POSITION AND SHAPE OF THE SURFACE SHADOW ZONE

by

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From surface reverberation studies conducted by SACLANTCEN's Target Classification Group*, it has been found necessary to know before any sea experiment the precise position of the first surface shadow zone. Since normal ray tracing programs usually do not answer such a question, a simple computer program has been implemented which, on a small shipborne computer, calculates within seconds: distance, extent and maximum thickness of the shadow zone as a function of the source depth.

From submarine detection trials subsequently performed, it was seen that a more accurate shape of this shadow zone was desirable and an extension of the previous program is underway.

DISTANCE, EXTENT AND THICKNESS OF THE SHADOW ZONE

Figure 1 shows the rays which limit the shadow zone both in range and depth when the source is between the minimum velocity depth and the critical depth. At the surface, the shadow zone is bounded by the rays which have zero grazing angle. The maximum depth of the shadow zone is the depth at which a ray horizontal at source becomes horizontal again. A similar figure would be obtained with a source

* W. Bachmann and B. de Raigniac, "The Calculation of the Surface Backscattering Coefficient of Underwater Sound from Measured Data", SACLANTCEN Technical Memorandum No. 174, November 1971, NATO UNCLASSIFIED

between surface and minimum velocity depth; the shadow zone is then of much larger dimensions. Once the Snell's constant k of the ray is known, the distance to the shadow zone is

$$D = \sum_i R_i \left(\sin \alpha_{i-1} - \sin \alpha_i\right) \quad , \qquad [\text{Eq. } 1]$$

where R_i is the radius of ray curvature in each layer i, α_{i-1} and α_i are the grazing angles of the ray at the boundaries of the ith layer, and the summation extends over all layers from the source to the surface.

The extent of the shadow zone is given by

$$E = 2 \sum_i R_i \left(\sin \alpha_{i-1} - \sin \alpha_i\right) \quad , \qquad [\text{Eq. } 2]$$

where the summation is now taken over the layers between the source and the critical depth Z_k .

The maximum thickness of the shadow zone is

$$Z_{max} = Z \Big|_{V = V_s} \qquad [\text{Eq. } 3]$$

where V_s is the sound speed at the source depth.

In Fig. 2 these three quantities are plotted as a function of source depth for a typical summer Mediterranean sound velocity profile.

SHAPE OF THE SHADOW ZONE

Figure 3 gives an idea of the shadow zone as obtained by a conventional ray tracing program. A precise determination of the shape requires a large number of rays and therefore a large amount of computer time is involved, particularly on a small shipborne machine.

An alternative method is to look directly for the rays (in caustics or limiting rays) which delimit the shadow zone. The exact solution is mathematically difficult. The shape is then approximated as the locus of the points where at closely spaced depths a ray vertexes. As limiting rays may occur when strong negative gradients are predominant, a comparison is performed at each depth between ranges of the vertex points and of intersection of rays vertexing at shallower depth. The points retained are those which indicate a smaller extent of the shadow zone, as indicated in Fig. 4.

Figure 5 shows how the shape of the shadow zone varies as a function of the source depth for the same summer velocity profile. It should be noted how the shape can be complicated and how the single knowledge of distance, extent and maximum thickness may not be sufficient.

In Fig. 6 different shapes are obtained from a typical winter sound velocity profile. It should be noted that the maximum shadow zone depth given by Eq. 3 is not always reached because of limiting rays.

DISCUSSION

In reply to a question, the author reiterated the point that a complete ray tracing was not required to obtain the shape of the shadow zone; the method described being very much simpler than that.

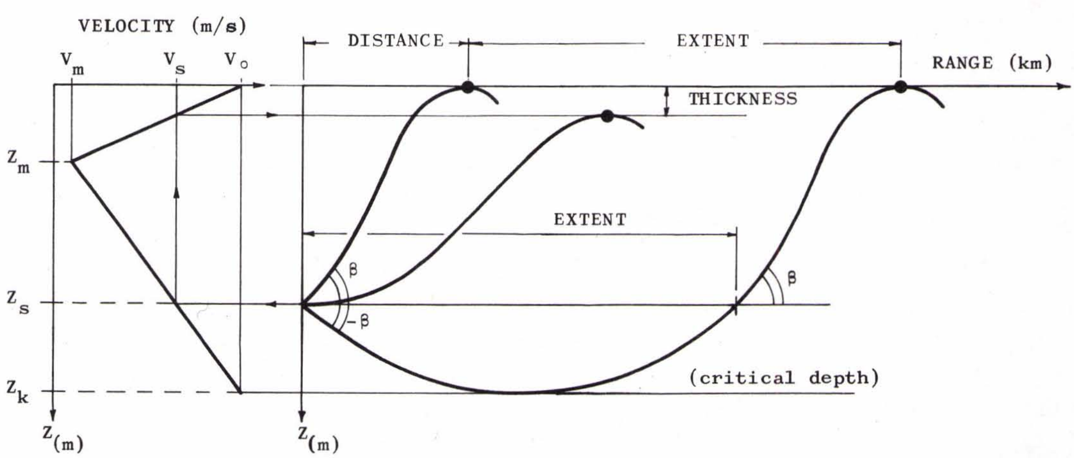

FIG. 1

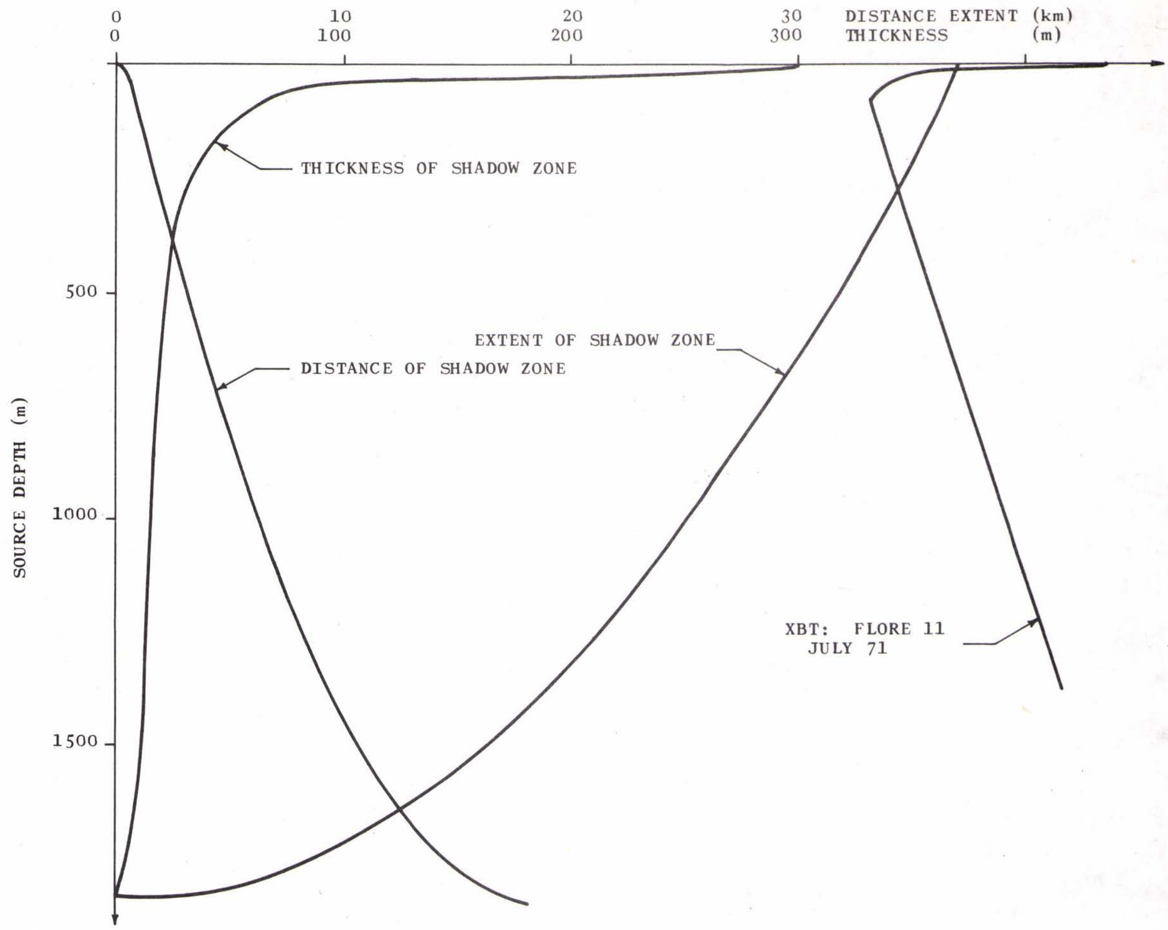
0
10
20
30
DISTANCE EXTENT (km)
0
100
200
300
THICKNESS (m)
THICKNESS OF SHADOW ZONE
500
EXTENT OF SHADOW ZONE
DISTANCE OF SHADOW ZONE
SOURCE DEPTH (m)
1000
XBT: FLORE 11
JULY 71
1500

FIG. 2

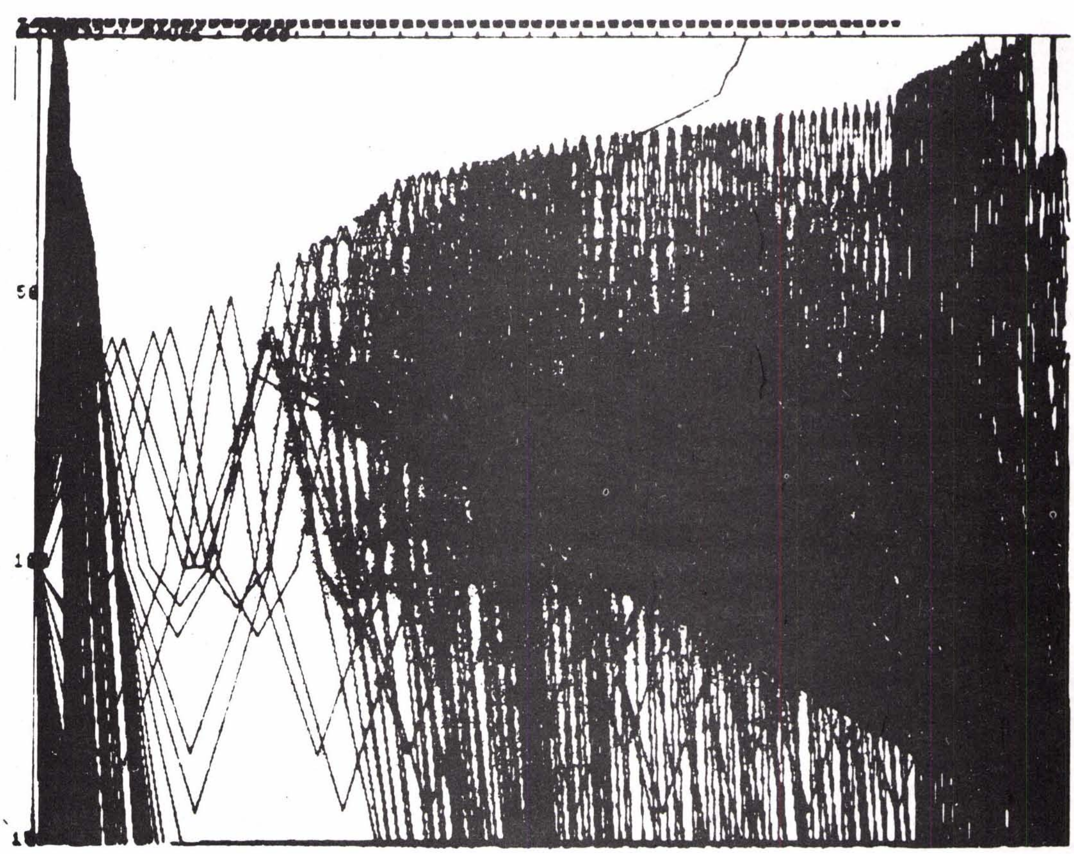

FIG. 3

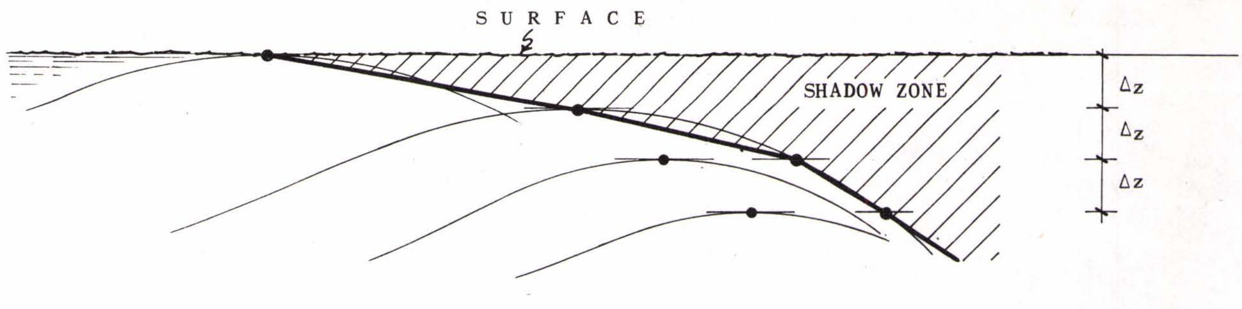

FIG. 4

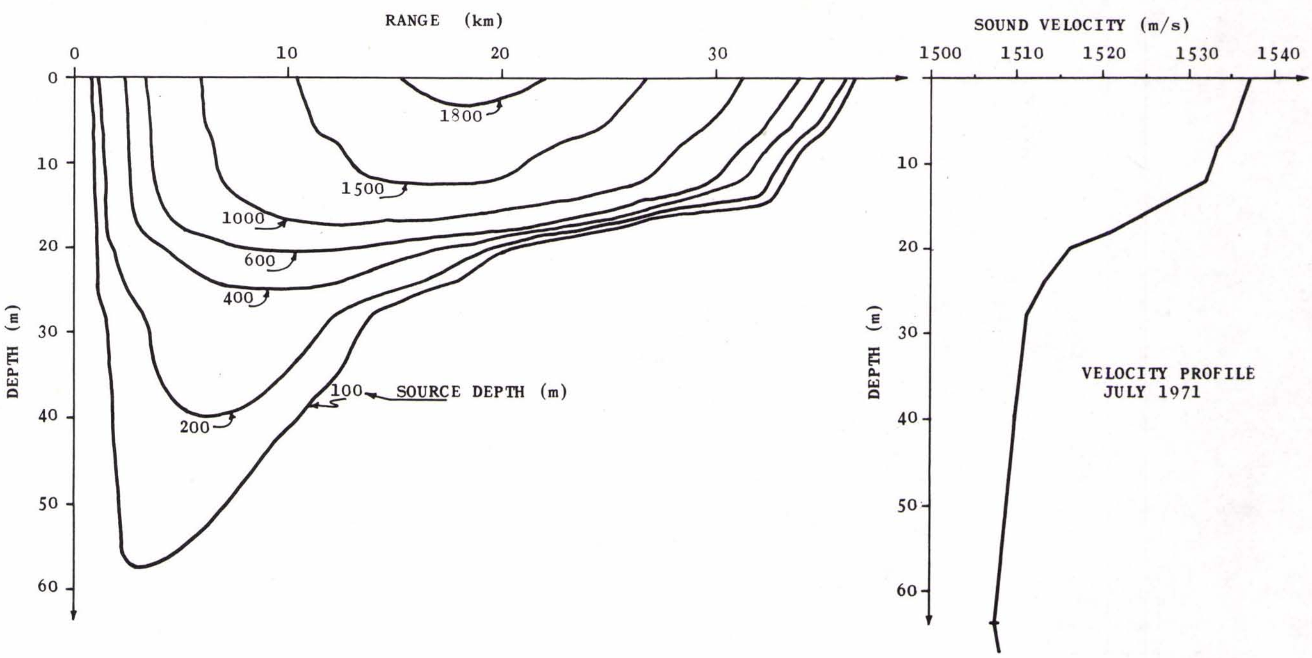

FIG. 5

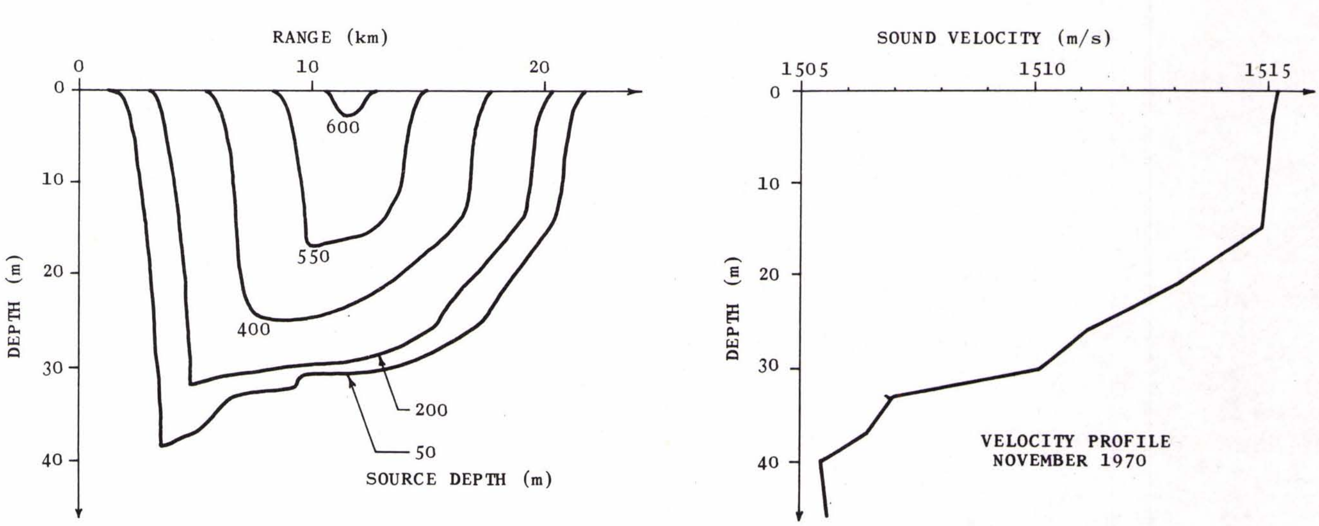

FIG. 6