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COMPARISON OF STRAIGHT LINE GEOMETRY VERSUS CURVILINEAR RAY TRA--ETC(U)
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Navy Underwater Sound Laboratory
New London, Connecticut 06320

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COMPARISON OF STRAIGHT LINE GEOMETRY VERSUS CURVILINEAR RAY TRACING TECHNIQUE

by

Thelda A. Garrett

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13p.

INTRODUCTION

CONGRATS is a collection of ray tracing programs designed to model acoustic propagation and reverberation. Although these programs produce a variety of useful printed and plotted output, there occasionally appears a need for specific information that is not provided by the basic programs. Rather than develop a large number of individual programs, it is usually simpler to modify the existing program in response to a particular need. This ease of modification makes the CONGRATS series an extremely versatile tool. In the present case a modified version of NUSL Program S0991, the CONGRATS Ray Plot Program, was used to construct tables showing propagation loss vs initial inclination angle for both continuous velocity gradient and constant velocity profiles. The tables also include horizontal range, slant range, and incident angle at the target as a function of initial angle. Propagation loss consists of spreading loss and attenuation loss. This memorandum includes a discussion of the tables, a comparison of the two methods of computing range and propagation loss, examples of the output, and graphs illustrating the discrepancy between the two techniques.

Technical memo.

DISCUSSION

The desired information was computed for given hydrophone depths. A table was printed for each depth, giving for each source angle the following information:

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1. CONGRATS velocity profile:
   a. Horizontal range in kiloyards
   b. Propagation loss in decibels
   c. Target angle in degrees
   d. Slant range in kiloyards
2. Constant velocity profile:
   a. Horizontal range in kiloyards
   b. Propagation loss in decibels
   c. Target angle in degrees
   d. Slant range in kiloyards

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Data used were as follows:

1. Velocity profiles:
   a. 9 November 1965
   b. 11 January 1966
   c. 12 February 1966
   d. 26 March 1968
2. Target depths for each velocity profile:
   a. 100 ft
   b. 865 ft
   c. 1696 ft
3. Sonar angles used were 1.5° to 89° in increments of 0.5°
4. Sonar depth = 18 ft
5. Transmission frequency = 3550 cps.

The tables produced by this modified program can show under what conditions straight line geometry is a reasonable approximation to the curvilinear ray tracing technique. Since the results for the profiles for 11 January 1966 and 9 November 1965 are representative of the results obtained from all the profiles considered, only these two cases are included in the examples of output illustrated.

Figures 1, 2, and 3 show examples of the output for the velocity profile of 11 January 1966. Although source angles used for all the tables were 1.5° to 89°, in this particular case the 1.5° ray is eliminated because it vertexes slightly above the 100 ft depth and does not reach the level of any target depth considered. Consequently, in the examples shown for this profile, the initial source angle is 2°. Figure 4 is a plot of the velocity profile for 11 January 1966. Figure 5 shows a graph representing the difference in the horizontal range obtained by using straight line geometry and the horizontal range obtained by means of the curvilinear ray tracing technique for this profile. A similar graph of the difference in propagation loss is shown in Fig. 6.

The sample page from the January table for the 100 ft target depth, (Fig. 1), shows a difference in horizontal range of 0.1347 kiloyard and a difference in slant range of 0.1346 kiloyard for a source angle of 2°. The difference in propagation loss is 1.04 dB. As the angles increase, the differences in ranges decrease, as well as the difference in propagation loss, so that at 2.5° the difference in both horizontal and slant range is only 53.4 yards and the difference in propagation loss is 0.4 dB. For larger angles the differences in both ranges and propagation loss become progressively smaller until at 14.5° the ranges agree to three decimal places and the propagation losses agree to two decimal places.

Figure 2 shows the first page from the table for the 865 ft target depth for 11 January 1966. For the 2° source angle the differences in horizontal and slant ranges are over 3 kiloyards, but the difference in propagation loss is less than 0.4 dB. As the angles increase, the differences in ranges decrease; however, the difference in propagation loss increases to 0.97 dB at 3.5° and then decreases as the angles increase. For the source angle of 10° the difference in the propagation loss is 0.4 dB and the ranges differ by approximately 130 yards. At higher angles the agreement is closer.

The first page of the table for the 1696 ft target depth of the January 1966 profile is shown in Fig. 3. The same pattern is found here as at the 865 ft level. At the source angle of 2° there are differences in range of over 9 kiloyards and the difference in propagation loss is 4.32 dB. As the source angles get larger, the differences in ranges decrease, but the difference in propagation loss increases to 4.84 dB at 2.5°, after which it decreases as the source angle increases. At 22° source angle the difference in propagation loss is 0.41 dB and the differences in horizontal and slant ranges are less than 100 yards. At greater angles the agreement becomes closer.

At all three target depths the greatest discrepancy between curvilinear ray tracing technique and straight line geometry appears for the shallow angles, while for large angles the two methods agree closely. The differences at all three depths are plotted as a function of the source angle in Figs. 5 and 6.

In all the cases considered, except the 9 November 1965 profile, both horizontal and slant ranges and propagation loss at the 100 ft depth are greater for straight line geometry than for curvilinear ray tracing technique, although in almost all instances the reverse is true for the 865 ft depth and 1696 ft depth.

All of the profiles considered are quite similar, but slight differences in velocity at numerous depths result in considerable variation in the differences in ranges and propagation losses between the two methods of computation. The most extreme variation is in the 9 November 1965 tables. The velocity profile for this date is shown in Fig. 7. Because, in this profile, velocity is the same at 100 ft as at the surface, the results of the two methods are the same at the 100 ft depth. However, at the 865 ft depth the greatest differences in ranges are more than 6.55 kiloyards and the greatest difference in propagation loss is 4.32 dB. At the 1696 ft depth the greatest differences in both horizontal and slant ranges are more than 15.5 kiloyards and the greatest difference in the propagation losses is almost 10 dB. Figure 8 presents the graph of horizontal range error vs source angle and Fig. 9 shows the graph of propagation loss error vs source angle for the same velocity profile.

CONCLUSION

The output shows there can be considerable discrepancy between the results obtained by using the continuous velocity gradient profile and the results obtained by using the constant velocity profile. In general, for the velocity profiles used in this study, the tables show similar patterns for the different cases. The surprising thing is that the difference in propagation loss does not necessarily vary according to the difference in range. For shallow angles the difference is greatest, the discrepancy being greater in the tables for the greater target depths. For large angles straight line geometry is a reasonable approximation. At what point straight line geometry becomes a good approximation depends upon the degree of accuracy desired and varies from one velocity profile to another. The tables constructed by this modified version of NUSL Program S0991 give a detailed picture of the situation in each case. This is an example of the versatility of the CONGRATS series of programs. With a small amount of effort, the existing program has been modified in response to a specific requirement to produce a specialized analysis and tabulated set of output.

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THELDA A. GARRETT
Mathematics Aid

PROPAGATION LOSS TABLES, 11 JAN 1966 PROFILE TARGET DEPTH = 100 FT

	CONGRATS VELOCITY PROFILE				CONSTANT VELOCITY PROFILE			
SOURCE ANGLE-DEG	HORIZONTAL RANGE-KYDS	PROPAGATION LOSS-DB	TARGET ANGLE-DEG	SLANT RANGE-KYD	HORIZONTAL RANGE-KYDS	PROPAGATION LOSS-DB	TARGET ANGLE-DEG	SLANT RANGE-KYD
2.00	.9174	59.09	1.18	.9178	.7827	58.05	2.00	.7832
2.50	.6794	56.48	1.91	.6800	.6260	56.08	2.50	.6266
3.00	.5494	54.69	2.53	.5500	.5216	54.47	3.00	.5223
3.50	.4635	53.26	3.11	.4643	.4469	53.12	3.50	.4477
4.00	.4016	52.05	3.66	.4025	.3909	51.95	4.00	.3918
4.50	.3547	50.99	4.20	.3557	.3473	50.92	4.50	.3484
5.00	.3177	50.06	4.73	.3189	.3124	50.00	5.00	.3136
5.50	.2878	49.21	5.26	.2891	.2839	49.16	5.50	.2852
6.00	.2631	48.45	5.78	.2645	.2601	48.41	6.00	.2615
6.50	.2422	47.74	6.30	.2438	.2399	47.71	6.50	.2415
7.00	.2245	47.09	6.81	.2261	.2226	47.06	7.00	.2243
7.50	.2091	46.49	7.33	.2109	.2076	46.46	7.50	.2094
8.00	.1957	45.93	7.84	.1976	.1945	45.91	8.00	.1964
8.50	.1839	45.40	8.35	.1859	.1829	45.38	8.50	.1849
9.00	.1734	44.90	8.86	.1756	.1726	44.88	9.00	.1747
9.50	.1641	44.43	9.36	.1663	.1633	44.42	9.50	.1656
10.00	.1556	43.99	9.87	.1580	.1550	43.97	10.00	.1574
10.50	.1480	43.57	10.38	.1505	.1475	43.55	10.50	.1500
11.00	.1411	43.16	10.88	.1437	.1406	43.15	11.00	.1432
11.50	.1348	42.78	11.39	.1375	.1343	42.77	11.50	.1371
12.00	.1290	42.41	11.89	.1318	.1286	42.40	12.00	.1315
12.50	.1236	42.06	12.40	.1266	.1233	42.05	12.50	.1263
13.00	.1187	41.73	12.90	.1218	.1184	41.72	13.00	.1215
13.50	.1141	41.40	13.41	.1173	.1139	41.40	13.50	.1171
14.00	.1099	41.09	13.91	.1132	.1096	41.08	14.00	.1130
14.50	.1059	40.79	14.41	.1094	.1057	40.79	14.50	.1092
15.00	.1022	40.50	14.92	.1058	.1020	40.50	15.00	.1056
15.50	.0987	40.22	15.42	.1024	.0986	40.22	15.50	.1023
16.00	.0955	39.95	15.92	.0993	.0953	39.95	16.00	.0992
16.50	.0924	39.69	16.42	.0964	.0923	39.69	16.50	.0962
17.00	.0895	39.44	16.93	.0936	.0894	39.44	17.00	.0935
17.50	.0868	39.20	17.43	.0910	.0867	39.19	17.50	.0909
18.00	.0842	38.96	17.93	.0886	.0841	38.95	18.00	.0885
18.50	.0818	38.73	18.43	.0862	.0817	38.72	18.50	.0861
19.00	.0795	38.50	18.93	.0840	.0794	38.50	19.00	.0840
19.50	.0773	38.29	19.44	.0820	.0772	38.28	19.50	.0819
20.00	.0752	38.07	19.94	.0800	.0751	38.07	20.00	.0799
20.50	.0732	37.87	20.44	.0781	.0731	37.86	20.50	.0780
21.00	.0713	37.67	20.94	.0763	.0712	37.66	21.00	.0763
21.50	.0695	37.47	21.44	.0746	.0694	37.47	21.50	.0746
22.00	.0677	37.28	21.94	.0730	.0677	37.28	22.00	.0730
22.50	.0660	37.10	22.45	.0715	.0660	37.09	22.50	.0714
23.00	.0644	36.91	22.95	.0700	.0644	36.91	23.00	.0700
23.50	.0629	36.74	23.45	.0686	.0629	36.73	23.50	.0685
24.00	.0614	36.57	23.95	.0672	.0614	36.56	24.00	.0672
24.50	.0600	36.40	24.45	.0660	.0600	36.39	24.50	.0659
25.00	.0587	36.23	24.95	.0647	.0586	36.23	25.00	.0647
25.50	.0573	36.07	25.45	.0635	.0573	36.07	25.50	.0635
26.00	.0561	35.91	25.95	.0624	.0560	35.91	26.00	.0624
26.50	.0549	35.76	26.45	.0613	.0548	35.76	26.50	.0613
27.00	.0537	35.61	26.96	.0602	.0536	35.61	27.00	.0602
27.50	.0525	35.46	27.46	.0592	.0525	35.46	27.50	.0592

Fig. 1 - Range and Propagation Loss Table, 100 Ft. Depth

PROPAGATION LOSS TABLES, 11 JAN 1966 PROFILE TARGET DEPTH = 865 FT

	CONGRATS VELOCITY PROFILE				CONSTANT VELOCITY PROFILE			
SOURCE ANGLE-DEG	HORIZONTAL RANGE-KYDS	PROPAGATION LOSS-DB	TARGET ANGLE-DEG	SLANT RANGE-KYD	HORIZONTAL RANGE-KYDS	PROPAGATION LOSS-DB	TARGET ANGLE-DEG	SLANT RANGE-KYD
2.00	4.9255	80.27	8.03	4.9359	8.0850	79.90	2.00	8.0899
2.50	4.1622	76.87	8.17	4.1734	6.4665	77.61	2.50	6.4727
3.00	3.6721	74.85	8.34	3.6842	5.3872	75.80	3.00	5.3946
3.50	3.3051	73.33	8.53	3.3182	4.6161	74.30	3.50	4.6247
4.00	3.0128	72.08	8.74	3.0268	4.0376	73.01	4.00	4.0474
4.50	2.7715	71.01	8.98	2.7865	3.5874	71.90	4.50	3.5985
5.00	2.5674	70.07	9.24	2.5834	3.2271	70.91	5.00	3.2394
5.50	2.3917	69.24	9.52	2.4088	2.9321	70.02	5.50	2.9457
6.00	2.2385	68.49	9.81	2.2566	2.6862	69.21	6.00	2.7010
6.50	2.1034	67.80	10.13	2.1225	2.4730	68.47	6.50	2.4940
7.00	1.9831	67.17	10.45	2.0033	2.2994	67.80	7.00	2.3167
7.50	1.8753	66.59	10.79	1.8966	2.1445	67.17	7.50	2.1630
8.00	1.7781	66.04	11.14	1.8005	2.0089	66.58	8.00	2.0286
8.50	1.6900	65.53	11.50	1.7135	1.8891	66.03	8.50	1.9101
9.00	1.6097	65.05	11.88	1.6343	1.7826	65.52	9.00	1.8048
9.50	1.5362	64.60	12.26	1.5620	1.6872	65.03	9.50	1.7106
10.00	1.4687	64.17	12.65	1.4956	1.6012	64.57	10.00	1.6259
10.50	1.4064	63.76	13.04	1.4345	1.5233	64.14	10.50	1.5493
11.00	1.3489	63.37	13.45	1.3782	1.4525	63.72	11.00	1.4797
11.50	1.2955	62.99	13.86	1.3260	1.3877	63.33	11.50	1.4161
12.00	1.2459	62.64	14.27	1.2775	1.3283	62.95	12.00	1.3579
12.50	1.1997	62.29	14.69	1.2325	1.2735	62.59	12.50	1.3044
13.00	1.1565	61.97	15.12	1.1904	1.2229	62.24	13.00	1.2551
13.50	1.1160	61.65	15.55	1.1512	1.1760	61.91	13.50	1.2094
14.00	1.0781	61.34	15.98	1.1144	1.1324	61.59	14.00	1.1670
14.50	1.0424	61.05	16.42	1.0799	1.0917	61.29	14.50	1.1276
15.00	1.0088	60.77	16.86	1.0475	1.0537	60.99	15.00	1.0909
15.50	.9770	60.49	17.30	1.0170	1.0181	60.70	15.50	1.0565
16.00	.9471	60.23	17.75	.9882	.9846	60.43	16.00	1.0243
16.50	.9187	59.97	18.20	.9611	.9531	60.16	16.50	.9941
17.00	.8918	59.72	18.65	.9354	.9235	59.90	17.00	.9657
17.50	.8662	59.46	19.10	.9111	.8954	59.65	17.50	.9389
18.00	.8420	59.25	19.56	.8880	.8689	59.41	18.00	.9136
18.50	.8188	59.02	20.02	.8661	.8438	59.18	18.50	.8898
19.00	.7968	58.80	20.48	.8453	.8200	58.95	19.00	.8672
19.50	.7758	58.58	20.94	.8255	.7973	58.73	19.50	.8458
20.00	.7557	58.37	21.40	.8067	.7757	58.51	20.00	.8255
20.50	.7365	58.17	21.87	.7887	.7551	58.30	20.50	.8062
21.00	.7181	57.97	22.33	.7716	.7355	58.10	21.00	.7878
21.50	.7005	57.77	22.80	.7552	.7167	57.90	21.50	.7703
22.00	.6836	57.58	23.27	.7396	.6988	57.71	22.00	.7537
22.50	.6674	57.40	23.74	.7246	.6816	57.52	22.50	.7378
23.00	.6518	57.22	24.21	.7103	.6651	57.33	23.00	.7226
23.50	.6368	57.04	24.69	.6965	.6493	57.15	23.50	.7080
24.00	.6223	56.87	25.16	.6833	.6341	56.98	24.00	.6941
24.50	.6084	56.70	25.63	.6707	.6195	56.81	24.50	.6808
25.00	.5950	56.54	26.11	.6585	.6055	56.64	25.00	.6681
25.50	.5820	56.38	26.58	.6468	.5919	56.48	25.50	.6558
26.00	.5695	56.22	27.06	.6356	.5789	56.32	26.00	.6441
26.50	.5574	56.07	27.54	.6248	.5663	56.16	26.50	.6328
27.00	.5457	55.92	28.02	.6144	.5541	56.01	27.00	.6219
27.50	.5344	55.77	28.50	.6044	.5424	55.86	27.50	.6114

Fig. 2 - Range and Propagation Loss Table, 865 Ft. Depth.

PROPAGATION LOSS TABLES, 11 JAN 1966 PROFILE   TARGET DEPTH = 1696 FT

	CONGRATS VELOCITY PROFILE				CONSTANT VELOCITY PROFILE			
SOURCE ANGLE-DEG	HORIZONTAL RANGE-KYDS	PROPAGATION LOSS-DB	TARGET ANGLE-DEG	SLANT RANGE-KYD	HORIZONTAL RANGE-KYDS	PROPAGATION LOSS-DB	TARGET ANGLE-DEG	SLANT RANGE-KYD
2.00	6.6809	83.23	10.53	6.7124	16.0172	87.55	2.00	16.0270
2.50	5.8930	80.08	10.63	5.9257	12.8108	84.92	2.50	12.8230
3.00	5.3743	78.28	10.76	5.4082	10.6727	82.88	3.00	10.6874
3.50	4.9752	76.96	10.91	5.0105	9.1450	81.21	3.50	9.1621
4.00	4.6480	75.89	11.08	4.6847	7.9988	79.81	4.00	8.0184
4.50	4.3696	75.00	11.27	4.4078	7.1070	78.59	4.50	7.1290
5.00	4.1269	74.22	11.47	4.1667	6.3932	77.53	5.00	6.4176
5.50	3.9116	73.54	11.70	3.9531	5.8089	76.58	5.50	5.8358
6.00	3.7181	72.93	11.94	3.7614	5.3217	75.72	6.00	5.3510
6.50	3.5426	72.37	12.19	3.5877	4.9092	74.94	6.50	4.9410
7.00	3.3822	71.86	12.46	3.4291	4.5554	74.22	7.00	4.5896
7.50	3.2348	71.38	12.75	3.2836	4.2486	73.56	7.50	4.2852
8.00	3.0986	70.93	13.05	3.1493	3.9799	72.95	8.00	4.0190
8.50	2.9723	70.51	13.36	3.0250	3.7426	72.37	8.50	3.7842
9.00	2.8549	70.11	13.68	2.9095	3.5315	71.84	9.00	3.5755
9.50	2.7453	69.73	14.01	2.8020	3.3424	71.33	9.50	3.3889
10.00	2.6428	69.36	14.35	2.7016	3.1721	70.85	10.00	3.2211
10.50	2.5468	69.01	14.70	2.6077	3.0179	70.40	10.50	3.0693
11.00	2.4567	68.68	15.05	2.5197	2.8775	69.97	11.00	2.9314
11.50	2.3719	68.35	15.42	2.4370	2.7492	69.56	11.50	2.8055
12.00	2.2921	68.04	15.79	2.3593	2.6315	69.17	12.00	2.6902
12.50	2.2167	67.74	16.17	2.2862	2.5230	68.80	12.50	2.5842
13.00	2.1455	67.45	16.55	2.2172	2.4227	68.45	13.00	2.4865
13.50	2.0782	67.16	16.95	2.1521	2.3298	68.11	13.50	2.3960
14.00	2.0144	66.89	17.34	2.0905	2.2434	67.78	14.00	2.3120
14.50	1.9538	66.62	17.74	2.0322	2.1628	67.46	14.50	2.2339
15.00	1.8963	66.37	18.15	1.9770	2.0875	67.16	15.00	2.1611
15.50	1.8417	66.12	18.56	1.9246	2.0169	66.87	15.50	2.0930
16.00	1.7896	65.87	18.98	1.8748	1.9506	66.58	16.00	2.0292
16.50	1.7400	65.64	19.40	1.8276	1.8883	66.31	16.50	1.9694
17.00	1.6927	65.41	19.82	1.7826	1.8295	66.05	17.00	1.9131
17.50	1.6475	65.18	20.24	1.7397	1.7740	65.79	17.50	1.8601
18.00	1.6044	64.96	20.67	1.6989	1.7215	65.54	18.00	1.8100
18.50	1.5630	64.75	21.10	1.6599	1.6717	65.30	18.50	1.7628
19.00	1.5235	64.54	21.54	1.6227	1.6244	65.07	19.00	1.7180
19.50	1.4856	64.34	21.98	1.5872	1.5795	64.84	19.50	1.6756
20.00	1.4492	64.14	22.42	1.5532	1.5368	64.62	20.00	1.6354
20.50	1.4142	63.95	22.86	1.5206	1.4960	64.41	20.50	1.5971
21.00	1.3807	63.76	23.30	1.4894	1.4571	64.20	21.00	1.5608
21.50	1.3484	63.57	23.75	1.4596	1.4200	64.00	21.50	1.5261
22.00	1.3173	63.39	24.20	1.4309	1.3844	63.80	22.00	1.4931
22.50	1.2874	63.22	24.65	1.4034	1.3504	63.61	22.50	1.4616
23.00	1.2585	63.04	25.10	1.3770	1.3177	63.42	23.00	1.4315
23.50	1.2307	62.88	25.56	1.3516	1.2864	63.24	23.50	1.4027
24.00	1.2038	62.71	26.01	1.3272	1.2563	63.06	24.00	1.3752
24.50	1.1779	62.55	26.47	1.3037	1.2273	62.89	24.50	1.3488
25.00	1.1528	62.39	26.93	1.2811	1.1995	62.72	25.00	1.3235
25.50	1.1285	62.24	27.39	1.2593	1.1727	62.55	25.50	1.2992
26.00	1.1051	62.09	27.85	1.2383	1.1468	62.39	26.00	1.2759
26.50	1.0823	61.94	28.31	1.2181	1.1218	62.23	26.50	1.2536
27.00	1.0603	61.79	28.77	1.1986	1.0978	62.08	27.00	1.2320
27.50	1.0390	61.65	29.24	1.1797	1.0745	61.93	27.50	1.2113

Fig. 3 - Range and Propagation Loss Table, 1696 Ft. Depth

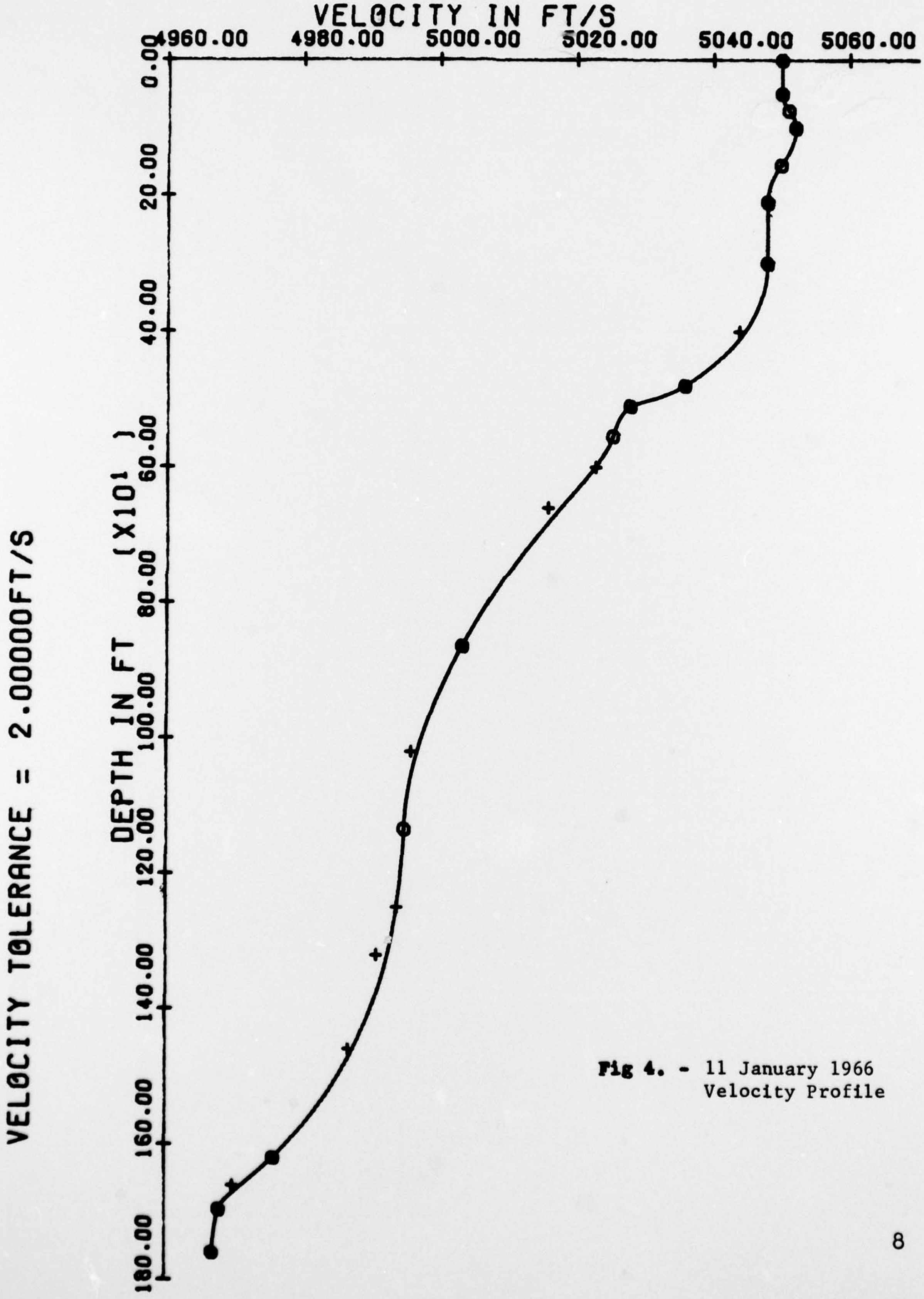

Fig 4. - 11 January 1966
Velocity Profile

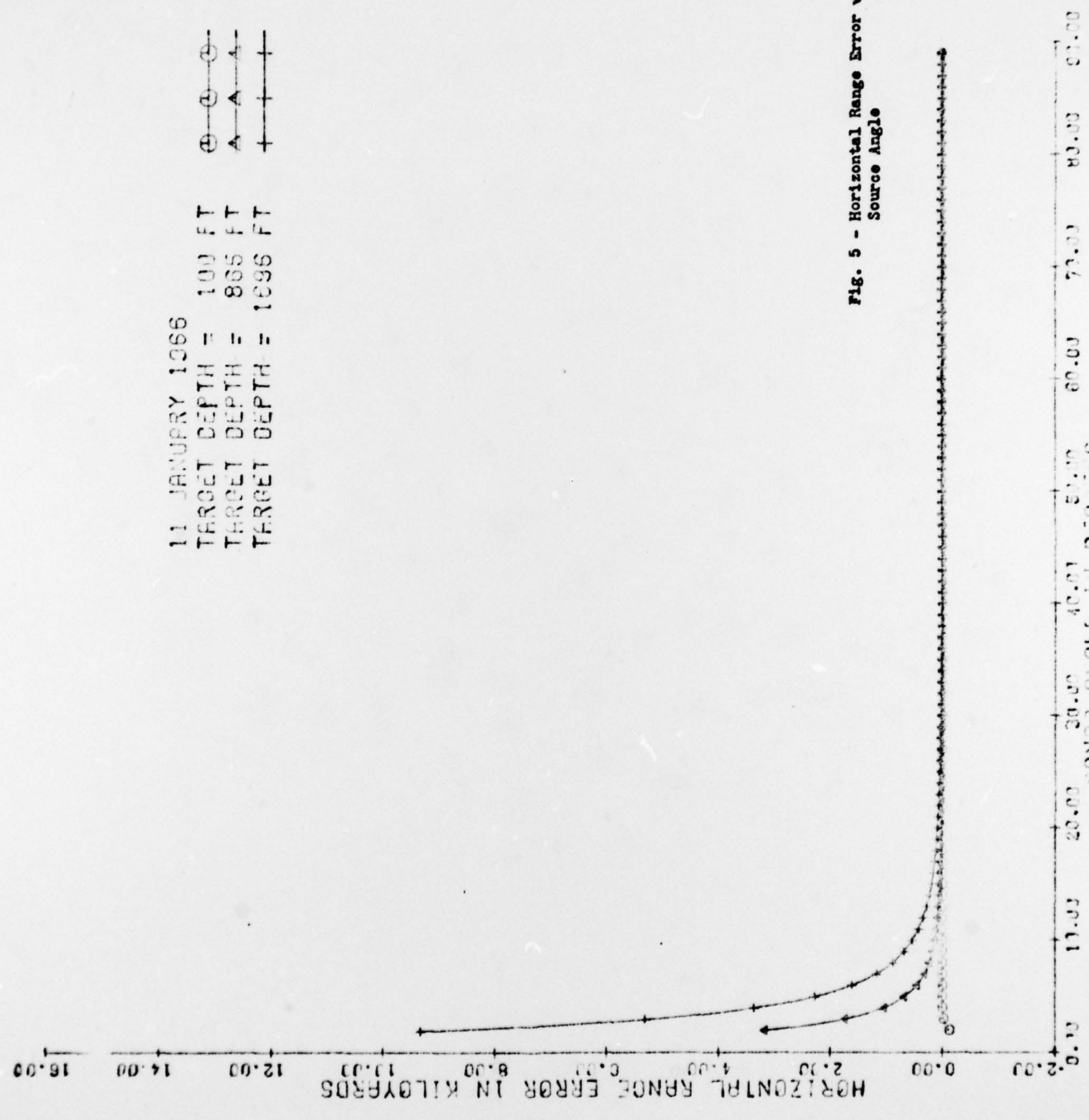

Fig. 5 - Horizontal Range Error vs. Source Angle

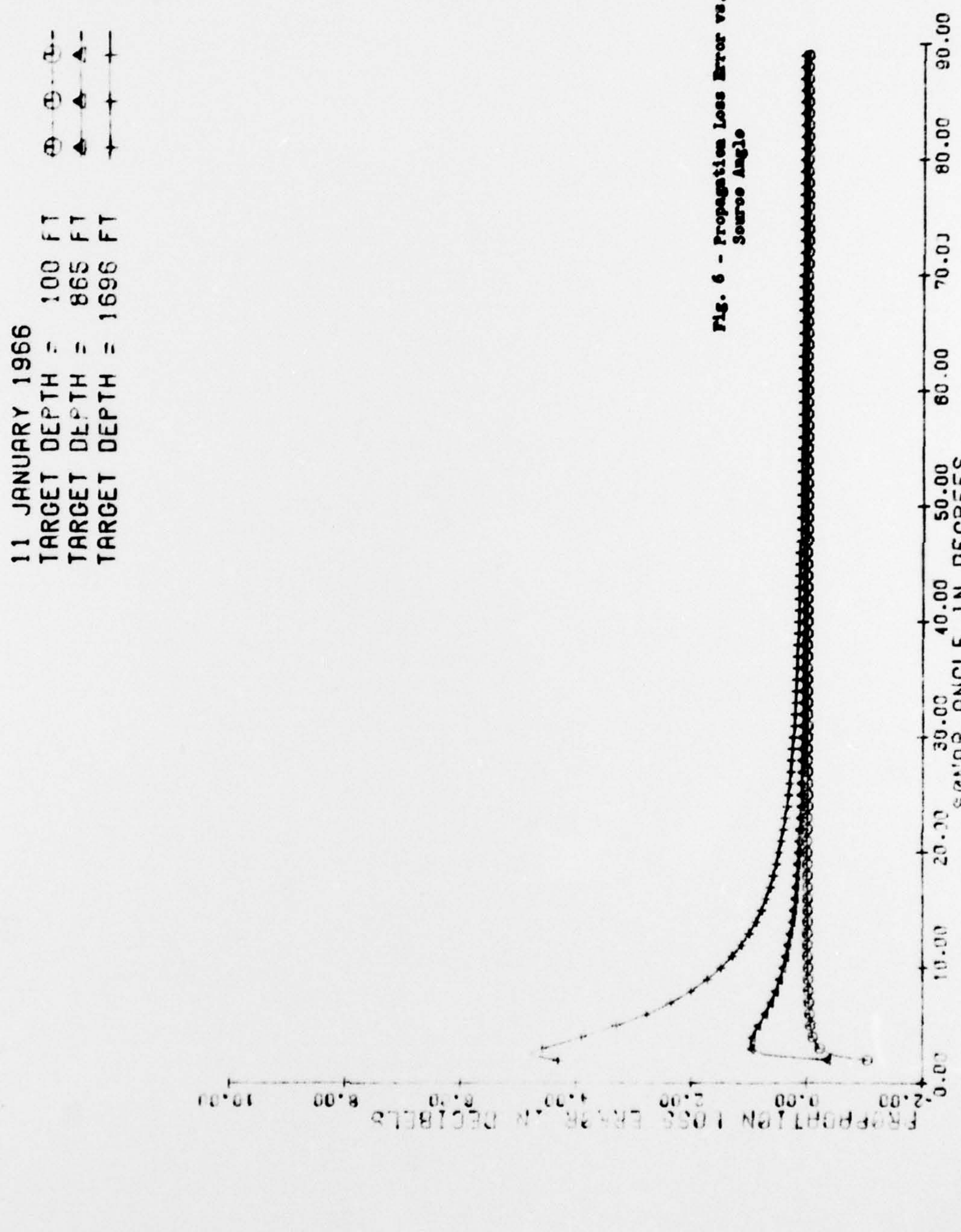

Fig. 6 - Propagation Loss Error vs. Source Angle

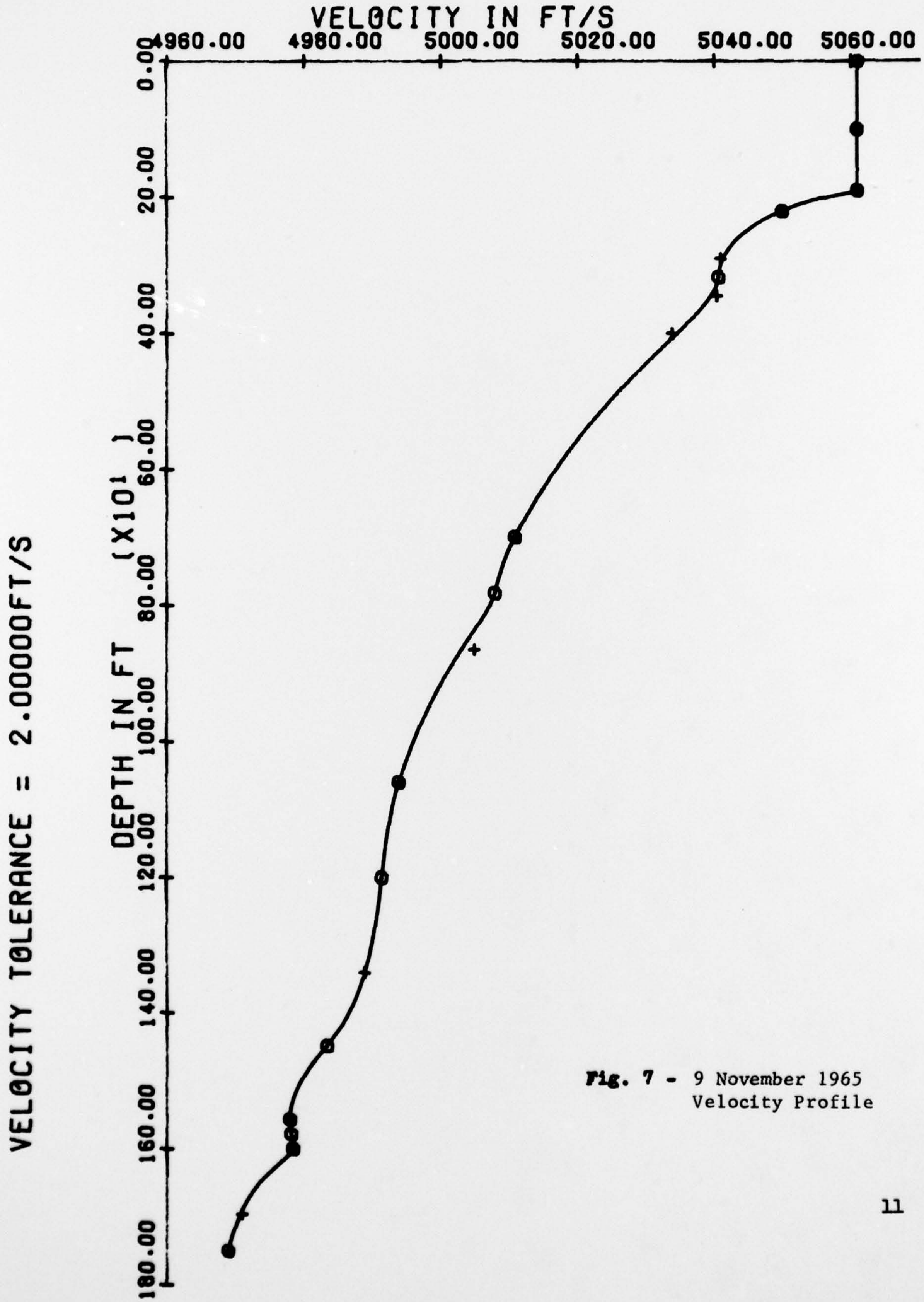

Fig. 7 - 9 November 1965
Velocity Profile

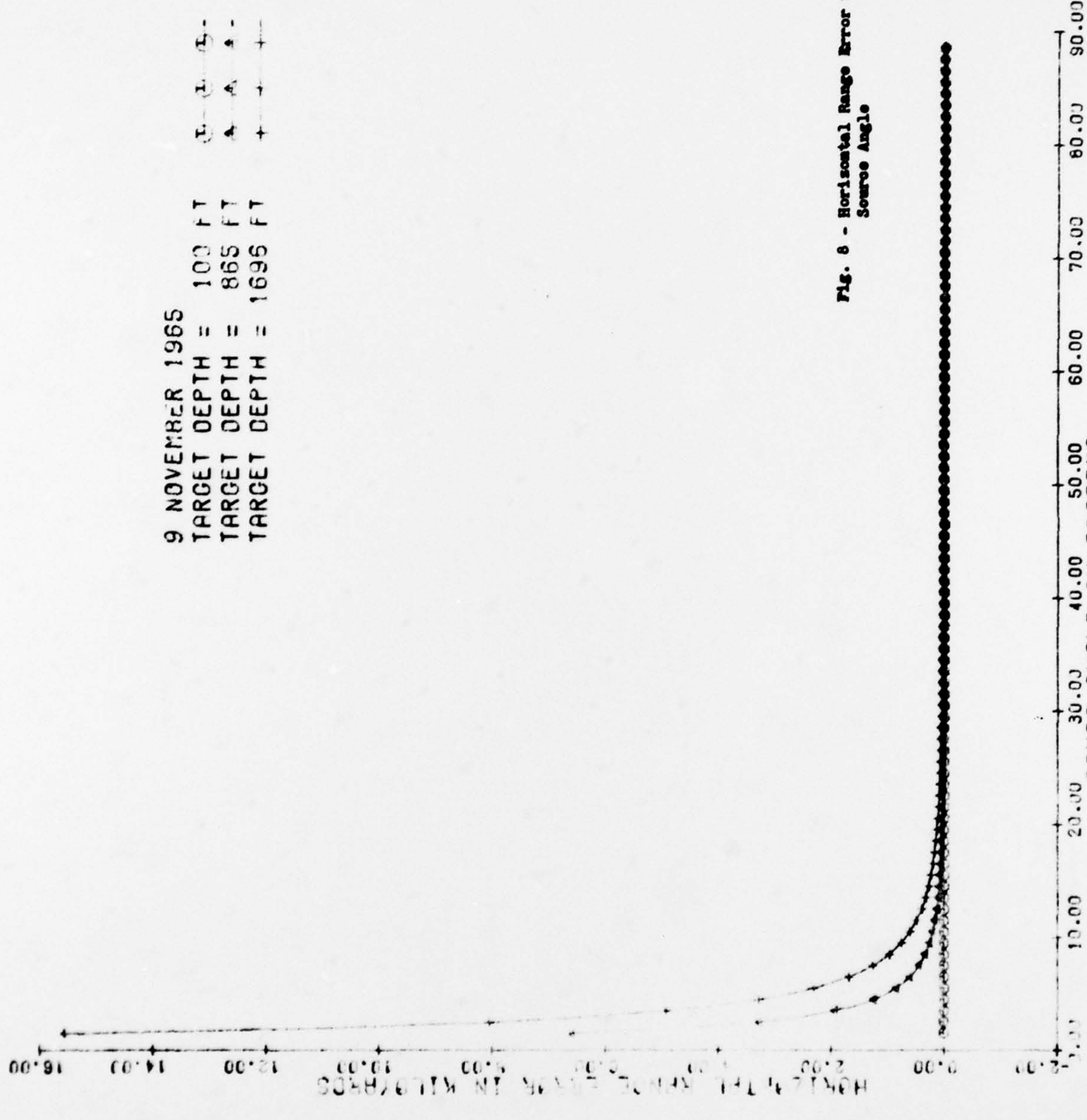

Fig. 8 - Horizontal Range Error vs. Source Angle

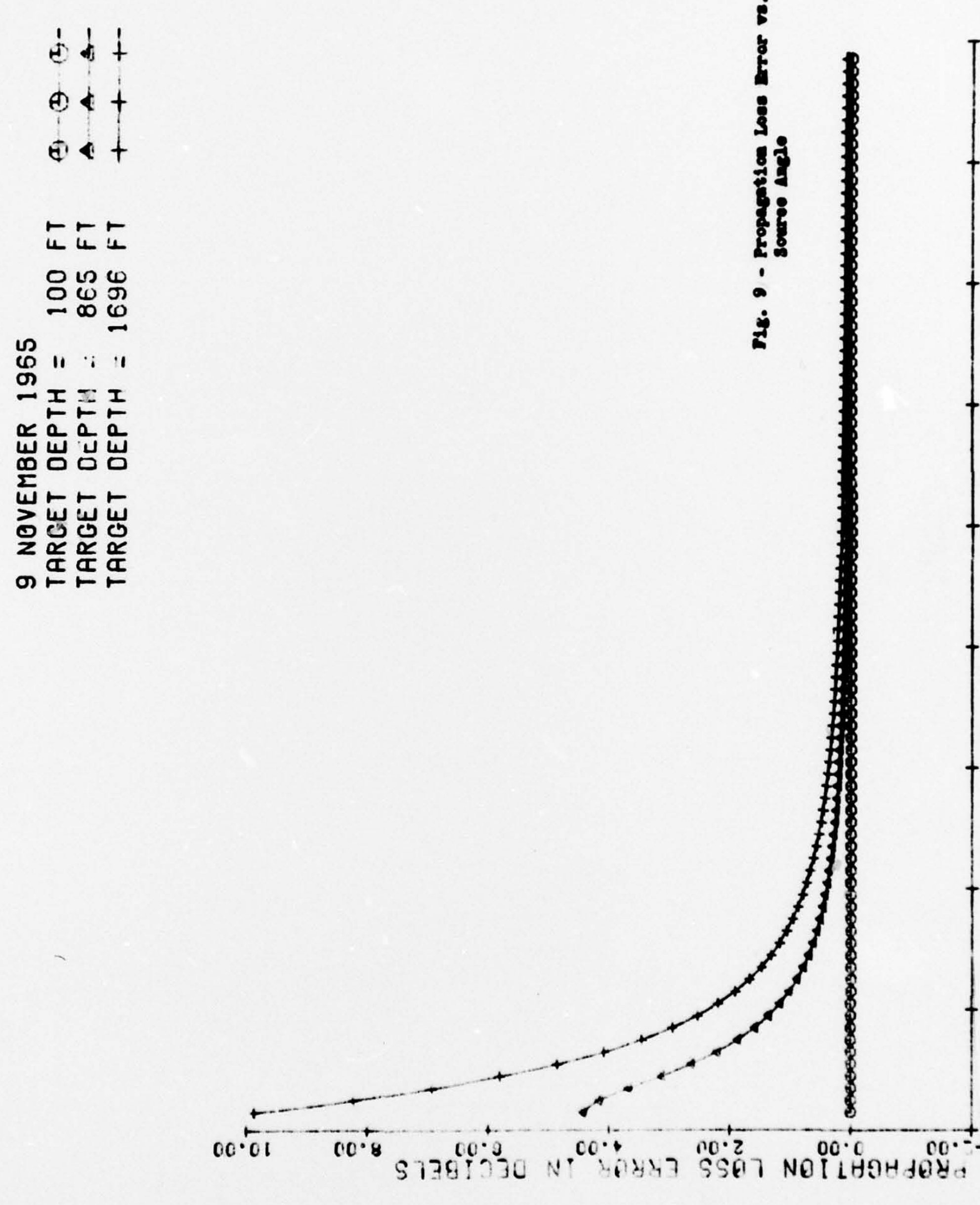

Fig. 9 - Propagation Loss Error vs.
Source Angle