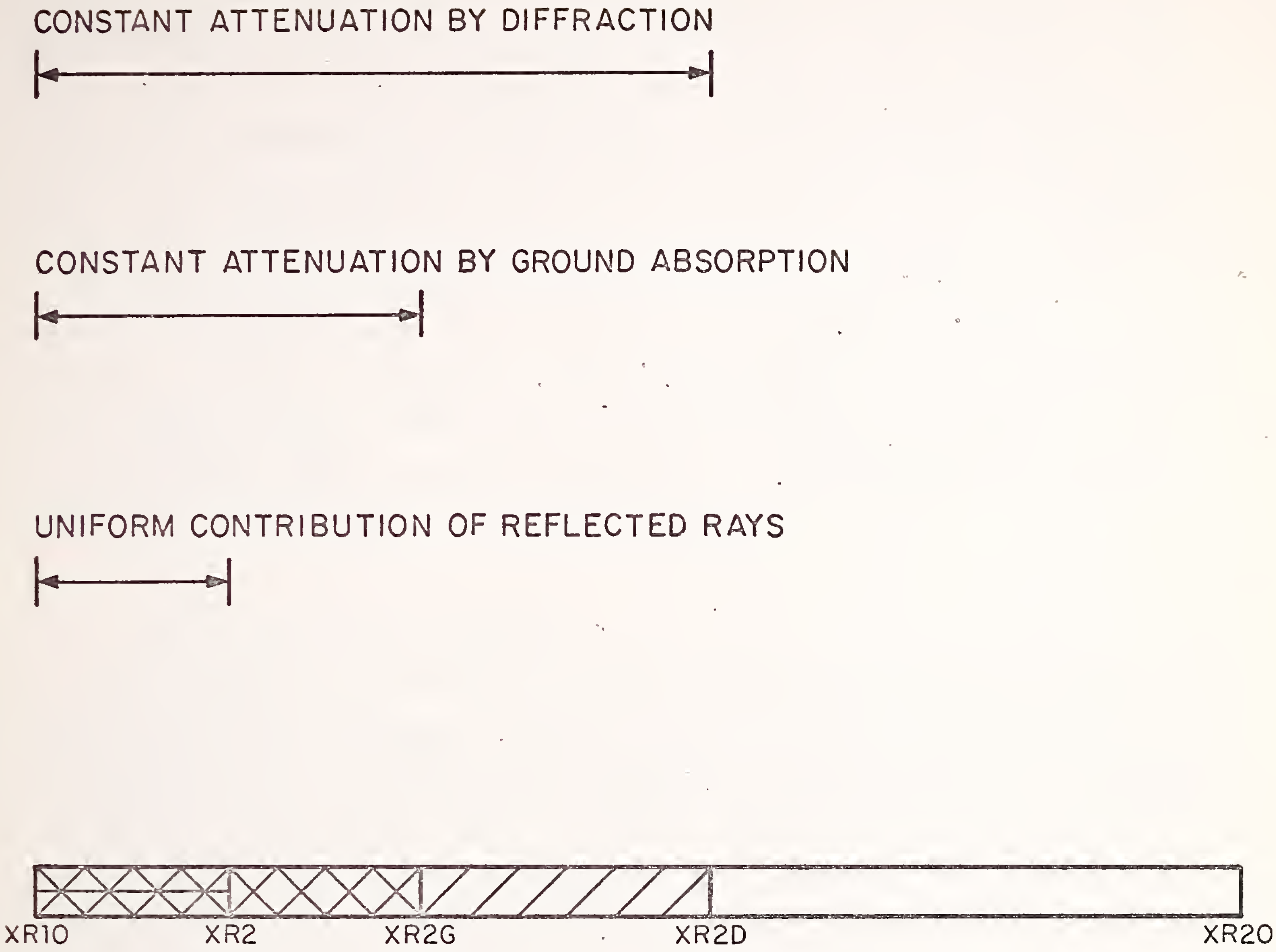


FIG.10 SUBDIVISION OF ROAD SECTION

from the road segment XR10, XR2 is analyzed, the computation continues for possible reflections from the road segment XR2, XR2G. After the noise from the road segment XR1, XR2G is completely analyzed, the computation continues with consideration of ground absorption and reflections for the road segment XR2G, XR2D. The designation of end points during the course of this analysis is illustrated in Fig. 11. Finally, the computation continues with the entire problem of barrier diffraction, ground absorption, and reflection for the remaining road segment XR2D, XR20 until the noise from the entire road section XR10, XR20 has been analyzed. At that point, program control is returned to the main program.

3.4.2 Detailed flow diagrams

The flow diagrams presented at the end of this section show the operations and important branch points of the computations that are indicated in the overview diagram presented above. Again, statement numbers are shown so that reference may be made to the corresponding block of code in the program listing given in Sec. 3.6. The following comments are provided to supplement the information contained in the flow diagrams.

Preliminary computations

The main computation shown in the first flow chart concerns the distance between the near point XNPT on the source line and the receiver XRC. This distance enters into the formula for the mean energy level and is a quantity that is characteristic of the entire road section.

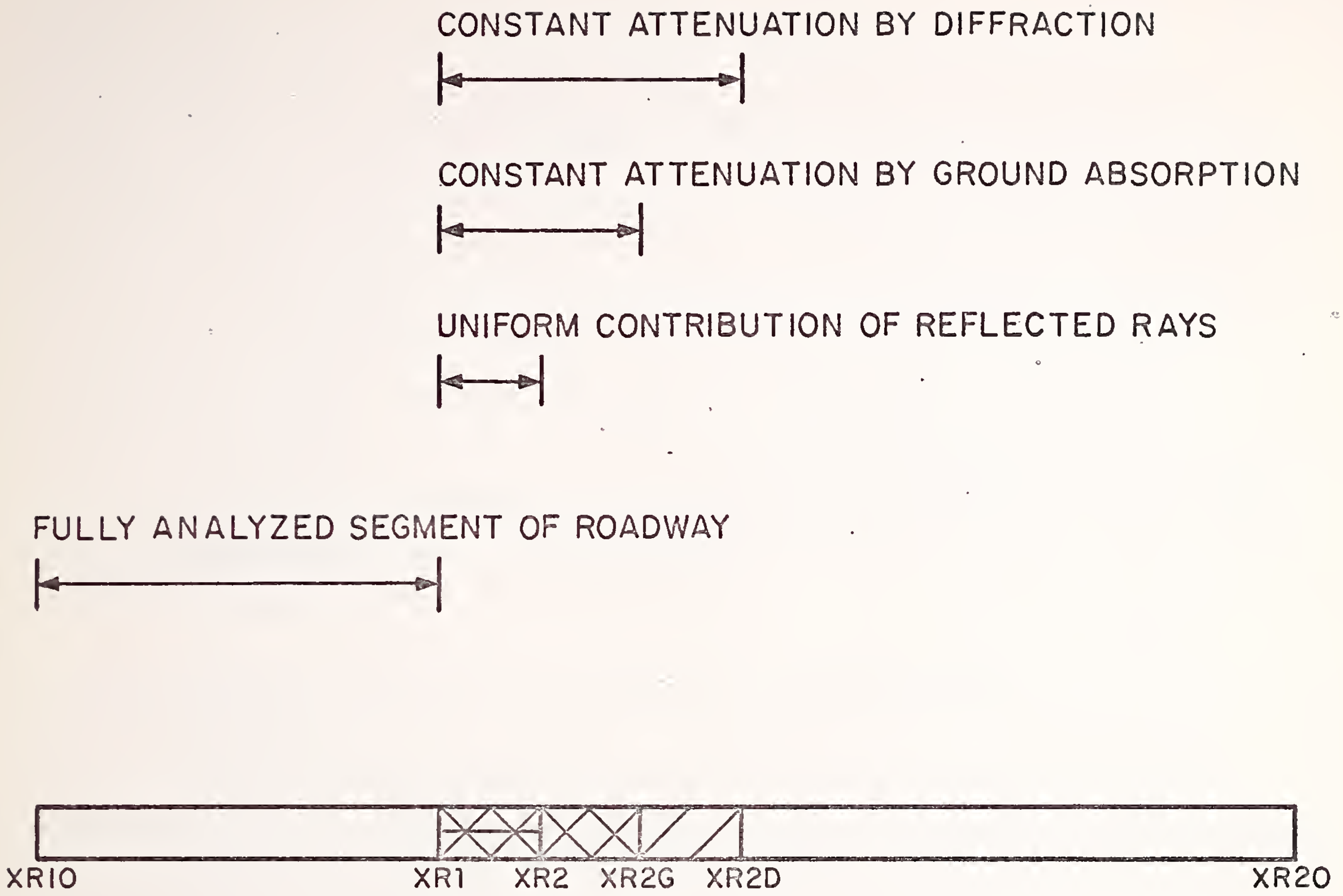


FIG.11 FURTHER SUBDIVISION OF ROAD SECTION

Preliminary selection of diffracting barriers

The computations are made in the two dimensions of the x-y plane, and no checks are made for the height of barriers. A barrier whose top line crosses the roadway in a projection on the x-y plane is considered illegal and causes the program to abort. Thus, even a barrier crossing underneath an elevated roadway is illegal. A barrier stored on file #IDF is not necessarily high enough actually to diffract sound rays travelling from the road section to the receiver. The storage of the relative location (see SUBROUTINE BLOCN) saves considerable computation for very high barriers that shield the entire road section against the receiver.

Preliminary selection of absorbing ground strips

The computations are entirely analogous to the preliminary selection of diffracting barriers. No check is made for the distance of the ground strip center line from the road section. Therefore, a road section, or a part of it, which is inadvertently specified on a ground strip will not be detected in all cases by the program.

Diffraction of direct ray

The initialization of a path length DELP0 = -0.2 means that the attenuation by diffraction is set equal to zero in the frequency band centered at 500 Hz.

The test for whether or not a barrier possibly shields the entire road is made in the x-y plane and does not account for the actual height of the barrier.

The height difference for sound rays from cars above the barrier provides a rather conservative check for possible effects of diffraction. A positive height difference means the source is visible from the receiver location.

Only the most effective of a number of parallel barriers is considered; thus, the barrier having the strongest diffraction is retained. Note that this barrier is not necessarily the highest one. It is just as likely to be the barrier nearest to the road or to the receiver.

The calculation of a road segment with sufficiently similar diffraction is performed for cars only. It is then assumed that the same result holds for trucks having a different source height.

The check for maximum diffraction of sound in the frequency band centered at 500 Hz is made for trucks only, because the higher source height of trucks will result in smaller diffraction than for cars. If this test reveals a path length difference of more than 12.5 ft, further checks on other barriers can be skipped for the road segment considered. If a very high barrier shields the entire remaining road section, no further tests for diffraction of the direct ray are made. This procedure may result in some inaccuracies for very long road sections for which the diffraction of sound from points near to the receiver is very strong but for which the diffraction of sound from remote points might be considerably weaker. However, these inaccuracies are no more serious than those resulting from the assumption of the arbitrary value of 12.5 ft for the maximum path length difference, and are thus neglected.

Ground absorption

Absorptive ground strips are disregarded for sound from a road segment whenever an attenuation different from zero is found due to barrier diffraction. The criterion for this decision may be modified in the future to be 5 or 10 dB, corresponding to path length differences of 0 or 0.1 ft at 500 Hz, if field experience shows that this is necessary. Furthermore, the decision to neglect ground strips, which is related to certain heights of rays above the center line of the ground strip, is not based on experimental evidence and may require modifications.

Preliminary selection of reflectors

By the introduction of an image receiver location, the reflection problem becomes similar to the diffraction problem. A reflector in the path from the road segment to an image receiver is effective whenever a barrier in the path from the road segment to a receiver strongly diffracts the sound.

In addition to the preliminary checks made above for diffracting barriers, the intensity of the direct (or diffracted) sound from the road segment considered is compared to the potential maximum contribution of each reflection. This check assures that only essential reflectors are considered. Since a reflector might not be high enough or reflections might be strongly attenuated by diffraction at additional barriers in the ray path, the reflectors found at this stage are considered "potential" reflectors.

Also involved in the part entitled "Preliminary Selection of Reflectors" is the preliminary selection of barriers which can possibly diffract the reflected sound. The check performed is based on the length and orientation of a barrier section and on the distance from the image receiver relative to the respective parameters of the road section and the receiver considered.

Calculation of potential reflections

The computations in this section are analogous to those made for the diffraction problem, except for a simplified decision concerning the height of the reflector. If the height difference above the reflector of a sound ray from the nearest point on the road segment leads to the acceptance or rejection of the reflector, no further check is made for other source points on the road segment.

Since diffraction of the reflected ray is not yet checked, a reflection is still called a potential one and the end point of the road segment is preliminary.

Consideration of diffraction before reflection

Checks for barriers in the area defined by projections of the four points XR1, XR2, XRB3, and XRB4 into the x-y plane are made by considering first the triangle containing image rays and then the triangle formed by the road segment and the image receiver.

If a barrier is found to be high enough for possible diffraction, the reflector is checked again to determine whether or not it is high enough to reflect the diffracted rays (which now come from an effective source that might be considerably higher than the roadway).

Calculation of the path length difference between diffracted and direct rays from only the near point of the road segment implies that the diffraction of sound rays from other source points is about the same.

Very strongly diffracted reflections are neglected. The decision is made on the basis of the diffraction of sound from trucks, since rays from cars are even more strongly diffracted.

Consideration of diffraction after reflection

Checks are made for diffracting barriers in the triangle defined by projections of the reflector segment XRB3, XRB4 and the receiver XRC onto the x-y plane.

After a barrier has been found which is high enough for possible diffraction, the reflector is checked to determine whether or not it is high enough to reflect sound towards the top line of the diffracting barrier, which might be considerably higher than the receiver.

The calculation of the path length difference implies simplifying assumptions similar to those for the problem of diffraction before reflection.

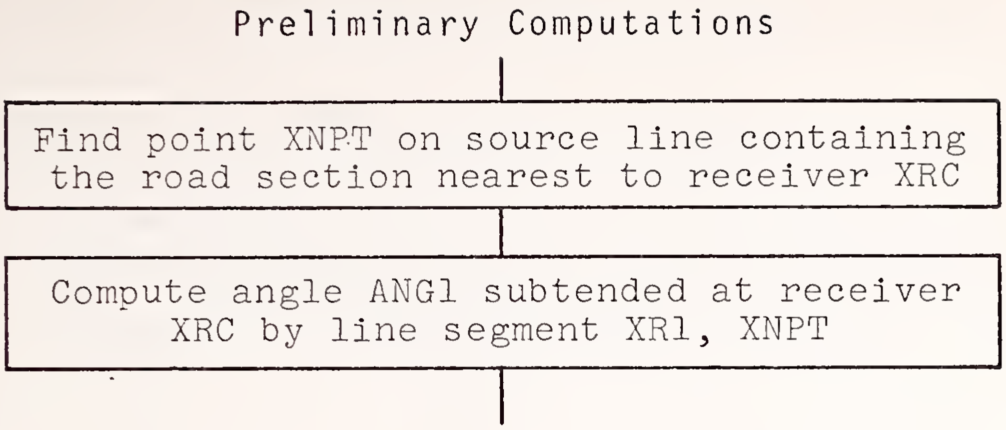
Reflections are neglected in the case of diffraction before and after reflection and in the case of very strong diffraction after reflection.

Final computations and summation of sound intensities

In order to facilitate future calculation of higher order statistical parameters of the noise, the contributions from all reflections are used to calculate a gain factor of the direct sound from a road segment. The subsequent computations are directly oriented at the formula of Eq. (8) for the mean sound intensity.

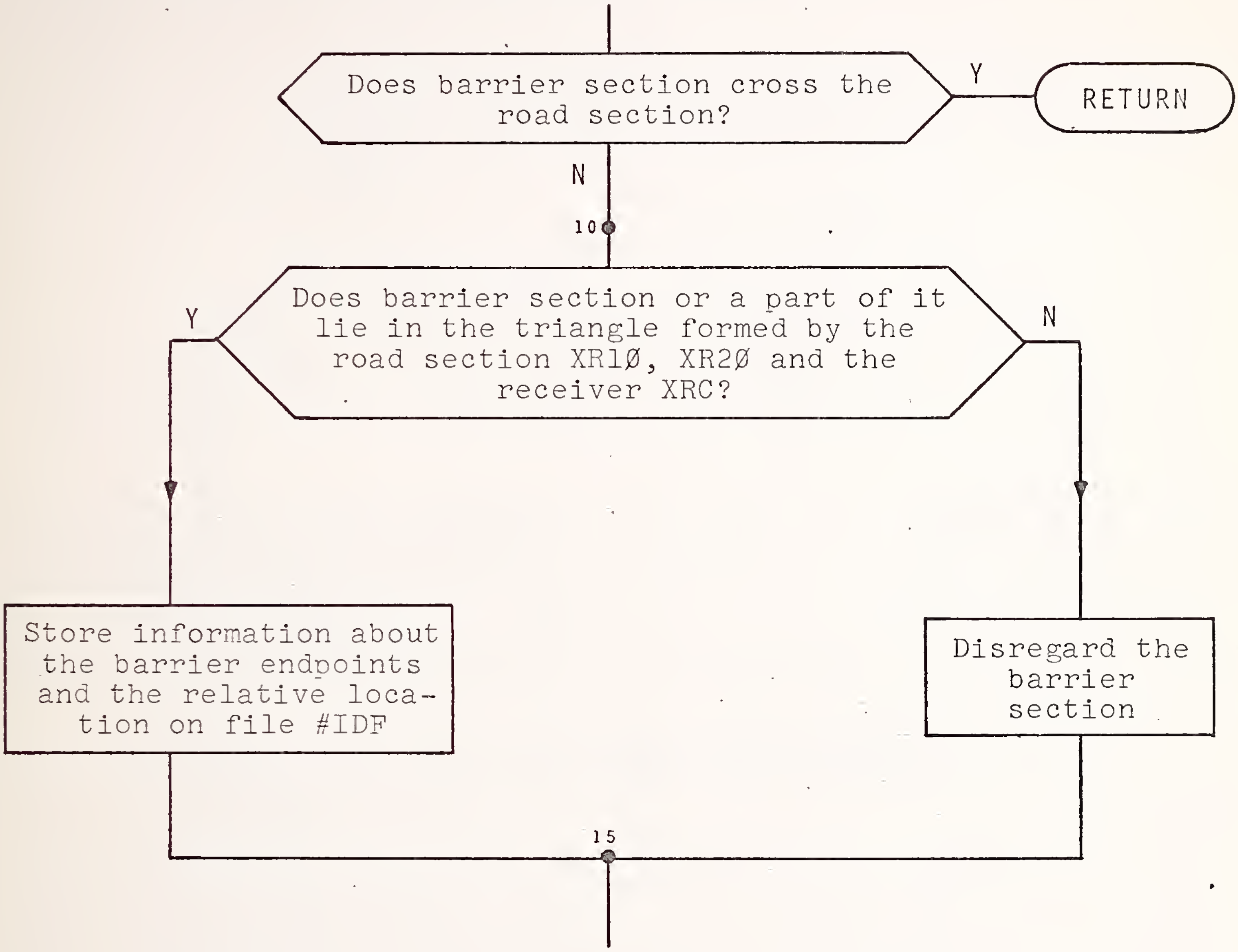
Also intended for future use is the separate computation of angles ANG1 and ANG2, of which only the absolute value of the difference is employed in Eq. (8).

After the calculation for a road segment has been completed, a point 1 ft beyond the end point of the segment is taken as the initial point of the next road segment. This procedure avoids computational complications without unduly sacrificing accuracy.


Preliminary Computations
Find point XNPT on source line containing the road section nearest to receiver XRC
Compute angle ANG1 subtended at receiver XRC by line segment XR1, XNPT

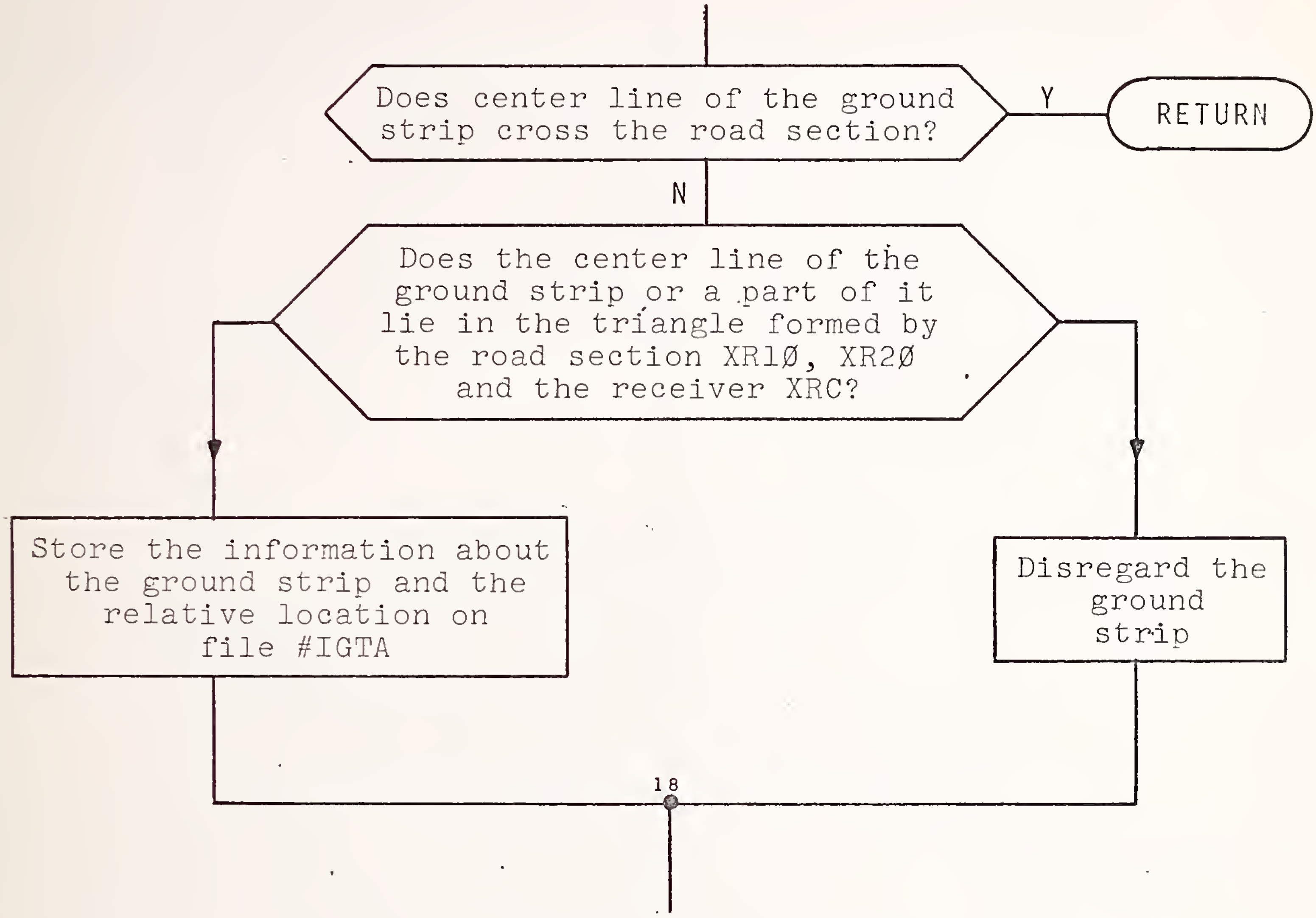
Preliminary Selection of Diffracting Barriers

For all sections of all barriers in file #IBR:

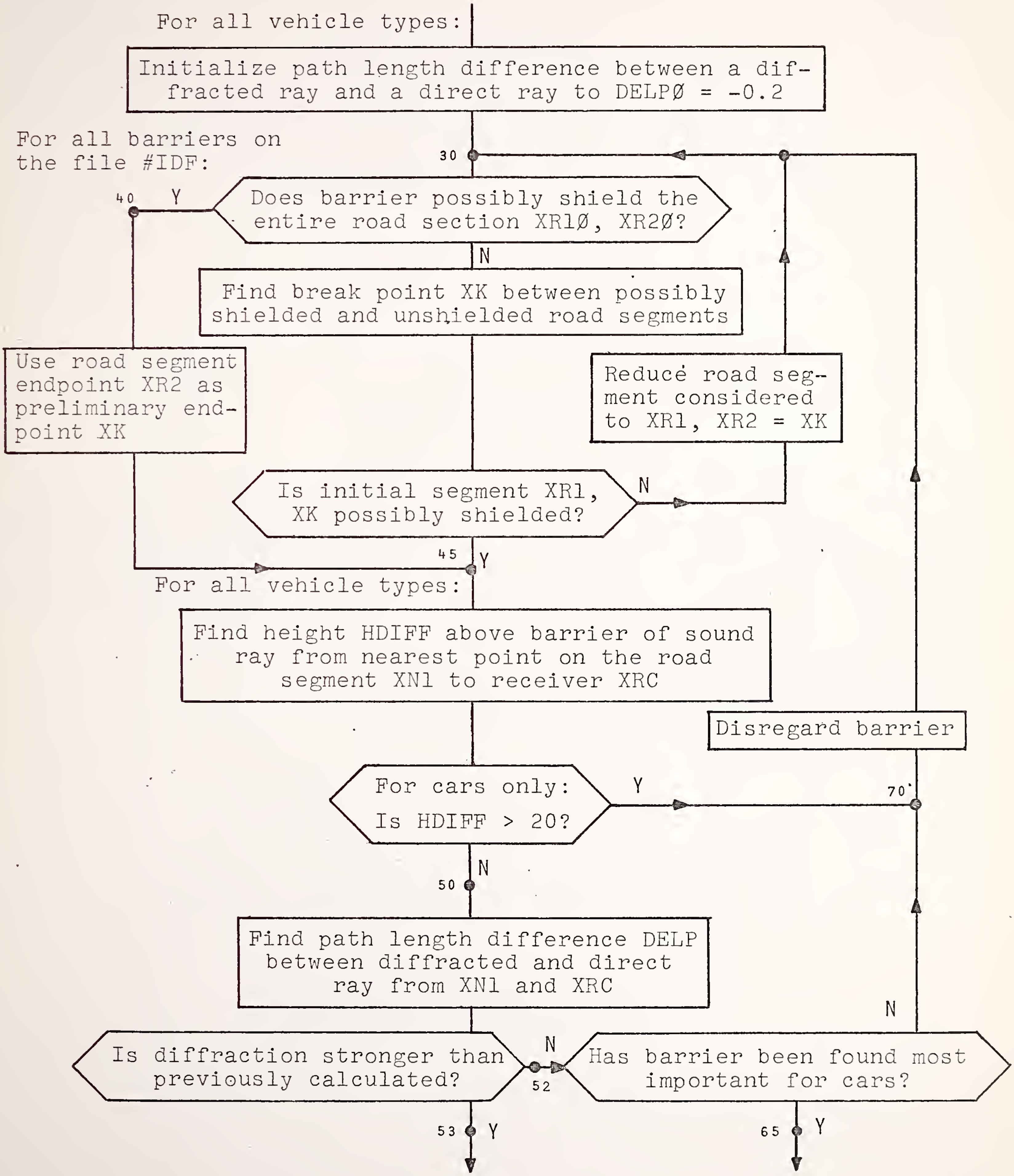


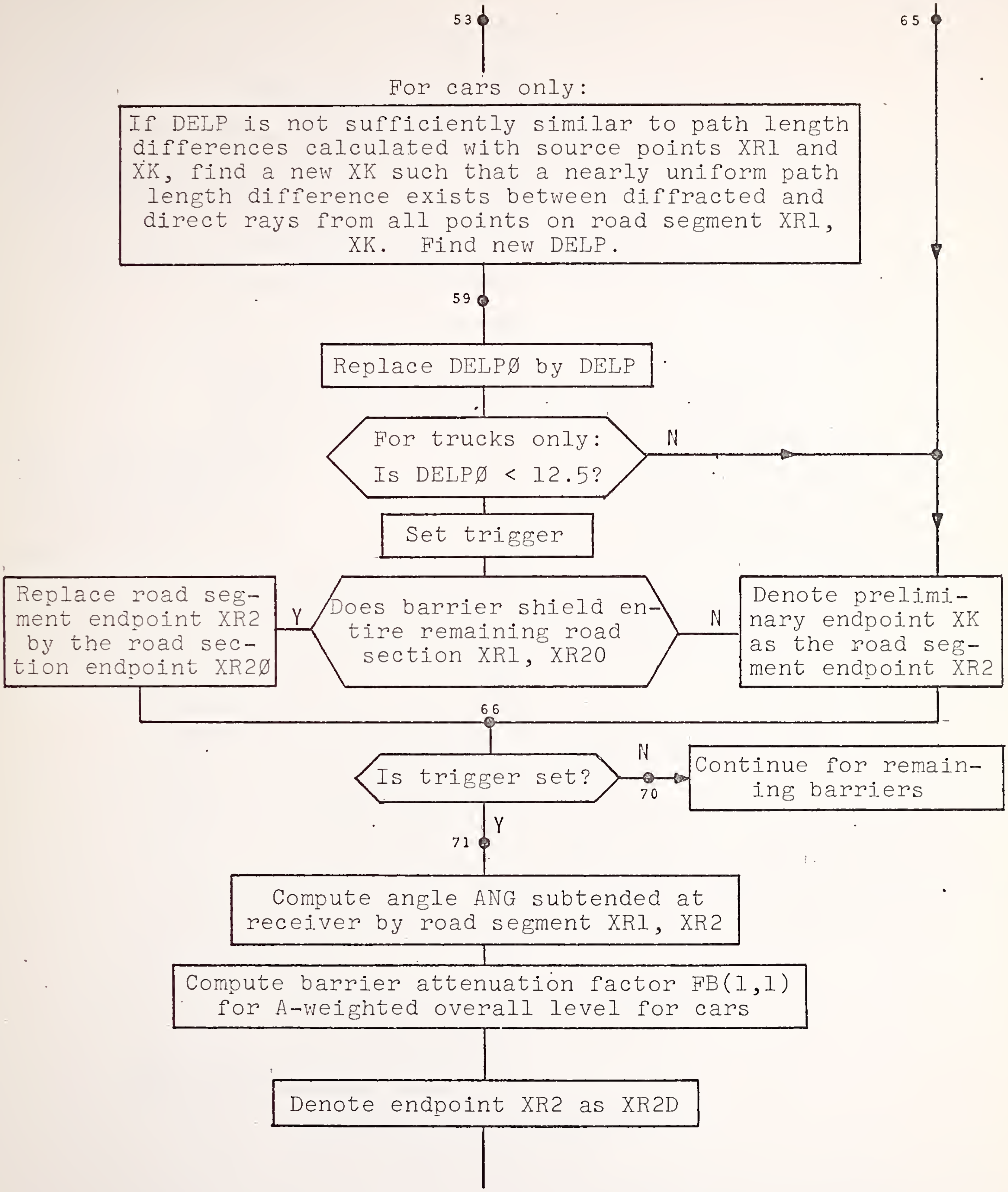
Preliminary Selection of Absorbing Ground Strips

For all ground strips on file #IGA:

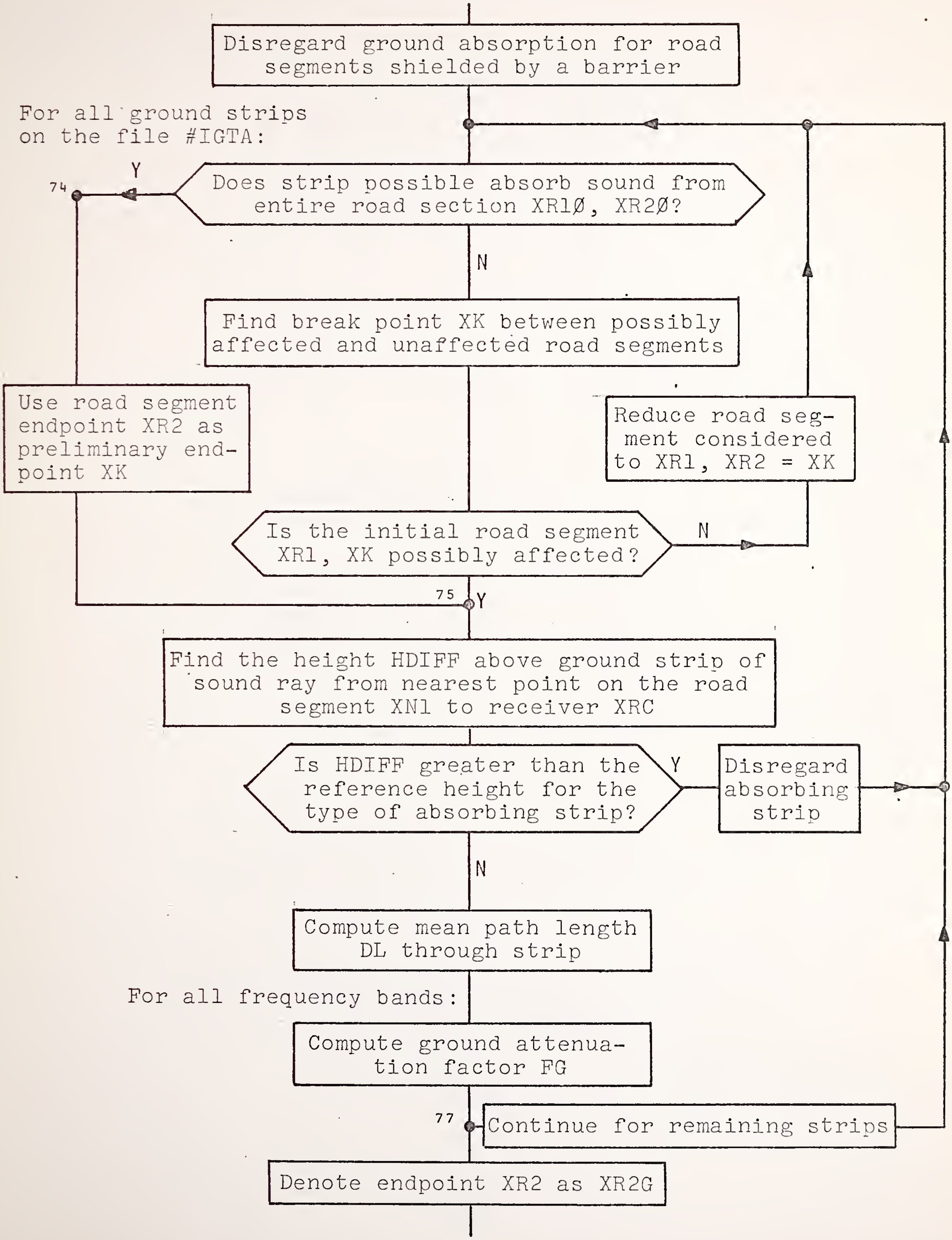


Diffraction of Direct Ray



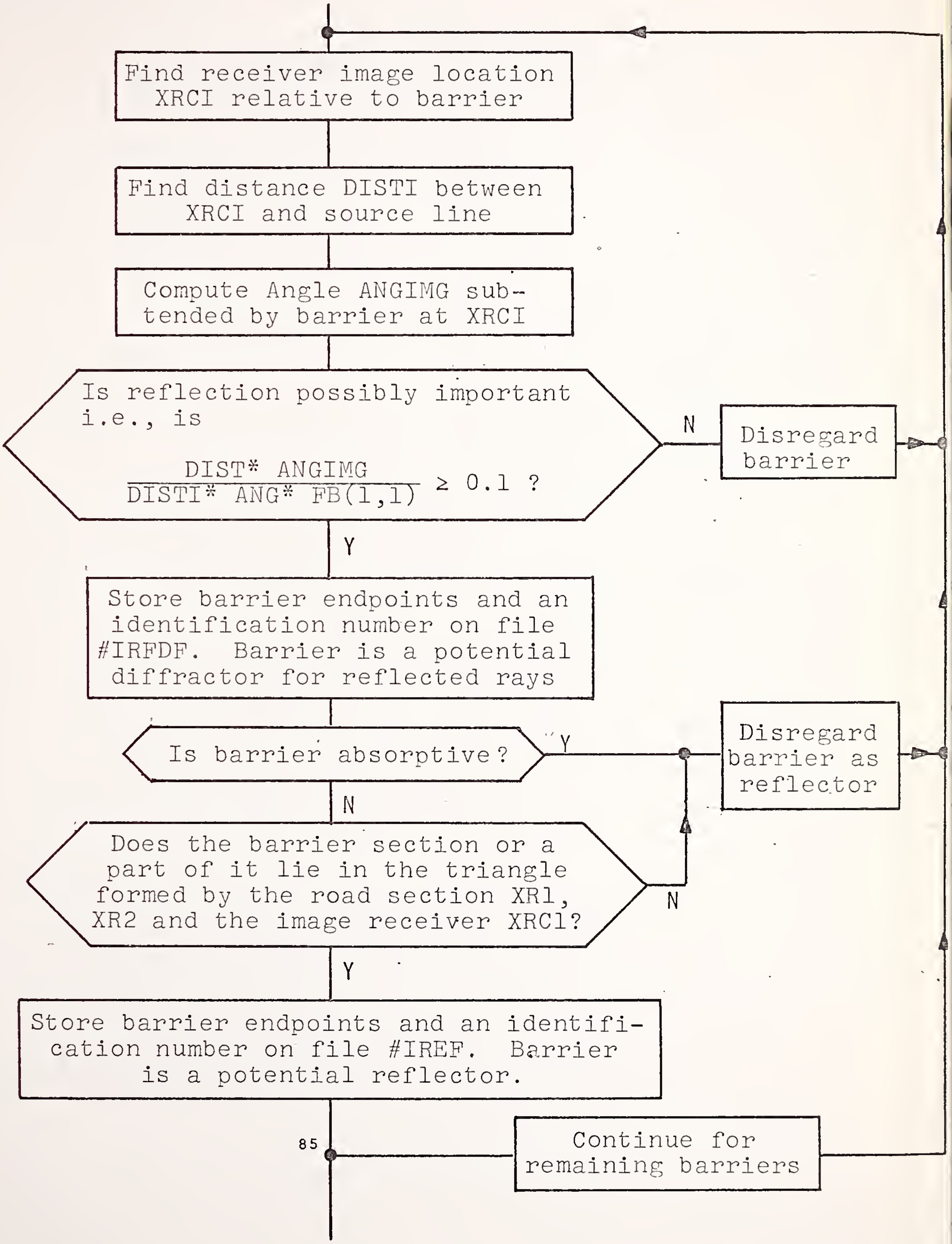

53
65
For cars only:
If DELP is not sufficiently similar to path length differences calculated with source points XR1 and XK, find a new XK such that a nearly uniform path length difference exists between diffracted and direct rays from all points on road segment XR1, XK. Find new DELP.
59
Replace DELP0 by DELP
For trucks only: Is DELP0 < 12.5?
N
Set trigger
Replace road segment endpoint XR2 by the road section endpoint XR20
Y
Does barrier shield entire remaining road section XR1, XR20
N
Denote preliminary endpoint XK as the road segment endpoint XR2
66
Is trigger set?
N
70
Continue for remaining barriers
Y
71
Compute angle ANG subtended at receiver by road segment XR1, XR2
Compute barrier attenuation factor FB(1,1) for A-weighted overall level for cars
Denote endpoint XR2 as XR2D

Ground Absorption



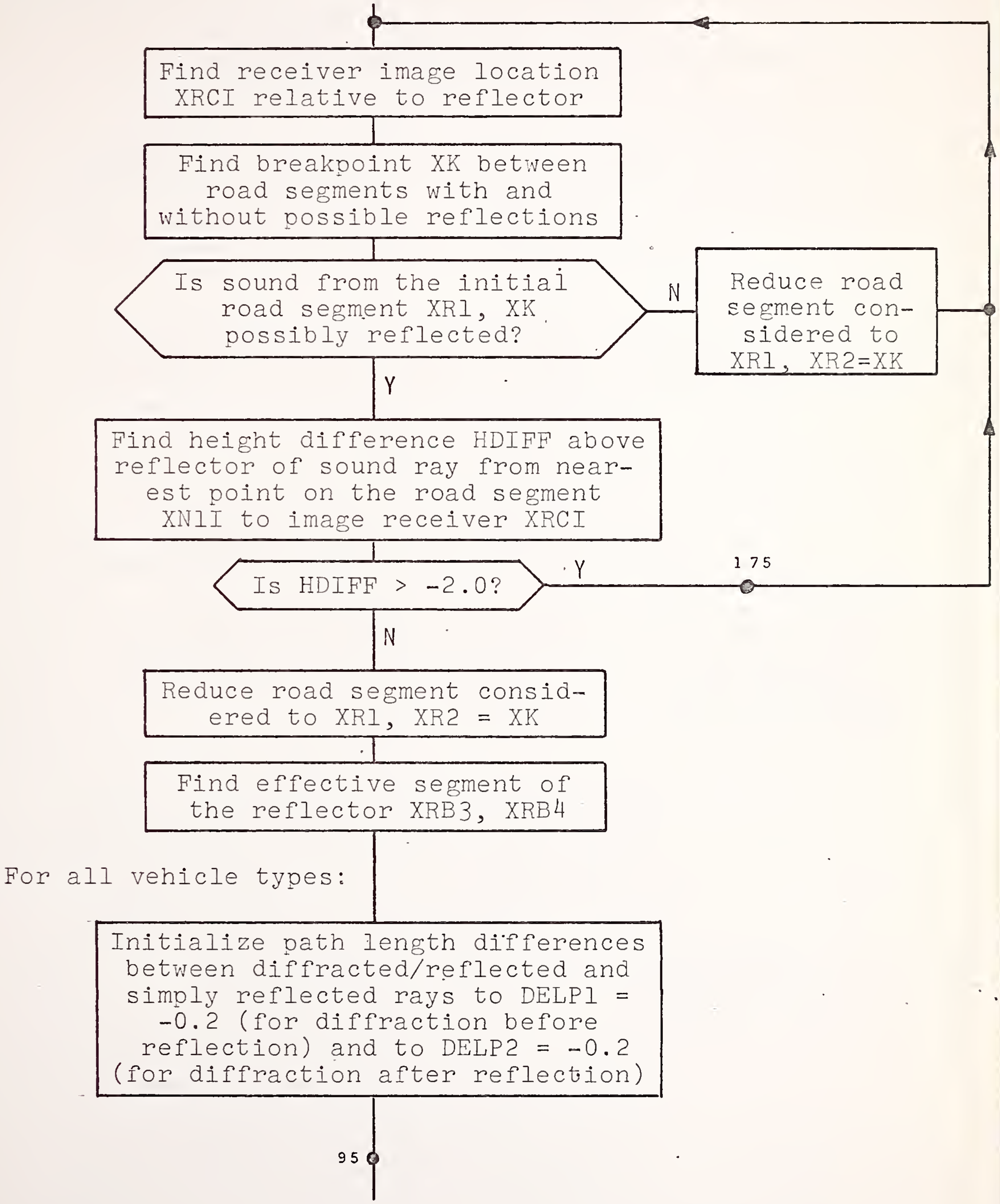
Preliminary Selection of Reflectors

For all sections of all barriers on file #IBR:

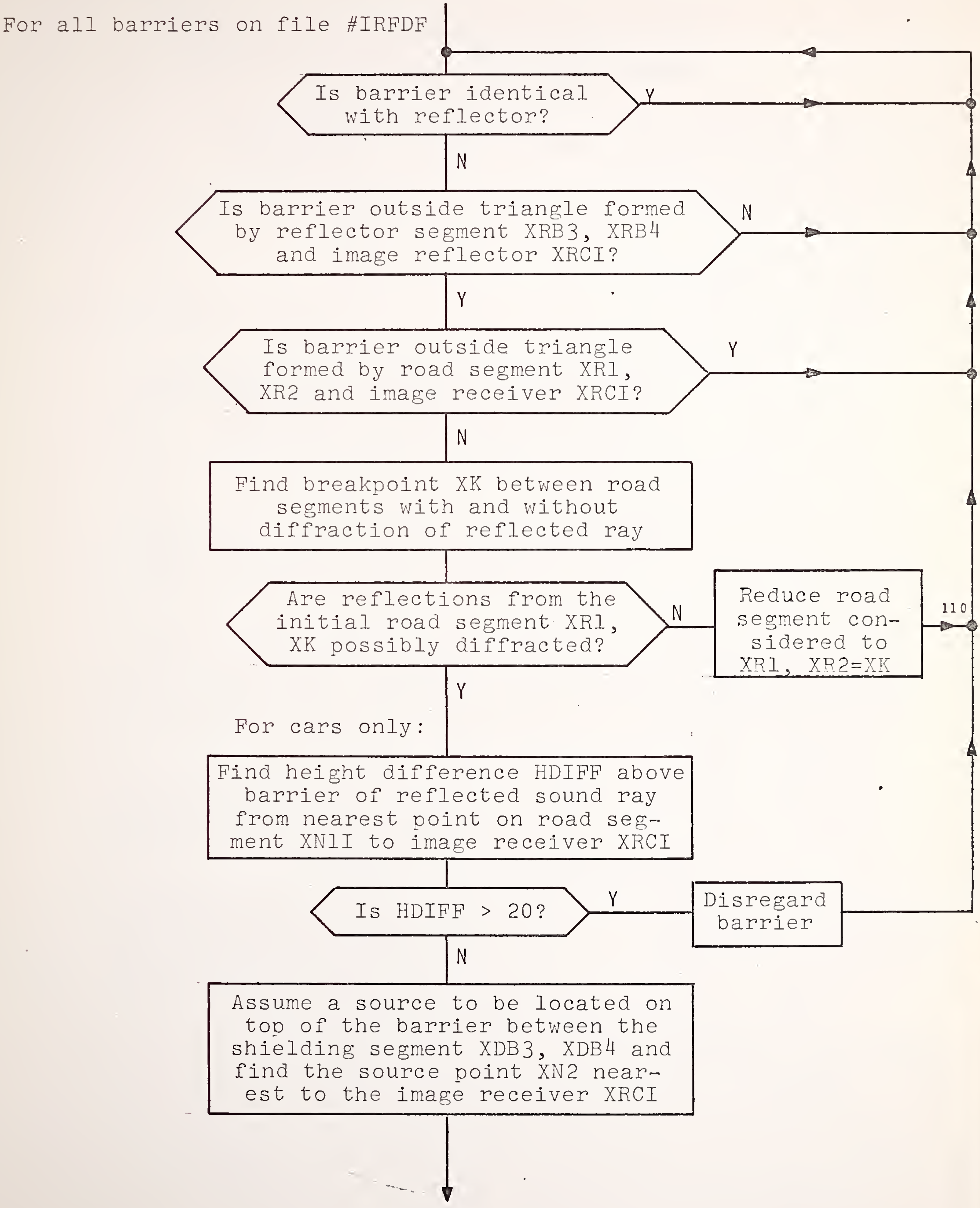


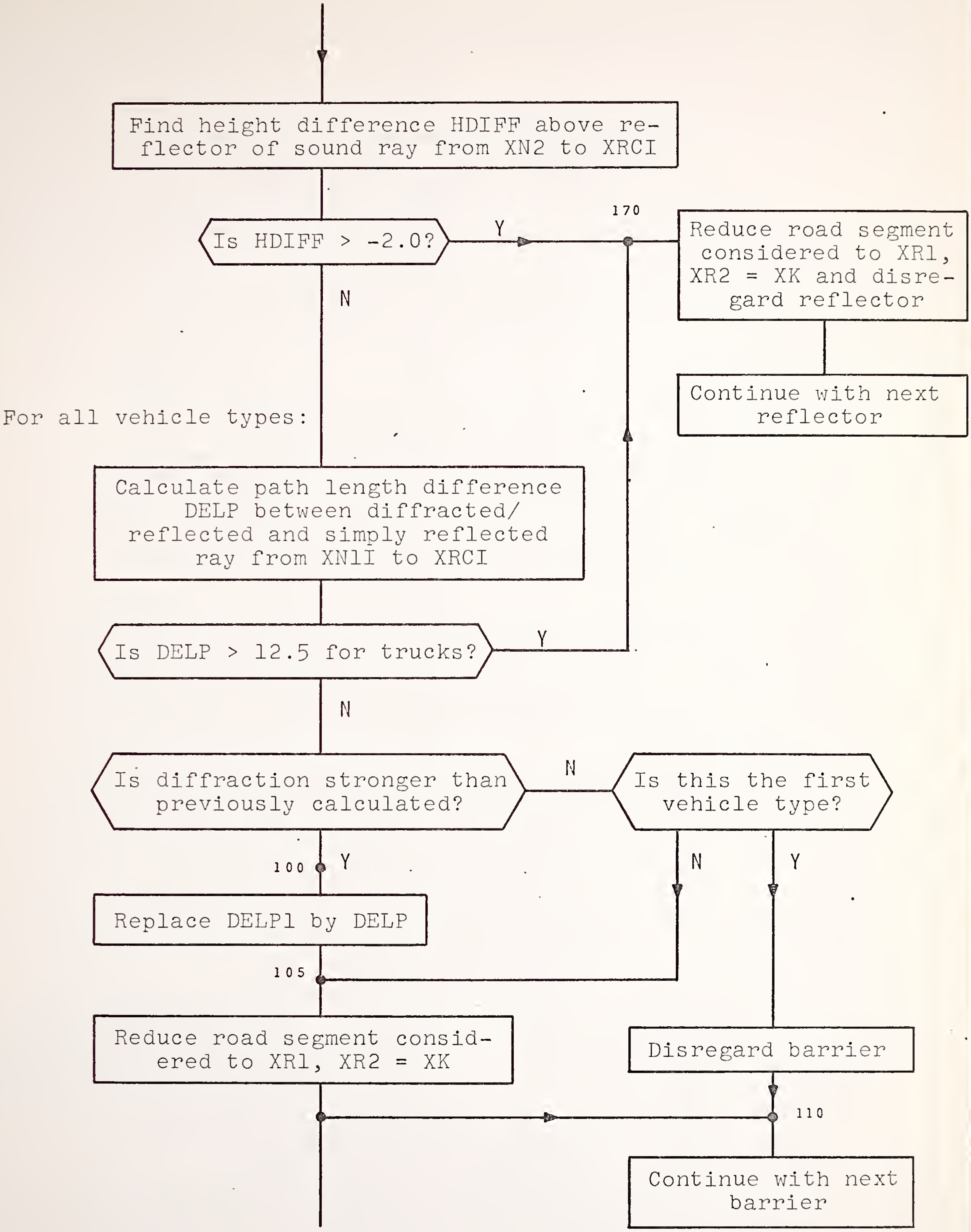
Calculation of Potential Reflections

For all reflectors on file #IREF:

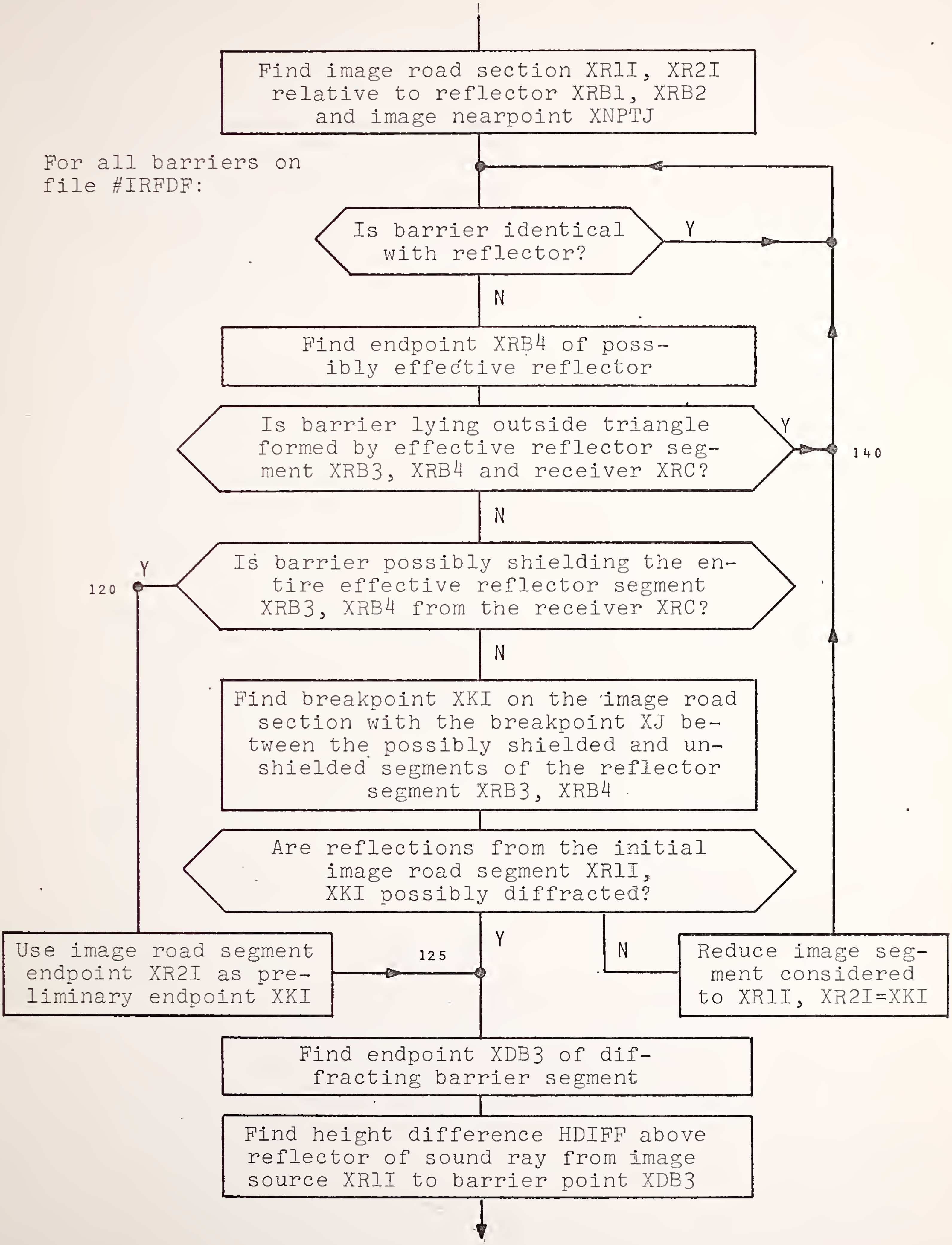


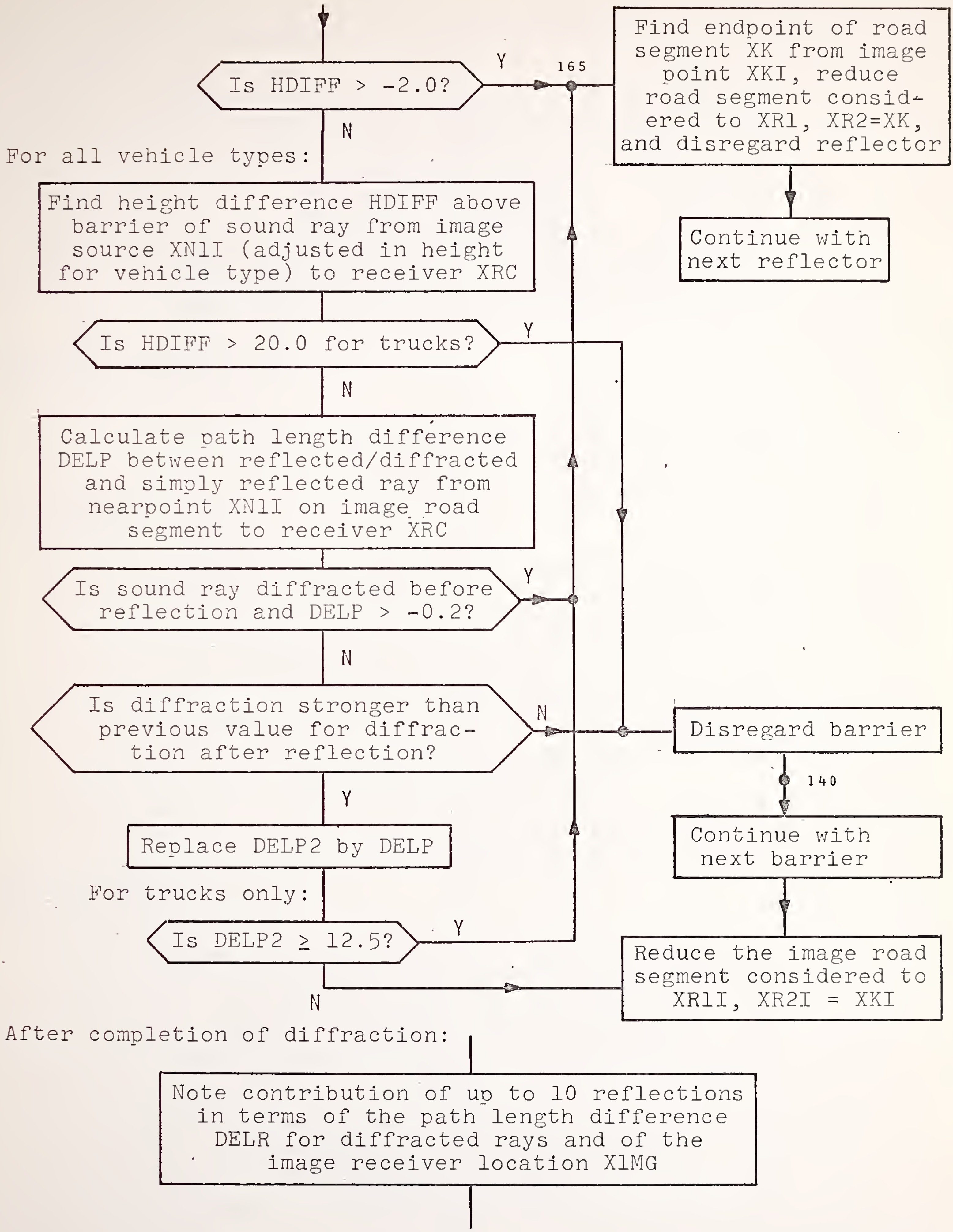
Consideration of Diffraction Before Reflection



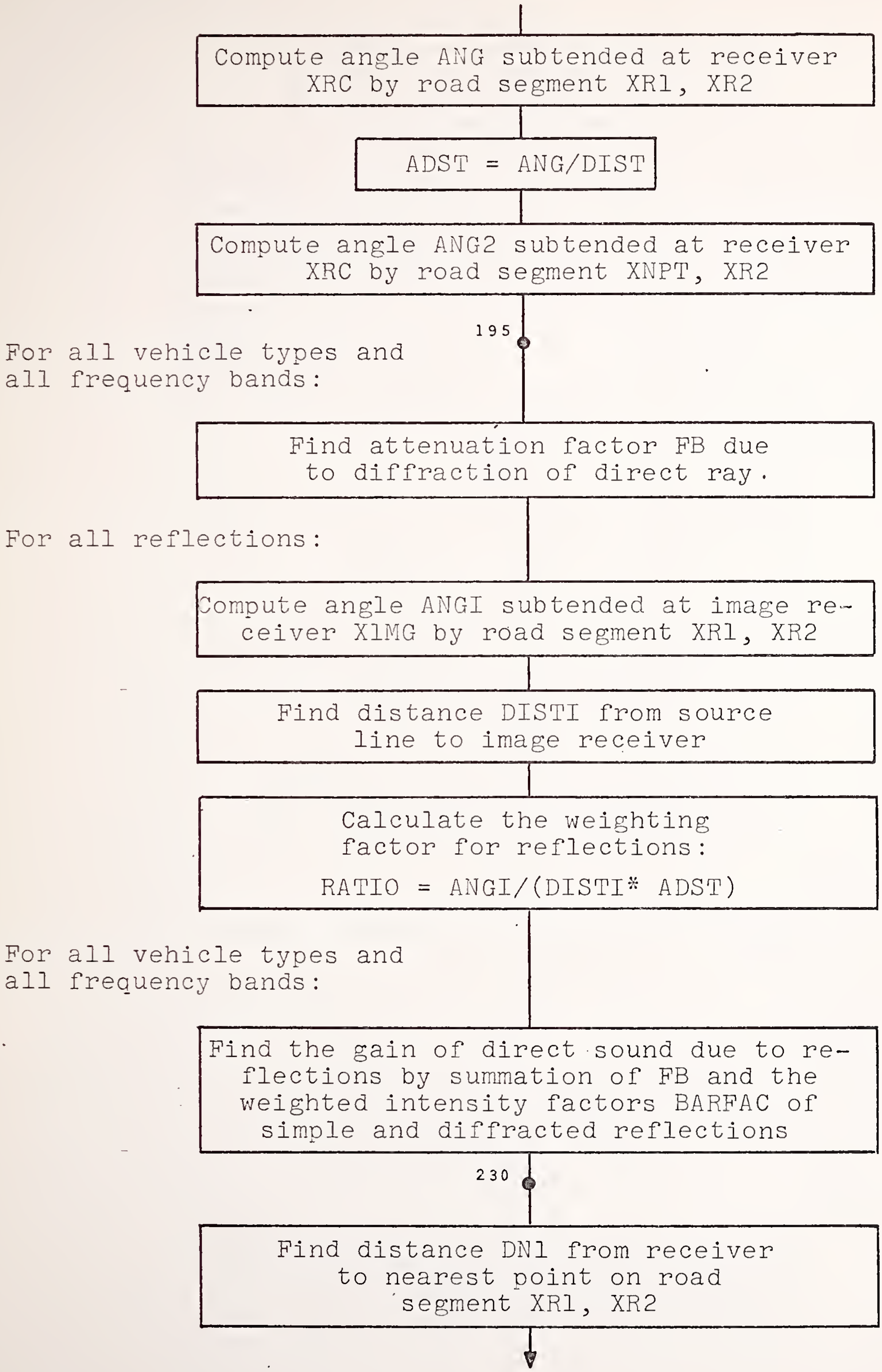

Find height difference HDIFF above reflector of sound ray from XN2 to XRCI
Is HDIFF > -2.0?
Y
170
Reduce road segment considered to XR1, XR2 = XK and disregard reflector
Continue with next reflector
N
For all vehicle types:
Calculate path length difference DELP between diffracted/ reflected and simply reflected ray from XN1I to XRCI
Is DELP > 12.5 for trucks?
Y
N
Is diffraction stronger than previously calculated?
N
Is this the first vehicle type?
100
Y
N
Y
Replace DELP1 by DELP
105
Reduce road segment considered to XR1, XR2 = XK
Disregard barrier
110
Continue with next barrier

Consideration of Diffraction After Reflection

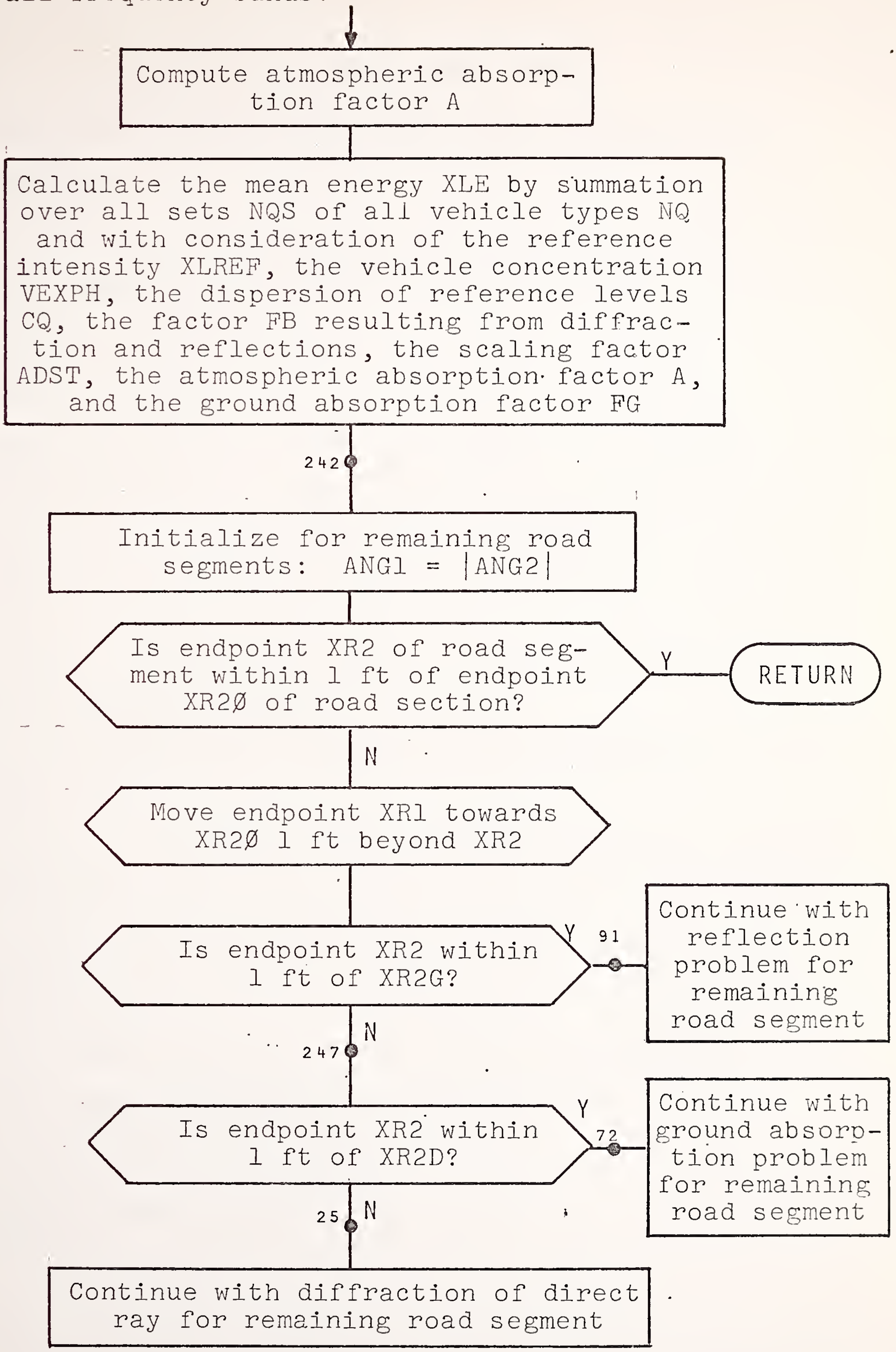



Is HDIFF > -2.0?
Y
165
Find endpoint of road segment XK from image point XKI, reduce road segment considered to XR1, XR2=XK, and disregard reflector
Continue with next reflector
N
For all vehicle types:
Find height difference HDIFF above barrier of sound ray from image source XN1I (adjusted in height for vehicle type) to receiver XRC
Is HDIFF > 20.0 for trucks?
Y
N
Calculate path length difference DELP between reflected/diffracted and simply reflected ray from nearpoint XN1I on image road segment to receiver XRC
Is sound ray diffracted before reflection and DELP > -0.2?
Y
N
Is diffraction stronger than previous value for diffraction after reflection?
N
Disregard barrier
140
Continue with next barrier
Y
Replace DELP2 by DELP
For trucks only:
Is DELP2 ≥ 12.5?
Y
Reduce the image road segment considered to XR1I, XR2I = XKI
N
After completion of diffraction:
Note contribution of up to 10 reflections in terms of the path length difference DELR for diffracted rays and of the image receiver location X1MG

Final Computations and Summation of Sound Intensities



For all frequency bands:



3.4.3 List of variables for subroutine GEOMRY

A	Atmospheric attenuation factor, ground absorption parameter
ADST	ANG/DIST
ANG	Angle subtended at receiver by road segment
ANG1	Angle α_1 in Fig. 1
ANG2	Angle α_2 in Fig. 1
ANGI	Angle subtended at image receiver by road segment
ANGIMG	Angle subtended at image receiver by barrier section
CQ	Factor accounting for standard deviation of reference level
DELM	Mean path length difference
DELP	Path length difference
DELP0	Maximum path length difference for diffraction of direct ray
DELP1	Maximum path length difference for diffraction before reflection
DELP2	Maximum path length difference for diffraction after reflection
DELPA	Path length difference for diffraction of direct ray
DELR	Path length difference for reflected ray
DELTA	Distance along the roadway
DIST	Distance from the receiver to the source line

DISTI	Distance from the image receiver to the source line
DISTJ	Distance from the image receiver to the diffracting barrier
DL	Mean path length over an absorptive ground strip
DN1	Distance from the receiver to the nearest point of the road segment
DN1I	Distance from the image receiver to the nearest point of the road segment
DN2	Distance from the image receiver to the nearest point of the diffracting barrier
DR1	Distance from the receiver to the initial point of the road segment
DRK	Distance from the receiver to the preliminary end point of the road segment
FB	Attenuation factor accounting for diffraction and reflections
FCTR	Weighting factor for reflections
FG	Ground attenuation factor
HDIFA	Height of ray from source point XR1 to receiver XRC above barrier
HDIFF	Height of ray above barrier, reflector, or ground strip
HGA	Data for effective height of ground cover
I	Index

IA	Alphanumeric "A"
IBAR	Barrier number
IBR	File device number for barriers
ICODE	Number for intermediate print out
IDF	Subfile device number for barriers
IDXR	Number of reflections
IERR	Error index
IGA	File device number for absorptive ground strips
IGRA	Ground strip number
IGTA	Subfile name for absorptive ground strips
IF	Index for frequency bands
II	Index
IK	Frequency band number
IKIND	Index for kind of absorptive ground cover
IP	Frequency band number
IQ	Index
IR	Alphanumeric "R"
IRD	File device number for roadways
IREF	File device number for reflectors
IRFDF	Subfile device number for barriers
ISEG	Barrier section number

ITRIG	Trigger
KAR	Alphanumeric indicator for type of barrier
KBAR	Total number of barrier sections; index for barriers
KBAR1	Reflector number on subfile IREF
KBAR2	Diffractor number on subfile IRFDF
KCD	Indicator for relative location of barrier
KDIFF	Barrier number on subfile IDF
KF	Index for frequency bands
KGA	Number of ground strips on file IGTA
KIMG	Reflection number
KREF	Reflector number on subfile IREF
KRFDF	Barrier number on subfile IRFDF
KTRIG	Indicator for intersection of barrier or ground strip
LOC	Indicator for relative location of barrier or ground strip
MDIFF	Indicator for diffraction before reflection
MODD	Indicator for diffraction of direct ray
NB	Number of barriers
NBSEC	Number of barrier sections
NDIFF	Number of barriers on subfile IDF
NF	Number of frequency bands
NG	Number of absorptive ground strips
NIMG	Number of reflections

NQ	Number of vehicle types
NQQ	Number of groups within one vehicle type
NQS	Vector notation for number of vehicle groups
NR	Number of roadways
NREF	Number of reflectors on subfile IREF
NRFDF	Number of barriers on subfile IRFDF .
PP	Frequency band number
RATIO	Weighting factor for reflected rays
RDIN	Vector notation for initialization parameters
T1	Temporary variable
T2	Temporary variable
VEXPH	Vehicles per foot
XB1	Initial point of barrier on subfile IDF
XB2	End point of barrier on subfile IDF
XDB1	Initial point of barrier on subfile IRFDF
XDB2	End point of barrier on subfile IRFDF
XDB3	Initial point of effective barrier segment
XDB4	End point of effective barrier segment
XG1	Initial point of center line of absorptive ground strip
XG2	End point of center line of absorptive ground strip
XG3	Initial point of effective ground strip segment
XG4	End point of effective ground strip segment

XIMG	Vector of image receivers for all reflections
XJ	Preliminary end point of effective reflector segment
XK	Preliminary end point of road segment
XKI	Preliminary end point of image road segment
XLE	Mean intensity
XLREF	Vector notation for reference intensities
XN1	Point on road segment nearest to receiver
XN1I	Point on road segment nearest to image receiver; point on image road segment nearest receiver
XN2	Point on barrier segment nearest to image receiver
XNPT	Point on source line nearest to receiver
XNPTI	Point on source line nearest to image receiver; point on image source line nearest receiver
XR	X-coordinate of receiver
XR1	Initial point of road segment
XRL0	Initial point of road section
XR1I	Initial point of image road segment
XR2	End point of road segment
XR20	End point of road section
XR2D	End point of road segment with constant attenuation by diffraction
XR2G	End point of road segment with constant attenuation by ground absorption
XR2I	End point of image road segment

XRB1	Initial point of reflector on subfile IREF
XRB2	End point of reflector on subfile IREF
XRB3	Initial point of effective reflector segment
XRB4	End point of effective reflector segment
XRC	Receiver point
XRCI	Image receiver point
YR	Y-coordinate of receiver
ZN10	Z-coordinate of XN1 or XN1I
ZR	Z-coordinate of receiver
ZS	Height adjustment for vehicles

3.5 Description of Other Subroutines and Functions

SUBROUTINE FILES

FILES defines file device numbers for the three files with roadway, barrier, and absorptive ground strip data created by the subroutine INPUT and for the four subfiles with barrier and ground strip data created by the subroutine GEOMRY.

SUBROUTINE INTER (IQ)

INTER interpolates between stored A-weighted overall and octave band reference levels to find reference intensities in frequency band numbers IQ as a function of the average speed of vehicles in a group.

FUNCTION AMAG (X1V, X2V)

AMAG is a function subroutine which calculates the distance between the points X1V and X2V.

FUNCTION ANGLE (X1V, X2V, X3V)

ANGLE is a function subroutine which calculates the angle at point X3V that is subtended by the line between X1V and X2V. The angle is positive with values between 0 and π.

FUNCTION BARFAC (KF, DELP)

BARFAC is a function subroutine which calculates the attenuation factor due to barrier diffraction as a function of the frequency band number KF and of the path length difference DELP of the diffracted ray path relative to the direct ray path.

SUBROUTINE BLOCN (X1V, X2V, X3V, X4V, X5V, X6V, LOC)

BLOCN calculates the location LOC of a barrier or a ground strip, defined by the end points X4V and X5V, relative to the triangle formed by two points X1V and X2V on a road segment and the receiver point X3V (see Fig. 12). The point X6V is identical with X2V if both points X4V and X5V are outside the triangle. If one of the points X4V or X5V is inside the triangle, X6V is the intercept of a line through X3V and X4V with the road segment X1V, X2V. If both points X4V and X5V are inside the triangle, then the point X6V is the intercept of the road segment X1V, X2V with the line through X3V and either X4V or X5V depending on which intercept is nearer to the point X1V.

LOC = 0	denotes that the line X4V, X5V is outside the triangle X1V, X2V, X3V.
LOC = 1	denotes that the line X4V, X5V intersects the line X1V, X3V.
LOC = 2	denotes that the line X4V, X5V intersects the line X2V, X3V.

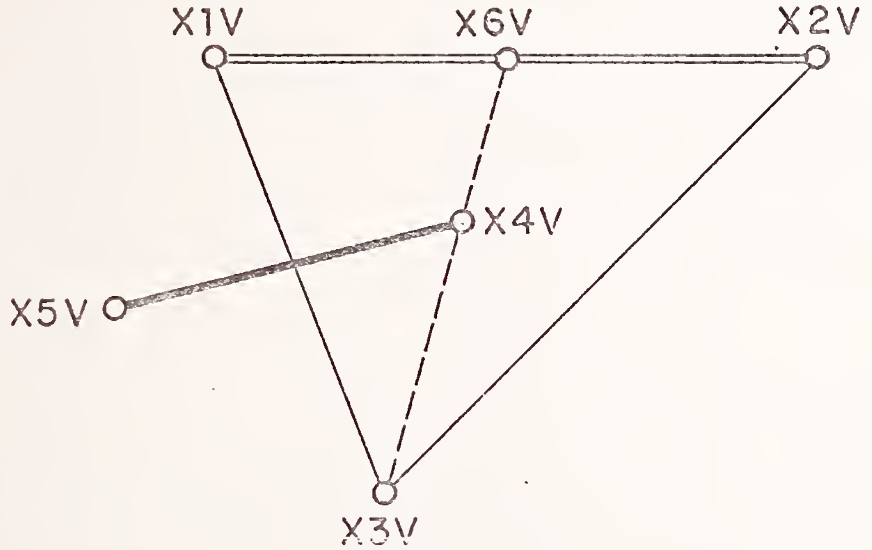


FIG.12 NOTATION FOR SUBROUTINE BLOCN

LOC = 3 denotes that the line X4V, X5V intersects both lines X1V, X3V and X2V, X3V.

LOC = 4 denotes that the line X4V, X5V is completely inside the triangle X1V, X2V, X3V.

FUNCTION DEL (X1V, X2V, X3V, X4V, HDIFF, DN1)

DEL is a function subroutine which calculates the path length difference between the ray emanating from the source point X1V and diffracted over the barrier X3V, X4V towards the receiver X2V and the direct ray from X1V to X2V. HDIFF is the height of the direct ray above the barrier, and DN1 is the path length traveled by the direct ray.

SUBROUTINE ENDPT (X1V, X2V, X3V, X4V, X5V, X6V, KTRIG, IERR)

ENDPT calculates the new end point of a road segment from which sound is uniformly attenuated during propagation towards the receiver X3V. The original road segment has the initial point X1V and the end point X2V. A barrier, reflector, or ground strip has the end points X4V, X5V. X6V is the break point on the road between segments that are affected and unaffected by the barrier, reflector, or ground strip. If the entire road segment X1V, X2V is unaffected, KTRIG = 0 and X6V is identical with X2V. If the entire road segment X1V, X2V is affected, KTRIG = 1 and X6V is identical with X2V. If a break point X6V is at a distance of less than 0.51 ft from the initial point X1V, this break point is disregarded. If the initial road segment X1V, X6V is affected by a barrier, reflector, or ground strip, KTRIG = 1, the break point X6V is moved towards X1V by 0.5 ft, and the new end point is denoted as X6V. If the initial road segment

is unaffected, KTRIG = 0, the break point X6V is moved towards X1V by 0.5 ft, and the new end point is denoted as X2V.

The error indicator IERR is set in the SUBROUTINE MOVE.

FUNCTION HEIGHT (X1V, X2V, X3V, X4V)

HEIGHT is a function subroutine which calculates the height of a ray from point X1V to point X2V above the line with the end points X3V, X4V.

FUNCTION IEPS (X1V, X2V, X3V, X4V, DEL1)

IEPS is a function subroutine which calculates whether the path length difference DEL1 is sufficiently similar to the path length difference between the ray emanating from X1V and diffracted over the barrier X3V, X4V towards the receiver X2V and the direct ray from X1V to X2V. If the two path length differences are sufficiently similar, IEPS = 1; otherwise, IEPS = 0.

SUBROUTINE IMAGE (X1V, X2V, X3V, X4V)

IMAGE calculates the location of an image receiver X4V relative to a receiver X2V and a reflector with the end points X1V, X2V.

SUBROUTINE INTCPT (X1V, X2V, X3V, X4V, X5V)

INTCPT calculates in the x-y plane the intercept X5V of two lines specified by the two pairs of points X1V, X2V and X3V, X4V.

FUNCTION KCUT (X1V, X2V, X3V, X4V)

KCUT is a function subroutine which checks whether two line segments with the end points X1V, X2V and X3V, X4V, respectively, cross in the x-y plane. If the two line segments cross, . KCUT = 1; otherwise, KCUT = 0.

FUNCTION KPOS (X1V, X2V, X3V)

KPOS is a function subroutine which checks whether the point X3V lies between two points X1V and X2V on a line. If it does, KPOS = 1; otherwise, KPOS = 0.

SUBROUTINE MIDP (X1V, X2V, X3V)

MIDP calculates the center point X3V between two points X1V and X2V.

SUBROUTINE NRPT (X1V, X2V, X3V, X4V, DIST)

NRPT calculates the point X4V, on a line specified by the points X1V, X2V, that is nearest to the point X3V. It also calculates the distance DIST between the points X3V and X4V. If the distance is zero, DIST = 1.

SUBROUTINE NR1 (X1V, X2V, X3V, X4V, DIST, X5V, DN1)

NR1 calculates the point X5V, on a line segment between the end points X1V, X2V, that is nearest to the point X3V. It also calculates the distance DN1 between the points X3V and X5V. The subroutine employs as input parameters the distance DIST between the receiver and the nearest point X4V on the entire line.

SUBROUTINE REPLCE (X1V, X2V)

REPLCE sets the vector X2V equal to the vector X1V.

SUBROUTINE SECTN (X1V, X2V, X3V, X4V, X5V, X6V, X7V)

SECTN calculates the segment X6V, X7V of the line between X4V and X5V that is bounded by the two lines from X3V to X1V and from X3V to X2V.

SUBROUTINE TRI (X1V, X2V, X3V, X4V, X5V, KTRI)

TRI determines whether or not the point X4V lies in the triangle formed by the points X1V, X2V, X3V. If X4V is in the triangle, KTRI = 1; otherwise, KTRI = 0. TRI also calculates the intercept X5V of two lines specified by the points X1V, X2V and X3V, X4V, respectively.

FUNCTION ZCOR (X1V, X2V, X3V)

ZCOR is a function subroutine which calculates the z-coordinate of the point X3V so that the point X3V lies on the line specified by the points X1V and X2V.

SUBROUTINE MOVE (X1V, X2V, X3V, DELTA, IERR)

MOVE calculates the point X2V, on the line specified by the points X1V and X2V, that is at a distance of DELTA feet from the point X1V in the direction away from X3V. MOVE gives the error message IERR = 4 if the two points X1V and X3V are identical.

FUNCTION TAN (X)

TAN is a function subroutine which calculates the tangent of X.

FUNCTION ACOS (X)

ACOS is a function subroutine which calculates the arc cos of X between 0 and π.

3.6 Computer Program Listing

```
C     TRAFFIC NOISE PREDICTION MODEL
      DIMENSION SIG(2)
      DIMENSION XR1(3),XR2(3)
      COMMON/INOU/IRD,IBR,IDF,IREF,IRFDF,IGA,IGTA
      COMMON/BLK2/NQ
      COMMON/INPT1/RDIN(15)
      COMMON/INPT2/NR,NB,NG
      COMMON/INPT3/XRC(15),YRC(15),ZRC(15),NRC
      COMMON/DRIV1/XMPH(5)
      COMMON/DRIV2/NQS(2),NF
      COMMON/DRIV3/CQ(2),VEXPH(5,2),XLE(9)
      COMMON/GEO1/IBAR,ISEG,IGRA
      INTEGER TITLE(30)
      EQUIVALENCE (RDIN(3),SIG(1))
      NQ=2
      NG=0
      NB=0
      CALL SEARCH(1,6HINPUT ,1,0)
      CALL FILES
    5 CALL SEARCH(4,6HROADS ,IRD,0)
      CALL SEARCH(4,6HBARRIR,IBR,0)
      CALL SEARCH(4,6HGRABS ,IGA,0)
      CALL SEARCH(4,6HDFFLEC,IDF,0)
      CALL SEARCH(4,6HGRTABS,IGTA,0)
      CALL SEARCH(4,6HREFLEC,IREF,0)
      CALL SEARCH(4,6HREFDFR,IRFDF,0)
      READ(4,1005) (TITLE(I),I=1,30)
      WRITE(1,2009)
      WRITE(1,1005) (TITLE(I),I=1,30)
      CALL INPUT
      NF=RDIN(2)
      WRITE(1,1002)(TITLE(I),I=1,30)
      WRITE(1,1003)
      DO 11 I=1,NQ
      CQ(I)=EXP(.5*(SIG(I)*.23026)**2)
   11 CONTINUE
      DO 60 I=1,NRC
      DO 15 J=1,NF
      XLE(J)=0.
   15 CONTINUE
      CALL SEARCH(1,6HROADS ,IRD,0)
      DO 50 M=1,NR
      DO 20 IQ=1,NQ
      CALL READ(IRD,NQQ,1,0)
      CALL READ(IRD,VEXPH( ,IQ),2*NQQ,0)
      CALL READ(IRD,XMPH(1),2*NQQ,0)
      NQS(IQ)=NQQ
      IF(NQQ.EQ.0)GO TO 20
      CALL INTER(IQ)
```

```
  20 CONTINUE
     CALL READ(IRD,NRSEC,1,0)
     CALL READ(IRD,XR1,6,0)
     DO 40 N=1,NRSEC
     CALL READ(IRD,XR2,6,0)
     CALL GEOMRY(XRC(I),YRC(I),ZRC(I),XR1,XR2,IERR)
     IF(IERR.EQ.1)GO TO 65
     IF(IERR.EQ.2)GO TO 70
     IF(IERR.EQ.3)GO TO 66
     IF(IERR.EQ.4) GO TO 60
     CALL REPLCE(XR2,XR1)
  40 CONTINUE
  50 CONTINUE
     CALL SEARCH(4,6HROADS ,IRD,0)
     DO 55 J=1,NF
     XLE(J)=34.+10.*ALOG10(XLE(J))
  55 CONTINUE
     WRITE(1,1004) I,XRC(I),YRC(I),ZRC(I)
     IF(NF.EQ.1) GO TO 56
     WRITE(1,2001)
     WRITE(1,2002) (XLE(II),II=2,NF)
56   WRITE(1,2003)
     WRITE(1,1007) XLE(1)
     IF(NF.LE.6) GO TO 60
     XLA=0.0
     DO 59 J=2,NF
     XLA=XLA+10.0**(XLE(J)/10.)
59   CONTINUE
     XLA=10.0*ALOG10(XLA)
     WRITE(1,2004)
     WRITE(1,1007) XLA
  60 CONTINUE
     GO TO 5
  65 WRITE(1,1006)I,M,N,IBAR,ISEG
     GO TO 5
  66 WRITE(1,1009)I,M,N
     GO TO 5
  70 WRITE(1,1008)I,M,N,IGRA
     GO TO 5
 1002 FORMAT(//30A2)
 1003 FORMAT(10HRECEIVER # 0X,3HXRC9X,3HYRC9X,3HZRC)
 1004 FORMAT(4X,I3,5X,3F12. )
 1005 FORMAT(30A2)
 1006 FORMAT(43HILLEGAL BARRIER INTERSECTS ROADWAY FOR REC#I2,2X,2HR#I2
    1,3HRS#I2,2X,2HB#I2,2X,3HBS#I2)
 1008 FORMAT(48HILLEGAL GROUND STRIP INTERSECTS ROADWAY FOR REC#I2,2X,2
    1HR#I2,3HRS#I2,2X,4HAGS#I2)
 1009 FORMAT(25HTOO MANY REFLECTIONS,RCV#,I2,4H  R#,I2,4H  S#,I2)
2001  FORMAT(/14X,2H635X,3H 254X,3H2504X,3H5003X,4H10003X,4H20003X,
    X 4H40003X,4H8000)
```

```
2002  FORMAT(10X,8F7.1)
2003  FORMAT(12X,6HA(500))
2007  FORMAT(10X,F7.1)
2004  FORMAT(14X,1HA)
2009  FORMAT(///15X,24HTRAFFIC NOISE PREDICTION//)
      END
$1
      SUBROUTINE FILES
      COMMON/INOU/IRD,IBR,IDF,IREF,IRFDF,IGA,IGTA
      IRD=2
      IBR=3
      IDF=4
      IREF=5
      IRFDF=6
      IGA=7
      IGTA=8
      RETURN
      END
$1
      SUBROUTINE INPUT
      INTEGER ALPHA(30)
      DIMENSION NQS(2),VEXPH(5,2),XMPH(5,2),
     1 X(11),Y(11),Z(11)
      COMMON/INOU/IRD,IBR,IDF,IREF,IRFDF,IGA,IGTA
      COMMON/BLK2/NQ
      COMMON/INPT1/FDIN(15)
      COMMON/INPT2/NR.NB,NG
      COMMON/INPT3/XRC(15),YRC(15).ZRC(15),NRC
      EQUIVALENCE (FDIN(1),XNIGHT)
      DATA   IA/2HA /
      DATA   IG/2HG /
      DATA   IR/2HR /
      DATA   IT/2HT /
      DATA LAST/2HL /
    5 READ(4,1000)IGO,I1,I2
      GO TO(10,20,30,36,40,50),IGO
C GARBAGE DATA....PROGRAM INITIALIZATION PARAMETERS
   10 WRITE(1,2003)
   11 READ(4,1001)VALUE,IDN,ILAST,(ALPHA(I),I=1,30)
      FDIN(IDN)=VALUE
      WRITE(1,2001)VALUE,IDN,(ALPHA(I),I=1,30)
      IF(ILAST.NE.LAST)GO TO 11
      GO TO 5
C
C
C VEHICLE DATA
```

```
C
  20 NR=I1
     CALL SEARCH(2,6HROADS .IRD,0)
     DO 28 J=1,NR
     NSEC=1
     DO 21 K=1,NQ
  21 NQS(K)=0
  22 READ(4,1002) VEH,XMH,ITY,ILAST
     NQS(ITY)=NQS(ITY)+1
     NQC=NQS(ITY)
     VEXPH(NQC,ITY)=VEH/XMH/5280.
     XMPH(NQC,ITY)=XMH
     IF(ILAST.NE.LAST)GO TO 22
     DO 23 K=1,NQ
     NQC=NQS(K)
     CALL WRITE(IRD,NQC,1,0)
     CALL WRITE(IRD,VEXPH( ,K),2*NQC,0)
     CALL WRITE(IRD,XMPH( ,K),2*NQC,0)
  23 CONTINUE
C ROADWAY DATA SECTIONS
  24 READ(4,1003)X(NSEC),Y(NSEC),Z(NSEC),ILAST
     IF(ILAST.EQ.LAST)GO TO 25
     NSEC=NSEC+1
     GO TO 24
  25 IF(NSEC-1.NE.0)GO TO 26
     WRITE(1,2000)
     CALL EXIT
  26 NSM1=NSEC-1
     CALL WRITE(IRD,NSM1, ,0)
     CALL WRITE(IRD,X(1),2,0)
     CALL WRITE(IRD,Y(1),2,0)
     CALL WRITE(IRD,Z(1),2,0)
     DO 27 I=2,NSEC
     CALL WRITE(IRD,X(I),2,0)
     CALL WRITE(IRD,Y(I),2,0)
     CALL WRITE(IRD,Z(I),2,0)
  27 CONTINUE
  28 CONTINUE
     CALL SEARCH(4,6HROADS ,IRD,0)
     GO TO 5
C BARRIER DATA SECTIONS
  30 NB=I1
     IF(NB.EQ.0)GO TO 5
     CALL SEARCH(2,6HBARRIR,IBR,0)
     DO 35 J=1,NB
     NSEC=1
  31 READ(4,1003)X(NSEC),Y(NSEC),Z(NSEC),ILAST
     IF(ILAST.EQ.IA.OR.ILAST.EQ.IR)GO TO 32
     NSEC=NSEC+1
     GO TO 31
```

```
   32 IF(NSEC-1.NE.0)GO TO 33
      WRITE(1,2001)
      CALL EXIT
   33 NSM1=NSEC-1
      CALL WRITE(IBR,NSM1,1,0)
      CALL WRITE(IBR,ILAST,1,0)
      CALL WRITE(IBR,X(1),2,0)
      CALL WRITE(IBR,Y(1),2,0)
      CALL WRITE(IBR,Z(1),2,0)
      DO 34 I=2,NSEC
      CALL WRITE(IBR,X(I),2,0)
      CALL WRITE(IBR,Y(I),2,0)
      CALL WRITE(IBR,Z(I),2,0)
   34 CONTINUE
   35 CONTINUE
      CALL SEARCH(4,6HBARRIR,IBR,0)
      GO TO 5
C ABSORBING GROUND STRIPS
   36 NG=I1
      IF(NG.EQ.0)GO TO 5
      CALL SEARCH(2,6HGRABS ,IGA,0)
      DO 37 I=1,NG
      READ(4,1004)XG1,YG1,ZG1,BG
      CALL WRITE(IGA,XG1,2,0)
      CALL WRITE(IGA,YG1,2,0)
      CALL WRITE(IGA,ZG1,2,0)
      CALL WRITE(IGA,BG,2,0)
      READ(4,1003)XG1,YG1,ZG1,IDUM
      IF(IDUM.EQ.IG)IDUM=1
      IF(IDUM.EQ.IT)IDUM=2
      CALL WRITE(IGA,XG1,2,0)
      CALL WRITE(IGA,YG1,2,0)
      CALL WRITE(IGA,ZG1,2,0)
      CALL WRITE(IGA,IDUM,1,0)
   37 CONTINUE
      CALL SEARCH(4,6HGRABS ,IGA,0)
      GO TO 5
C RECEIVER DATA
   40 NRC=I1
      DO 41 I=1,NRC
      READ(4,1003)XRC(I),YRC(I),ZRC(I),IDUM
      ZRC(I)=ZRC(I)+10.0
   41 CONTINUE
      GO TO 5
50    CALL SEARCH(1,6HROADS ,IRD,0)
      DO 65 J=1,NR
      WRITE(1,2002)J
      DO 55 K=1,NQ
      CALL READ(IRD,NQC,1,0)
      CALL READ(IRD,VFXPH(1,K),2*NQC,0)
      CALL READ(IRD,XMPH(1,K),2*NQC,0)
      IF(NQC.EQ.0)GO TO 55
      DO 54 I=1,NQC
```

```
54 VEXPH(I,K)=VEXPH(I,K)*XMPH(I,K)*5280.
   WRITE(1,2004)K,(I,VEXPH(I,K),XMPH(I,K),I=1,NQC)
55 CONTINUE
   CALL READ(IRD,NSEC,1,0)
   CALL READ(IRD,XT,2,0)
   CALL READ(IRD,YT,2,0)
   CALL READ(IRD,ZT,2.0)
   WRITE(1,2003)
   WRITE(1,2005)XT,YT,ZT
   NSEC=NSEC+1
   DO 60 I=2.NSEC
   CALL READ(IRD,XT,2,0)
   CALL READ(IRD,YT,2.0)
   CALL READ(IRD,ZT,2,0)
   WRITE(1,2006)I,XT,YT,ZT
60 CONTINUE
65 CONTINUE
   CALL SEARCH(4,6HROADS ,IRD,0)
   IF(NB.EQ.0)GO TO 80
   CALL SEARCH(1,6HBARRIR,IBR,0)
   DO 75 J=1,NB
   CALL READ(IBR,NSEC,1,0)
   CALL READ(IBR,ILAST,1,0)
   CALL READ(IBR,XT,2,0)
   CALL READ(IBR,YT,2.0)
   CALL READ(IBR,ZT.2.0)
   WRITE(1,2007)J,ILAST
   WRITE(1.2005)XT,YT,ZT
   NSEC=NSEC+1
   DO 70 I=2,NSEC
   CALL READ(IBR,XT,2,0)
   CALL READ(IBR,YT,2,0)
   CALL READ(IBR,ZT,2,0)
   WRITE(1,2006)I,XT,YT,ZT
70 CONTINUE
75 CONTINUE
   CALL SEARCH(4,6HBARRIR,IBR,0)
80 IF(NG.EQ.0) GO TO 90
   CALL SEARCH(1,6HGRABS ,IGA,0)
   DO 85 I=1,NG
   CALL READ(IGA,XG1,2,0)
   CALL READ(IGA,YG1,2,0)
   CALL READ(IGA,ZG1,2,0)
   CALL READ(IGA,BG,2,0)
   CALL READ(IGA,XT,2,0)
   CALL READ(IGA,YT,2,0)
   CALL READ(IGA,ZT,2,0)
   CALL READ(IGA,IDUM,1,0)
   IF(IDUM.EQ.1)IDUM=IG
   IF(IDUM.EQ.2)IDUM=IT
   WRITE(1,2002)I,IDUM,XG1,YG1,ZG1,BG,XT,YT,ZT
```

```
  85 CONTINUE
     CALL SEARCH(4,6HGRABS ,IGA,0)
  90 WRITE(1,2008)
     DO 95 I=1,NRC
     WRITE(1.2006)I,XRC(I),YRC(I),ZRC(I)
  95 CONTINUE
     RETURN
1000 FORMAT(3I5)
1001 FORMAT(E10.0,I5,4X,A1,10X,30A2)
1002 FORMAT(2E10.0,I5,5X,A )
1003 FORMAT(3E10.0,A1)
1004 FORMAT(4E10.0)
2000 FORMAT(33HPROGRAM INITIALIZATION PARAMETERS)
2001 FORMAT(1X,E12.5,I10,5X,30A2)
2002  FORMAT(/9HROADWAY #,I3)
2004 FORMAT(9HNUMBER OF13X,5HVEH/H8X,3HMPH/5H TYPE,I2,4H VEH/(3X,I2
    1,15X,2E13.4))
2005 FORMAT(5HNUMBER5X,1HX12X,1HY12X,1HZ/4X,1H1,2X,3E13.4)
2006 FORMAT(3X,I2,2X,3E13.4)
2007 FORMAT(/9HBARRIER #I3,2X,1H(A1,1H)10X,19HBARRIER COORD IN FT)
2008 FORMAT(/8HRECEIVER14X,20HRECEIVER COORD IN FT/7H NUMBER5X,1HX12X,1
    1HY12X,1HZ)
2010 FORMAT(26HINSUFFICIENT ROAD SECTIONS)
2011 FORMAT(29HINSUFFICIENT BARRIER SECTIONS)
2012 FORMAT(17HABSORBING STRIP #I3,2X,1H(A1,1H)//5H PT #7X,1HX12X,1HY1
    A2X,1HZ12X,5HWIDTH/4X,1H12X,4E13.4/4X,1H22X,3E13.4)
2013  FORMAT(22X,18HSOURCE COORD IN FT)
     END
51
     SUBROUTINE GEOMRY(XR,YR,ZR,XR10,XR20,IERR)
     DIMENSION XG1(3),XG2(3),XG3(3),XG4(3)
     DIMENSION
    D DELP0(2),DELP1(2),DELP2(2),FB(9,2),DELR(2,10),FG(9),HGA(2),
    X XB1(3),XB2(3),XDB1(3),XDB2(3),XDB3(3),XDB4(3),
    X XRB1(3),XRB2(3),XRB3(3),XRB4(3),XRC(3),XRCI(3),
    X XR1(3),XR2(3),XR1I(3),XR2I(3),XR10(3),XR20(3),
    X XK(3),XKI(3),XJ(3),XNPT(3),XNPTI(3),XNPTJ(3),
    X XN1(3),XN2(3),XN1I(3),XIMG(3,10),XR2D(3),XR2G(3),
    Z ZS(2)
     COMMON/INOU/IRD,IBR,IDF,IREF,IRFDF,IGA,IGTA
     COMMON/BLK2/NQ
     COMMON/INPT1/RDIN(15)
     COMMON/INPT2/NR,NB,NG
     COMMON/DRIV2/NOS(2),NF
     COMMON/DRIV3/CQ(2),VEXPH(5,2),XLE(9)
     COMMON/GEO1/IBAR,ISEG,IGRA
     COMMON/INTER1/XLREF(5,9,2)
     EQUIVALENCE (RDIN(5),ZS(1))
     DATA   IA/2HA /
     DATA   IR/2HR /
```

```
      DATA HGA(1),HGA(2)/10.,30./
      XRC(1)=XR
      XRC(2)=YR
      XRC(3)=ZR
      IERR=0
      CALL NRPT(XR10,XR20,XRC,XNPT,DIST)
      ANG1=ANGLE(XR10,XNPT,XRC)
C     ICODE=1
C     WRITE(1,1000)ICODE,XR10,XR20,XRC,XNPT
C PRELIMINARY SELECTION OF BARRIERS
      NDIFF=0
      IF(NB.EQ.0) GO TO 16
      CALL SEARCH(1,6HBARRIR,IBR,0)
      CALL SEARCH(2,6HDEFLEC,IDF,0)
      KBAR=0
      DO 15 IBAR=1,NB
      CALL READ(IBR,NBSEC, ,0)
      CALL READ(IBR,KAR,1,0)
      CALL READ(IBR,XB1,6,0)
      DO 15 ISEG=1,NBSEC
      CALL READ(IBR,XB2,6,0)
      KBAR=KBAR+1
C     ICODE=2
C     WRITE(1,1001)ICODE,KBAR,XB1,XB2
      IF(KCUT(XR10,XR20,XB1,XB2).NE.1)GO TO 10
      IERR=1
      RETURN
   10 CALL BLOCN(XR10,XR20,XRC,XB1,XB2,XK,LOC)
      IF(LOC.EQ.1)GO TO 11
      NDIFF=NDIFF+1
      CALL WRITE(IDF,KBAR, ,0)
      CALL WRITE(IDF,LOC,1,0)
      CALL WRITE(IDF,XB1,6,0)
      CALL WRITE(IDF,XB2,6,0)
   11 CALL REPLCL(XB2,XB1)
   15 CONTINUE
      CALL SEARCH(4,6HBARRIR,IBR,0)
      CALL SEARCH(4,6HDEFLEC,IDF,0)
C PRELIMINARY SELECTION OF STRIPS
   16 KGA=0
      IF(NG.EQ.0)GO TO 20
      CALL SEARCH(1,6HGRABS ,IGA,0)
      CALL SEARCH(2,6HGRTABS,IGTA,0)
      DO 18 IGRA=1,NG
      CALL READ(IGA,XG1,6,0)
      CALL READ(IGA,BG,2,0)
      CALL READ(IGA,XG2,6,0)
      CALL READ(IGA,IKIND, ,0)
C     ICODE=3
```

```
C     WRITE(1,1001)ICODE,IGRA,XG1,XG2
      IF(KCUT(XR10,XR20,XG ,XG2).NE.1)GO TO 17
      IERR=2
      RETURN
   17 CALL BLOCN(XR10,XR20,XRC,XG1,XG2,XK,LOC)
      IF(LOC.EQ.0)GO TO 18
      KGA=KGA+1
      CALL WRITE(IGTA,LOC, ,0)
      CALL WRITE(IGTA,XG1,6,0)
      CALL WRITE(IGTA,XG2,6,0)
      CALL WRITE(IGTA,BG,2,0)
      CALL WRITE(IGTA,IKIND,1,0)
   18 CONTINUE
      CALL SEARCH(4,6HGRABS ,IGA,0)
      CALL SEARCH(4,6HGRTABS,IGTA,0)
C DIFFRACTION OF DIRECT RAY
   20 CALL REPLCE(XR10,XR1)
   25 CALL REPLCE(XR20,XR2)
      DO 30 IQ=1,NQ
      DELP0(IQ)=-.2
   30 CONTINUE
C     ICODE=4
C     WRITE(1,1002)ICODE,XR1,XR2
      IF(NDIFF.EQ.0)GO TO 71
      CALL SEARCH(1,6HDEFLEC,IDF,0)
      KTRIG=0
      DO 70 KDIFF=1,NDIFF
      CALL READ(IDF,KBAR,1,0)
      CALL READ(IDF,KCD,1,0)
      CALL READ(IDF,XB1,6,0)
      CALL READ(IDF,XB2,6,0)
C     ICODE=5
C     WRITE(1,1001)ICODE,KBAR,XR1,XR2,XB1,XB2
      IF(KCD.EQ.3)GO TO 40
      CALL ENDPT(XR1,XR2,XRC,XB1,XB2,XK,KTRIG,IERR)
      IF(IERR.EQ.4) RETURN
      IF(KTRIG.EQ.0)GO TO 70
      GO TO 45
   40 CALL REPLCE(XB2,XK)
   45 MODD=0
C     ICODE=6
C     WRITE(1,1001)ICODE,KCD,XR2,XK
      DO 60 IQ=1,NQ
      CALL NR1(XR1,XK,XRC,XNPT,DIST,XN1,DN1)
      ZN10=XN1(3)
      XN1(3)=ZN10+ZS(IQ)
      HDIFF=HEIGHT(XN1,XRC,XB1,XB2)
      IF(IQ.NE.1)GO TO 50
      IF(HDIFF.GT.20.)GO TO 70
   50 DELP=DEL(XN1,XRC,XB1,XB2,HDIFF,DN1)
      IF(DELP.GT.DELP0(IQ))GO TO 53
```

```
   52 IF(MODD.EQ.1)GO TO 65
      GO TO 70
   53 IF (IQ.NE.1) GO TO 59
      DR1 = AMAG(XRC,XR1)
      IF (ABS(DR -DN1).LT.1.) GO TO 54
      HDIFA = HEIGHT (XR1,XRC,XB1,XB2)
      DELPA = DEL (XR1,XRC,XB1,XB2,HDIFA,DR1)
      DELM= (DELPA + DELP)/2.
C     ICODE=107
C     WRITE(1,1002)ICODE,DELP,DELPA
      IF((ABS(DELPA-DELP)-0.1-DELM/50.*(1.+DELM)).LT.0.) GO TO 55
      CALL MIDP (XR1,XN1,XK)
C     ICODE=7
C     WRITE(1,1002)ICODE.XR ,XN1,XK
      DELP = DELPA
   54 IF (IEPS(XK,XRC,XB1,XB2,DELP).EQ.0) GO TO 58
      CALL MIDP (XR1,XK,XK)
C     ICODE=8
C     WRITE(1,1002)ICODE,XR ,XK
      GO TO 54
   55 DRK= AMAG (XRC,XK)
      IF (ABS(DRK-DN1).LT. .) GO TO 58
   56 IF(IEPS (XK,XRC,XB1,XB2,DELP).EQ.0) GO TO 58
      CALL MIDP(XN1,XK,XK)
      GO TO 56
   58 IF (DELP.LE,DELP0(1)) GO TO 52
   59 DELP0 (IQ) = DELP
C     ICODE=10
C     WRITE(1,1002)ICODE,DELP0(1),DELP0(2)
      MODD=1
   60 CONTINUE
      IF(DELP0(2).LT.12.5)GO TO 65
      ITRIG=1
      IF(KCD.NE.3.OR.KCD.NE.2)GO TO 65
      CALL REPLCE(XR20,XR2)
      GO TO 66
   65 CALL REPLCE(XK,XR2)
   66 IF(ITRIG.EQ.1)GO TO 71
   70 CONTINUE
   71 CALL SEARCH(4,6HDEFLEC,IDF,0)
C     ICODE=11
C     WRITE(1,1002)ICODE,XR2
      ANG=ANGLE(XR1,XR2,XRC)
      DELP=DELP0(1)
      FB(1,1)=BARFAC(1,DELP)
C     ICODE=12
C     WRITE(1,1002)ICODE.FB(1,1)
      CALL REPLCE(XR2,XR2D)
C GROUND ABSORPTION
   72 DO 73 KF=1,NF
      FG(KF)=1.
   73 CONTINUE
```

```
C     ICODE=13
C     WRITE(1,1020)ICODE,XR1,XR2,XR2D
      IF(DELPW(1).GT.-3.2)GO TO 78
      IF(KGA.EQ.0)GO TO 78
      CALL SEARCH(1,6HGRTABS,IGTA,0)
      DO 77 IGRA=1,KGA
      CALL READ(IGTA,LOC,1,0)
      CALL READ(IGTA,XG1,6,0)
      CALL READ(IGTA,XG2,6,0)
      CALL READ(IGTA,BG,2,0)
      CALL READ(IGTA,IKIND,1,0)
C     ICODE=14
C     WRITE(1,1021)ICODE,LOC,XG1,XG2
      IF(LOC.EQ.3)GO TO 74
      CALL ENDPT(XR1,XR2,XRC,XG1,XG2,XK,KTRIG,IERR)
      IF(IERR.EQ.4) RETURN
      IF(KTRIG.EQ.0)GO TO 77
      GO TO 75
   74 CALL REPLCE(XR2,XK)
   75 CALL NR1(XR1,XK,XRC,XNPT,DIST,XN1,DN1)
      HDIFF=HEIGHT(XN1,XRC,XG1,XG2)
      IF(HDIFF.GT.HGA(IKIND))GO TO 77
      CALL SECTN(XR1,XK,XRC,XG1,XG2,XG3,XG4)
      DL=1.57/(1./BG+1./AMAG(XG3,XG4))
      DO 76 IK=1,NF
      IP=IK
      IF(IK.EQ.1)IP=5
      PP=IP
      IF(IKIND.EQ.1) A=(0.0016*PP-0.0028)*DL
      IF(IKIND.EQ.2) A=2.0**(PP/3.0)/1310.*DL
      IF(A.GT.3.) A=3.0
      FG(IP)=FG(IP)/10.**A
      IF(FG(IP).LT.1.E-3)FG(IP)=1.E-3
      CALL REPLCE(XK,XR2)
   76 CONTINUE
C     ICODE=15
C     WRITE(1,1022)ICODE,FG(1),FG(9)
   77 CONTINUE
      CALL SEARCH(4,6HGRTABS,IGTA,0)
   78 CALL REPLCE(XR2,XR2G)
C PRELIMINARY SELECTION OF REFLECTORS
      NREF=0
      IF(NB.EQ.0)GO TO 91
      NRFDF=0
      KBAR=0
      CALL SEARCH(1,6HBARRIR,IBR,0)
      CALL SEARCH(2,6HREFLEC,IREF,0)
      CALL SEARCH(2,6HREFDFR,IRFDF,0)
      DO 85 IBAR=1,NB
      CALL READ(IBR,NBSEC,1,0)
      CALL READ(IBR,KAR,1,0)
      CALL READ(IBR,XRB1,6,0)
      DO 85 ISEG=1,NBSEC
      CALL READ(IBR,XRB2,6,0)
      KBAR=KBAR+1
```

```
C      ICODE=16
C      WRITE(1,1001)ICODE,KBAR,XR1,XR2,XRB1,XRB2
       CALL IMAGE(XRB1,XRB2,XRC,XRCI)
       CALL NRPT(XR1,XR2,XRCI,XNPTI,DISTI)
C      ICODE=17
C      WRITE(1,1001)ICODE,XRCI,XNPTI
       ANGIMG=ANGLE(XRB1,XRB2,XRCI)
       FCTR=(DIST*ANGIMG)/DISTI/ANG/FB(1,1)
       IF(FCTR.LT.0.1)GO TO 80
       NRFDF=NRFDF+1
       CALL WRITE(IRFDF,KBAR,1,0)
       CALL WRITE(IRFDF,XRB ,6,0)
       CALL WRITE(IRFDF,XRB2,6,0)
C      ICODE=18
C      WRITE(1,1001)ICODE,NRFDF,XRB1,XRB2
       IF(KAR.NE.IR)GO TO 80
       CALL BLOCN(XR1,XR2.XRCI,XRB1,XRB2,XK,LOC)
       IF(LOC.EQ.0)GO TO 80
       NREF=NREF+1
       CALL WRITE(IREF,KBAR,1,0)
       CALL WRITE(IREF,XRB1,6,0)
       CALL WRITE(IREF,XRB2,6,0)
C      ICODE=19
C      WRITE(1,1001)ICODE,NREF,XRB1,XRB2
    80 CALL REPLCE(XRB2,XRB )
    85 CONTINUE
       CALL SEARCH(4,6HREFDFR,IRFDF,0)
C BEGIN REFLECTION PROBLEM
       CALL SEARCH(4,6HBARRIR,IBR,0)
       CALL SEARCH(4,6HREFLEC,IREF,0)
90     CALL SEARCH(1,6HREFLEC,IREF,0)
    91 IDXE=0
       IF(NREF.EQ.0)GO TO 179
       DO 175 KREF=1.NREF
       CALL READ(IREF,KBAR1,1,0)
       CALL READ(IREF,XRB1,6,0)
       CALL READ(IREF,XRB2,6,0)
C      ICODE=20
C      WRITE(1,1001)ICODE,KBAR1,XRB1,XRB2,XR1,XR2
       CALL IMAGE(XRB1,XRB2,XRC,XRCI)
       CALL ENDPT(XR1,XR2,XRCI,XRB1,XRB2,XK,KTRIG,IERR)
       IF(IERR.EQ.4) RETURN
C      ICODE=21
C      WRITE(1,1001)ICODE,KTRIG,XRCI,XK
       IF(KTRIG.EQ.0)GO TO  75
       CALL NRPT(XR1,XR2,XRCI,XNPTI,DISTI)
       CALL NR1(XR1,XK,XRCI,XNPTI,DISTI,XN1I,DN1I)
C      ICODE=22
```

```
C     WRITE(1,10[illegible])ICODE,XNPTI,XN1I
      XN1I(3)=XN1I(3)+ZS(2)
      HDIFF=HEIGHT(XN1I,XRCI,XRB1,XRB2)
      IF(HDIFF.GT.-2.0)GO TO 175
      CALL REPLCE(XK,XR2)
      CALL SECTN(XR1,XR2,XRCI,XRB1,XRB2,XRB3,XRB4)
C     ICODE=23
C     WRITE(1,10[illegible])ICODE,XR ,XR2,XRB3,XRB4
      HDIFF=0
      DO 95 IQ=1,NQ
      DELP1(IQ)=-0.2
      DELP2(IQ)=-0.2
   95 CONTINUE
C DIFFRACTION BEFORE REFLECTION
      IF(NRFDF.EQ.0)GO TO [illegible]5
      CALL SEARCH(1,6HREFDFR,IRFDF,0)
      DO 110 KRFDF=1,NRFDF
      CALL READ(IRFDF,KBAR2,1,0)
      CALL READ(IRFDF,XDB1,6,0)
      CALL READ(IRFDF,XDB2,6,0)
C     ICODE=24
C     WRITE(1,1031)ICODE,KBAR2,XDB1,XDB2
      IF(KBAR2.EQ.KBAR1)GO TO 110
      CALL BLOCN(XRB3,XRB4,XRCI,XDB1,XDB2,XK,LOC)
      IF(LOC.NE.1)GO TO 110
      CALL ENDPT(XR1,XR2,XRCI,XDB1,XDB2,XK,KTRIG,IERR)
      IF(IERR.EQ.4) RETURN
C     ICODE=25
C     WRITE(1,1031)ICODE,KTRIG,XK
      IF(KTRIG.EQ.0)GO TO 110
      CALL NR1(XR1,XK,XRCI,XNPTI,DISTI,XN1I,DN1I)
C     ICODE=26
C     WRITE(1,10[illegible])ICODE,XN1I
      ZN10=XN1I(3)
      XN1I(3)=ZN10+ZS(1)
      HDIFF=HEIGHT(XN1I,XRCI,XDB1,XDB2)
      IF(HDIFF.GT.20.0)GO TO 110
      CALL SECTN(XR1,XK,XRCI,XDB1,XDB2,XDB3,XDB4)
C     ICODE=27
C     WRITE(1,10[illegible])ICODE,XDB3,XDB4
      CALL NRPT(XDB3,XDB4,XRCI,XNPTJ,DISTJ)
      CALL NR1(XDB3,XDB4,XRCI,XNPTJ,DISTJ,XN2,DN2)
C     ICODE=127
C     WRITE(1,1030)ICODE,XNPTJ,XN2,DISTJ,DN2
      HDIFF=HEIGHT(XN2,XRCI,XRB1,XRB2)
C     ICODE=227
C     WRITE(1,10[illegible]2)ICODE,HDIFF
      IF(HDIFF.GT.-2.0)GO TO 169
      DO 105 II=1,NQ
      IQ=NQ+1-II
      XN1I(3)=ZN10+ZS(IQ)
      HDIFF=HEIGHT(XN1I,XRCI,XDB1,XDB2)
      DELP=DEL(XN1I,XRCI,XDB1,XDB2,HDIFF,DN1I)
```

```
C       ICODE=327
C       WRITE(1,1002)ICODE,DELP
        IF(DELP.GE.12.5.AND.IQ.EQ.2)GO TO 169
        IF(DELP.GT,DELP1(IO))GO TO 100
        IF(IO,EQ.1)GO TO 110
        GO TO 105
  100 NDIFF=1
        DELP1(IQ)=DELP
  105 CONTINUE
C       ICODE=28
C       WRITE(1,1017)ICODE,DELP1(1),DELP1(2)
        CALL REPLCE(XK,XR2)
  110 CONTINUE
        CALL SEARCH(4,6HREFDFR,IRFDF,0)
C       ICODE=29
C       WRITE(1,1003)ICODE,XR2
C DIFFRACTION AFTER REFLECTION
        CALL IMAGE(XRB1,XRB2,XNPTI,XNPTJ)
        CALL IMAGE(XRB1,XRB2,XR1,XR1I)
  115 CALL IMAGE(XRB1,XRB2,XR2,XR2I)
C       ICODE=30
C       WRITE(1,1010)ICODE,XR1I,XR2I,XNPTI
        IF(NRFDF.EQ.0)GO TO 145
        CALL SEARCH(1,6HREFDFR,IRFDF,0)
        DO 140 KRFDF=1,NRFDF
        CALL READ(IRFDF,KBAR2,1,0)
        CALL READ(IRFDF,XDB1,6,0)
        CALL READ(IRFDF,XDB2,6,0)
C       ICODE=31
C       WRITE(1,1011)ICODE.KBAR2,XDB1,XDB2
        IF(KBAR2.EQ.KBAR1)GO TO 140
        CALL INTCPT(XRB1,XRB2,XRC.XR2I,XRB4)
        CALL BLOCN(XRB3,XRB4,XRC,XDB1,XDB2,XJ.LOC)
        IF(LOC.EQ.0)GO TO 140
        IF(LOC.EQ.3)GO TO 120
        CALL INTCPT(XR1I,XR2I,XRC,XJ,XKI)
        XKI(3)=ZCOR(XR1I,XR2I,XKI)
        DELTA=-0.5
        CALL MOVE(XKI,XKI,XR1I,DELTA,IERR)
        IF(IERR.EQ.4) RETURN
        IF(LOC.NE.1)GO TO 135
        GO TO 125
  120 CALL REPLCE(XR2I,XKI)
  125 CALL INTCPT(XR1I,XRC,XDB1,XDB2,XDB3)
C       ICODE=32
```

```
C       WRITE(1,1001)ICODE.LOC,XJ,XKI,XDB3
        XDB3(3)=ZCOR(XDB1,XDB2,XDB3)
        HDIFF=HEIGHT(XR1I,XDB3,XRB1,XRB2)
        IF(HDIFF.GT.-2.0)GO TO 164
        CALL NR1(XR1I,XKI,XRC,XNPIJ,DISTI,XN1I,DN1I)
        ZN10=XN1I(3)
        DO 130 II=1,NQ
        IQ=NQ+1-II
        XN1I(3)=ZN10+ZS(IQ)
        HDIFF=HEIGHT(XN1I,XRC,XDB1,XDB2)
        IF(HDIFF.GT.20.0.AND.IQ.EQ.2)GO TO 140
        DELP=DEL(XN1I,XRC,XDB ,XDB2,HDIFF,DN1I)
        IF(HDIFF.EQ.1.AND.DELP.GT.-0.2)GO TO 164
        IF(DELP.LE.DELP2(IQ))GO TO 140
        DELP2(IQ)=DELP
  130   CONTINUE
C       ICODE=33
C       WRITE(1,1007)ICODE.DELP2(1),DELP2(2)
        IF(DELP2(2).GE.12.5)GO TO 164
  135   CALL REPLCE(XKI,XR2I)
  140   CONTINUE
        CALL SEARCH(4,6HREFDFR,IRFDF,0)
  145   CALL REPLCE(XR2I,XKI)
        IDXR=IDXR+1
C       ICODE=34
C       WRITE(1,1031)ICODE.IDXR,XR2I
        IF(IDXR.LT.11)GO TO 150
        IERR=3
        RETURN
  150   DO 155 IQ=1,NQ
        DELP(IQ,IDXR)=AMAX1(DELP1(IQ),DELP2(IQ))
  155   CONTINUE
        DO 160 I=1,3
        XIMG(I,IDXR)=XRCI(I)
  160   CONTINUE
        GO TO 165
  164   CALL SEARCH(4,6HREFDFR,IRFDF,0)
  165   CALL IMAGE(XRB1,XRB2,XKI,XK)
  169   CALL SEARCH(4,6HREFDFR,IRFDF,0)
  170   CALL REPLCE(XK,XR2)
C       ICODE=35
C       WRITE(1,1030)ICODE,XR2
  175   CONTINUE
C       ICODE=36
C       WRITE(1,1030)ICODE,XR1,XR2
C BEGIN BARRIER FACTOR COMPUTATION
 179    CALL SEARCH(4,6HREFLEC,IREF,0)
  180   NIMG=IDXR
        ANG=ANGLE(XR1,XR2,XRC)
        ADST=ANG/DIST
        IF(KPOS(XNPT,XR2,XR1).EQ.1)GO TO 190
        ANG2=ANG1-ANG
        GO TO 195
  190   ANG2=ANG1+ANG
```

```
C CONTRIBUTION FROM DIRECT RAY
  195 DO 205 IQ=1,NQ
      IF(NQS(IQ).EQ.0)GO TO 205
      DELP=DELP0(IQ)
      DO 200 KF=1,NF
      FB(KF,IQ)=BARFAC(KF,DELP)
  200 CONTINUE
C     ICODE=37
C     WRITE(1,1002)ICODE,FB(1,IQ),FB(9,IQ)
  205 CONTINUE
C CONTRIBUTION FROM REFLECTIONS
      IF(NIMG.EQ.0)GO TO 230
      DO 225 KIMG=1,NIMG
      DO 210 I=1,3
      XRCI(I)=XIMG(I,KIMG)
  210 CONTINUE
      ANGI=ANGLE(XR1,XR2.XRCI)
      CALL NRPT(XR1,XR2,XRCI,XNPTI,DISTI)
      RATIO=(ANGI/DISTI)/ADST
      DO 220 IQ=1,NQ
      IF(NQS(IQ).EQ.0)GO TO 220
      DELP=DELR(IQ.KIMG)
      DO 215 KF=1,NF
      FB(KF,IQ)=FB(KF,IQ)+BARFAC(KF,DELP)*RATIO
  215 CONTINUE
  220 CONTINUE
C     ICODE=38
C     WRITE(1,1002)ICODE,FB(1,1),FB(1,2),FB(9,1),FB(9.2)
  225 CONTINUE
C COMPUTE MEAN ENERGY LEVEL
  230 CALL NR1(XR1.XR2,XRC,XNPT,DIST,XN1,DN1)
      DO 242 IF=1,NF
      IP=IF
      IF(IF.EQ.1)IP=5
      A=10.**(-1.E-8*4.**IP*DN1)
      T1=0.
      DO 240 IQ=1,NQ
      IF(NQS(IQ).EQ.0)GO TO 240
      NQQ=NQS(IQ)
      T2=0.
      DO 235 I=1,NQQ
      T2=T2+VEXPH(I.IQ)*XLREF(I,IF,IQ)
  235 CONTINUE
      T1=T1+FB(IF,IQ)*CQ(IQ)*T2
  240 CONTINUE
      XLE(IF)=XLE(IF)+ADST*T1*A*FG(IP)
  242 CONTINUE
C     ICODE=39
C     WRITE(1,1002)ICODE,XLE(1),XLE(9),CAP2
      ANG1=ABS(ANG2)
```

```
C      ICODE=40
C      WRITE(1,1000)ICODE,XR2,XR2G,XR2D,XR20
       IF(DSQR(XR2,XR20).LT.1.)RETURN
       DELTA=1.
       CALL MOVE(XR2,XR1,XR20,DELTA,IERR)
       IF(IERR.EQ.0) RETURN
C      ICODE=41
C      WRITE(1,1002)ICODE,XR[illegible]
       IF(DSQR(XR2,XR2G).LT.1.0)GO TO 247
       CALL REPLCE(XR2G,XR2)
       GO TO 90
  247 IF(DSQR(XR2,XR2D).LT.1.0)GO TO 25
       CALL REPLCE(XR2D,XR2)
       GO TO 72
C1000 FORMAT(6H0CODE@I3,6F9.2/6F9.2)
C1001 FORMAT(6H0CODE@I3,I4,6F9.2/6F9.2)
C1002 FORMAT(6H0CODE@I3,6F9.2)
       END
$1
       SUBROUTINE INTER(IQ)
       DIMENSION TL(2,9,2)
       COMMON/BLK2/NQ
       COMMON/DRIV1/XMPH(5)
       COMMON/DRIV2/NQS(2),NF
       COMMON/INTER1/XLREF(5,9,2)
       DATA TL(1), TL(2), TL(3), TL(4), TL(5), TL(6), TL(7), TL(8),
     1      TL(9),TL(10),TL(11),TL(12),TL(13),TL(14),TL(15),TL(16),
     2     TL(17),TL(18),TL(19),TL(20),TL(21),TL(22),TL(23),TL(24),
     3     TL(25),TL(26),TL(27),TL(28),TL(29),TL(30),TL(31),TL(32),
     4     TL(33),TL(34),TL(35),TL(36)/
     5  61.,75.,38.,48.,45.,57.,47.,62.,55.,66.,58.,70.,54.,72.,49.,63.,
     6  42.,57.,
     7  2*67.,2*6[illegible].,2*73.,2*78.,2*83.,2*82.,2*79.,2*74.,2*66./
       NQQ=NQS(IQ)
       CONS=ALOG10(70./30.)
       DO 10 IF=1,NF
       TEMP=TL(2,IF,IQ)-TL(1,IF,IQ)
       DO 10  I=1,NQQ
       XLREF1=TL(1,IF,IQ)+TEMP*ALOG10(XMPH(I)/30.)/CONS
       XLREF(I,IF,IQ)=10.**(XLREF1/10.)
    10 CONTINUE
       RETURN
       END
$1
       FUNCTION AMAG(X1V,X2V)
C FIND MAGNITUDE OF VECTOR
       DIMENSION X1V(3),X2V(3)
       AMAG=SQRT(DSQR(X1V,X2V))
       RETURN
       END
```

```
$1
      FUNCTION ANGLE(X1V,X2V,X3V)
      DIMENSION X1V(3),X2V(3),X3V(3)
      D13=DSQR(X1V,X3V)
      D23=DSQR(X2V,X3V)
      ANGLE=1.5708
      IF(D13*D23.EQ.0.)RETURN
      D12=DSQR(X1V,X2V)
      ANGLE=ACOS((D23+D13-D12)/(SQRT(D13*D23)*2.))
      RETURN
      END
$1
      FUNCTION BARFAC(KF,DELP)
C FIND BARRIER FACTOR
      IF(DELP.EQ.-0.2)GO TO 3
      IF(DELP.GE.12.5)GO TO 4
      IP=KF
      IF(KF.EQ.1)IP=5
      A=DELP*(2.**IP)/5.7
      IF(A.GE.78.5)GO TO 4
      IF(A.GT.0..AND.A.LT.78.5)GO TO 5
      IF(A.EQ.0.)GO TO 6
      IF(A.GT.-1.25.AND.A.LT.0.)GO TO 7
    3 BARFAC=1.0
      RETURN
    4 BARFAC=4.0E-3
      RETURN
    5 BARFAC=(TANH(SQRT(A))**2)/A/3.16
      RETURN
    6 BARFAC=.316
      RETURN
    7 A1=ABS(A)
      BARFAC=(TAN(SQRT(A1)))**2/A1/3.16
      RETURN
      END
$1
      SUBROUTINE BLOCN(X1V,X2V,X3V,X4V,X5V,X6V,LOC)
C FIND RELATIVE LOCATION OF BARRIER
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2),X6V(2),XAV(2),XBV(2)
      LOC=KCUT(X1V,X3V,X4V,X5V)
      LOC=LOC+KCUT(X2V,X3V,X4V,X5V)*2
      IF(LOC.EQ.3)RETURN
      CALL TRI(X1V,X2V,X3V,X4V,XAV,KTRI)
      IF(LOC.EQ.0)GO TO 4
      IF(KTRI.EQ.1)GO TO 6
    2 CALL INTCPT(X1V,X2V,X3V,X5V,XBV)
      IF(LOC.EQ.4)GO TO 5
    3 X6V(1)=XBV(1)
      X6V(2)=XBV(2)
      RETURN
```

```
    4 IF(KTRI.EQ.1)RETURN
      LOC=4
      GO TO 2
    5 IF(KPOS(X1V,XAV,XBV).EQ.1)GO TO 3
    6 X6V(1)=XAV(1)
      X6V(2)=XAV(2)
      RETURN
      END
$1
      FUNCTION DEL(X1V,X2V,X3V,X4V,HDIFF,DN1)
C FIND PATH LENGTH DIFFERENCE
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),XAV(3),XBV(3)
      CALL NRPT(X3V,X4V,X1V,XAV,DISTA)
      CALL NRPT(X3V,X4V,X2V,XBV,DISTB)
      DISTC=DSQR(XBV,XAV)
      DEL=SQRT((DISTA+DISTB)**2+DISTC)-DN1
      IF(HDIFF.GT.0.)DEL=-DEL
      RETURN
      END
$1
      FUNCTION DSQR(X1V,X2V)
      DIMENSION  X1V(3),X2V(3)
      DSQR=0.0
      DO 10 I=1,3
   10 DSQR=(X1V(I)-X2V(I))**2+DSQR
      RETURN
      END
$1
      SUBROUTINE ENDPT(X1V,X2V,X3V,X4V,X5V,X6V,KTRIG,IERR)
C FIND NEW ENDPOINT
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),X5V(3),X6V(3),XDUM(3)
      IERR=0
      KTRIG=0
      ITRIG=1
      CALL REPLCE(X1V,XDUM)
1     CALL BLOCN(XDUM,X2V,X3V,X4V,X5V,X6V,LOC)
      IF(LOC.EQ.0) RETURN
      IF(LOC.NE.3) GO TO 2
      CALL REPLCE(X2V,X6V)
      GO TO 4
2     X6V(3)=ZCOR(X1V,X2V,X6V)
      IF(ITRIG.EQ.0) GO TO 5
      IF(AMAG(X1V,X6V).GT.0.51) GO TO 5
      ITRIG=0
      DELTA=-0.51
      CALL MOVE(XDUM,XDUM,X2V,DELTA,IERR)
      GO TO 1
5     DELTA=-0.5
      IF(LOC.EQ.1) GO TO 3
      CALL MOVE(X6V,X2V,X1V,DELTA,IERR)
      RETURN
```

```
3     CALL MOVE(X6V,X6V,X1V,DELTA,IERR)
4     KTRIG=1
      RETURN
      END
$1
      FUNCTION HEIGHT(X1V,X2V,X3V,X4V)
C FIND HEIGHT DIFFERENCE
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),XI(3)
      CALL INTCPT(X1V,X2V,X3V,X4V,XI)
      HEIGHT=ZCOR(X1V,X2V,XI)-ZCOR(X3V,X4V,XI)
      RETURN
      END
$1
      FUNCTION IEPS (X1V, X2V, X3V, X4V, DEL1)
C     CHECK ON PATH LENGTH DIFFERENCE
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3)
      IEPS =0
      DIST = AMAG (X1V,X2V)
      HDIFF = HEIGHT (X1V,X2V,X3V,X4V)
      DEL2 = DEL (X1V, X2V, X3V, X4V, HDIFF, DIST)
      DELM= (DEL1+DEL2)/2.
      IF((ABS(DEL2-DEL1) - 0.1-DELM/50.* (1.+DELM)) .GT.0.) IEPS=1
      RETURN
      END
$1
      SUBROUTINE IMAGE(X1V,X2V,X3V,X4V)
C  FIND IMAGE POINT
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3)
      AX=X2V(1)-X1V(1)
      AY=X2V(2)-X1V(2)
      AXY=AX**2+AY**2
      RATIO=0.
      IF(AXY.EQ.0.)GO TO 10
      RATIO=(((X3V(2)-X2V(2))*AX-(X3V(1)-X2V(1))*AY)*2.0)/AXY
   10 X4V(1)=X3V(1)+AY*RATIO
      X4V(2)=X3V(2)-AX*RATIO
      X4V(3)=X3V(3)
      RETURN
      END
$1
      SUBROUTINE INTCPT(X1V,X2V,X3V,X4V,X5V)
C FIND INTERCEPT OF TWO LINES IN A PLANE
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2)
      AX=X2V(1)-X1V(1)
      AY=X2V(2)-X1V(2)
      BX=X4V(1)-X3V(1)
      BY=X4V(2)-X3V(2)
      C1=AY*X2V(1)-AX*X2V(2)
      C2=BY*X4V(1)-BX*X4V(2)
      D=AX*BY-AY*BX
```

```
      IF(D**2.LT.1.E-6)GO TO 2
      X5V(1)=(AX*C2-BX*C1)/D
      X5V(2)=(AY*C2-BY*C1)/D
      RETURN
    2 D=SQRT(AX**2+AY**2)
      X5V(1)=X1V(1)+(AX/D)*1.E+15
      X5V(2)=X1V(2)+(AX/D)*1.E+15
      RETURN
      END
$1
      FUNCTION KCUT(X1V,X2V,X3V,X4V)
C DETERMINE IF TWO LINE SEGMENTS CROSS
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2)
      KCUT=0
      CALL INTCPT(X1V,X2V,X3V,X4V,X5V)
      IF(KPOS(X1V,X2V,X5V).NE.1)RETURN
      IF(KPOS(X3V,X4V,X5V).EQ.1)KCUT=1
      RETURN
      END
$1
      FUNCTION KPOS(X1V,X2V,X3V)
C FIND POSITION OF POINT ON LINE
      DIMENSION X1V(2),X2V(2),X3V(2)
      KPOS=1
      IF(((X3V(1)-X1V(1))*(X3V(1)-X2V(1))+(X3V(2)-X1V(2))*(X3V(2)-X2V(2)
     1)).GT.0.)KPOS=0
      RETURN
      END
$1
      SUBROUTINE MIDP (X1V, X2V, X3V)
C     FIND CENTER POINT
      DIMENSION X1V(3), X2V(3), X3V(3)
      DO 10 I=1,3
   10 X3V(I) = (X1V(I)+X2V(I))/2.
      RETURN
      END
$1
      SUBROUTINE NRPL(X1V,X2V,X3V,X4V,DIST)
C FIND NEAREST POINT TO LINE
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),AV(3),BV(3)
      EQUIVALENCE (AV(1),AX),(AV(2),AY),(AV(3),AZ),(BV(1),BX),(BV(2),BY
     1),(BV(3),BZ)
      DO 5 I=1,3
      AV(I)=X2V(I)-X1V(I)
      BV(I)=X3V(I)-X1V(I)
    5 CONTINUE
      RATIO=0.
      TEMP=DSQR(X2V,X1V)
      IF(TEMP.NE.0.)RATIO=(AX*BX+AY*BY+AZ*BZ)/TEMP
      DO 10 I=1,3
      X4V(I)=X1V(I)+RATIO*AV(I)
```

```
   10 CONTINUE
      DIST=AMAG(X4V,X3V)
      IF(DIST.EQ.0.)DIST=1.
      RETURN
      END
$1
      SUBROUTINE NR1(X1V,X2V,X3V,X4V,DIST,X5V,DN1)
C FIND NEAREST POINT TO LINE SEGMENT
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),X5V(3)
      IF(KPOS(X4V,X2V,X1V).EQ.1)GO TO 2
      IF(KPOS(X1V,X4V,X2V).EQ.1)GO TO 4
      CALL REPLCE(X4V,X5V)
      DN1=DIST
      RETURN
    2 CALL REPLCE(X1V,X5V)
      GO TO 6
    4 CALL REPLCE(X2V,X5V)
    6 DN1=AMAG(X5V,X3V)
      RETURN
      END
$1
      SUBROUTINE REPLCE(X1V,X2V)
      DIMENSION X1V(3),X2V(3)
      X2V(1)=X1V(1)
      X2V(2)=X1V(2)
      X2V(3)=X1V(3)
      RETURN
      END
$1
      SUBROUTINE SECTN(X1V,X2V,X3V,X4V,X5V,X6V,X7V)
C  FIND EFFECTIVE BARRIER SECTION
      DIMENSION X1V(3),X2V(3),X3V(3),X4V(3),X5V(3),X6V(3),X7V(3)
      CALL INTCPT(X1V,X3V,X4V,X5V,X6V)
      X6V(3)=ZCOR(X4V,X5V,X6V)
      CALL INTCPT(X2V,X3V,X4V,X5V,X7V)
      X7V(3)=ZCOR(X4V,X5V,X7V)
      RETURN
      END
$1
      SUBROUTINE TRI(X1V,X2V,X3V,X4V,X5V,KTRI)
C FIND IF POINT IN TRIANGLE AND LOCATE INTERCEPT
      DIMENSION X1V(2),X2V(2),X3V(2),X4V(2),X5V(2)
      CALL INTCPT(X1V,X2V,X3V,X4V,X5V)
      KTRI=0
      IF(KPOS(X1V,X2V,X5V).EQ.0)RETURN
      IF(KPOS(X3V,X5V,X4V).EQ.1)KTRI=1
      RETURN
      END
$1
      FUNCTION ZCOR(X1V,X2V,X3V)
```

```
C FIND Z COORDINATE
      DIMENSION X1V(3),X2V(3),X3V(3)
      TEM1=X2V(1)-X1V(1)
      TEM2=X2V(2)-X1V(2)
      TEM3=X2V(3)-X1V(3)
      IF(ABS(TEM1).GT.ABS(TEM2))GO TO 10
      ZCOR=X1V(3)+(X3V(2)-X V(2))*TEM3/TEM2
      RETURN
   10 ZCOR=X1V(3)+(X3V(1)-X V(1))*TEM3/TEM1
      RETURN
      END
$1
      SUBROUTINE MOVE(X1V,X2V,X3V,DELTA,IERR)
C MOVE ENDPOINT OF ROAD
      DIMENSION X1V(3),X2V(3),X3V(3)
      IERR=0
      TEMP=AMAG(X1V,X3V)
      IF(TEMP.EQ.0.) GO TO 3
      FCTR=DELTA/TEMP
      DO 2 I=1,3
      X2V(I)=X1V(I)+(X1V(I)-X3V(I))*FCTR
2     CONTINUE
      RETURN
3     IERR=4
      RETURN
      END
$1
      FUNCTION TAN(X)
      TAN=SIN(X)/COS(X)
      RETURN
      END
$1
      FUNCTION ACOS(X)
      IF(X.EQ.0.) GO TO 5
      ACOS=ATAN(SQRT(1.0-X*X)/X)
      IF(X.LT.0.) ACOS=3.1416+ACOS
      RETURN
5     ACOS=1.5708
      RETURN
      END
$0
```

4. USER'S GUIDE TO THE COMPUTER PROGRAM

4.1 Format and Sequence of Data Input

The computer program is written to accept input data from a card reader. Three types of input data are allowed:

Integer — a fixed-point number written without a decimal point. All integers must be right-adjusted within the allotted field.

Real Constant — a floating point number written with a decimal point. The real constant may be situated anywhere within its allotted columns.

Alphanumeric — any combination of alphabetic and numeric characters. Alphanumeric data may be situated anywhere within its allotted columns.

The first card read by the program is a title card with arbitrary alphanumeric information that may appear in columns 2 through 60. Up to five blocks of data may follow, in arbitrary sequence, with information about the following:

1 Program initialization parameters,
2 Road and vehicle parameters,
3 Barrier parameters,
4 Ground cover parameters,
5 Receiver data.

Each data block must be preceded by a control card containing an integer between 1 and 5 in column 5. This integer characterizes the data block as listed above. A card with the integer 6 in column 5 indicates the end of the input data string.

Multiple cases may be run back to back, whereby each case starts with a title card and terminates with a card having a 6 in column 5. The entire situation need not be redefined for each additional case; rather, it is sufficient to specify only those aspects of the problem that differ from the case immediately preceding.

The first of a series of cases must specify initialization parameters, vehicle and road parameters, and receiver locations. If no information is provided for barriers for the first case, the computer program assumes that there are no barriers, and all calculations related to barrier diffraction and reflection are bypassed. Ground absorption is treated in the same manner. Once barrier information has been provided, however, failure to specify barrier data in subsequent cases of the same series of cases will not reinitialize the number of barriers to zero. Instead, the barrier data appropriate to the preceding case will be retained.

Specifications for the five types of data blocks accepted by the program are given below.

4.1.1 Program initialization parameters

Initialization parameters must appear in the first of a series of cases. A control card is provided with the integer 1 in column 5 to identify the data block. Six data cards must follow, in arbitrary sequence, to provide information about:

1 Receiver height adjustment,
2 Number of frequency bands,
3 Standard deviation for cars,

4 Standard deviation for trucks,
5 Height adjustment for cars,
6 Height adjustment for trucks.

An initialization parameter is entered as a real constant in columns 1 through 10 of each data card. Column 15 contains an integer between 1 and 6 to identify the parameter, as indicated in the above list, and alphanumeric information is contained in columns 31 through 60. The last of the set of six cards must contain the letter L in column 20 to signify the end of the data block.

The receiver height adjustment is a height in feet to be added to the z-coordinate of all receivers specified in data block 5. For normal conditions, it will be 0.0. For special cases, such as the comparison of levels at the ground floor of a building with levels at a higher floor, a height adjustment of 10.0 feet per floor is recommended. Negative height adjustments are allowable. Such an adjustment will not cause the program to assume that the receiver is shielded by the ground.

The number of frequency bands for which calculations are to be performed is indicated by a number (entered as a real constant) between 1.0 and 9.0. By using the number 1.0, all attenuations due to atmospheric absorption, ground absorption, and barrier diffraction will be calculated for a frequency of 500 Hz. This frequency is most typical for the spectrum of road traffic noise. By using the number 9.0, the attenuations will be calculated in addition in eight octave bands with center frequencies ranging from 62.5 Hz to 8000 Hz. The final results will be more accurate in this case, but total computation time will be increased. By using any number n between 1.0 and 9.0, the attenuations will be calculated for 500 Hz and for n-1 octave band starting from the 62.5 Hz band.

The standard deviation for cars and trucks is the standard deviation of reference levels at a short distance (r_0 = 50 ft) from individual vehicles. The value recommended for cars is 2.5 (dB) and for trucks 3.5 (dB).

The height adjustment for cars should be 0.0, since tire noise is assumed to be the dominant noise source. Other height adjustments for engine or fan noise should not be made.

The height adjustment for trucks is typically 8.0 (ft) for exhaust noise. Other height adjustments for engine or fan noise will result in slightly higher attenuation by barrier diffraction. A height adjustment 0.0 for tire noise is incompatible with the noise spectrum stored in the program.

4.1.2 Road and vehicle data

The control card for this data block must have the integer 2 in column 5 and a second integer right-adjusted in columns 6 through 10 to indicate the number of roadways.

The number of roads to be specified depends on the number of traffic arteries with constant hourly traffic flow that one wants to consider. For a receiver located far from a multilane highway without ramps, consideration of a single traffic artery is sufficient. For receiver locations closer to the highway, many traffic arteries in parallel might be considered to account for individual lanes. Ramps to highways and independent highways are treated as separate roads.

Following the control card, a set of one or more cards is required to provide vehicle data for the first roadway. Each card contains a real constant in columns 1 through 10 to indicate vehicles per hour, a real constant in columns 11 through

20 to indicate vehicle speed in miles per hour, and the integer 1 or 2 in column 25 to indicate vehicle type. The final card of this set has, in addition to the above information, an L in column 31.

An integer 1 in column 25 stands for passenger cars, a 2 for trucks. Up to five cards for each vehicle type can be used in random order to specify hourly traffic flow at different average speeds. Unless the speed distribution is known from measurements, the "Highway Capacity Manual" is recommended for determining the average speed from the hourly traffic volume and the average highway speed.

Following the vehicle information for the first road are cards with Cartesian coordinates for the end points of straight-line approximations to the first road. The x-y plane is parallel to sea level and the z-coordinate gives the height above sea level or above any plane parallel to sea level. All coordinates are in feet. The x, y, and z-coordinates are entered as real constants in the fields bounded by columns 1 and 10, 11 and 20, and 21 and 30, respectively. The card with the last point of the road has an L in column 31. A roadway may contain up to eleven end points (i.e., ten sections). A road containing more than ten sections should be treated as two or more roads, each having fewer than ten sections.

Vehicle and road data are specified for the remaining roadways in a similar manner. Data must be specified for as many roads as indicated by the integer contained in the second field of the control card.

4.1.3 Barrier parameters

The data block with information about obstacles (i.e., "barriers") in the sound propagation paths is headed by a card having a 3 in column 5 and an integer right-adjusted in columns 6 through 10 to indicate the number of barriers.

The top contour of a barrier is approximated by a straight-line segment, and no sound is assumed to penetrate below this contour. A single barrier may contain up to ten sections. The end points of these sections are specified in the same format as the end points of road sections, except that the last point of a line is identified by an A or an R in column 31 (rather than L as for roads).

An R in column 31 indicates that the preceding points describe the top line of a rigid plane oriented perpendicularly to the ground, such as artificial barriers without absorbing material, facades of buildings, rigid walls of a depressed highway, etc.

An A in column 31 indicates that the preceding points describe the top line of a tilted barrier, a barrier with absorbing material, an earth berm, a hill, or some other obstacle that reflects sound either weakly or towards the sky, directly or via a ground reflection.

The top line of a barrier must not cross a road.

4.1.4 Ground cover parameters

The control card for this data block contains a 4 in column 5 and an integer in columns 6 through 10 to indicate the number of absorptive ground strips.

The areas of ground cover are described by the center line and the width of rectangles. The x, y, and z-coordinates of one end point of the center line are given as real constants in the fields between columns 1 and 10, 11 and 20, and 21 and 30, respectively of a single card. The same card contains the width of the rectangle in real formats in the field between columns 31 and 40. The x, y, and z-coordinates of the other end point of the center line are written on the next card together with a G or a T in column 31.

A G identifies the ground cover as high grass or shrubbery, and a T identifies the ground cover as trees.

The rectangles with ground cover must not cross a road.

4.1.5 Receiver data

The control card contains a 5 in column 5 and an integer in columns 6 through 10 to indicate the number of receivers. A card is provided for each receiver to indicate the x, y, and z-coordinates of the receiver location. These data are entered as real constants in the fields bounded by columns 1 and 10, 11 and 20, and 21 and 30, respectively.

A maximum of fifteen receivers is allowed.

A receiver cannot be located on a road, nor on, over or underneath a top line of an obstacle (barrier), nor on a ground strip. However, a receiver can be located between two adjacent ground strips if the location is not identical with an end point of the ground strip center line.

4.2 Error Messages

Errors are detected by the computer in the following cases.

a. If the top line of an obstacle intersects a roadway, the computer prints out

ILLEGAL BARRIER INTERSECTS ROADWAY

together with the following data: receiver number, roadway number, road section number, barrier number, barrier section number.

The computer then proceeds with the next case.

b. If the center line of a ground strip intersects a roadway, the computer prints out

ILLEGAL GROUND STRIP INTERSECTS ROADWAY

together with the following data: receiver number, roadway number, road section number, ground strip number.

The computer then proceeds with the next case.

c. If the number of reflections contributing to the sound level at a receiver exceeds 10, the computer prints out

TOO MANY REFLECTIONS

together with the following data: receiver number, roadway number, road section number.

The computer then proceeds with the next receiver.

d. Should the geometry of the situation be such that a line segment that is needed for computation appears to have zero length, the program continues with the next receiver without giving an error message.

4.3 Data Output

The data output starts immediately after the input file is read. The heading TRAFFIC NOISE PREDICTION is typed and input data are then typed in the following order:

Title card;

Program initialization parameters (for the first of a series of cases only);

Vehicle and road parameters, where all parameters of Type 1 vehicles (passenger cars) on a given road are typed first, following by parameters for Type 2 vehicles (trucks);

Barrier parameters, with the type of barrier, A or R, given in parentheses after the barrier number;

Ground cover parameters, with identification G or T following the ground strip number in parentheses;

Receiver data.

The title card is then printed out again together with a headline for the receiver identification. The output consists of the following data for each receiver. After the sound pressure level for a given receiver has been calculated, the receiver number and coordinates are typed. The octave band center frequencies are typed out; underneath them are the calculated A-weighted octave band levels. The final typeouts consist of the A-weighted overall level based on attenuations at 500 Hz, which appears under the heading A(500), and the A-weighted overall level resulting from the octave band calculations, which appears under the heading A.

4.4 Recommendations for Usage

The computation time required to compute sound levels at a given receiver increases with the number of roadways, barriers, and ground strips, but it is independent of the total number of receivers. Therefore, if one wishes to analyze a situation in which many receivers and barriers are located along or near a highway many miles in length, we suggest that the problem be modularized so that a smaller geographical area can be associated with each receiver.

Maps showing the elevation of the terrain should be used for a detailed description of the roadway and of top lines of hills (barriers of Type A). It should be borne in mind that the computer program accounts for 5 dB attenuation for sound rays grazing over hills.

Results obtained when ground absorption is considered should be interpreted with caution. Because of the lack of reliable data in this area, results from the first-order approximations used in the computer program are intended for comparison with field data rather than for prediction purposes.

4.5 Test Cases

As an example, a listing of input data for two cases and the corresponding computer printout is given on the following pages. A graph of the geometry in the x-y plane is shown on Fig. 13.

In the example, test case 1 involves two roadways, a tree zone, and two receivers. The curved, major roadway with 1000 passenger cars per hour at an average speed of 60 mph and with 100 trucks per hour at 50 mph is approximated by two straight

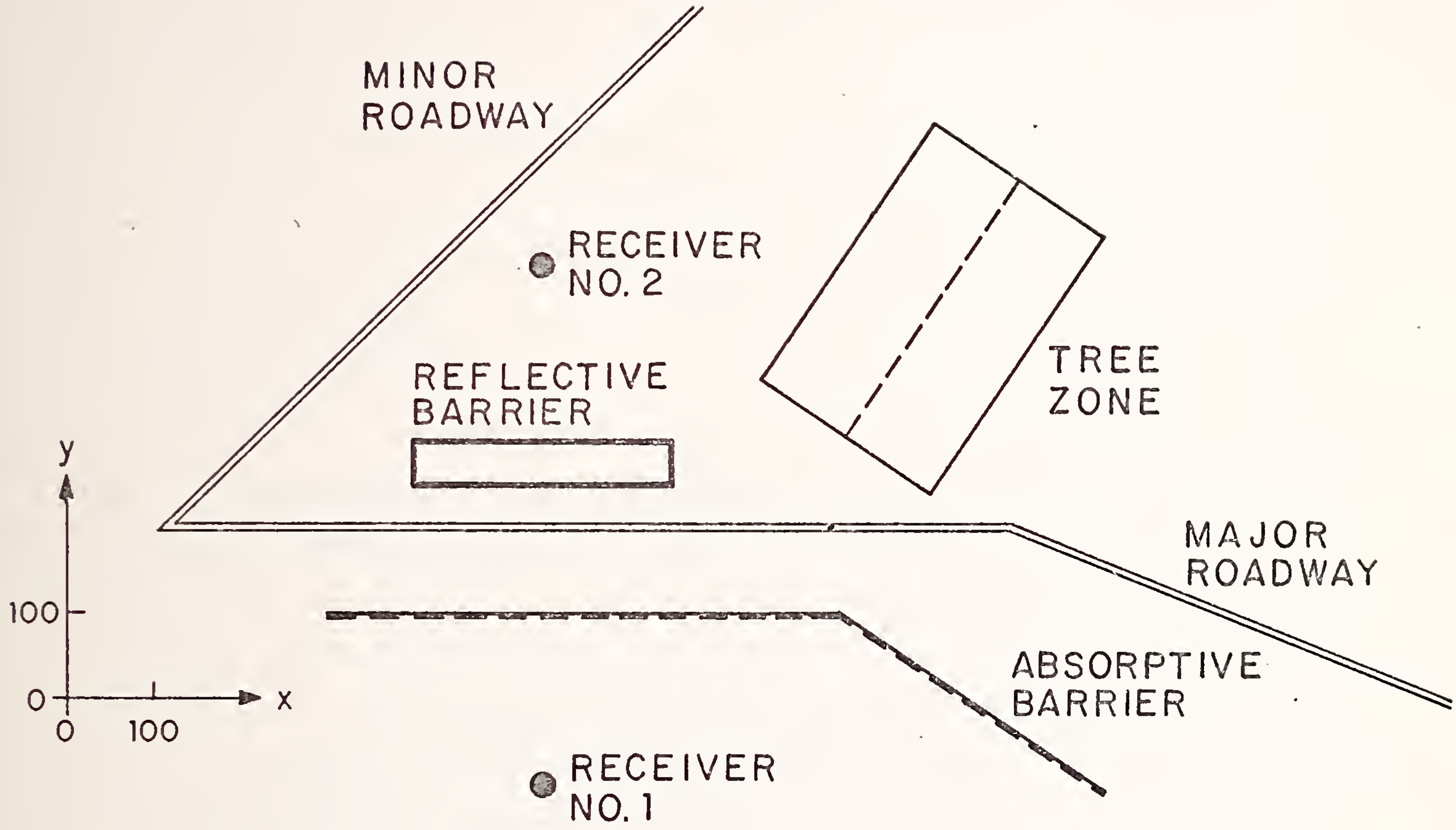


FIG.13 PLAN VIEW OF THE GEOMETRY USED IN THE TEST CASES

sections. The straight, minor roadway with 300 passenger cars per hour at an average speed of 40 mph has only one section.

Since most of the sound is radiated from the major roadway and the receiver locations are symmetrical about its first section, the sound pressure levels calculated at the two receivers are about equal.

Test case 2 involves the same parameters as in test case 1 as well as two barriers. One of the barriers might be a hill or an earth berm and is therefore of an absorptive type. The other barrier might be a building and is specified by four reflective sections.

The absorptive barrier is between 10 and 20 ft higher than the major roadway and shields receiver no. 1 against noise from almost the entire major roadway. However, diffraction of sound over the barrier and reflections from the other barrier limit the noise reduction at this receiver to about 8 dB(A). Receiver no. 2 is only partially shielded by the reflective barrier against noise from the major roadway so that the noise reduction is only about 3 dB(A).

```
COLUMN NUMBER
    5    10   15   20   25   30        40        50        60

 TEST CASE 1
    1
0.            1               RECEIVER HEIGHT ADJUSTMENT
9.            2               NUMBER OF FREQUENCY BANDS
2.5           3               STANDARD DEVIATION FOR CARS
3.5           4               STANDARD DEVIATION FOR TRUCKS
0.            5               HEIGHT ADJUSTMENT FOR CARS
8.            6    L          HEIGHT ADJUSTMENT FOR TRUCKS
    2    2
1000.     60.           1
100.      50.           2     L
100.      200.      20.
1100.     200.      0.
1600.     0.        0.        L
300.      40.           1     L
700.      800.      10.
100.      200.      20.       L
    4    1
900.      300.      -5.       240.
1100.     600.      -5.       T
    5    2
550.      -100.     15.
550.      500.      10.
    6
 TEST CASE 2
    3    2
300.      100.      30.
900.      100.      20.
1200.     -100.     10.       A
400.      250.      40.
700.      250.      40.
700.      300.      40.
400.      300.      40.
400.      250.      40.       R
    6
```

```
                   TRAFFIC NOISE PREDICTION


TEST CASE 1

PROGRAM INITIALIZATION PARAMETERS
 0.00000E+00          1      RECEIVER HEIGHT ADJUSTMENT
 0.90000E+01          2      NUMBER OF FREQUENCY BANDS
 0.25000E+01          3      STANDARD DEVIATION FOR CARS
 0.35000E+01          4      STANDARD DEVIATION FOR TRUCKS
 0.00000E+00          5      HEIGHT ADJUSTMENT FOR CARS
 0.80000E+01          6      HEIGHT ADJUSTMENT FOR TRUCKS

ROADWAY #  1

NUMBER OF                VEH/H         MPH
TYPE 1 VEH
   1                     0.1000E+04    0.6000E+02

NUMBER OF                VEH/H         MPH
TYPE 2 VEH
   1                     0.1000E+03    0.5000E+02
                        SOURCE COORD IN FT

NUMBER       X             Y             Z
   1      0.1000E+03    0.2000E+03    0.2000E+02
   2      0.1100E+04    0.2000E+03    0.0000E+00
   3      0.1600E+04    0.0000E+00    0.0000E+00

ROADWAY #  2

NUMBER OF                VEH/H         MPH
TYPE 1 VEH
   1                     0.3000E+03    0.4000E+02
                        SOURCE COORD IN FT

NUMBER       X             Y             Z
   1      0.7000E+03    0.8000E+03    0.1000E+02
   2      0.1000E+03    0.2000E+03    0.2000E+02

ABSORBING STRIP #  1  (T)

PT #         X             Y             Z               WIDTH
   1      0.9000E+03    0.3000E+03   -0.5000E+01    0.2400E+03
   2      0.1100E+04    0.6000E+03   -0.5000E+01

RECEIVER                 RECEIVER COORD IN FT
NUMBER       X             Y             Z
   1      0.5500E+03   -0.1000E+03    0.1500E+02
   2      0.5500E+03    0.5000E+03    0.1000E+02


TEST CASE 1

RECEIVER #             XRC           YRC           ZRC
     1                550.0        -100.0          15.0

               63      125      250      500     1000     2000     4000     8000
              41.2     53.5     58.4     63.4     63.0     60.8     53.1     39.5
             A(500)
```

```
        68.0
         A
        68.1
2                 550.0         500.0         10.0

         63       125      250      500     1000     2000     4000     8000
        41.5      53.6     58.4     63.4     63.2     60.9     53.4     40.6
       A(500)
        68.1
         A
        68.2
```

```
TEST CASE 2

ROADWAY #   1

NUMBER OF               VEH/H          MPH
TYPE 1 VEH
   1                    0.1000E+04    0.6000E+02

NUMBER OF               VEH/H          MPH
TYPE 2 VEH
   1                    0.1000E+03    0.5000E+02
                       SOURCE COORD IN FT

NUMBER        X             Y              Z
   1       0.1000E+03    0.2000E+03    0.2000E+02
   2       0.1100E+04    0.2000E+03    0.0000E+00
   3       0.1600E+04    0.0000E+00    0.0000E+00

ROADWAY #   2

NUMBER OF               VEH/H          MPH
TYPE 1 VEH
   1                    0.3000E+03    0.4000E+02
                       SOURCE COORD IN FT

NUMBER        X             Y              Z
   1       0.7000E+03    0.8000E+03    0.1000E+02
   2       0.1000E+03    0.2000E+03    0.2000E+02

BARRIER #   1   (A)            BARRIER COORD IN FT

NUMBER        X             Y              Z
   1       0.3000E+03    0.1000E+03    0.3000E+02
   2       0.9000E+03    0.1000E+03    0.2000E+02
   3       0.1200E+04   -0.1000E+03    0.1000E+02

BARRIER #   2   (R)            BARRIER COORD IN FT

NUMBER        X             Y              Z
   1       0.4000E+03    0.2500E+03    0.4000E+02
   2       0.7000E+03    0.2500E+03    0.4000E+02
   3       0.7000E+03    0.3000E+03    0.4000E+02
   4       0.4000E+03    0.3000E+03    0.4000E+02
   5       0.4000E+03    0.2500E+03    0.4000E+02

ABSORBING STRIP #   1   (T)

PT #          X             Y              Z             WIDTH
   1       0.9000E+03    0.3000E+03   -0.5000E+01    0.2400E+03
   2       0.1100E+04    0.6000E+03   -0.5000E+01

RECEIVER                RECEIVER COORD IN FT
NUMBER        X             Y              Z
   1       0.5500E+03   -0.1000E+03    0.1500E+02
   2       0.5500E+03    0.5000E+03    0.1000E+02
```

```
TEST CASE 2

RECEIVER #            XRC           YRC          ZRC
     1               550.0        -100.0         15.0

             63      125      250      500      1000     2000     4000     8000
            36.6     48.4     52.4     56.1     54.1     50.3     41.2     23.0
           A(500)
            60.5
             A
            60.1
     2               550.0         500.0         10.0

             63      125      250      500      1000     2000     4000     8000
            38.8     50.3     55.0     59.8     59.9     57.6     49.7     37.0
           A(500)
            64.7
             A
            64.8
```

References

1. N. Olson, "Statistical Study of Traffic Noise," National Research Council of Canada, Division of Physics, APS-476 (1970).

2. W.J. Galloway, W.E. Clark, and J.S. Kerrick, "Highway Noise Measurement, Simulation, and Mixed Reactions," NCHRP Report 78 (1969).

3. RRL Report LR 357, "A Review of Road Traffic Noise," Road Research Laboratory, Crowthorne, Berkshire (England) (1970).

4. U.J. Kurze and L.L. Beranek, "Sound Propagation Outdoors," in L.L. Beranek (ed.) *Noise and Vibration Control*, McGraw-Hill Book Company, New York, 1971, p. 170.

5. E.J. Rathé, "Note on Two Common Problems of Sound Propagation," *J. Sound Vib*, 10(2) 472-479 (1969).

6. U.J. Kurze, G.S. Anderson, "Sound Attenuation by Barriers," *Applied Acoustics*, 4, 35-63 (1971).

7. W.E. Scholes, A.C. Salvidge, and J.W. Sargent, "Field Performance of a Noise Barrier," Building Research Station, Ministry of Public Building and Works, EN 40/70 England (August 1970).

8. H. Jonasson, "The Propagation of Sound over Ground With and Without Acoustic Barriers," Division of Building Technology, Lund Institute of Technology, Sweden, Report 18 (Ph.D. thesis) (May 1971).