SIDE SCANNING SONAR - A THEORETICAL STUDY

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ABSTRACT

The principle of operation in side scanning sonars is here studied.

After briefly describing the various existing equipments, the influence of different design factors on the range is first examined, and then the resolution in both the horizontal and the vertical plane. Next distortions are analysed. Firstly there are those inherent in the principle adopted for the instrument : these distortions are due either to the obliquity of the acoustic waves, or to the ratio between recording scales, or again to the slope of the sea bottom. Secondly, accidental distortions are discussed : these result from the pitch, roll or yawing of the fish carrying the transducer, from the crabwise motions of the vessel due to cross winds or currents, and from variations in the velocity of sound in water. Finally acoustic interferences are discussed : those attributable to the recording paper, to several instruments being operated simultaneously, or to shoals of fish, the Deep Scattering Layer, or to airbubbles in the water.

Some indications as to how to achieve satisfactory results with a side scanning sonar for specified purposes are given in a brief conclusion.

For illustrated examples the reader is referred to various earlier issues of the *International Hydrographic Review*.

GENERAL

It was to geologists in Great Britain towards the end of the 1950s that the idea of applying side scan sonar methods first came — and it is the British who have contributed the most to the development of this equipment.

Its principle is simple. For observing the sea bottom we do not have the advantage of an underwater beam composed of parallel rays, as is the case on land with the sun's rays. We can, however, scan acoustically in an oblique direction, and thus the surface covered by the acoustic emission is much larger than the classic " line of soundings ". However, precise measurements of the distance between the vessel and a given reflector — i.e. the reflecting surface — and especially measurement of the height of this reflector will not be possible unless many and complicated precautions are taken. In other words, a side scan sonar is a valuable tool for rapid identification of the shape and irregularities of the sea floor — but not an instrument for precise topographic use.

An oblong transducer with its axis inclined horizontally directs its acoustic beam obliquely. Since it is oblong (its length being equivalent to 10 - 50 λ, where λ is the wavelength of the emitted sound), the transducer consequently has good horizontal directivity, i.e. in the forward direction of the vessel on which it is installed. Since it is slender (its width is the equivalent of 2 - 5 λ) it has a large lobe in the vertical plane so as to be able to cover a wide band of terrain in the direction perpendicular to its axis (fig. 1).

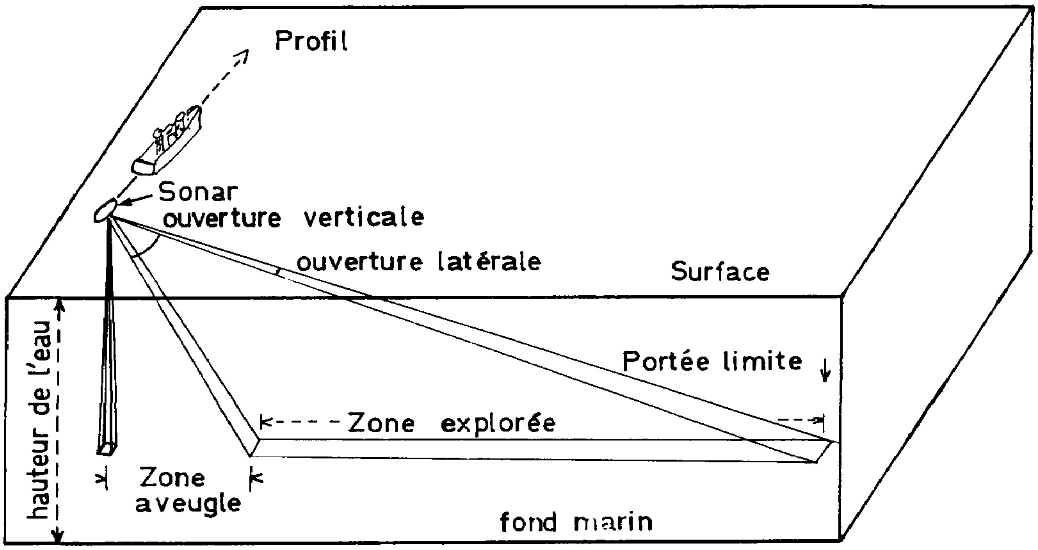

FIG. 1. — Principle of a side scan sonar.
In the example shown the sonar is only scanning to one side of the ship.

Profil = Ship's track
Ouverture verticale = Vertical beamwidth
Ouverture latérale = Lateral beamwidth
Portée limite = Limit of range
Zone explorée = Area scanned
Zone aveugle = Shadow zone
Fond marin = Sea floor
Hauteur de l'eau = Water depth.

The first instruments were those devised by the National Institute of Oceanography (NIO) and by the firm of Kelvin Hughes. Their respective frequencies were 48 kHz and 36 kHz and they were specially designed for geological studies of the continental shelf off Great Britain and in the approaches to Hong Kong.

In 1965 the Institut français du pétrole (IFP) developed a side scan sonar with comparable characteristics and capable of improved performances, and this was also put to marine geological use. It is mainly in the realm of the various methods of processing recordings that the IFP's contribution has been the most valuable.

During the late 1960's a whole crop of small side scan sonars made their appearance. These use frequencies of about 100 kHz and have a maximum range of the order of 300 m. Their resolution is excellent. These sonars are used mainly for industrial activities stemming from the search for oil at sea which is becoming increasingly intensified.

More recently (1970) the British have developed a large side scanning sonar — the GLORIA — which is made for long-range geological exploration in deep water.

In the field of side scanning sonar the various requirements have been clearly defined, and each kind of equipment has quite distinct functions. There can thus be no confusion in the minds of the uninitiated between one type and another, whereas the contrary is still often the case in continuous seismic profiling (LEENHARDT, 1972).

Generally speaking, the transducers are coupled in pairs so as to cover the sea floor both to starboard and to port of the ship's route. With an appropriate recorder the two lateral views can then be registered side by side. The transducers are usually mounted in a fish towed behind the recording vessel, although there are some which are hull-mounted (i.e. those on naval vessels and on submersibles).

Piezo-electric ceramics are nowadays invariably used in the construction of transducers; the earlier models had magneto-strictive vibrators.

It is the transducer's principal lobe which scans the bottom and

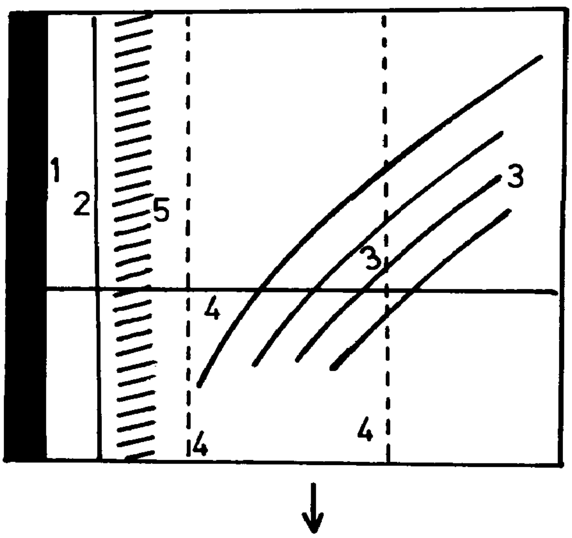

FIG. 2. — A side scan record. Explanations are given in the text. Note, however, that the geologic features (3) are simplified; (4) indicates the two scale lines and a time mark; and (5) the secondary lobe of the transducer.

supplies the required picture. The transducer will have either a single or several "side" lobes according to the degree of care taken in its design. The best instruments are those where only one side lobe is retained. This lobe will emit vertically below the transducer and will function like an echo-sounder (*cf.* STRIDE, fig. 2).

A typical record which has two symmetrical halves, one of which is shown in diagram form in figure 2, will consist of :

— A wide dark line (marked 1) which is the emission signal;

— A narrow and more or less straight line (marked 2) which gives the height of the transducer above the bottom;

— A series of more or less regular traces (marked 3) which are the echoes reflected from the bottom;

— Supplementary details such as scale lines and time marks (marked 4);

— False traces (marked 5), a subject to be treated later in this article (*cf.* STUBBS, fig. 3).

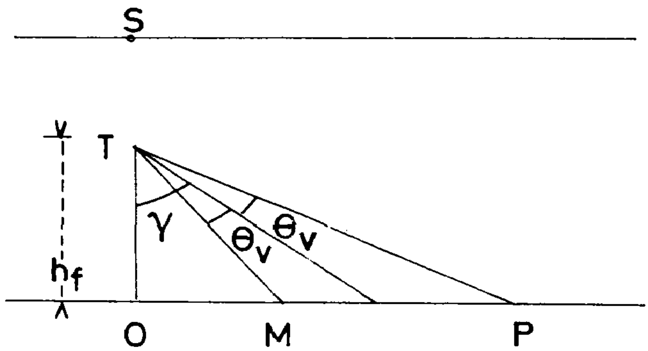

FIG. 3. — Vertical section, showing the shadow zone OM, and the scanned area MP. S indicates the ship.

TYPES OF EQUIPMENT

There are three distinct families of existing equipment :

(a) Sonars for specific sub-marine operations.

These are instruments designed for such operations as searching for an obstruction in a navigational channel, wreck or mine searching, locating of sub-marine cables, etc. They are also used by certain researchers for sediment studies.

These sonars utilize high frequencies (300 kHz) and have good resolution but limited range (300 m). They have been conceived for small depths in view of the fact that today industrial activity at sea is still necessarily limited to continental shelf areas (cf. ROBERTS).

Apart from the recorders, the essential differences between the various types of equipment on the market concern the streamlining of the fish and its cable. This streamlining is better in the Ocean Research Equipment (ORE) Company's instruments (with whose sonar it is possible to work at as much as 8 knots or more) than it is in those manufactured by Edgerton, Germeshausen & Grier (EG&G) or Klein Associates. The latter two have however developed recorders that are an improvement on the Ocean Sonics recorder incorporated in the ORE instruments.

The ORE sonar is contained in a fish which also incorporates a sediment sounder. Thus the two channel record can show either the two side scan views of the bottom, or alternatively one of these views and a cross section of the layer of sediment.

Mine searching is essentially a naval problem and is carried out with naval equipment which has roughly the following points of difference with their civilian counterparts :

— A higher frequency and a smaller range;

— No recorder, but real time is observed on an oscillograph screen by trained personnel;

— A sonar mounted for *panoramic* viewing : there is only one transducer which rotates horizontally to explore the whole of the plane. Civilian versions of this equipment are manufactured by various firms (Strazza, Thomson Csf.) and are used aboard exploratory submersibles (the bathyscaphe *Archimède* for example) chiefly for purposes of navigational safety near the bottom.

(b) Geological sonars.

These are sonars whose fundamental use is for geological research. They operate at 36 kHz and have ranges varying between 1000 and 1500 m. They include the British sonars developed by the NIO and by Kelvin Hughes, and the SONAL of the IFP. The SONAL uses a very wide three-track recorder, two for lateral views and the third for a seismic profile which is supplied by a sparker coupled with a side scan sonar.

These instruments have made possible many particularly useful surveys in areas where the sediment layer is thin, and in consequence where outcropping is fairly usual, giving evidence of the contours of the underlying geology. (*Cf.* CHESTERMAN *et al.*).

(c) A long-range sonar.

To meet the requirements of geological studies in deep water the NIO has designed the GLORIA sonar (Geological LOng Range Inclined Asdic) which uses a frequency of 6.5 kHz. The maximum range of this equipment is 22 km and it emits every 30 seconds. Its fish is towed under the thermocline in order to obtain increased range by avoiding the effect of refraction in the upper layers of water where velocity gradients decrease as the depths increase. (*Cf.* RUSBY).

The transducer only scans one side at a time. It is about 6.5 m by 1 m in size. The fish itself is 15 m long and has has a weight in air of 7 tons and of 30 tons as it emerges from the water. In order to give it good stability the fish is equipped with active fins and is disassociated from the ship's motion. The onboard gyroscope is used to direct the outgoing beam, and the reflected beam is compensated electronically.

The GLORIA sonar works on a compressed pulse system which means it can emit sufficient energy (50 kW) without being obliged to incorporate further transducers, but above all without requiring an electric power source of more than 1 kW.

The following table shows the characteristics of some of these sonars.

Type	Research sonar	Geological sonar	Long-range sonar
Mark	EG&G	IFP	GLORIA
Frequency	120 kHz	36.5 kHz	6.5 kHz
Pulselength	0.1 ms	1 ms	12 ms
Horozontal lobe	1°	2°	2.7°
Vertical lobe	20°	20°	10°
Maximum range to each side	300 m	1 500 m	22 000 m
Maximum submergence	600 m	Close to the bottom	Under the thermocline
Towing speed	< 8 knots	5 knots	4-6 knots

OPERATING PRINCIPLE

Range and resolution are the side scan sonar's two operational parameters. Distortions must also be taken into account when interpreting the record.

(a) Range — this is determined by the choice of :

— A frequency for the transducer (the higher this frequency the smaller will be the range, on account of the absorption of sound by the water);

— The scanning speed for the recorder (i.e. the scale of the record). This may be increased by adjusting the recorder;

— The angle of inclination γ between the transducer axis and the vertical (*cf.* STUBBS 'horizontal tilt angle', fig. 4);

— The directivity of the transducer in the vertical plane, a directivity that is always slight, and which can also be expressed in terms of the width of the lobe ($2\,\theta_v$);

— The height above the bottom at which the transducer is to be operated.

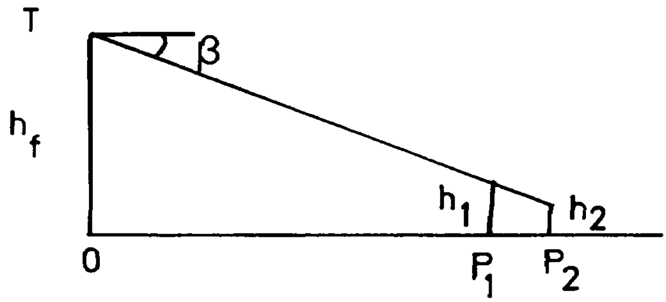

FIG. 4. — Effect of the height of two targets on the resolution. In this example $h_2 = P_2 \tan \beta$.

An analysis of the range factors can therefore start from the points of view of geometry and energetics.

1. ***Geometry*** (fig. 3).

Let h_f be the height of the transducer T above the bottom, γ the angle of inclination of the instrument's axis in relation to the vertical, θ_v the semi-lobes in the vertical plane, and O a point on the seabed vertically below the transducer. The range is then :

$$\overline{OP} = h_f \tan(\gamma + \theta_v)$$

On the assumption that there are no secondary lobes scanning the bottom under the transducer, the shadow zone will be :

$$\overline{OM} = h_f \tan(\gamma - \theta_v)$$

We will now study the relationship between the range, the operating height of the sonar, its inclination, and the vertical lobe.

Putting :

$$P = \frac{\overline{OP}}{h_f} = \tan(\gamma + \theta_v)$$

and :

$$M = \frac{\overline{OM}}{h_f} = \tan(\gamma - \theta_v)$$

$$\theta = \tan \theta_v$$

and :

$$\gamma = \tan(\gamma - \theta)$$

we obtain :

$$P = \frac{\gamma + \theta}{1 - \gamma\theta}$$

$$M = \frac{\gamma - \theta}{1 + \gamma\theta}$$

whence :

$$\theta\,(1 + \gamma P) = P - \gamma$$

$$\theta\,(1 + \gamma M) = \gamma - M$$

that is :

$$\theta^2\,(P - M) + 2\theta\,(1 + MP) - (P - M) = 0$$

$$\gamma^2\,(P + M) + 2\gamma\,(1 - MP) - (P + M) = 0$$

which are the equations determining θ and γ in terms of P and M, i.e. for computing the inclination and the lobe in the light of the conditions of use. This confirms our supposition : to obtain the smallest shadow zone the lobe has to be widened and the transducer tilted downwards to reduce the angle of inclination between the transducer axis and the vertical.

2. ***Energy.***

If the reflectivity index of the reflecting surface is known, we can use the equation for propagation of sound in water to calculate the approximate range of an acoustic wave. For the case of a given reflector the range will therefore vary uniquely with the frequency. Acoustic text-books give the relationship as :

$$2N = S_{w} + D + R_{s} - B - A$$

where

N = the loss of the acoustic signal over a one-way path;
S_w = the emission level in the axis of the transducer;
D = its directivity index;
R_s = the reflectivity index of the reflector;
B = the noise level at the given frequency;
and A = the surplus of emitted power.

All these values are expressed in dB (reference 1 barye at 1 m).

From them we are able to deduce a suitable range, knowing the reflectivity of the reflector.

For example, taking a source with a frequency of 260 kHz, an emission level in the axis of 120 dB (reference 1 barye at 1 m), a directivity index of 26 dB, with a noise level of — 26 dB in a 10 kHz wide band around the emission frequency, and assuming that an echo can be registered normally with 6 dB of excess power, then in function of the reflector's reflectivity index (R) we shall obtain the following ranges (P)

R	— 50 dB	— 30 dB	— 10 dB
P	220 m	290 m	400 m

3. ***Scales.***

The range is in fact finally controlled by the cadence of the emission. If the recording is not programmed (*cf.* ALDEN and FARRINGTON), this cadence determines the recording scale. However, if the recording is programmed the bottom band will be scanned according to the particular programme selected.

4. ***Resolution.***

A distinction is made between resolution in the vertical plane and that in the horizontal plane.

(a) *Resolution in the vertical plane.*

At right angles to the direction of the ship's advance, this resolution is the shortest distance separating two reflectors that are different distances from the transducer. Thus, the resolution is dependent upon :

— the *reflectivity* of the target : the two reflectors must naturally contrast with the bottom around them;

— the *height* of the reflectors above the surrounding seabed. Let h_1 and h_2 be the respective heights of two targets at ranges P_1 and P_2 from the point on the seabed vertically below the transducer, P_1 and P_2 being taken horizontally, and where $(\gamma - \theta_v \leqslant \beta \leqslant \gamma + \theta_v)$, let β be the angle of incidence of a ray such that (fig. 4) :

$$\tan \beta = h_1/P_1$$

If $h_2 \leqslant P_2 \tan \beta$, the second reflector will be entirely masked by the first.

— *the recording scale :* On the records it will at best be possible to distinguish two signals 1 mm apart. If, for example the recording scale is 250 m, and the paper width 250 mm it will just be possible to distinguish objects 1 m apart.

— *the pulse length :* In order to be able to distinguish one target behind the other, the signal from the first must not mask the one from the second. Let d be the pulse length, l the sound path corresponding to the pulse length, x the resulting increase in horizontal range, and T the oblique distance in metres from transducer to target. Disregarding the squares of x and l we have (fig. 5) :

$$h_f^2 + (P + x)^2 = T^2 + l^2$$

and

$$h_f^2 + P^2 = T^2$$

$$x = \frac{Tl}{P} = l\sqrt{1 + \frac{h_f^2}{P^2}}$$

The lower the angle from which the target is viewed — that is to say either the closer the transducer to the bottom or the further away the target — the better will be the resolution.

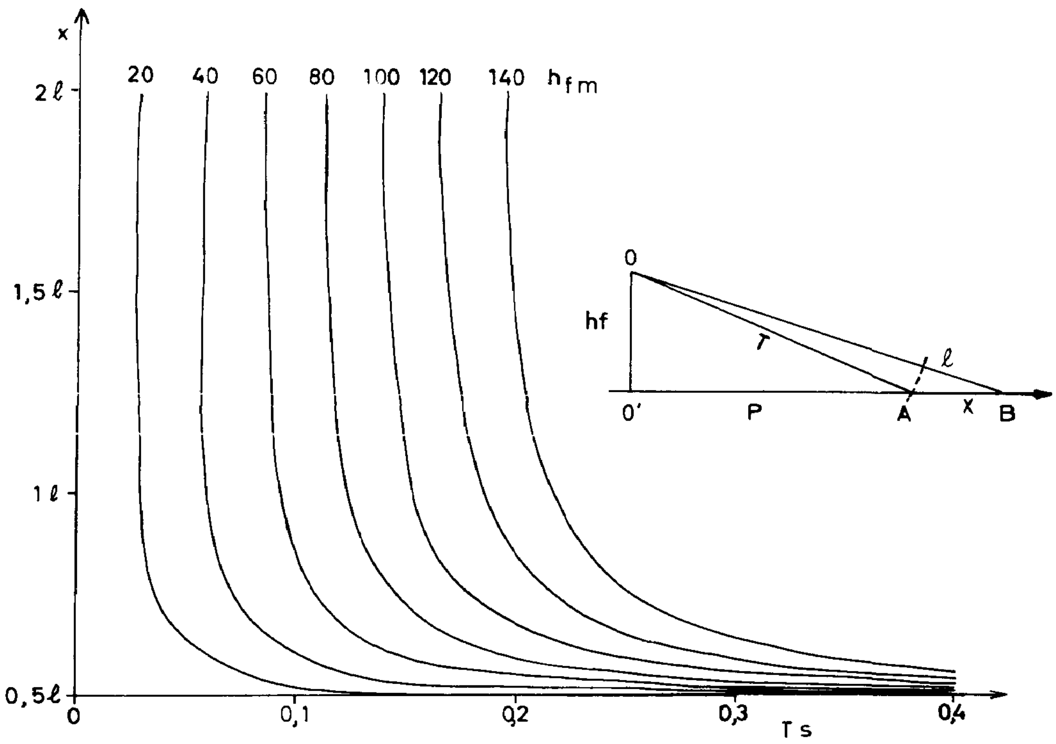

FIG. 5. — Effect of the pulse length on resolution. l is the path corresponding to the pulse length, and X the resulting loss of resolution. Entering T, from the time read on the recorder, the resulting curves will indicate the loss of resolution in terms of pulselength and the transducer height above the bottom.
(Figure taken from CHOLET *et al.*)

On the record the pulselengths used are in practice always inferior to the graphic resolution that is possible with the paper width.

(b) *Resolution in the horizontal plane.*

In the horizontal plane the transducer's angular width $2\,\theta_h$ is always small. It is this that will determine resolution in the horizontal plane. We shall here first examine the conditions for perceiving as small an object as possible and secondly two objects as close to one another as possible (this is resolution in the strict sense of the word).

For viewing the small object : Let us assume that it will be necessary to detect k $(3 \leqslant k \leqslant 5)$ reflections on the same target in order to assure that it is discernible on the record.

At each emission the rays cover a reflected length of $L = 2\,P\,\theta_h$ (θ_h being expressed in radians) at a distance P along the bottom profile (fig. 6).

The ship advances at a speed of V m/s and emits N signals per second. It has thus moved a length of $\frac{V}{N}m$ between two emissions.

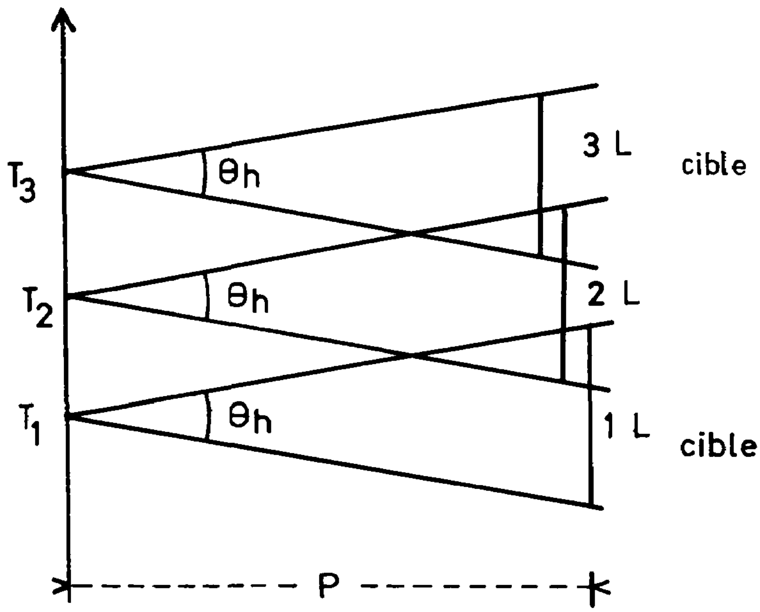

FIG. 6. — Successive positions of the surfaces covered by a transducer moving from position 1 through to position 3.
Cible = Target.

In order to have k emissions on the same target we must have :

$$\frac{kV}{N} \leqslant L \leqslant 2\ P\theta_h k$$

and this imposes a ship speed of :

$$V \leqslant 2\ \frac{NP\theta_h}{k}$$

a condition that may be invariably met using present-day towed fish (< 12 knots). There is also a minimum range condition :

$$P \leqslant \frac{kV}{2N\theta_h}$$

This may be important when working in shallow depths at small distances from the bottom profile, and may also require a reduction in the vessel's speed.

In order to distinguish between two objects that are situated parallel to the ship's route it will be necessary, during an emission sequence, that k emissions are not reflected against either of these objects. During the time of these k emissions the ship steams kV/N metres. Each outer emission covers a length $kV/N + P\theta_h$. The minimum interval of distance (I) between two objects is thus :

$$I \geqslant \frac{kV}{N} + 2\ P\theta_h$$

which is at least the distance run during two k emissions. Resolution in the horizontal plane is therefore controlled by the speed of the ship if it is a case of distinguishing between two separate reflectors; whilst the width of the horizontal lobes of the emissions is relevant when it is desired to show a break between two elongated reflectors.

Examples.

1. Take a good reflector in the form of a cube with 1 m sides and at a distance of 100 m from the point vertically below the tranducer.

(a) *EG&G Sonar.*

$k = 3$, $N = 2.5/s$, $P = 100$ m, $2\,\theta_h = 0.015$ radian
$v \leqslant 1.25$ m/s

(b) *Sonal.*

$k = 3$, $N = 1/2$ s, $P = 100$ m, $2\,\theta_h = 0.03$ radian
$v \leqslant 0.5$ m/s

(If the cube is at a distance of 1000 m — and this distance is better suited to the instrument's capabilities — then the velocity can be of up to 5 m/s).

2. For a break in a sea-wall of minimum length I, the velocities and distances being the same as mentioned above :

(a) *EG&G Sonar.*

$I = 3$ m

(b) *Sonal.*

$I = 6$ m

(For a velocity of 5 m/s and a distance of 1000 m we obtain $I = 60$ m).

Distortions.

We have just been studying the theoretical conditions for recording. If our study is to be a complete one we must take account of both distortions and false traces. Such interference can result from either independent elements, from the instrument itself, or from the sea floor. Some of the distortions are inherent in the principle adopted for the equipment, and others result from faulty handling of the equipment.

(a) ***Basic distortions.***

1. *Obliquity of rays.*

As a result of the principle adopted for the instrument it is not the true horizontal distances (P) from a point on the bottom vertically below the ship to the reflectors that are registered, but the oblique distances (T) from the transducer to the reflectors. These measurements are linked by the relation :

$$P^2 = T^2 - h_f^2$$

that can be represented by a set of straight lines $P = f(T)$, h_f being taken as the parameter (fig. 7). The longer the range the smaller will be this distortion.

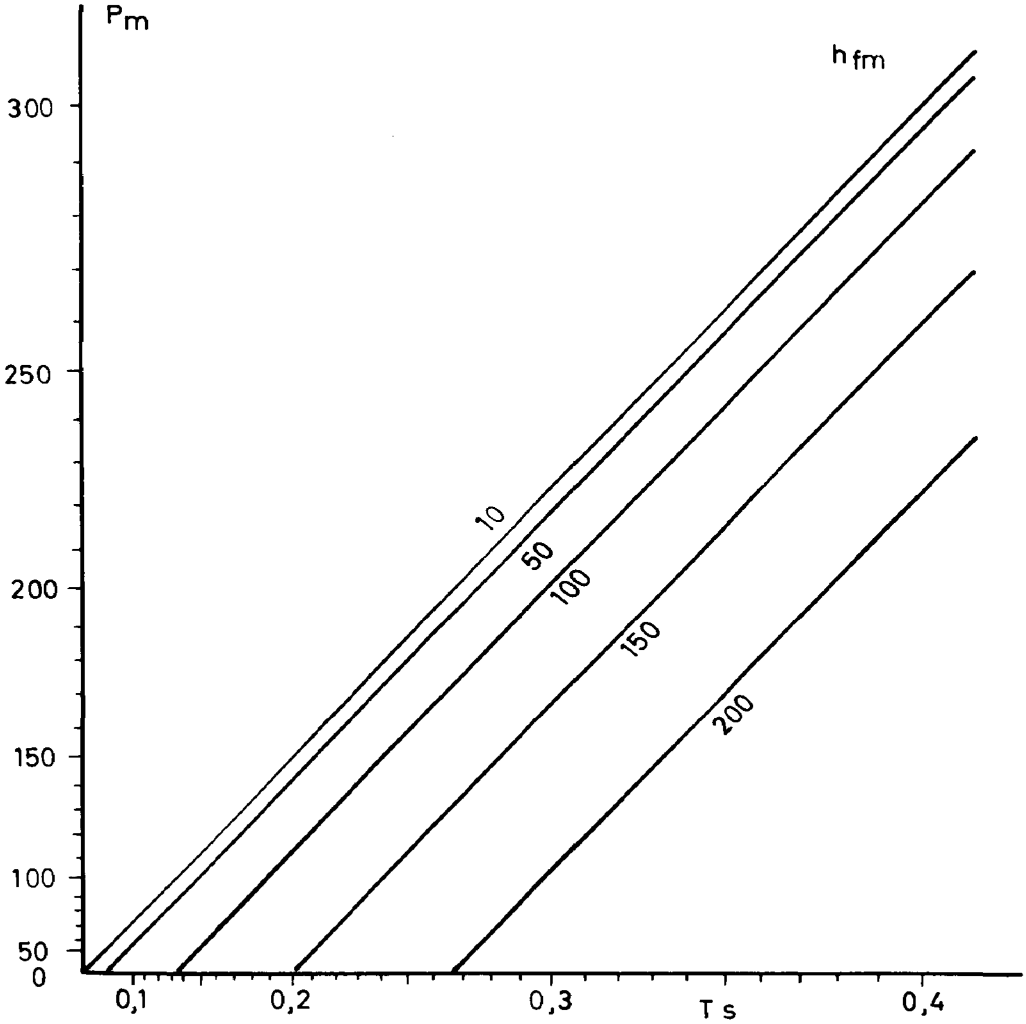

FIG. 7. — Distortion of the record due to ray obliquity.
(Figure taken from CHOLET *et al.*)

Using parabolic scales the relation between the sonar range, the height of the fish above the bottom and the echo time read on the record can be written in linear form.

Correction of the obliquity distortion.

At the time of the early sonars a method was devised of correcting the non-linearity of the normal recording with respect to the echo time by means of a non-linear recorder. The Westinghouse Company's *Deep Star* had a non-linear recorder, its helix having a parabolic pitch. This solution can only be adopted when the height of the transducer above the bottom is always the same.

The most sophisticated method of making this correction is by anamorphosis, or making a distorted projection, of the records. This procedure is particularly necessary when a mosaic of the different strips recorded has to be assembled, in the same way as aerial photographs are assembled. This is a method necessitating a very exact knowledge of the ship's position during the whole of the time the work is being carried out. It was perfected by the IFP which is at present the only organization to use it (CHOLET *et al.*).

2. *Scale ratio.*

The lateral exaggeration on our recordings is dependent on the recording parameters, the paper-width, and the speed of the vessel — just as the vertical exaggeration is in seismic profiling. In order to restitute this exaggeration a precise knowledge of the ship's speed and its variations is most essential.

3. *Bottom slope.*

Let us take a bottom inclined at an angle of α with the horizontal, and a vessel following a contour line (fig. 8).

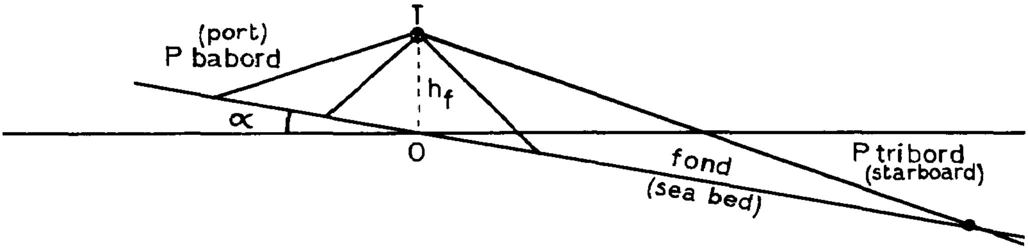

FIG. 8. — Effect of the inclination of the bottom on range. (after CHOLET *et al.*)

Assuming that on the port side the angle of inclination is positive ($\alpha > 0$) :

$$P = T \cos \left(+ \alpha \text{ arc sin } h_f \frac{\cos \alpha}{T} \right)$$

which may also be written as :

$$P = \cos \alpha \sqrt{T^2 - h_f^2 \cos^2 \alpha} + h_f \sin \alpha \cos \alpha$$

For the starboard side α will be negative. $h_f \cos \alpha$ is the depth displayed on the echo sounder and which can be deduced by taking measurements of the slope (*cf.* CHESTERMAN *et al.*, fig. 13).

(b) ***Accidental distortions.***

These distortions are the result of working the equipment in heavy seas. In order to hold its course the vessel may have to proceed crabwise, and thus to tow the fish similarly. The fish may be affected by pitching or rolling of the ship, or can itself yaw.

1. *Rolling :* This has the effect of altering the angle of inclination of the acoustic beam. Thus we can only work where the bottom slope varies sinusoidally with the cycle of the roll.

If there is a heavy roll the acoustic beams may be caused to alternately point towards the sea surface. This will occasion white bands on the record, first to the right and then to the left (*cf.* STRIDE, fig. 3).

2. *Pitching :* This cause intensive dark traces on the record. The bottom appears undulated, the true depth being the one at the top of the sinusoidal curve. Here the best scanned band is no longer parallel to the ship but at an oblique angle to it, and the bottom features are accordingly poorly positioned. However, pitching is generally on a fairly small scale and thus does not have very much effect on the record.

3. *Yawing of the fish :* This may arise if there are shortcomings in the hydrodynamics of the fish and its cable, or with certain types of swell which cause the cable to vibrate. On figure 9, let A, B, C, D, E be the

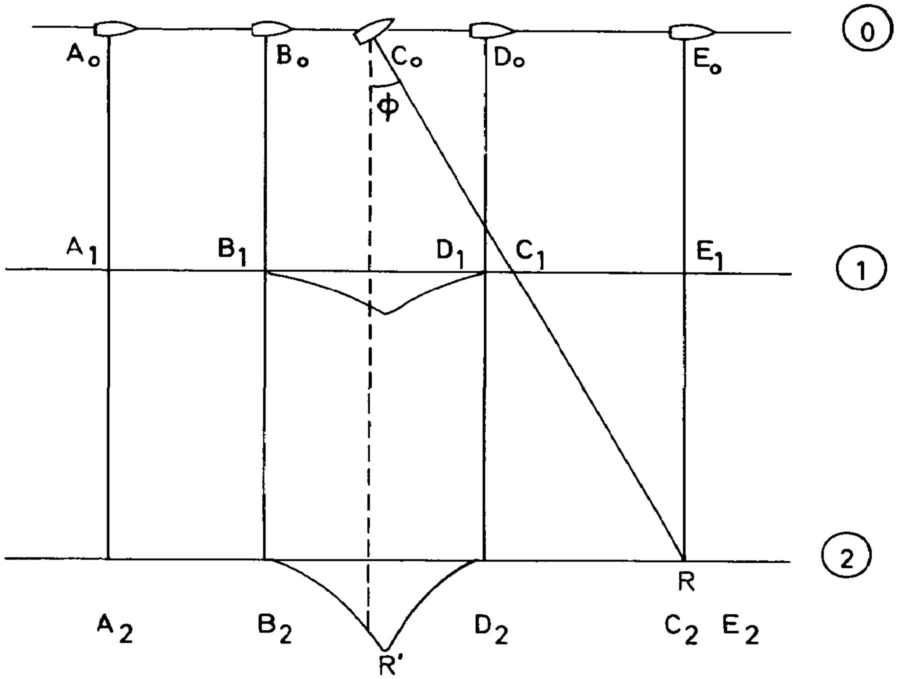

FIG. 9. Effect of yawing of the fish. (after CHOLET *et al.*)
In the absence of yawing, the sonar would see lines 1 and 2 as straight lines. On account of yawing the sonar registers points between B and D that are not in alignment. In particular point R, seen from C_0, will be registered at R′, and seen from E_0 will be at E_2.

track of the fish and Φ an angle of yaw between B_0 and D_0. Let A_1 etc. and A_2 etc. be points viewed from the fish at two different distances, 1 and 2. In position C_0 the fish will see points C_1 and C_2 lying obliquely to the track. However, the distances to points C_1 and R will be recorded as if they were normal to the ship's route 0 and thus further away on the beam than the distances represented by lines 1 and 2. As a result a particular point R as scanned from the yawing fish at C_0 will be recorded as if it were R′, and may be again correctly recorded from E_0 when the fish is again running straight (see fig. 9). Furthermore, the longer the distance between the reflector and the fish, the greater the distortion (*cf.* CHESTERMAN *et al.*, fig. 24).

4. *Crabwise motion of ship.* Under certain angles of wind or swell, the ship has to correct for drift in order to hold to the direction of its route, and thus has to proceed crabwise.

The recorded profile is then offset sideways in relation to the route the ship is following. If the angle of drift is constant, this effect can be corrected proportionally to the distance between the reflector and the ship's route. This distortion is particularly troublesome when we wish to obtain two views of the same part of the bottom, one to the right and the other to the left, whilst running two successive profiles.

5. *Variations of velocity of sound in water.*

On account of currents the water mass is not homogeneously distributed. As a result there are differences in the velocity of propagation of sound. These differences are negligible in seismic profiling where it can be reasonably considered that vertical paths are straight since the relative variation in velocities is small and because the rays have an almost zero angle of incidence.

As the distribution of velocity V (x, y, z) is poorly understood it is not usually possible to correct for this effect, and accordingly we cannot calculate the consequent errors of positioning. Furthermore there can be a limitation of range resulting from the shadow zone phenomenon, a recognized phenomenon in sub-marine acoustics.

If, at a first approximation, velocity V varies with depth h :

$$V = V_0 + ah$$

a being a coefficient, and $t = \int \frac{dh}{V}$ the integral of the acoustic ray, this will mean we shall obtain a circular ray with its concavity turned upwards when a is positive, but downwards when a is negative. On figure 10 these limitations of range are indicated alongside the respective lines. Such limitations only take on noticeable proportions for high values of h_f and P (*cf.* STUBBS, fig. 12, and CHESTERMAN *et al.*, fig. 28).

In addition to distortions the records can also show false traces.

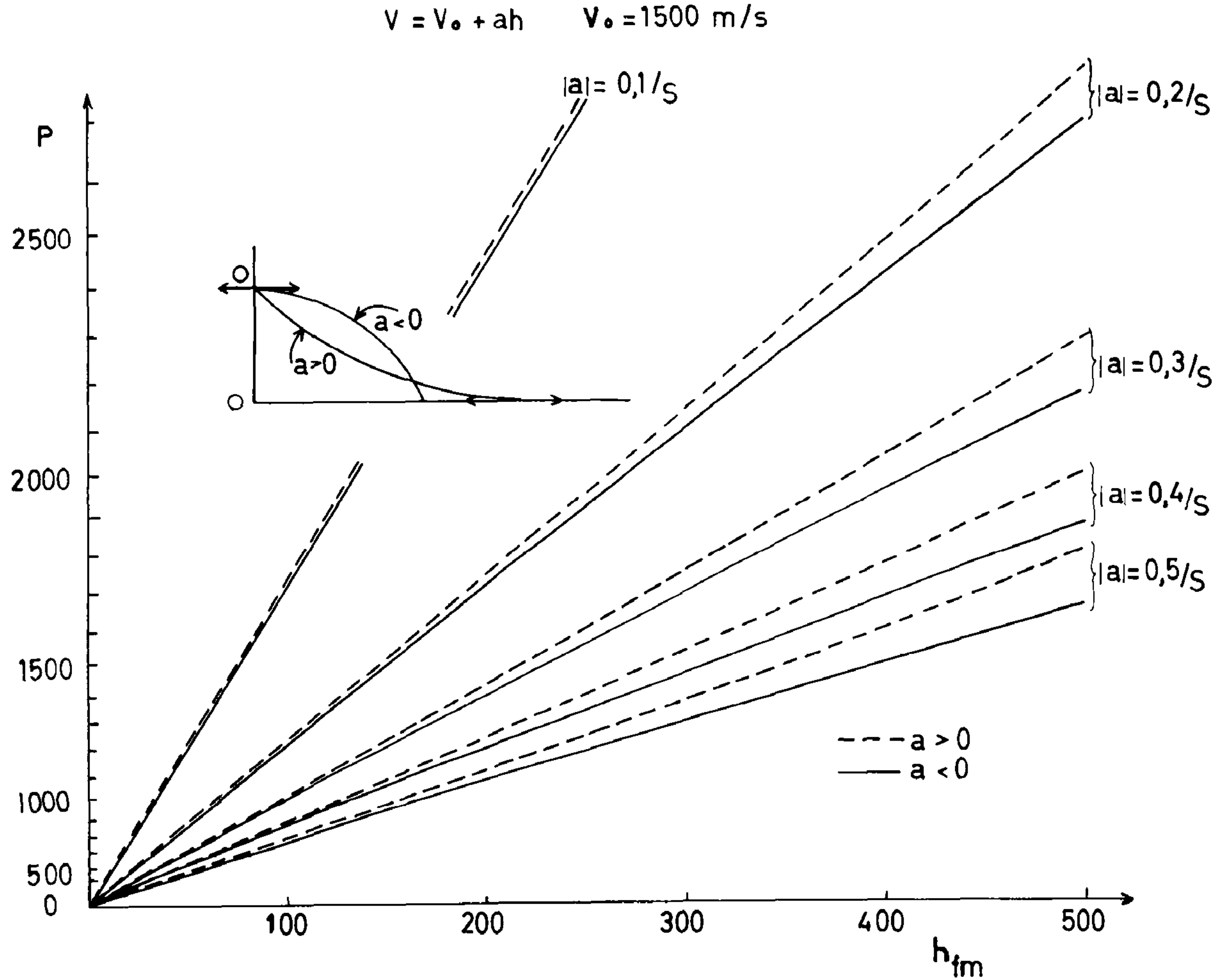

FIG. 10. — Effect of variations in the velocity of sound in water.
(Figure taken from CHOLET *et al.*)

The concavity of the acoustic wave is upwards when the gradient *a* of this velocity variation is positive and downwards when it is negative. In practice the gradients of the various water layers usually take different directions and different values so that only very exceptionally has this effect to be taken into account.

FALSE TRACES

1. *From the recording paper.*

The first type of false trace, and the easiest for a trained observer to recognize, arises from defective recording. This can be a question of folds in the paper, of dirt in the helix, or of the helix shaft scraping the paper, or else of the vanes being unevenly worn (*cf.* ALDEN and FARRINGTON, and STUBBS, fig. 13 and 14).

2. *From instruments being used simultaneously.*

In certain cases simultaneous use can be made of the side scan sonar and an echo sounder of very similar frequency, or again this sonar and a sparker having a very wide emission band. The signals are then received by the transducers of the side scan sonar.

These signals will be inscribed in regular strips, or else as false traces evenly distributed over the record, according to whether or not they are synchronous with the side scan sonar recorder. In either case they are easily recognized, and are very unlikely to lead to difficulties of interpretation (*cf.* STRIDE, fig. 6).

3. *From dolphin squeaks.*

On some records the signals are distributed in a random fashion. If a wide-band loud speaker is connected to a hydrophone on an acoustic frequency then recognition of these as dolphin squeaks will be possible.

4. *From fish and the Deep Scattering Layer* (DSL).

The bodies of fish and their swim bladders cause echoes at certain frequencies. This will depend on the size of their bladders and the depth at which they are swimming. According to the number of fish, the record will show either individual echoes curved in shape, or else continuous and often thick lines. The phenomenon is similar to that experienced in echo sounding. In certain cases it may be difficult to distinguish the bottom reflection from the DSL which may be close to it (*cf.* STUBBS, fig. 6).

5. *From air bubbles.*

Air bubbles in the water can also form an acoustic screen which will resonate. The bubbles can be caused by a ship's wake, or simply by a rough sea (*cf.* STUBBS, fig. 8, and CHESTERMAN *et al.*, fig. 37).

6. *Interferences.*

In certain modes of operation or for certain types of equipment the beamwidth θ_v and the angle of inclination γ of the transducer's axis are such that :

$$\theta_v + \gamma > \frac{\pi}{2}$$

When the sea is calm the reflection is specular and an interference fringe forms between the direct path and the path that has been reflected once from the surface (figure 11, and *cf.* STUBBS, figure 11 and CHESTERMAN *et al.*, fig. 32. CHESTERMAN, and also WONG, have made some calculations on these interferences, and the use to which they might be put for exact determinations of water depth).

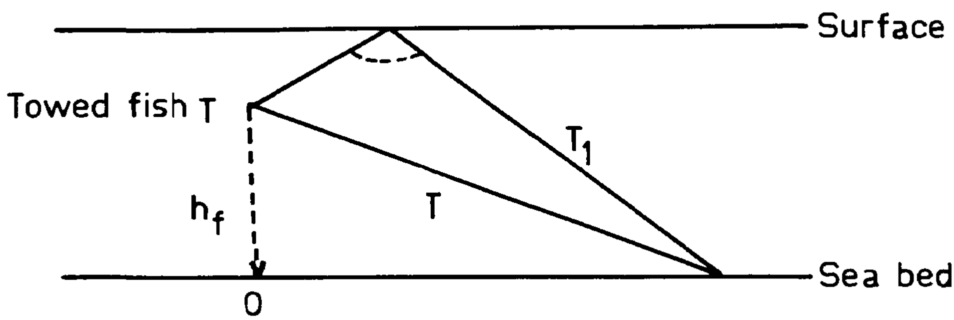

FIG. 11. — Diagram showing how interferences are formed between a normal path T and a path T_1 that has been reflected once on the water surface.

In shallow water there can also be interference between the direct path and a ray that has been reflected once by the bottom and once by the surface.

Finally, there is the particular case of interferences when using a two-channel transducer which means that acoustic or electric interactions between the two channels are observed.

CONCLUSION

The present study has been an entirely theoretic one. Some of the figures appearing in earlier articles published in the *International Hydrographic Review* will illustrate various points. These articles are here preceded by the notation "*cf.*". Strangely enough, there has so far never been a work which has examined all the different aspects of working with a side scan sonar. However, its use for geological interpretation has been described by BELDERSON *et al.*, and I have drawn freely on this work, as well as on that by CHOLET *et al.*

From the present study we can conclude that :

— When using side scan sonars for marine engineering purposes :

- The equipment selected must have the fish and its cabling well streamlined, and the recorders must be robust.

- The range should be kept below the maximum range advocated by the manufacturer.
- Great attention should be paid to positioning quality and to navigational regularity.
- Optimum navigational conditions should be sought when planning how the ship will cover the area.
- Work should not be carried out in bad weather.

— For geological reconnaissance work we should not limit ourselves to the data from side scan sonar; a sediment probe should be used at the same time — or even better, seismic equipment integrated into the side scan sonar (as for instance the IFP's SONAL).

— For hydrographic uses even more care must be taken in positioning, in order that anamorphic methods may be used on the record. The data from side scan sonar should always be considered merely as indications. For cartographic uses the submarine features must continue to be measured with the classical hydrographic methods.

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