Technical Report: NAVTRAEQUIPCEN IH-200

ANALYSIS OF UNDERWATER ACOUSTIC PROGATION LOSS MATH MODELS IN CURRENT TRAINING DEVICES

PA

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August 1972

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ABSTRACT

This report analyzes and compares the various simulation designs and math models of underwater acoustic simulation presently being utilized in current training devices developed by the Naval Training Device Center. The analysis contains model simplifications and their affects on acoustic propagation loss. The comparative analysis includes Device 14E19, Basic AN/SQS-26 Sonar Operator Trainer; Device 14B44, P-3C DIFAR Operator Trainer; Device 2F69, P-3A Weapon System Trainer; Device 21A37, Submarine Fleet Ballistic Missile Training Facility; and Device 21A39/2, Sonar Room Tactical Team Trainer. The results of these models are then compared with the results of the ray trace model developed by the Naval Air Development Center.

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Naval Training Equipment Center,
Orlando, Florida 32813

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
Analysis of Underwater Acoustic Propagation Loss Math Models In Current Training Devices

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report May 1972

5. AUTHOR(S) (First name, middle initial, last name)
E. F. Meyer

6. REPORT DATE
May 1972

7a. TOTAL NO. OF PAGES
40

7b. NO. OF REFS
17

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. NAVTRADEVCEN E.W.A. 71-3047

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
NAVTRAEQUIPCEN IH-200

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Naval Training Equipment Center,
Orlando, Florida 32813.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mathematical Models						
Underwater Acoustics						
Sound Transmission						
Ray Tracing						
Transmission Loss						
Training Devices						

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ANALYSIS OF UNDERWATER ACOUSTIC PROPAGATION LOSS MATH MODELS IN CURRENT TRAINING DEVICES

I. INTRODUCTION

This report analyzes and compares the various simulation designs and math models of underwater acoustic simulation presently being utilized in current training devices developed by the NAVTRADEVCEN.

First, the basic underwater acoustic terms are defined which are required in the discussion of the various math models. Secondly, a study and comparative analysis is made of the propagation loss models utilized in five current training devices.

I.I SOUND PROPAGATION LOSSES IN THE OCEAN

As sound travels through the ocean, the pressure associated with the wave front diminishes, this decrease in pressure is referred to as propagation loss. There are three factors which contribute to this loss.

a. Spreading Loss. Spreading of the wave front causes the total energy associated with the wave front to be distributed over a larger area, resulting in a decrease in intensity. This loss is generated by the inverse square spreading law. As the energy travels away from the source, it spreads in the form of spherical shell. The decrease in intensity is exactly proportional to the increase in the surface area of the sphere. Since the surface area is given by $A = 4\pi R^2$ the decrease in intensity is proportional to the square of the radius. The loss in dB due to spreading between a point one yard from the source and the receiver is given by:

$$\text{Spherical Spreading Loss (db)} = 10 \log R^2 = 20 \log R$$

where R is the range in yards between the source and receiver. The intensity loss from spherical spreading increases about 6 dB per distance doubled.

In cylindrical spreading, the wave front expands in the form of a cylinder having a constant height which is determined by the thickness of the sound channel or sound duct. Cylindrical spreading loss is one-half of the spherical spreading loss in dB over equal ranges, and is presented by 10 log R in place of 20 log R. Therefore, intensity loss from cylindrical spreading increases about 3 dB per distance doubled and is given by:

$$\text{Cylindrical Spreading Loss (dB)} = 10 \log R.$$

b. Attenuation Loss. The reduction in sound pressure level due to absorption and scattering is usually termed attenuation loss. Absorption is essentially the conversion of acoustic energy to heat. As a sound wave passes through the ocean it is accompanied by successive compressions and expansions of the medium which produces some frictional heat loss from the sound wave as well as heat loss produced by the disassociation of dissolved salts in sea water.

Although scattering is a component in the attenuation of sound, its contribution is not as important as that of absorption. When sound rays strike reflectors such as bubbles, fish, and suspended matter, sound energy is reflected away from the direction in which the major portion of the sound field is traveling, so that the wave itself suffers a loss in energy and hence, the intensity decreases.

c. Reflection. The surface of the ocean is rarely smooth; therefore, sound energy striking it is seldom reflected specularly (mirror reflection). Since the ocean surface is constantly changing, the sound energy is reflected in many directions. Surface reflection is a function of both sea state and frequency.

The ocean bottom may also reflect sound waves. Sound reflected from the ocean bottom usually suffers a significant loss in intensity. Part of this loss is due to scattering effects discussed above. The ocean bottom may be irregular and consequently reflect sound in many directions. The amount of energy lost through scattering will vary with the roughness of the bottom and frequency. Most of the bottom loss, however, results from the fact that a portion of the sound energy will enter the bottom and travel in it as a new sound wave. The amount of energy which is lost into the bottom will vary with the composition of the bottom, frequency of the sound wave, and the angle at which the sound wave strikes the bottom.

The total propagation loss over any given path is the sum of the losses due to spreading, attenuation, and reflection. Each of these component losses is subject to some degree of variability and uncerttainty. For these reasons the total propagation loss of sound waves traveling between any two points in the ocean cannot be predicted exactly. In practice, the propagation loss over any particular path can only be estimated by use of average measured values obtained from many observations.

1.2 DEVICE 14E19 PROPAGATION LOSS MODELS

This section provides the propagation loss models for Basic AN/SQS-26 Sonar Operator Trainer, Device 14E19 (reference 1). The propagation loss models used to simulate AN/SQS-26 surface duct mode of propagation are based upon the AMOS (Acoustic Meterological, and Oceanographic Survey) equations (references 2 and 3). AMOS variables and definitions are as follows:

L = Surface isothermal layer depth (ft)

S = Sea state

T = Water temperature (°F)

R = Range (kyds)

Z_0 = Own ship depth (ft)

z = Target depth (ft)

f = Acoustic freq. (kHz)

N_W = Transmission loss (db)

a = Absorption coeff. (db/kyd)

a_S = Scattering coeff (db/kyd)

G = First depth loss factor (db)

H = Second depth loss factor (db)

The basic AMOS propagation loss equations are divided into three primary zones. Analytical definitions of these zones and corresponding propagation loss equations are as follows:

a. Direct Radiation Zone ($0 \leq r \leq 1$)

When both ends of the transmission path lie within or at the bottom of the surface layer, $0 \leq z_0 \leq 1$, $0 \leq z \leq 1$, the following equation applies:

$$Nw = 20 \log R + aR + G\ (z-z_0)\ r + 60. \qquad (3.1)$$

At all other times the smaller of the two transmission losses computed using equation (3.1) and equation (3.2) is used.

$$Nw_2 = 20 \log R + aR + [25 - \sqrt{|Z - L|} - \sqrt{|Z_0 - L|} + 25]\ (f/25)^{1/3} + 60 \qquad (3.2)$$

The term within the brackets is taken to be zero where it is negative.

b. Zone of First Order Surface Reflection ($z_0 \leq 1$, $r_1 \leq r \leq r_1 + 1/2$)

Energy has been reflected at least once from the surface, the following is used:

$$Nw_3 = 20 \log R + aR + 2\ (r-r_1)\ H\ (z, z_0) + [1-2\ (r-r_1)]\ G\ (z-z_0) + 60 \qquad (3.3)$$

The shadow zone beyond the limiting ray is delineated by:

$z_0 \leq 1$, $z \leq 1$, $r_1 \leq r \leq (r_1 + 1/2)$

For this zone equation (3.3) or equation (3.2) is used, whichever is smaller.

c. Zone of the Second or Higher Order Surface Reflection

$(z_0 \leq 1,\ r_1 + \frac{1}{2} \leq r)$

The following equation is used:

$$Nw_4 = 10 \log R + (a + a_s) R + H (z, z_0) - a \sqrt{L} (r_1 + \tfrac{1}{2}) + 10 \log [\sqrt{L} (r_1 + \tfrac{1}{2})] + 60 \qquad (3.4)$$

The shadow zone beyond the limiting ray is delineated by:

$z_0 \geq 1,\ z \geq 1,\ r_1 + \frac{1}{2} \leq r$

For this zone, equation (3.4) or (3.2) is used, whichever yields the smaller propagation loss.

The required parameters are as follows:

(1) Scaled Variables

$$r = \frac{R}{\sqrt{L}}$$

$$z = \sqrt{\frac{Z}{L}}$$

$$z_0 = \sqrt{\frac{Z_0}{L}}$$

$$r_1 = \tfrac{1}{4}[2 - z - z_0] \qquad z < 1,\ z_0 < 1$$

$$r_1 = \frac{\sqrt{z_0^2 - 1} + \sqrt{z^2 - 1}}{5} \qquad z > 1,\ z_0 \geq 1$$

(2) Absorption Coefficient (db/kyd)

$$a = \frac{Af^2 f_T}{f^2 + f_T^2} + \frac{Bf^2}{f_T}$$

where A = .651 B = .0269 and $f = 1.23 \times 10^6 \times e^{[-4830/(T + 459.6)]}$

For frequencies less than 4 kHz

$$a = \frac{.678 f^2}{f_T}$$

(3) Scattering Attenuation Coefficient (db/kyd)

$$a_s = 4.5 \sqrt{\frac{f}{L}} \qquad s < 3$$

$$a_s = 9 \sqrt{\frac{f}{L}} \qquad s \geq 3$$

(4) First Depth Loss Factor (db) G as a function of $z - z_0$ is defined as follows:

$$G\ (z - z_0) = .1 \times 10^{2.3\ (z - z_0)}\ (f/25)^{1/3} \qquad z - z_0 < 1$$

$$G\ (z - z_0) = 20\ (f/25)^{1/3} \qquad z - z_0 \geq 1$$

(5) Second Depth Loss Factor (db) H as a function of z_1, and z_0 is defined as follows:

$$H\ (z_1, z_0) = F\ (z - z_0) + F\ (z) + F\ (z_0)$$

where x is a dummy variable and F (x) is defined as follows:

$$F\ (x) = .4 \times 10^{x}\ (f/8)^{1/3} \qquad F > 8\ \text{kHz}$$

$$F\ (x) = .4 \times 10^{x} \qquad F \leq 8\ \text{kHz}$$

The objective of this subsection is to present the analytic functions that are used to simulate the AN/SQS-26 bottom bounce mode of propagation. Bottom bounce conditions will be assumed to exist only for bottom depths of 6,400 feet or greater and deflection/elevation angles greater than or equal to 10 degrees. For all other conditions, it is assumed that propagation takes place via surface duct or shallow water conditions. These assumptions are based upon the recommended modes of operation given in reference 4. For the simulation, it is assumed that the propagation loss to the target from the point of transmission is equal to the loss from the sound source to the point of reception. Based on this assumption, the one-way path loss in db for the bottom path is: BB

$$Nw_B = 20 \log R_s + aR_s + L_B\ (\theta_{TB})$$

where R_s = Slant range (yds)

a = Attentuation coeff (db/yd)

L_B = Bottom Loss (db)

θ_{TB} = Real bottom grazing angle (degrees)

Initially a function is required that determines the vertical angle θ_{Bi} as follows: $\theta_{Bi} = \tan^{-1} \dfrac{2D_{Bi} - D_T}{R_H}$

where D_{Bi} = Depth of bottom

D_T = Depth of target

R_H = Horizontal range

These variables are shown in figure 1.

Total slant range is calculated by the following equation:

$$R_s = \frac{D_{Bi}}{\sin \theta_{Bi}} + \frac{D_{Bi} - D_T}{\sin \theta_{Bi}} = \frac{2D_{Bi} - D_T}{\sin \theta_{Bi}}$$

The isovelocity angle θ_{Bi} is converted to a real angle equivalent in order to provide the real transmitted beam deviation loss angles to the target. The transmitted deviation loss angle is calculated as follows:

$$\theta_{Tbi} = -a_1 + \frac{\sqrt{a_1^2 - 4a_2 (a_0 - \theta_{Bi})}}{2a_2}$$

The a coefficients were generated by Honeywell and are included in table 1.

θ_{TB} is the real bottom grazing angle and is given by the following equation:

$$\text{Cos } \theta_{TB} = c^1 \cos \theta_{TBi}$$

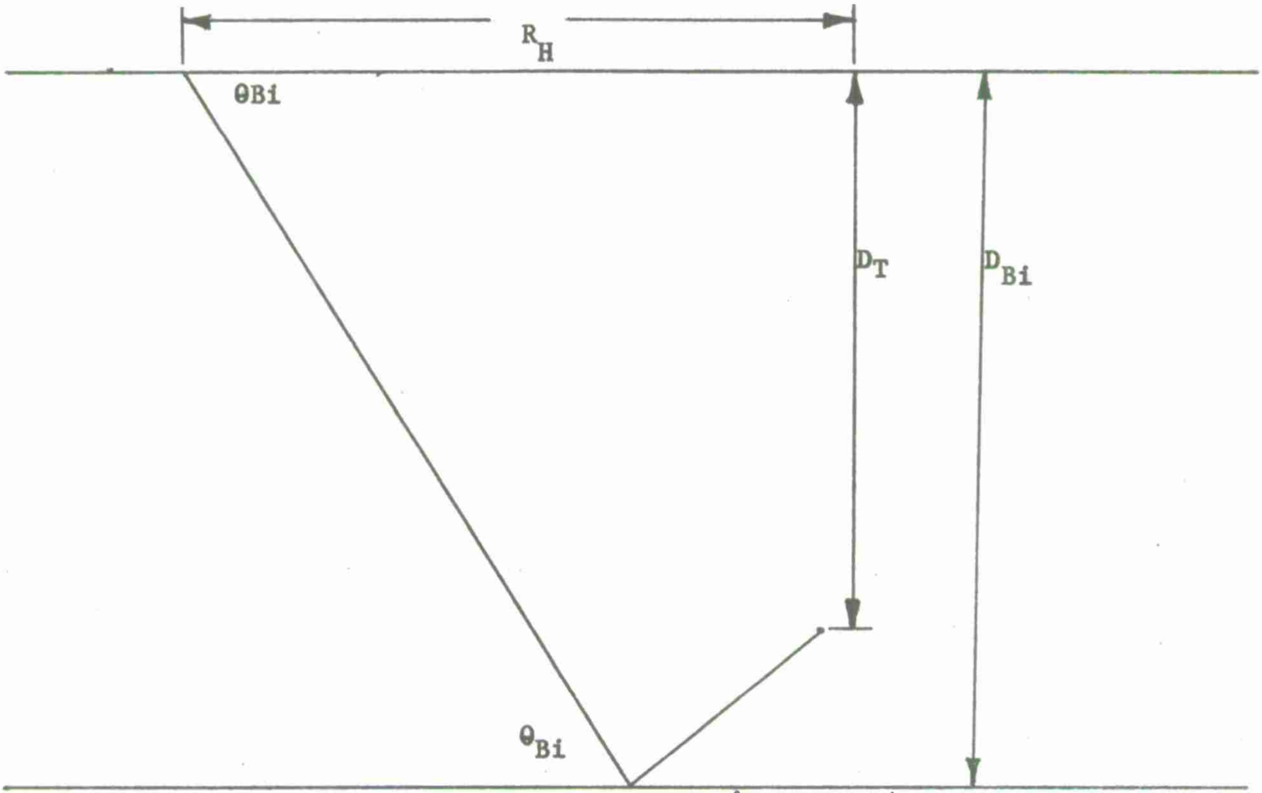
where c^1 are constants generated by Honeywell and given in table 2.

The attenuation coefficient is given by:

$$a = .033 (f)^{3/2}$$

where f = frequency (kHz)

and bottom loss simulation functions are analytically described by the following:



where $\theta_{Bi} = \tan^{-1}\left(\frac{2D_{Bi} - D_T}{R_H}\right)$ = Isovelocity Angle

Figure 1. Ray Angles Defined

TABLE 1. ISOVELOCITY/REAL-RAY ANGLE COEFFICIENTS

Isovelocity/Real-Ray Angle Coefficients						
Profile	Depth (Feet)	a_0	a_1	a_2	Standard Deviation	θ_{MIN}* Degrees
Standard 50 Foot Layer	6400	8.6023	0.6603	0.004213	±0.2688	2
	9600	9.1153	0.6226	0.004580	±0.3446	2
	12,800	8.2957	0.6442	0.004413	±0.3275	2
	16,000	5.0734	0.8200	0.001993	±0.0762	6
	25,600	-4.1881	1.2230	-0.002824	±0.2205	16
Standard 100 Foot Layer	6400	8.5830	0.6575	0.004051	±0.3257	2
	9600	8.8283	0.6394	0.004197	±0.3230	2
	12,800	8.0539	0.6602	0.004199	±0.3004	2
	16,000	4.7018	0.8417	0.001642	±0.0735	6
	25,600	-5.3533	1.2846	-0.003624	±0.3230	16
Standard 150 Foot Layer	6400	8.2015	0.6800	0.003792	±0.3237	2
	9600	8.5083	0.6594	0.004059	±0.2962	2
	12,800	7.7826	0.6703	0.004105	±0.2863	2
	16,000	4.3802	0.8616	0.001356	±0.2035	6
	25,600	-6.0692	1.3195	-0.004083	±0.3894	16
Standard 200 Foot Layer	6400	7.8392	0.7091	0.003424	±0.2613	4
	9600	8.0729	0.6832	0.003897	±0.2645	4
	12,800	7.1932	0.7087	0.003510	±0.2254	4
	16,000	4.2367	0.8610	0.001355	±0.0644	8
	25,600	-3.8743	1.1904	-0.002265	±0.1200	18
Standard 300 Foot Layer	6400	7.4898	0.7121	0.003468	±0.2399	4
	9600	7.6342	0.6993	0.003571	±0.2460	4
	12,800	6.6991	0.7257	0.003225	±0.2212	4
	16,000	3.8759	0.8760	0.001217	±0.1382	8
	25,600	-4.3241	1.2033	-0.002387	±0.1158	18
Standard 400 Foot Layer	6400	6.7703	0.7554	0.002769	±0.2747	4
	9600	7.2025	0.7099	0.003458	±0.2188	4
	12,800	6.1839	0.7527	0.003021	±0.2020	4
	16,000	2.7324	0.9477	0.000233	±0.3097	8
	25,600	-4.5184	1.2034	-0.002303	±0.1215	18
Temperate Summer 90 Foot Layer	6400	10.8105	0.5667	0.005255	±0.3742	2
	9600	10.6152	0.5615	0.005308	±0.3730	2
	12,800	9.6249	0.5991	0.004836	±0.3917	2
	16,000	6.7419	0.7527	0.002707	±0.1513	4
	25,600	-4.4007	1.2526	-0.003285	±0.2847	16
Temperate Autumn 260 Foot Layer	6400	8.4710	0.6676	0.004021	±0.2818	4
	9600	8.1893	0.6692	0.003965	±0.2718	4
	12,800	6.7723	0.7266	0.003110	±0.2283	4
	16,000	3.6068	0.8883	0.001142	±0.0593	8
	25,600	-5.4342	1.2542	-0.003012	±0.1717	18

TABLE 1. ISOVELOCITY/REAL-RAY ANGLE COEFFICIENTS (Continued)

Isovelocity/Real-Ray Angle Coefficients (continued)						
Profile	Depth (Feet)	a_0	a_1	a_2	Standard Deviation	θ_{MIN}* (Degrees)
Temperate Winter 350 Foot Layer	6400	3.8082	0.8795	0.001232	±0.1780	4
	9600	4.4706	0.8296	0.001974	±0.1486	4
	12,800	1.0820	0.8876	0.002349	±0.5132	8
	16,000	0.5318	1.0083	-0.002682	±0.1479	10
	25,600	-9.3678	1.4144	-0.004823	±0.4047	18
Equator Summer 215 Foot Layer	6400	10.1425	0.6102	0.004671	±0.2882	2
	9600	10.1572	0.5962	0.004847	±0.3291	2
	12,800	9.0422	0.6379	0.004252	±0.3152	2
	16,000	6.6005	0.7588	0.002645	±0.1591	4
	25,600	-3.4573	1.2037	-0.002655	±0.2279	16
Equator Autumn 215 Foot Layer	6400	9.5204	0.6509	0.003782	±0.2656	4
	9600	9.6214	0.6333	0.004030	±0.2537	4
	12,800	8.7852	0.6591	0.004052	±0.2521	4
	16,000	6.7517	0.7503	0.002748	±0.1578	4
	25,600	-2.9756	1.1783	-0.002332	±0.1924	16
Equator Winter 246 Foot Layer	6400	9.4627	0.6479	0.004053	±0.2129	2
	9600	9.7181	0.6155	0.004542	±0.2463	2
	12,800	8.9231	0.6462	0.004080	±0.3182	3
	16,000	6.6245	0.7504	0.002805	±0.1439	4
	25,600	-3.8493	1.2231	-0.002927	±0.2506	16
Polar Summer Zero Layer	6400	-9.6344	1.4214	-0.004949	±0.2494	14
	9600	-13.6549	1.5721	-0.006375	±0.4530	16
	12,800	-18.4531	1.7780	-0.008931	±0.5219	18
	16,000	-21.4276	1.8700	-0.009692	±0.4870	20
	25,600	-21.9089	1.9727	-0.009836	±0.1871	26
Polar Autumn Zero Layer	6400	3.3871	0.8592	0.001752	±0.1417	4
	9600	-0.3767	1.0361	-0.0004649	±0.1561	10
	12,800	-3.6426	1.1756	-0.002106	±0.1475	14
	16,000	-6.7215	1.2971	-0.003489	±0.2888	16
	25 600	-13.3254	1.4774	-0.004728	±0.1279	24
Polar Winter 462 Foot Layer	6400	-1.9621	1.0925	-0.009983	±0.1815	10
	9600	-4.1731	1.1687	-0.001777	±0.1272	14
	12,800	-7.4945	1.3072	-0.003417	±0.2077	16
	16,000	-10.7718	1.4317	-0.004738	±0.2356	18
	25,600	-18.8003	1.6906	-0.007045	±0.1744	24

* θ_{MIN} is the minimum ray angle that will strike the bottom. Angles less than θ_{MIN} are refracted upward before striking the bottom and do not give rise to bottom bounce coverage. For ray angles greater than 50 degrees, the isovelocity and real-ray angles can be assumed equal.

TABLE 2. BOTTOM BOUNCE CONSTANTS

Bottom Bounce Constant C'					
	Bottom Depth (Feet)				
Profile	6400	9600	12,800	16,000	25,600
<u>STANDARD</u>					
50 Foot Layer	0.97504	0.98297	0.99346	1.00436	1.03882
100 Foot Layer	0.97562	0.98355	0.99405	1.00495	1.03944
150 Foot Layer	0.97620	0.98414	0.99465	1.00555	1.04006
200 Foot Layer	0.97679	0.98472	0.99524	1.00615	1.04067
300 Foot Layer	0.97795	0.98590	0.99642	1.00735	1.04191
400 Foot Layer	0.97912	0.98707	0.99761	1.00855	1.04316
<u>EQUATOR</u>					
Autumn	0.97232	0.98082	0.99011	1.00099	1.03697
Summer	0.97232	0.98102	0.99071	1.00118	1.03718
Winter	0.97269	0.98100	0.99070	1.00119	1.03800
<u>TEMPERATE</u>					
Autumn	0.97790	0.98765	0.99701	1.00796	1.04440
Summer	0.97268	0.98099	0.98931	1.00218	1.03841
Winter	0.98438	0.99259	1.00280	1.01422	1.05026
<u>POLAR</u>					
Autumn	1.00103	1.01301	1.02478	1.03613	1.07062
Summer	1.02734	1.03963	1.05128	1.06336	1.09875
Winter	1.01104	1.02250	1.03417	1.04563	1.08043

(a) Mud Bottom

$L_B = 0$	$\theta_{TB} \leq 1$
$L_B = 1.1\ \theta_{TB} - .403$	$1 < \theta_{TB} \geq 19$
$L_B = 21.5$	$\theta_{TB} > 19$

(b) Mud/Sand Bottom

$L_B = 0.1$	$\theta_{TB} \leq 3$
$L_B = .825\ \theta_{TB} - 2.2549$	$3 < \theta_{TB} \leq 25$
$L_B = 17.4$	$\theta_{TB} > 25$

(c) Sand Bottom

$L_B = 0$	$\theta_{TB} \leq 5$
$L_B = .365\ \theta_{TB} - 1.738$	$5 < \theta_{TB} \leq 36$
$L_B = 11.5$	$\theta_{TB} > 36$

(d) Rock Bottom

$L_B = 0$	$\theta_{TB} \leq 21$
$L_B = .247\ \theta_{TB} -5.278$	$21 < \theta_{TB} \leq 50$
$L_B = 7.1$	$\theta_{TB} > 50$

The convergence zone mode of operation of the AN/SQS-26 is used to provide extremely long range detection capability by taking advantage of the refractive properties of the deep ocean. To determine the convergency zone range window and propagation losses within the window, acoustic ray path and propagation loss calculations were performed and provided by the USNUSL (Navy Underwater Sound Laboratory), (references 5 and 6). This data has been compiled in look-up tables and is not included in this report due to its voluminous content.

1.3 DEVICE 14B44 PROPAGATION LOSS MODELS

This section provides the propagation loss models for the P-3C DIFAR Operator Trainer, Device 14B44 (reference 7). The math model for total propagation loss is given by the following equation:

$$TL_T = TL_1 + TL_2 + TL_3 - TG$$

where TL_T = Total propagation loss

TL_1 = Loss due to spreading and attenuation

TL_2 = Surface bounce loss

TL_3 = Bottom bounce loss

TG = Convergence zone gain

The propagation loss is determined by linear approximations of transmission loss curves as shown in figure 2.

In the surface bounce mode of propagation, the propagation loss is determined as a function of sea state as indicated in table 3. The values in the table were determined by extrapolating Schulkins empirical curve (reference 8) which establishes the leakage loss as a function of frequency - waveheight product.

When operating in the bottom bounce mode of propagation, the loss due to reflection from the bottom is a function of bottom type only. In determining the bottom loss for simulation, average reflection values were taken for each of the three bottom types simulated. (References 9 and 10.) The bottom bounce loss is assumed to be zero for a hard bottom. For a medium and soft bottom the loss is assumed to be 3 dB and 9 dB respectively, as shown in table 4.

If a convergence zone exists between the source and receiver, a gain factor is subtracted from the total transmission loss. The convergence zone gain provides a minimum gain of 12 db with a further increase up to 3 db for the first convergence zone and up to 1.5 db for the second and third convergence zones as a function of the distance of the hydrophone to the center of the zone. The following model is based on a quantitative discussion of convergence zones by R. J. Urick (reference 9).

$$TG = 12 + \frac{3}{N} \frac{(1 - X_T - X_D)}{X_A}$$

where X_T = Target to sonobuoy flat range

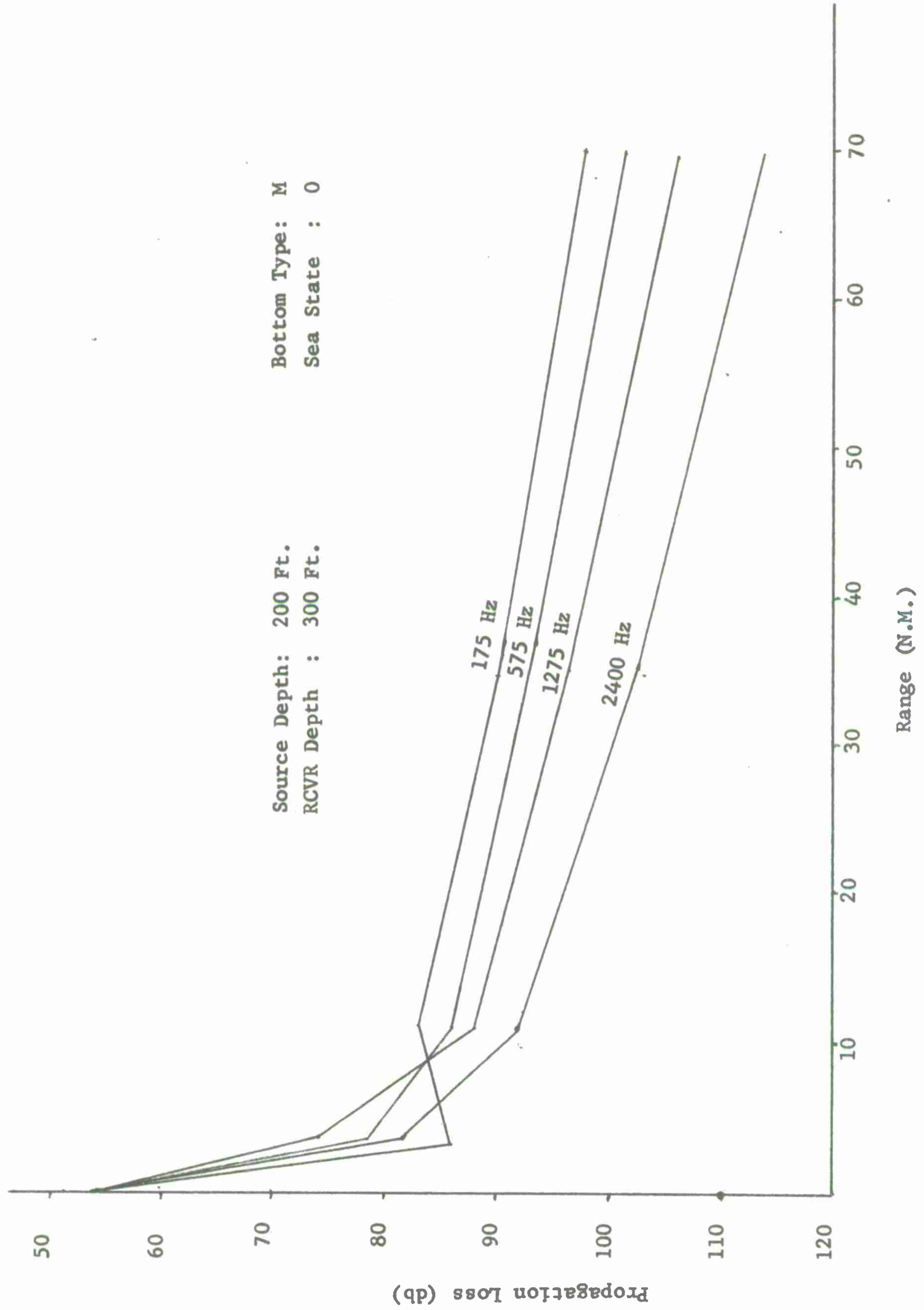


Figure 2. Propagation Loss Device 14B44

TABLE 3. SURFACE BOUNCE LOSS

SURFACE BOUNCE LOSS AS A FUNCTION OF SEA STATE	
Sea State	Surface Bounce Loss (TL_2)
0	2 db
1	2 db
2	3 db
3	4 db
4	6 db

TABLE 4. BOTTOM BOUNCE LOSS

BOTTOM BOUNCE LOSS AS A FUNCTION OF BOTTOM TYPE	
Bottom Type	Bottom Bounce Loss (TL_3)
Hard	0 db
Medium	3 db
Soft	9 db

X_D = Ranges between midpoint of convergence zone and target

X_A = 1/2 convergence zone width

N = Number of the convergence zone

It is important to note that these models are limited to frequencies less than approximately 2500 Hz.

1.4 DEVICE 2F69, PROPAGATION LOSS MODELS

The objective of this section is to present the propagation loss math model for Device 2F69, P-3A Weapon System Trainer (reference 11). The sound energy is attenuated in the simulated environment by the following equation:

$$N = 20 \log R + (.2f + .00015 f^2) R + 60 \text{ db}$$

where N = nominal statistical average propagation loss between two points (db)

where R = range from source (Kyd)

where f = signal frequency (kHz)

The frequency dependent term is small for low frequencies and would indicate a 20 db loss per range decade or again, the spreading loss varies as a function of the inverse of R^2.

1.5 DEVICE 21A37, PROPAGATION LOSS MODELS

This section describes the acoustic propagation loss model for Device 21A37, Submarine Fleet Ballistic Missile Training Facility (reference 12). The earlier sonar math modes for Device 21A37 were constructed on the basis of ray and wave acoustic theory, using references 13 and 14, and additional data was obtained from reference 15. T. Einstein of USNUSL pointed out that this procedure was erroneous since project AMOS showed that classical sound theory applied only for short ranges and at high frequencies. Consequently, work in this area was discontinued and USL Research Report 491 (reference 16) was adopted as the basis for sonar simulation. Two separate cases are considered:

a. Shallow target and shallow sonar

b. Deep target or deep sonar.

For a particular set of parameters, bottom-path detection range and direct path detection range should be investigated and the greater of the two chosen. Curve α represents the bottom path detection curve; curve β the direct-path detection curve for case a; and curve γ, the direct-path detection curve for case b. The curves for layer depths, 0 ft. and 400 ft., were obtained directly from the corresponding curves in reference 16. The curves corresponding to other values of layer depth were obtained by graphically interpolating between 0 ft. and 400 ft., curves. The curve for 100 ft. layer depth is shown in figure 3. Each curve is individually analyzed and subsequently approximated by linear segments.

1.6 DEVICE 21A39/2 PROPAGATION LOSS MODELS

This section provides the propagation loss models for Device 21A39/2 Sonar Room Tactical Team Trainer (reference 17) Transmission effects of the direct path mode of propagation are simulated as a function of range, frequency, layer depth, target depth and own ship depth. The total direct path propagation loss is taken as the sum of a nominal loss and a layer depth correction factor. The nominal propagation loss is shown in figure 4, for representative ranges between 1 and 100 Kyds. The layer depth correction factor A is defined by the following equations:

$$A = (Z/L)\,R \qquad Z \leq 2.7\,L$$

$$A = (2.7)\,R \qquad Z > 2.7\,L$$

where Z = Average of own ship and target depth (ft)
L = Layer depth (ft)
R = Target range (Kyds)

The minimum value of Z is 20 ft.

Transmission effects of the bottom bounce mode of propagation are simulated as a function of range and frequency as shown in figure 5. Bottom bounce loss equals the value at 4 Kyds for ranges less than 4 Kyds.

1.7 COMPARATIVE ANALYSIS AND MODEL SIMPLIFICATION

This section includes a discussion on the comparative analysis of the five previously discussed propagation loss math models and the NADC (Naval Air Development Center) ray trace model. The models have been analyzed on the basis of the major modes of propagation. Figures 6, 7, and 8 contain a comparative analysis of the direct path propagation, surface bounce propagation, and bottom bounce propagation respectively. The propagation loss curves were constructed from the various math models as a function of the variables listed in table 5. However, target and source depths, layer depth, temperature, sea state, bottom type and depth are not functions in all of the math models.

Analysis of the direct path propagation models, figure 6, shows that the propagation loss curves for Devices 21A39, 21A37, and 2F69 are approximately the same. Further analysis indicated that the propagation loss curve

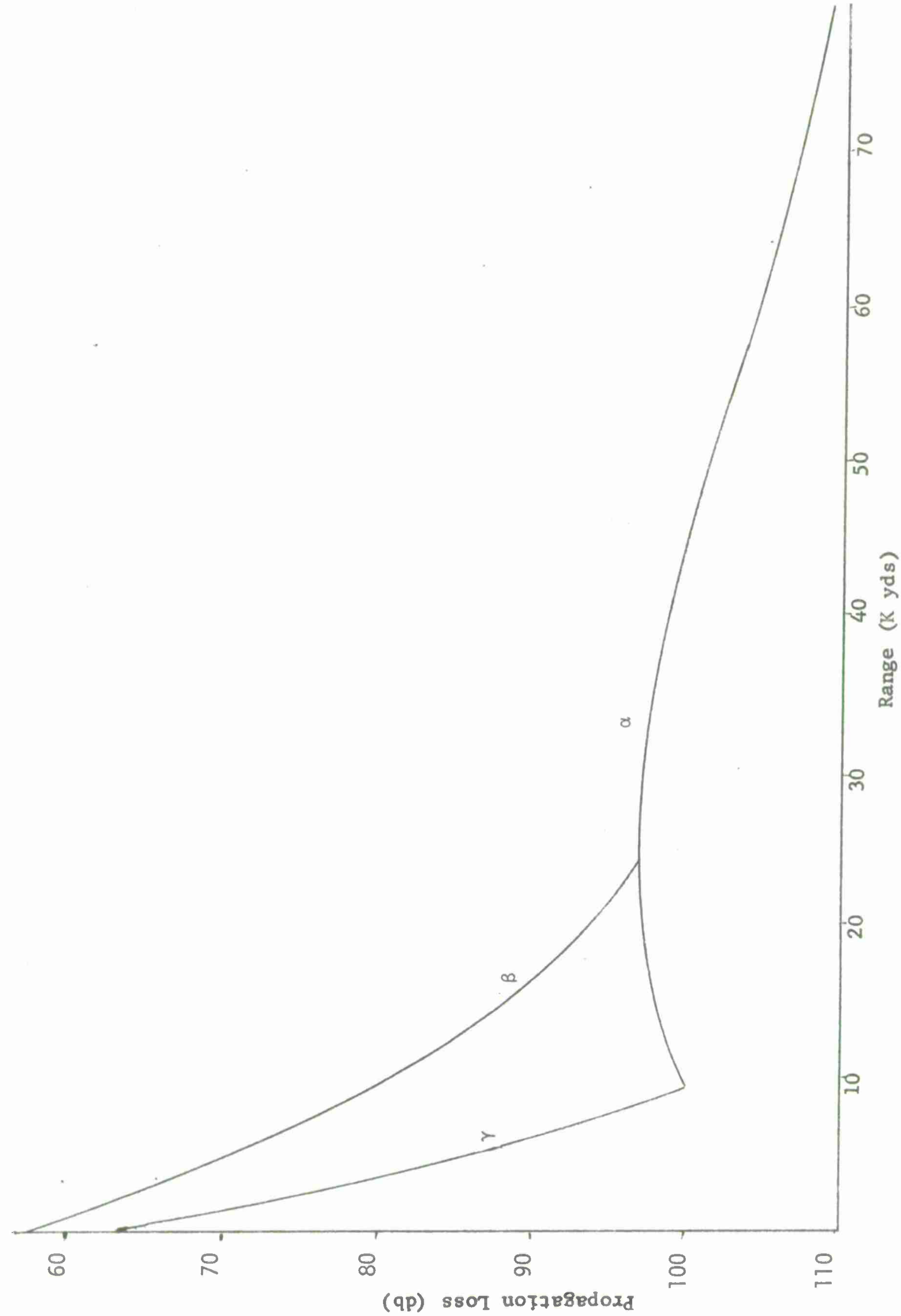


Figure 3. Propagation Loss Device 21A37

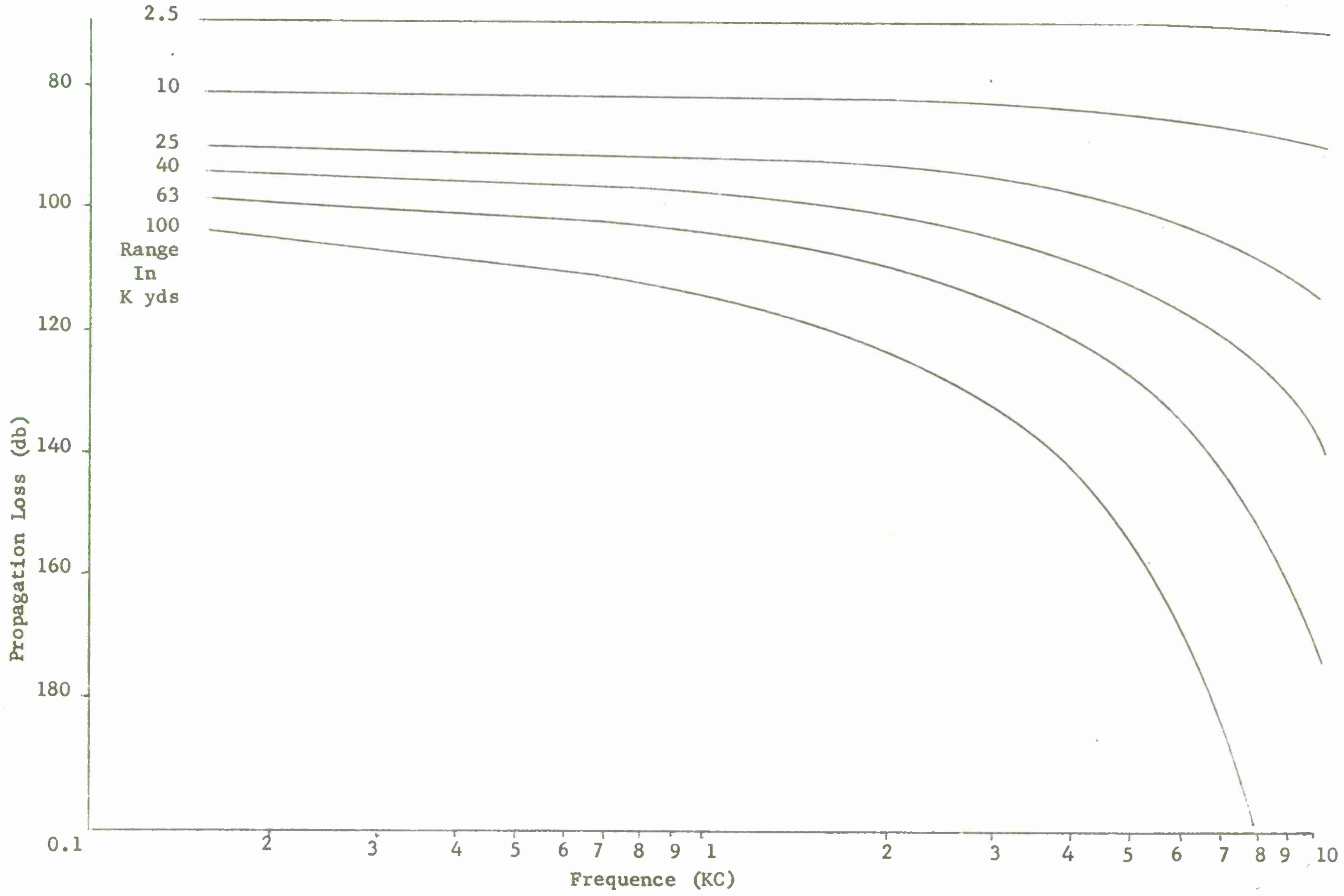


Figure 4. Nominal Direct Path Propagation Loss Device 21A39

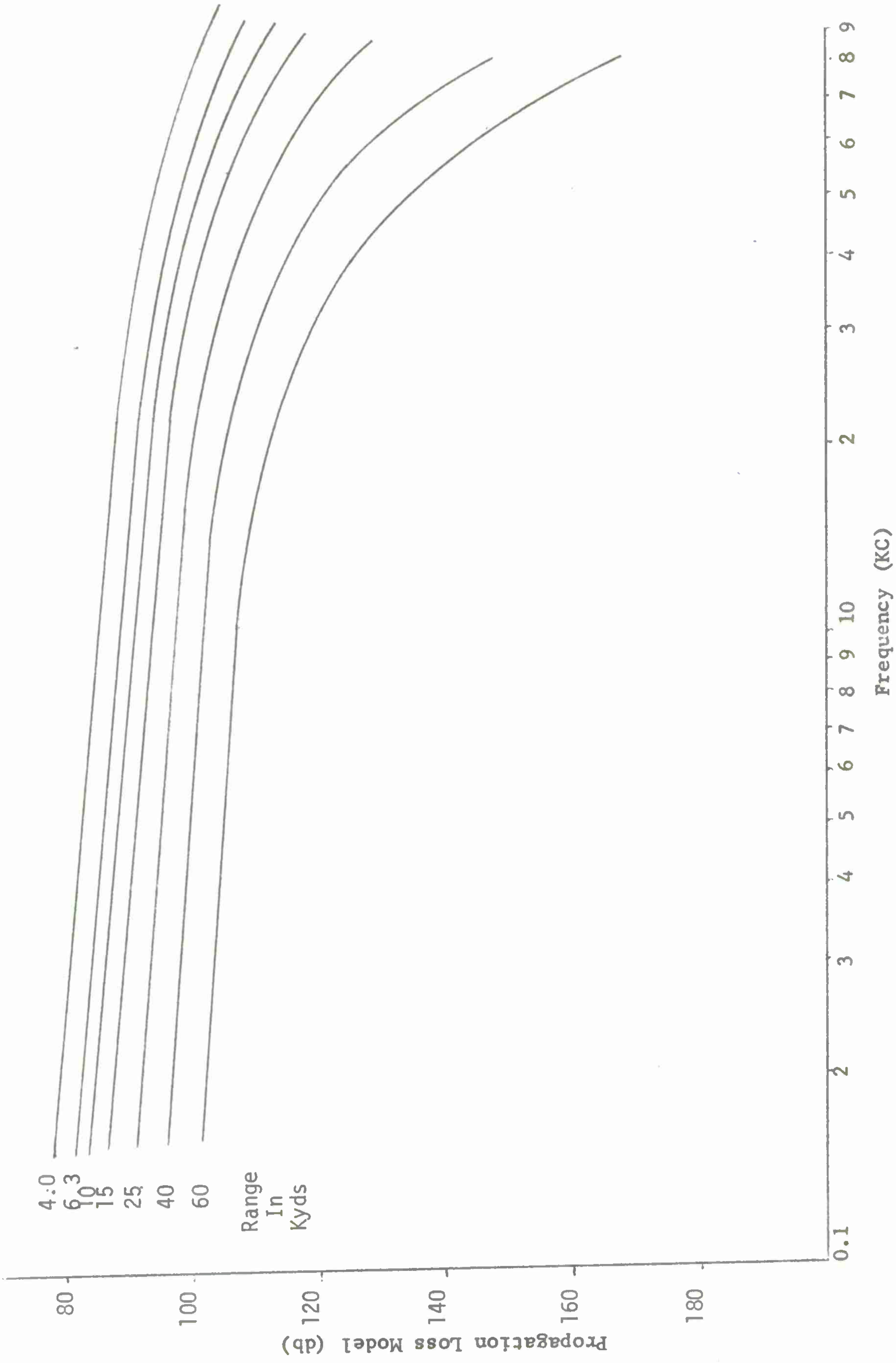


Figure 5. Bottom Bounce Propagation Loss Device 21A39

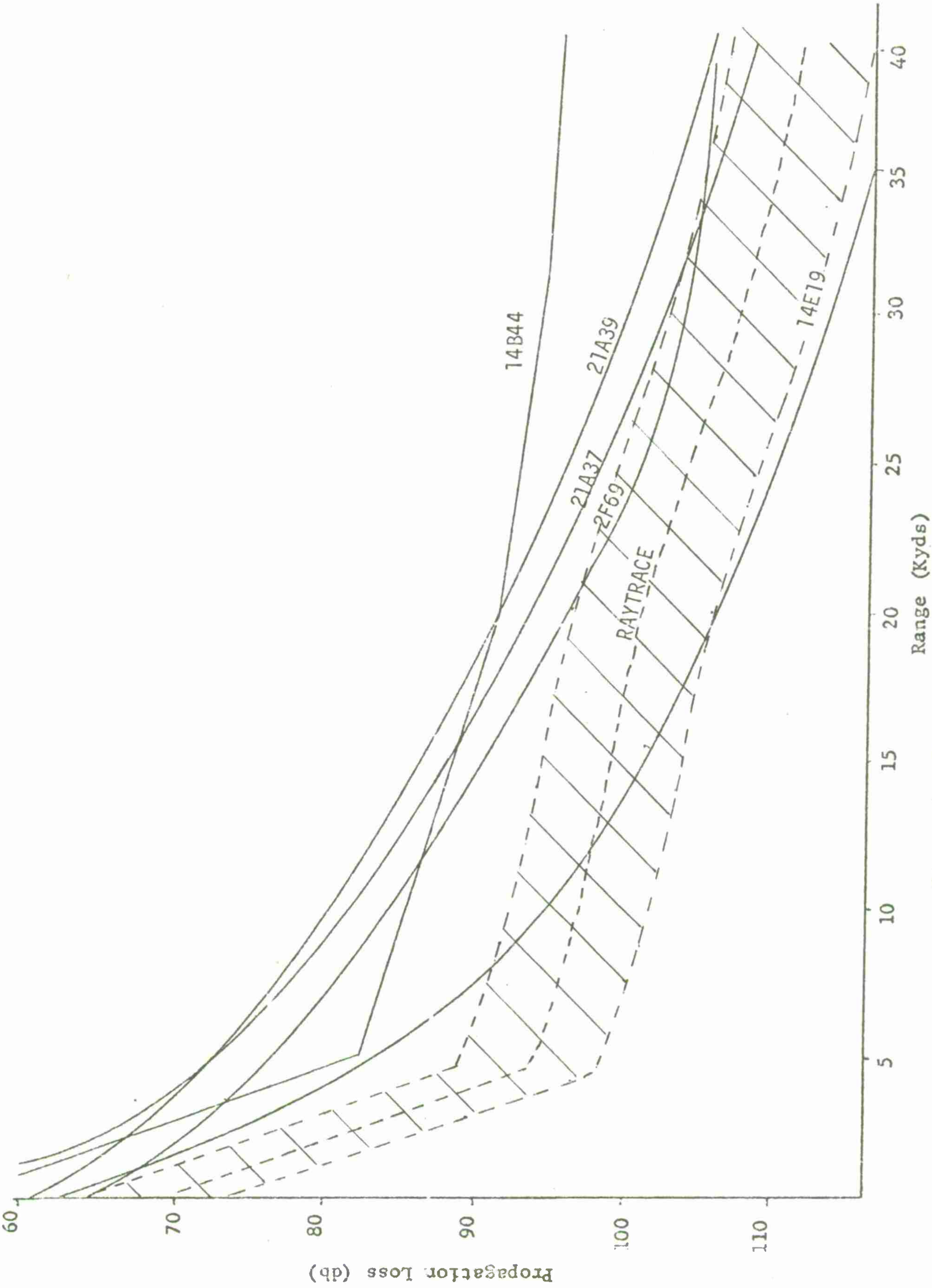


Figure 6. Comparative Analysis - Direct Path Propagation

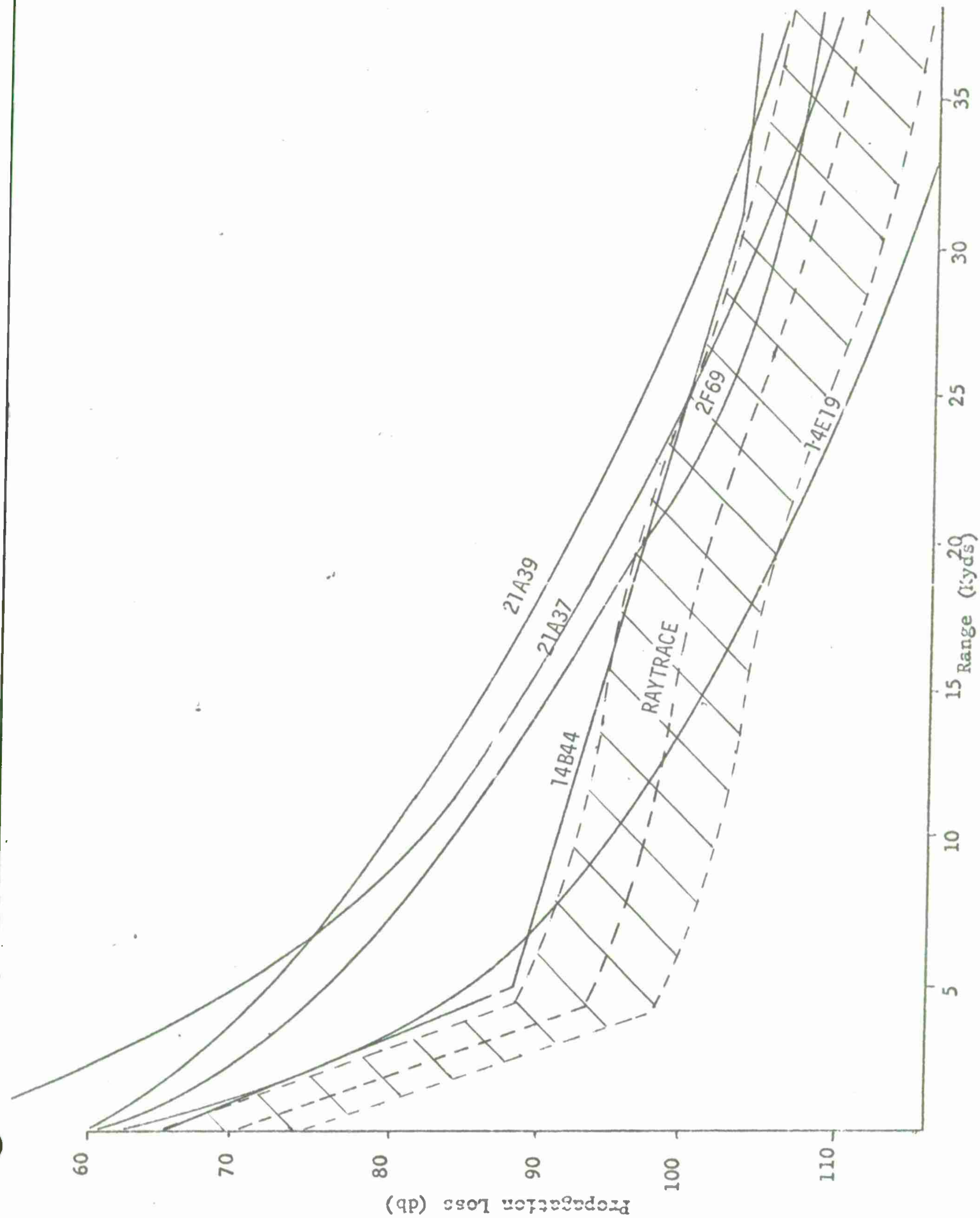


Figure 7. Comparative Analysis - Surface Bounce Propagation

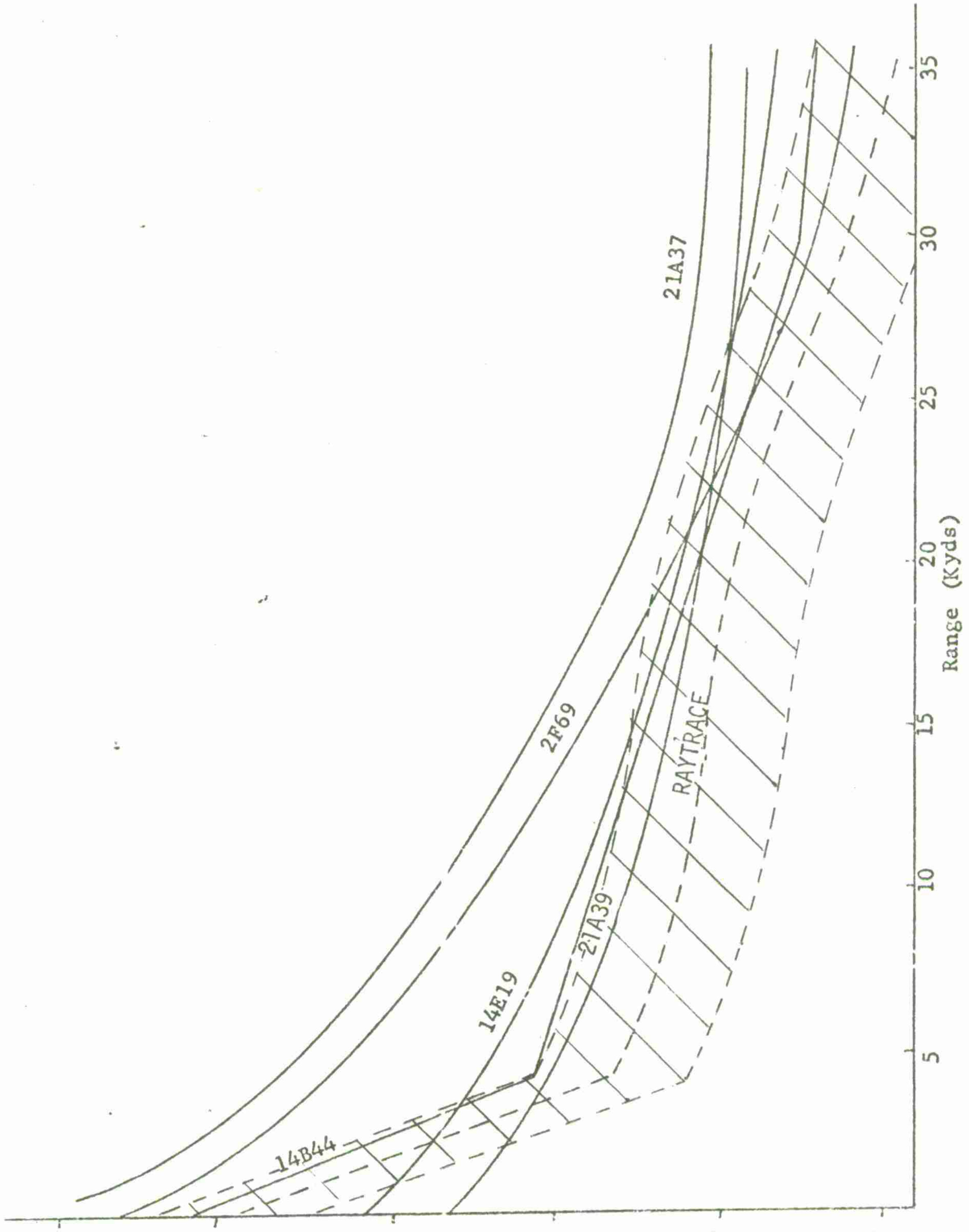


Figure 8. Comparative Analysis - Bottom Bounce Propagation

TABLE 5. MATH MODEL VARIABLES

Math Model Variables	Selected values
Target depth	200 feet
Source depth	20 feet
Layer depth	300 feet
Temperature	50° Fahrenheit
Sea state	$\geq$ 3
Bottom type	Soft
Bottom depth	12,800 feet
Range	0 - 35 Kyds
Frequency	2.5 kHz

for Device 14E19 consists of basically three separate slopes as a function of range. The slope for ranges less than 5 Kyds compares favorably with the other models discussed. The major problem arises from the slope of the curve for ranges between 5 and 25 kyds and the slope for ranges greater than 25 kyds. The goal to be realistically achieved would be ± 5 db of the NADC ray trace model. Therefore, tolerance limits have been set at ± 5 db and are shown by the shaded area.

Further analysis of figure 6 indicates definite break points in the propagation loss curve for Device 14B44. The propagation model consists of basically four parts: A basic loss term, a convergence zone term, a surface loss term, and a bottom loss term. The basic loss term is derived from Fleet Numericals' ASWEPS data package. ASWEPS is designed to function in all ocean areas. Incoming synoptic reports are summarized, analyzed, and then transmitted daily from the U.S. Naval Oceanographic Office. Passive sonar ranges are derived from a high speed propagation loss model valid for low frequencies. This model is a modified ray trace which calculates losses via surface duct, and convergence zones, assuming initially that the ocean is isovelocity and then making an empirical correction for refraction. The ASWEPS data is broken down for various ocean areas, summer and winter conditions, and a combination of four source and receiver depths. This information is provided at four discrete frequencies up to 1,700 Hz. The NADC ray trace model was chosen for comparison here since it is very similar to the ray trace model utilized in generating the ASWEPS curves.

In the Device 14B44 propagation loss model, all source and receiver depths have been averaged, then the data is averaged over winter and summer and finally averaged over all areas. The result is four curves, one for each frequency, of propagation loss versus range. These curves are then approximated with four linear approximations resulting in the definite break points in the curves. There are also very significant differences in propagation loss between different areas and also in the same area for different seasons which have an important bearing on training, as illustrated by the difference in the propagation loss resulting from the averaging of depths, seasons, and latitudes in the Device 14B44 model.

Analysis of the surface bounce propagation models, figure 7, again shows the steeper slope of the Device 14E19 propagation loss curve and the definite break points in the Device 14B44 propagation loss curve. Although the basic loss term for the Device 14B44 propagation loss model is derived from the ASWEPS data, the surface loss term is derived from AMOS data. The data from which the AMOS results were derived only covered the frequency range from 2 KHz to 25 KHz. The AMOS results were not intended to be used at low frequencies. To extend these results below 2 KHz will result in error. An error exists in the fact that the same surface bounce loss is added to the basic curves at all ranges. In the real world the surface bounce loss increases as a function of range and the number of surface bounces. Still another error exists in that the surface loss has previously been included in the composite ASWEPS data and should not be included a second time.

Analysis of the bottom bounce propagation models, figure 8, reveals an unusually large initial propagation loss variation. The deviation here can be as much as 25 dB and should be revised by adding a correction factor for short ranges.

The bottom bounce propagation loss model for Device 14E19 was based on the assumption of ideal straight line (isovelocity) propagation paths. In the real world, the ocean rarely provides ideal isovelocity conditions and the propagation paths differ radically from straight line paths. The variation depends on the ocean velocity structure. Even though real ray angles are computed from the equivalent isovelocity angles, it appears as though an error is introduced here, particularly at short ranges.

In the Device 14B44 bottom bounce propagation model, if the bottom loss is considered important, a loss of 0, 3, or 9 dB is added to the basic loss term depending on the bottom type. The same bottom loss is added to the basic curves at all ranges. This is contrary to what actually happens. Operating in deep water at low frequencies, energy incident on the bottom at low grazing angles suffers considerably less than higher grazing angles. The same error also arises here as in the surface loss propagation model, in that the bottom loss has previously been included in the composite ASWEPS data and should not be included a second time.

To aid in error analysis, relative error was plotted versus range for each model and each major mode of propagation as shown in figures 9, 10, and 11. A positive error indicates a decreased propagation loss resulting in a stronger signal strength and premature target detection. A negative error indicates too great a magnitude of propagation loss resulting in a weaker signal and delayed target detection. At short ranges it is shown that the error is consistantly positive, resulting in premature target detection. At greater ranges, it is found that the relative error is still generally positive although considerably less than that found at shorter ranges.

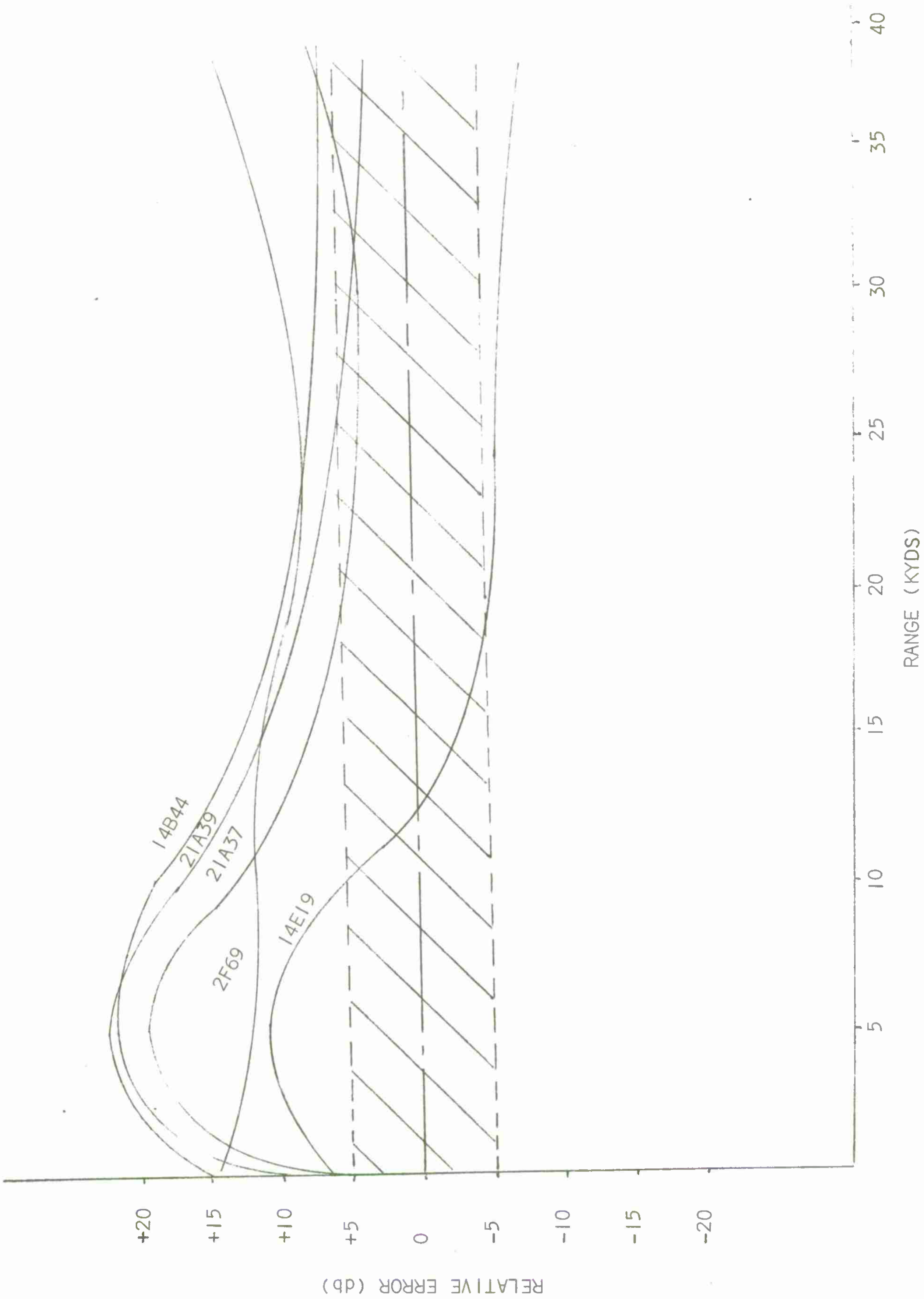


Figure 9. Relative Error -- Direct Path Propagation

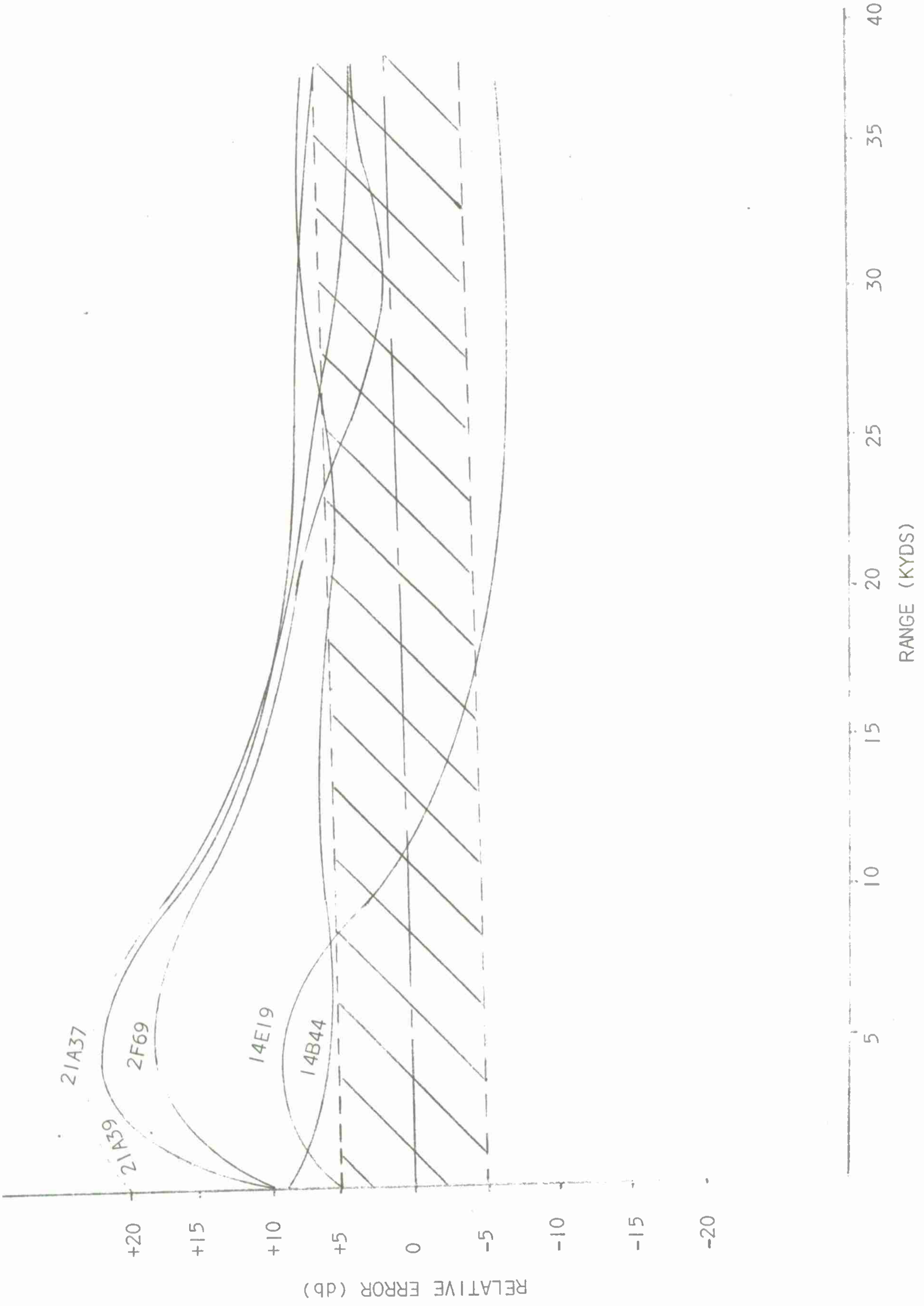


Figure 10. Relative Error -- Surface Bounce Propagation

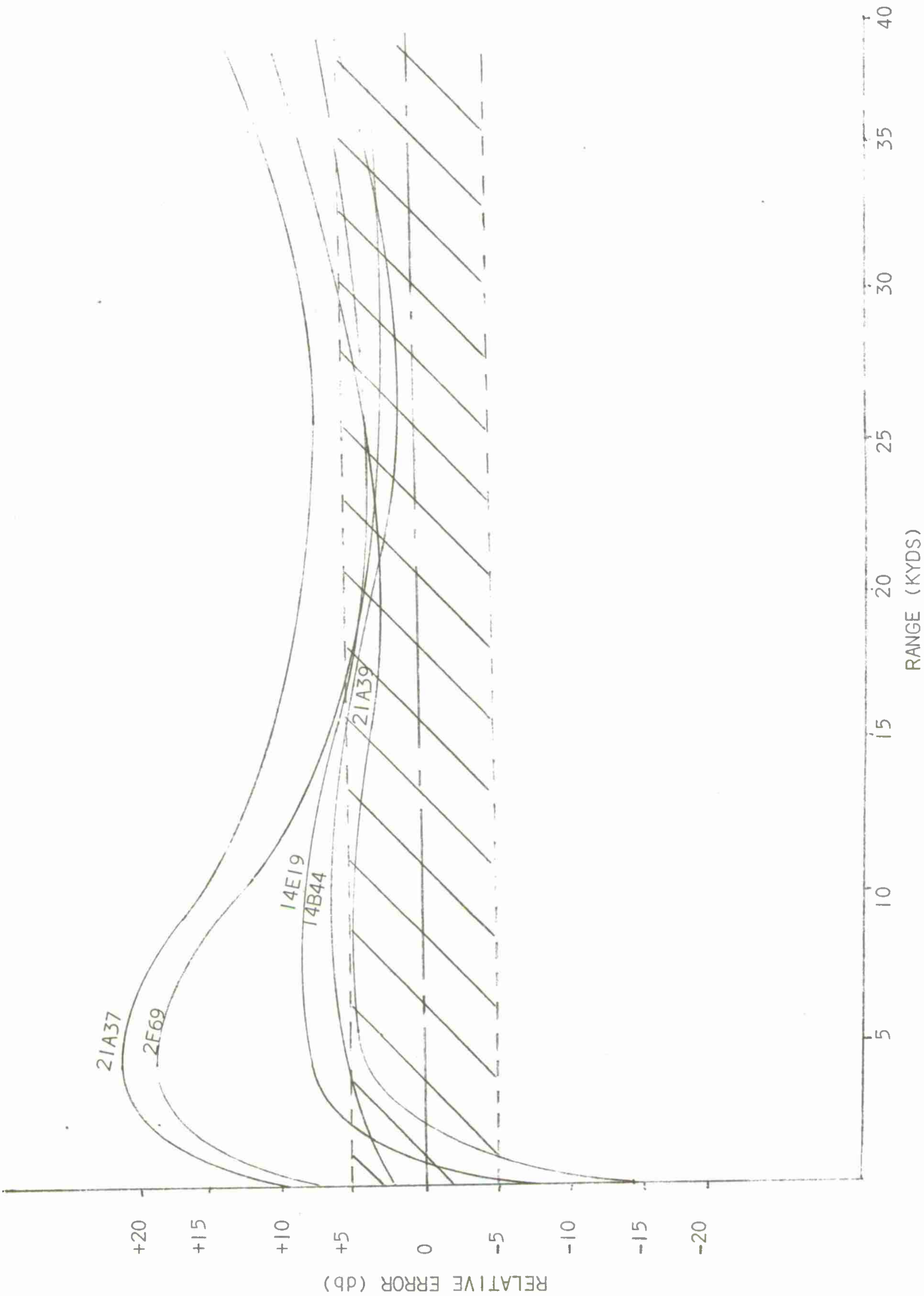


Figure 11. Relative Error -- Bottom Bounce Propagation

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15. Woods Hole Oceanographic Institute, "Sound Beam Patterns in Sea Water," Oct. 10, 1944

16. BELL, Thaddeus, "Sonar Detection and Detectability Range for Submarines," Navy Underwater Sound Lab., USL Research Dept. #491, 21 Oct. 1960, CONFIDENTIAL

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APPENDIX A

SYMBOL DEFINITIONS

L = Surface isothermal layer depth

S = Sea state

T = Water Temperature

R_H = Horizontal Range

R_S = Slant Range

Z = Ownship depth

z = Target depth

f = Acoustic frequency

N_W = Transmission loss

a = Absorption coefficient

a_S = Scattering coefficient

G = First depth loss factor

H = Second depth loss factor

r, r_1, z, z_0 = Scaled variables

θ_{Bi} = Isovelocity range angle

θ_{TBi} = Transmitted deviation loss angle

θ_{TB} = Real bottom grazing angle

D_{Bi} = Depth of bottom

D_T = Depth of target

L_B = Bottom bounce loss as function of bottom type

TL_T = Total propagation loss

TL_1 = Loss due to spreading and attenuation

TL_2 = Surface bounce loss

APPENDIX A (Continued)

TL_3 = Bottom bounce loss

TG = Convergence zone

X_T = Target to sonobuoy flat range

X_D = Range between midpoint of convergence zone and target

X_A = 1/2 convergence zone width

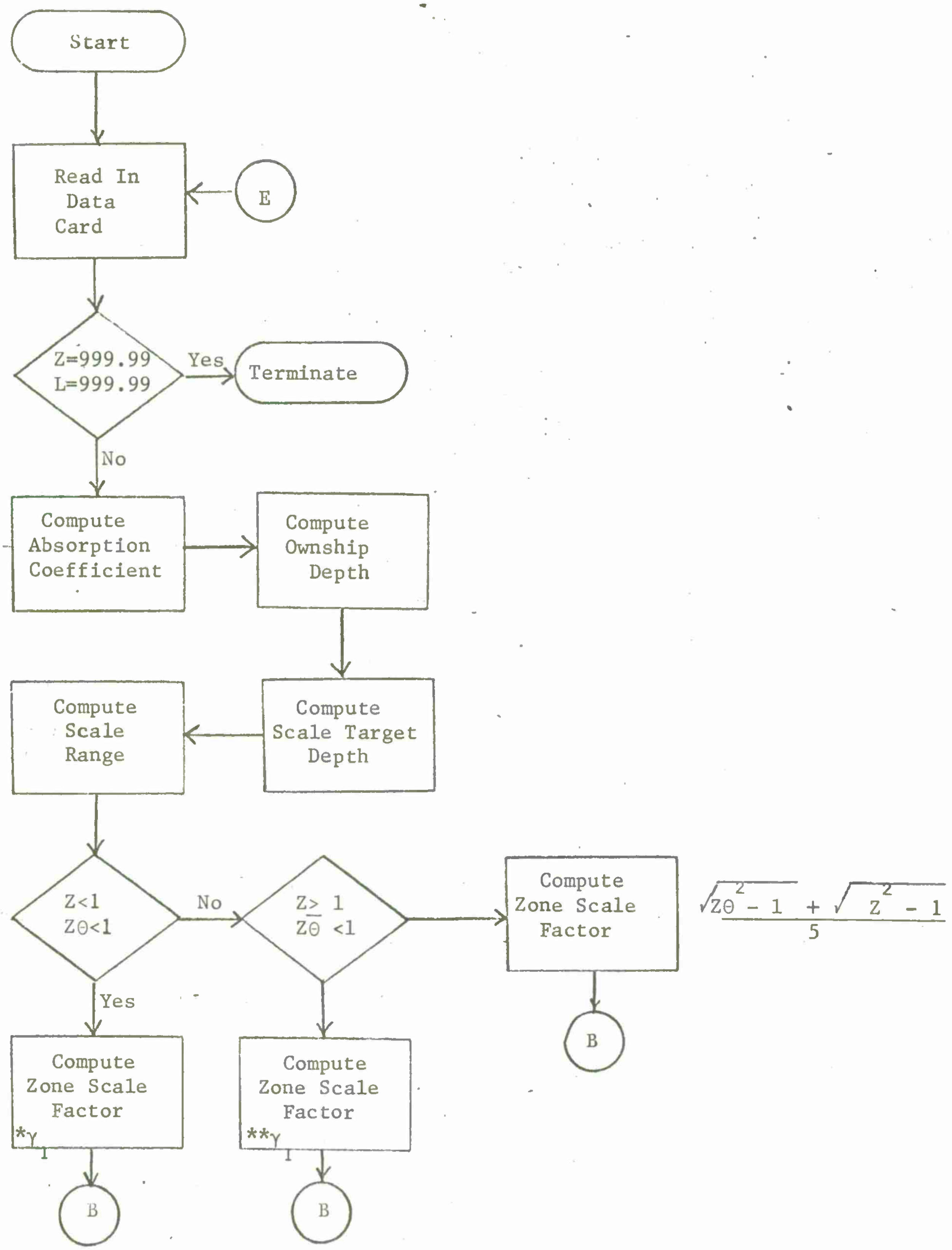
N = Number of convergence zone

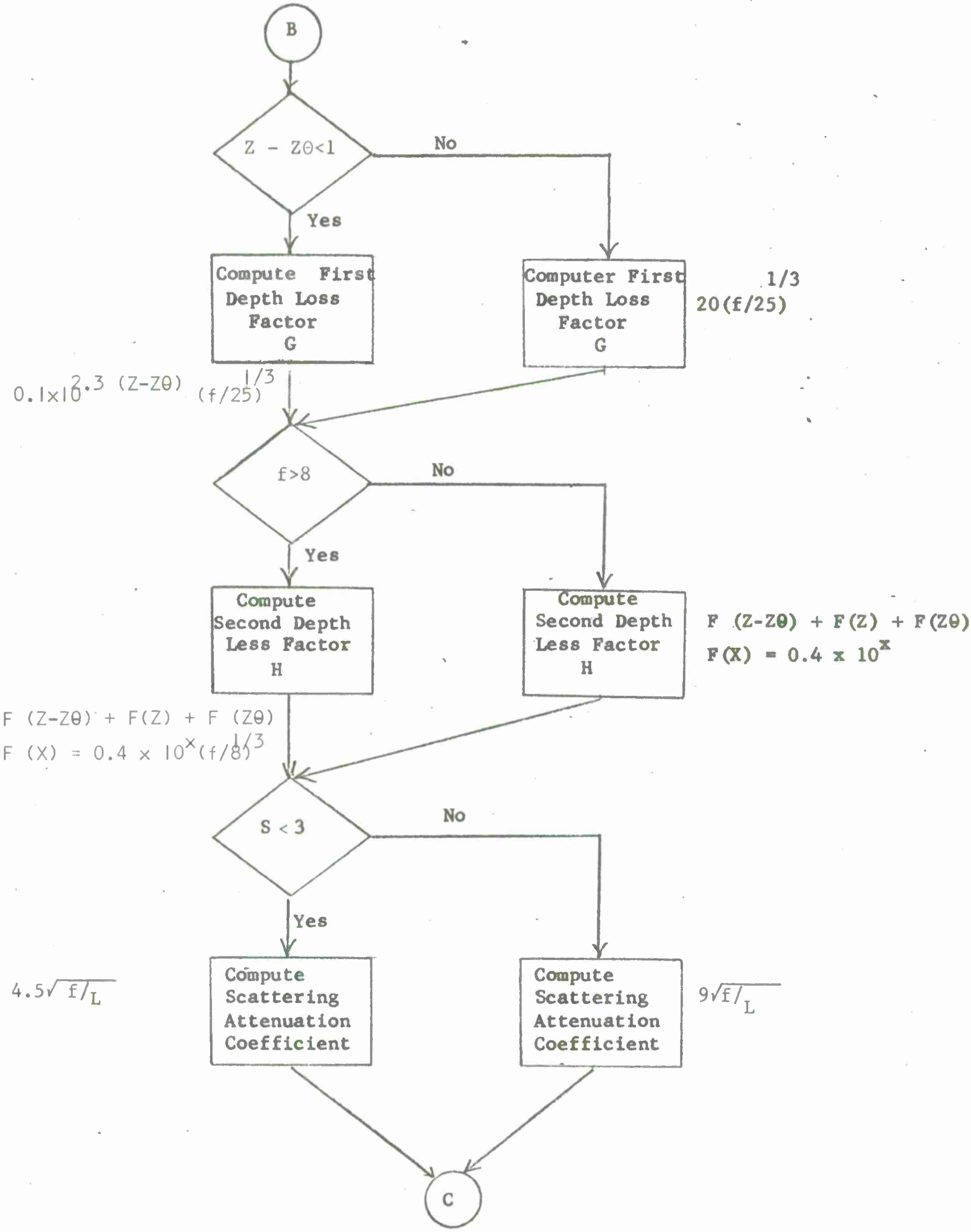
A = Layer depth correction factor

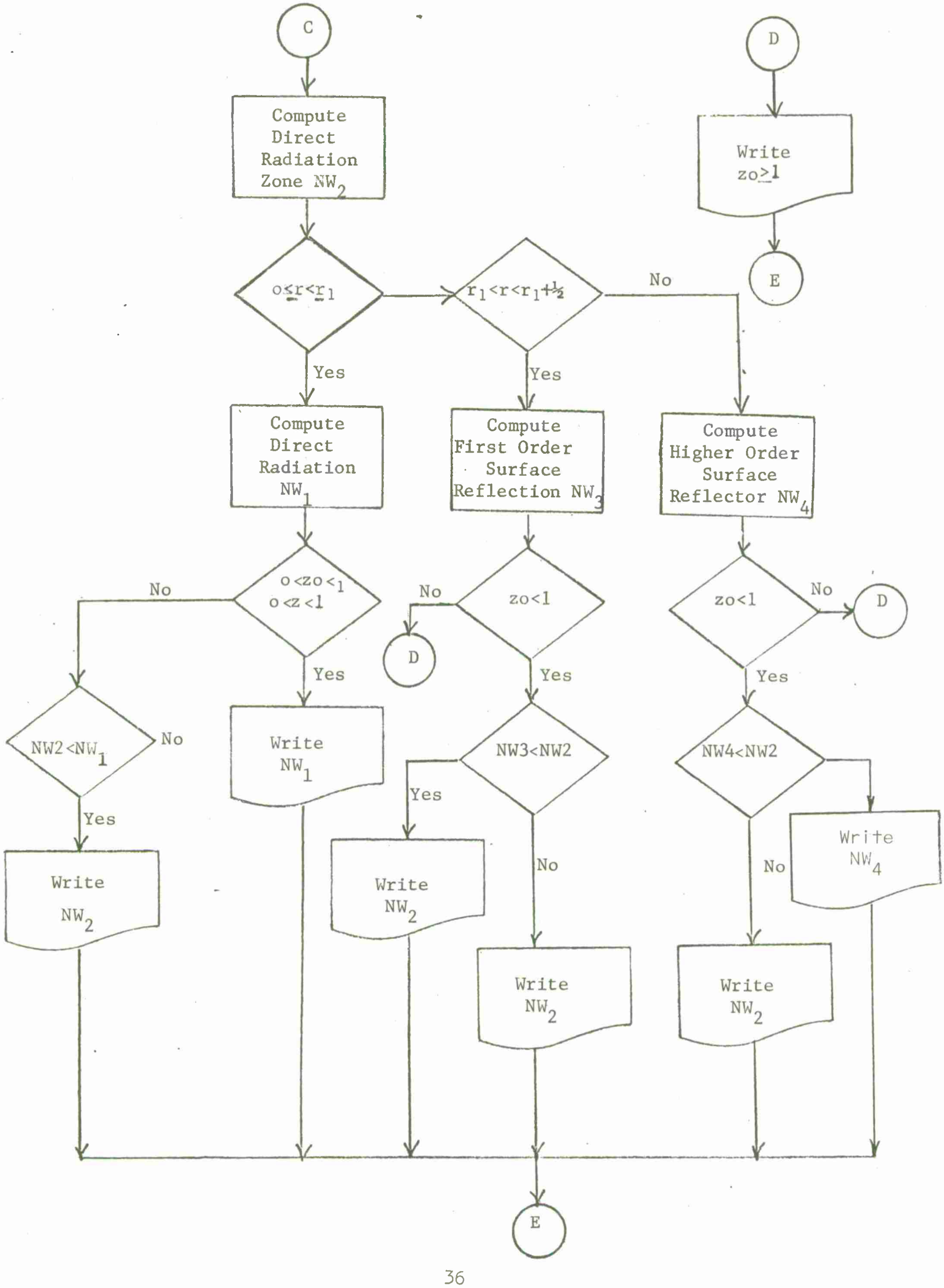
APPENDIX B

FLOW DIAGRAM AND FORTRAN IV PROGRAM

Appendix B contains the flow diagram and FORTRAN IV Program for Device 14E19 math model. The FORTRAN Program was generated by J. H. Gardner (Code 38) to aid in calculating the Device 14E19 math model from the following input data; target depth, layer depth, own ship depth, actual range, acoustic frequency, and sea state. With this program many sets of data can be computed on the Sigma 7 computer in a reasonably short time for comparative analysis with other math models.


Start
Read In Data Card
E
Z=999.99 L=999.99
Yes
Terminate
No
Compute Absorption Coefficient
Compute Ownship Depth
Compute Scale Target Depth
Compute Scale Range
Z<1 ZΘ<1
No
Z≥ 1 ZΘ <1
Compute Zone Scale Factor
$\frac{\sqrt{Z\Theta^2 - 1} + \sqrt{Z^2 - 1}}{5}$
B
Yes
Compute Zone Scale Factor
*γ1
Compute Zone Scale Factor
**γ1
B
B


B
Z - ZΘ<1
No
Yes
Compute First Depth Loss Factor G
Computer First Depth Loss Factor G
20(f/25) 1/3
0.1x10 2.3 (Z-ZΘ) (f/25) 1/3
f>8
No
Yes
Compute Second Depth Less Factor H
Compute Second Depth Less Factor H
F (Z-ZΘ) + F(Z) + F(ZΘ)
F(X) = 0.4 x 10x
F (Z-ZΘ) + F(Z) + F (ZΘ)
F (X) = 0.4 x 10x(f/8) 1/3
S < 3
No
Yes
4.5√ f/L
Compute Scattering Attenuation Coefficient
Compute Scattering Attenuation Coefficient
9√f/L
C


C
Compute Direct Radiation Zone NW2
o≤r<r1
Yes
r1<r<r1+½
Yes
No
Compute Direct Radiation NW1
o<zo<1
o<z<1
No
Yes
NW2<NW1
No
Yes
Write NW2
Write NW1
Compute First Order Surface Reflection NW3
zo<1
No
D
Yes
NW3<NW2
Yes
No
Write NW2
Write NW2
Compute Higher Order Surface Reflector NW4
zo<1
No
D
Yes
NW4<NW2
No
Write NW4
Write NW2
D
Write zo≥1
E
E

```
                 CALCULATION OF PROPAGATION LOSS FOR DEVICE 14E19

                            J. H. GARDNER - CODE 381

             SURFACE BOUNCE WITH SHADOW ZONE
             DIRECT PATH WITH SHADOW ZONE
             DATA INPUT AND VARIABLES WILL BE READ AS
                        HORIZONTAL RANGE = HRANGE
                            SLANT RANGE  = SLANTR
                   BIG Z = TARGET DEPTH = TDEPTH
                    BIG L = LAYER DEPTH = XDEPTH
                 BIG ZO = OWN SHIP DEPTH = ODEPTH
                               SEA STATE = JSEA
                 F = ACOUSTIC FREQUENCY = ACFREQ
                            BOTTOM SLOPE = BSLOPE
                        DEPRESSION ANGLE = DEPRAG
                            BOTTOM DEPTH = BDEPTH
                            SCALED RANGE = SRANGE
                 ABSORPTION COEFFICIENT = A
                            ACTUAL RANGE = ARANGE
                    SCALED OWNSHIP DEPTH = ZO
                     SCALED TARGET DEPTH = Z
                 SHADOW ZONE SCALE FACTOR = SZSF


          FIRST DEPTH - LOSS FACTOR(DB) = G
          SECONDDEPTH - LOSS FACTOR(DB) = H
5         FORMAT (4F6.2, F7.2,11)
7         READ (105, 5) TDEPTH,XDEPTH,ODEPTH,ARANGE,ACFREQ,JSEA
          IF (TDEPTH .EQ. 999.99) IF (XDEPTH .EQ. 999.99)
         $STOP
          COMPUTE ABSORPTION COEFFICIENT***COMPUTE SCALE OWNSHIP DEPTH
          COMPUTE SCALE TARGET DEPTH***COMPUTE SCALE RANGE
          A = 0.033*ACFREQ **(3./2)
          ZO     = (ODEPTH/XDEPTH)**.5
          Z      = (TDEPTH/XDEPTH)**.5
          SRANGE = ARANGE/(XDEPTH)**.5
          IF (Z<1.)IF(ZO<1.) SZSF=((1.-ZO)/4.)+(SQRT((Z**2.)-1))/5.);
1         GO TO 3
          SZSF = (SQRT((ZO**2.) - 1.) + SQRT ((Z**2.)-1.))/5.
          COMPUTE FIRST DEPTH - LOSS FACTOR
3         IF (Z -ZO < 1.) GO TO 8
          G = ((ACFREQ/25.)**(1./3.))*20.
          GO TO 9
8         G = ((.1)*(10.)**(2.3*(Z - ZO)))*((ACFREQ/25.)**.3334)
```

```
 9  IF (ACFREQ < 8.) GO TO 10
    COMPUTE SECOND DEPTH LOSS FACTOR
    H = .4*((ACFREQ/8.)**(1./3.))*((10.**(Z-ZO)) + (10.**Z) +(10.**ZO))
    GO TO 11
10  H = .4*((10.**(Z-ZO))+(10.**Z)+(10.**ZO))
11  IF (JSEA < 3) GO TO 12
    COMPUTE SCATTERING ATTENUATION COEFFICIENT
    AS = ((ACFREQ/XDEPTH)**.5)*9.
    GO TO 14
12  AS = ((ACFREQ/XDEPTH)**.5)*4.5
    BASIC AMOS PROPAGATION LOSS***START WITH XNW2
14  XYZ = 25.-((ABS(TDEPTH-XDEPTH))**.5) - ((ABS(ODEPTH-XDEPTH))**.5)
    1+5. * ARANGE
    IF (XYZ)15,16,16
15  XYZ = 0.0
16  XNW2 = 20. * (ALOG10(ARANGE)) + (A * ARANGE) + XYZ *((ACFREQ/25.)
    1**(1./3.)) + 60.
    COMPUTE DIRECT RADIATION ZONE
    IF (SRANGE .GE. 0.)IF(SRANGE < SZSF) GO TO 20
    IF(SZSF < SRANGE) IF (SRANGE < SZSF +.5) GO TO 21
    IF (SZSF + .5 < SRANGE) GO TO 22
20  XNW1=20.*ALOG10(ARANGE)+(A*ARANGE)+(G*(SRANGE/SZSF)+60.)
    IF (ZO > 0.) IF (Z > 0.) IF (ZO < 1.) IF (Z < 1.)
   $WRITE (108,30)XNW1; GO TO 7
    IF (XNW2 > XNW1)WRITE (108,30)XNW1; GO TO 7
    WRITE (108,31)XNW2
    GO TO 7
21  XNW3 = 20.*(ALOG10(ARANGE)) + (A*ARANGE)+ 2.*(SRANGE-SZSF)*H+
   $(1.-2.*(SRANGE - SZSF))* G + 60.
    IF (ZO > 1.) WRITE (108,36); GO TO 7
    IF XNW2 > XNW3)WRITE(108,32)XNW3; GO TO 7
    WRITE (108,33)XNW2
    GO TO 7
22  XNW4 - 10. * (ALOG10(ARANGE))+(A+AS)* ARANGE + H
    1-AS * ((XDEPTH **.5) * (SZSF + .5)) + 10. *
    2(ALOG 10((XDEPTH ** .5) * (SZSF + .5))) + 60.
    IF (ZO > 1.) WRITE (108,37); GO TO 7
    IF (XNW2 > XNW4) WRITE (108,34)XNW4; GO TO 7
    WRITE (108,35) XNW2
    GO TO 7
30  FORMAT (3/30H WITHIN DIRECT RADIATION ZONE ,//12X,8HNW(1) = ,F6.2,
   $4H(DB))
31  FORMAT (3/30H WITHIN DIRECT RADIATION ZONE ,//12X,8HNW(2) = ,F6.2,
   $4H(DB))
32  FORMAT (3/62H WITHIN ZONE OF FIRST ORDER SURFACE REFLECTION AND SHA
   $ DOW ZONE//12X,8HNW(3) = ,F6.2,4H(DB))
33  FORMAT (3/62H WITHIN ZONE OF FIRST ORDER SURFACE REFLECTION AND SHA
   $DOW ZONE//12X,8HNW(2) = ,F6.2,4H(DB))
34  FORMAT (3/   'WITHIN ZONE OF SECOND OR HIGHER ORDER SURFACE REFLECT
   $ION ZONE'/12X,8HNW(4) = ,F6.2,4H(DB))
```

```
35  FORMAT (3/   'WITHIN ZONE OF SECOND OR HIGHER ORDER SURFACE REFLECT
   $ION ZONE'/12X,8HNW(2) = ,F6.2,4H(DB))
36  FORMAT (3/   'ZO> 1,WITHIN ZONE OF FIRST ORDER SURFACE REFLECTOR AND
    1 SHADOW ZONE--NW3')
37  FORMAT (3/  'ZO > 1, WITHIN ZONE OF SECOND OR HIGHER ORDER SURFACE R
    1EFLECTION ZONE--NW4')
    END
```