On the Acoustic Disturbances Produced by Small Bodies in Plane Waves Transmitted through Water, with special Reference to the Single-plate Direction Finder.

By A. B. Wood, D.Sc., F.Inst.P., and F. B. Young, B.A., D.Sc., F.Inst.P.

(Communicated by Sir W. Bragg, F.R.S. Received March 10, 1921.)

1. Introductory.

The experiments to be described were carried out for the Board of Invention and Research, under the direction of Sir William Bragg, between October 1916 and February 1917, on the Cullaloe Reservoir, near Aberdour, Fifeshire, and are now published with the permission of the Admiralty.

A form of directional hydrophone has already been described by Sir William Bragg. It consists of a metal diaphragm, A, about four inches in diameter, mounted in a heavy ring, B, and open to the water on both sides (*vide* Chart 9). In the centre of the diaphragm is a small metal box, C, carrying a carbon granule microphone of the button type. The microphone is connected into an ordinary telephone circuit. If the instrument is rotated about a vertical diameter in water through which sound waves are passing the sound heard in the receivers passes through a number of maxima and minima. When the diaphragm is turned "edge-on" to the source of sound it is obvious that the pressure pulses will reach the two faces of the diaphragm symmetrically and the diaphragm will fail to vibrate. As, however, either face is turned toward the source this symmetry ceases to exist and the diaphagm is thrown into vibration, which reaches a maximum amplitude when the instrument is "broad-side" on to the source. The instrument, therefore, indicates the line of propagation of the sound, but owing to the existence of two positions of maximum or minimum its indications are ambiguous as regards the sense of direction.

Attempts were made to remove this ambiguity by mounting a small screen or baffle plate opposite one face of the diaphragm. Discs of lead, iron or wood appeared to be without influence, but a wooden disc covered with sheet lead actually gave the desired result, the response of the microphone being less when the shielded face was turned toward the source than when the exposed face was so directed (*vide* Section 3).

Though the lead-wood baffle acted as though it were casting an acoustic shadow upon the diaphragm, the production of a shadow in the optical sense would be impossible, since the diameter of the disc was small compared with the wave-length of the sound; the wave-length in water for a frequency of

1000 ~/sec. is about 5 feet whilst the diameter of the disc was 10 inches only. Calculation of the disturbances produced by small screens is possible only in certain simple cases, and the experiments to be described were undertaken with the object of elucidating the essential conditions of baffle action.

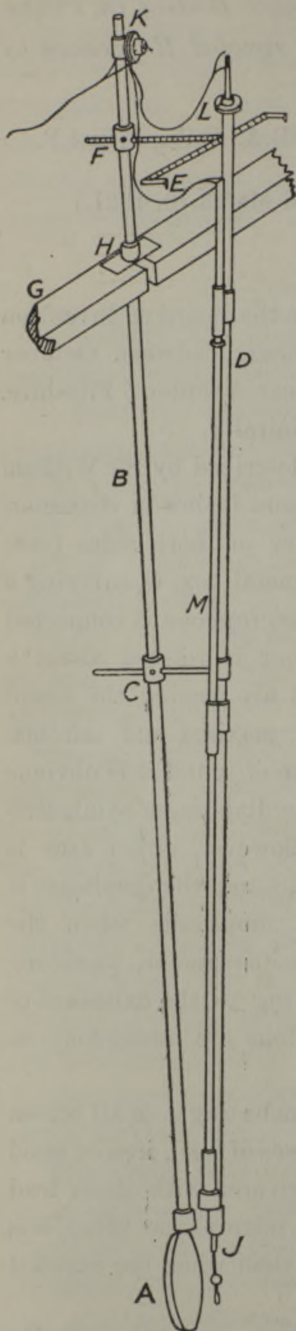


Fig. 1.

Work in a laboratory tank was rendered impossible by the interference of reflections from the sides. The investigation was, therefore, carried out on a raft moored on the Cullaloe Reservoir.

2. Exploration of the Acoustic Fields in the Neighbourhood of Small Screens Immersed in Water.

The acoustic fields were charted around a variety of small discs placed in the path of a train of (approximately) plane sound waves propagated through water. The preparation of the charts involved the determination at a series of points of—

(i) the direction of oscillation of the water particles.

(ii) the amplitude of the displacement of the particles.

(iii) the amplitude of the pressure oscillations.

(a) *Apparatus.*

The exploring apparatus is shown in fig. 1. The screen, A, is suspended from an iron tube, B, about 11 feet in length. A light steel tube, D, is so mounted near its centre point as to be free to rock in any direction but not to rotate. The exploring instruments are carried at the lower end of D, whilst the upper end travels along a graduated guide bar, E, the graduated supporting rod of which slides in a boss, F. By means of E and F the positions of the exploring instruments with respect to the disc could be determined.

The "Displacement Explorer" (fig. 2A), is a small "light body" hydrophone,* consisting of a hollow ebonite sphere, A, about 1 inch in diameter, in which an A.T.M. button microphone, B, is rigidly mounted by its back. It is suspended by the rubber tubing, D, and held in a vertical position by the brass weight, F. As elsewhere explained (*loc. cit.*), this instrument acts as a directional

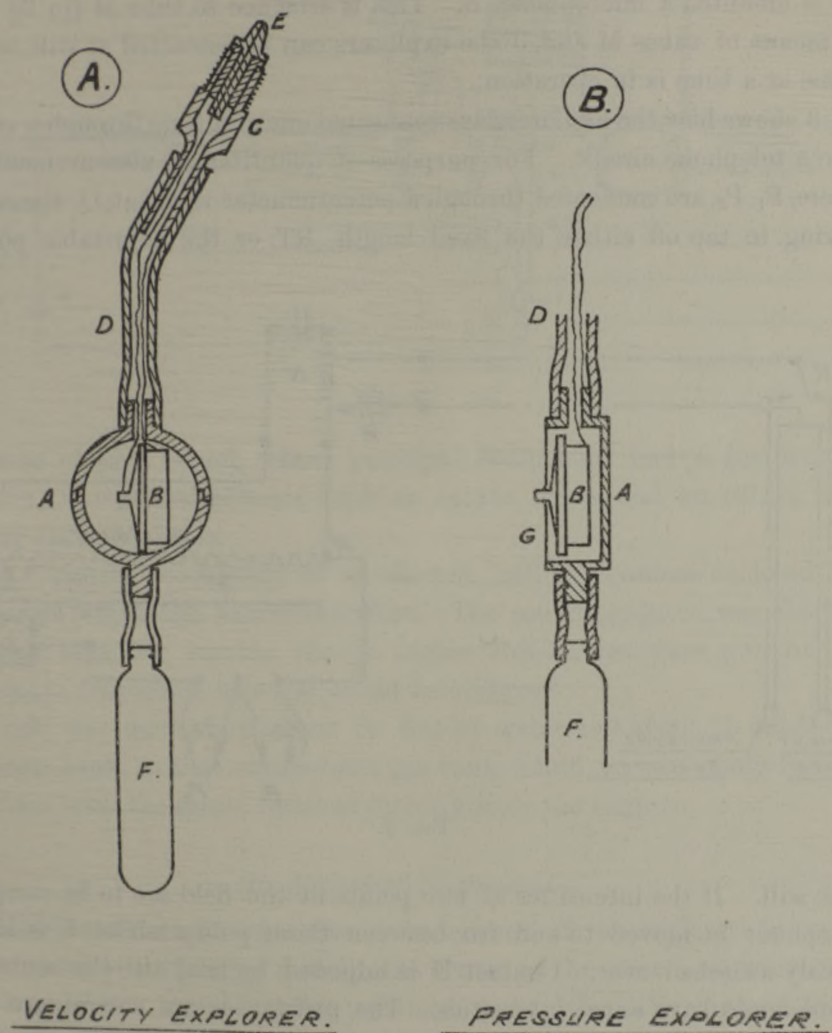


Fig. 2.

hydrophone, the microphone responding readily to sound waves which travel in a direction parallel to its axis, but very slightly to those whose direction is parallel to its diaphragm. The flexible suspension is rendered necessary by the sensitiveness of the microphone to slight changes of inclination and also

* *Vide* the preceding paper, "On 'Light Body' Hydrophones and the Directional Properties of Microphones."

serves the purpose of acoustic insulation. The instrument is attached to a light rotatable tube, J, passing up through D, and indicating the orientation of the sphere on a dial, L. (see fig. 1).

The "Pressure Explorer" (fig. 2B) is a shallow brass cylindrical box, A, about 1 inch in diameter, the lid of which consists of a thin diaphragm, G, on which is mounted a microphone, B. This is attached to tube M (in fig. 1).

By means of tubes M and J the explorers can be retracted at will, so that only one at a time is in operation.

Fig. 3 shows how the explorers are connected one at a time through a switch, K, into a telephone circuit. For purposes of quantitative measurements the receivers, P_1, P_2, are connected through a potentiometer rheostat, Q, the switch, S, serving to tap off either the fixed length, RT, or the adjustable portion,

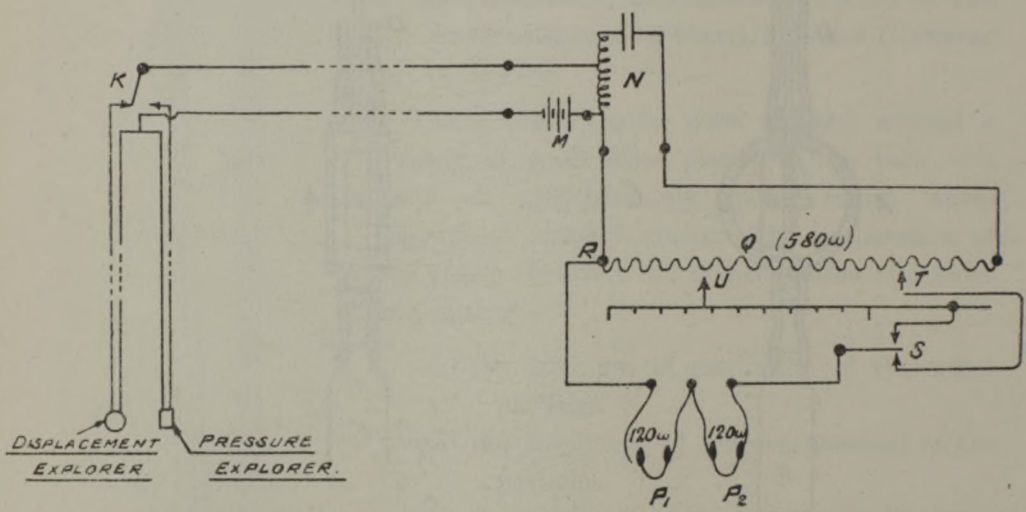


FIG. 3.

RU, at will. If the intensities at two points in the field are to be compared the explorer is moved to and fro between those points whilst S is simultaneously switched over. Contact U is adjusted by trial till the sounds in the telephones have equal intensities. The resistances are so arranged that the ratio of the amplitudes at the two points is given by the inverse ratio of the lengths of the rheostat tapped off.

Fig. 4 shows the general dispositions. The exploring apparatus is supported in the well, A, of a raft so that the disc and explorers are immersed to a depth of about 8 feet. The walls of the well, which dip into the water, ensure calm water immediately round the apparatus. A light wooden hut serves both to shelter the observers from the weather and to facilitate listening by screening them from the wind. The sources of sound are

suspended at the end of a light boom extending from the front of the hut. These are two in number :—

(i) An electric "buzzer" enclosed in a watertight case and giving a

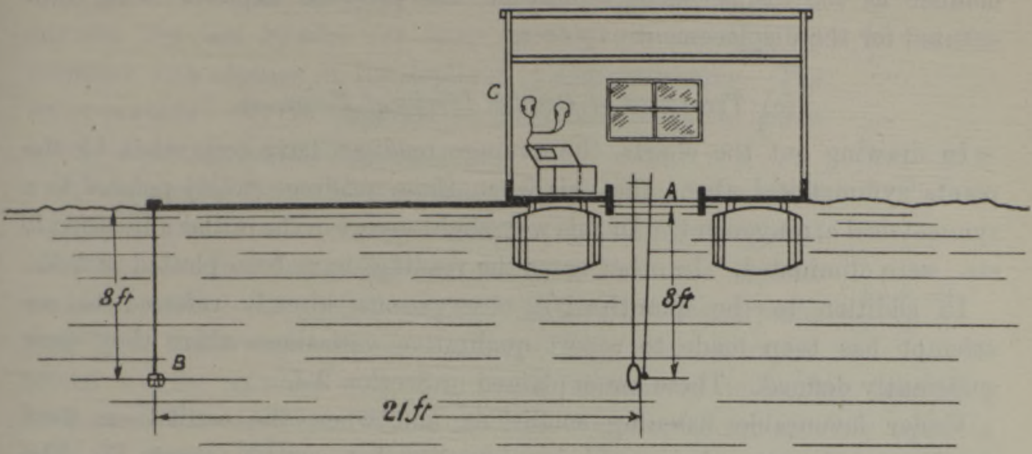


FIG. 4.

continuous musical sound, whose principal component had a frequency of 580∼/sec., though components both an octave below and an octave above this were distinguishable.

(ii) A "tapper," consisting of an electric bell mechanism enclosed in a case, against which the hammer strikes. The sound produced was chiefly of the nature of a low rumble, though higher frequencies were present. No predominant frequency, however, could be observed.

The raft was moored in about 25 feet of water and about 70 yards from the nearest bank, so that echoes from the bank would be extremely feeble in comparison with the sound received directly from the source.

(b) *Method of Experiment.*

A point-to-point exploration was made by each of the explorers in turn in the horizontal plane passing through the centre of the screen, the movements of the end of the lever, D, being assumed to be practically confined to this plane. The direction of the oscillations at a given point was first determined by rotation of the displacement explorer to the position of minimum response, this position being taken in preference to that of maximum response, as being more sharply defined.

The amplitude of the water particles was compared with that at a reference point 10 inches from the axis of the screen by means of the potentiometer employed as explained in (*a*). Since the reference point was always taken in the same parallel, it was necessary subsequently to compare

directly the various reference points, and, if necessary, to adjust the readings.

The amplitude of the pressure oscillations was determined in the same manner as the displacement amplitude, the pressure explorer being substituted for the displacement explorer.

(c) *Treatment of Results, Limits of Error, etc.*

In drawing out the charts, the average readings have been taken for the points symmetrical about the axis when those readings clearly pointed to a symmetrical arrangement. In this way slight errors in the initial adjustment, etc., were eliminated. In other cases the readings have been plotted in full.

In addition to the quantitative observations already referred to, an attempt has been made to report qualitative variations where they were sufficiently defined. These are explained in Section 2 *d*.

Under favourable listening conditions, and when the oscillations were rectilinear, the direction could be determined to within about 5°. The accuracy of the readings was naturally diminished in cases of confused direction (*e.g.*, Chart 3), and cases occurred in which no variation with rotation of the displacement explorer could be observed.

Tests of the observers showed that, under favourable listening conditions it was possible to distinguish a difference of 10 per cent. between two sounds of the same quality. The accuracy of the observations was, however, diminished somewhat during windy weather. The season of the year was in this respect rather unfavourable, though it may be mentioned that many of the charts were made during a prolonged frost, when for five weeks the frozen surface of the reservoir rendered listening conditions ideal. The most serious obstacle to accurate intensity determinations was the occasional occurrence of qualitative differences in the sounds to be compared, due apparently to the differences in the renderings of the harmonics. In such cases divergencies of opinion between the observers often occurred, and it was noticeable that one appeared relatively more sensitive than the other to sounds of a higher general pitch.

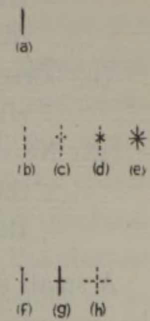
In view of the above sources of error, the quantitative observations should be regarded as giving the general character of the acoustic field rather than as affording precise data. At the same time, it should be stated that, where observations were repeated on different days, they were generally in good agreement.

(d) *Symbols employed in Charts.*

(i) *Direction.*—A stroke (*a*) denotes the direction of oscillation of a water particle at the centre point of the stroke. The simple stroke implies

that the minima are well marked, indicating that the oscillations are sensibly rectilinear.

A dotted stroke (*b*) indicates that the minima are not clearly marked, and the symbols (*c*), (*d*), and (*e*) represent increasing blurring of the minima, the last symbol (*e*) denoting that no variation in intensity with rotation of the explorer is distinguishable. The water particles may be regarded as describing elliptical paths which in (*e*) approximate to circles.



It frequently happens that as the explorer is rotated marked changes of quality occur together with, or instead of, changes of intensity, the effect being such as to suggest that two distinct trains of waves are passing through the given point along paths roughly at right angles to one another. This effect is represented by the symbols (*f*), (*g*), (*h*), progressively indicating increasing loudness of the minima. When the two components are sensibly equal in intensity the two lines are dotted (*h*), since in this case their directions can rarely be determined with accuracy.

The fine lines are drawn through regions, where the directional indications are definite, to indicate the acoustic "rays." Where the directional indications are confused and complex, these lines are omitted. The lines are intended to assist in gaining a comprehensive view of the chart rather than as an analysis of the acoustic conditions.

(ii) *Amplitude Readings.*—The relative amplitudes are represented by numbers. The amplitude at the point in the chart where the sound distribution is considered to be least disturbed by the disc is taken as the standard and given the value 10. The point of reference is denoted by a ring, thus (10). Numbers representing displacement are printed to the right of the stroke indicating direction; those representing pressure amplitudes are printed to the left of the stroke and are turned through 90°.

(iii) *Corresponding Points on Opposite Faces.*—If the faces of the disc are similar, the transition from the side near the source to the side remote from it was affected by rotating the whole of the apparatus, including the disc, through 180°, so that the exploration was carried out opposite the same face throughout. This is indicated in the diagram by the letters a_1, b_1, a_2, b_2, which denote the successive positions of the face *ab*.

(e) *Notes on Charts.*

It will be observed that the principal phenomena exhibited by the charts are of two distinct types, according as the acoustic field is produced around (i) a solid body, (ii) a hollow body.

(i) *Solid Bodies.*—The charts of the lead disc are given as typical of fields procured by solid bodies, which exhibit the following characteristics:—

(i) The lines of direction bend round the edges of the disc. At the same time a considerable portion of the sound energy is transmitted directly through it. The direction is clearly defined at every point.

(ii) There is in general a diminution in the displacement amplitude near either face of the disc.

(iii) No variation in the pressure amplitude is observable. This implies that any such variation from the primary amplitude must be less than 10 per cent.

A small dense solid obstacle such as the lead discs in Charts 1 and 2 may be regarded as acting the part of (i) a simple source, due to its great rigidity relatively to that of the water; (ii) a double source, due to its greater density and the lesser mobility resulting therefrom. Considered as a simple source, it virtually expands and contracts relatively to the adjacent

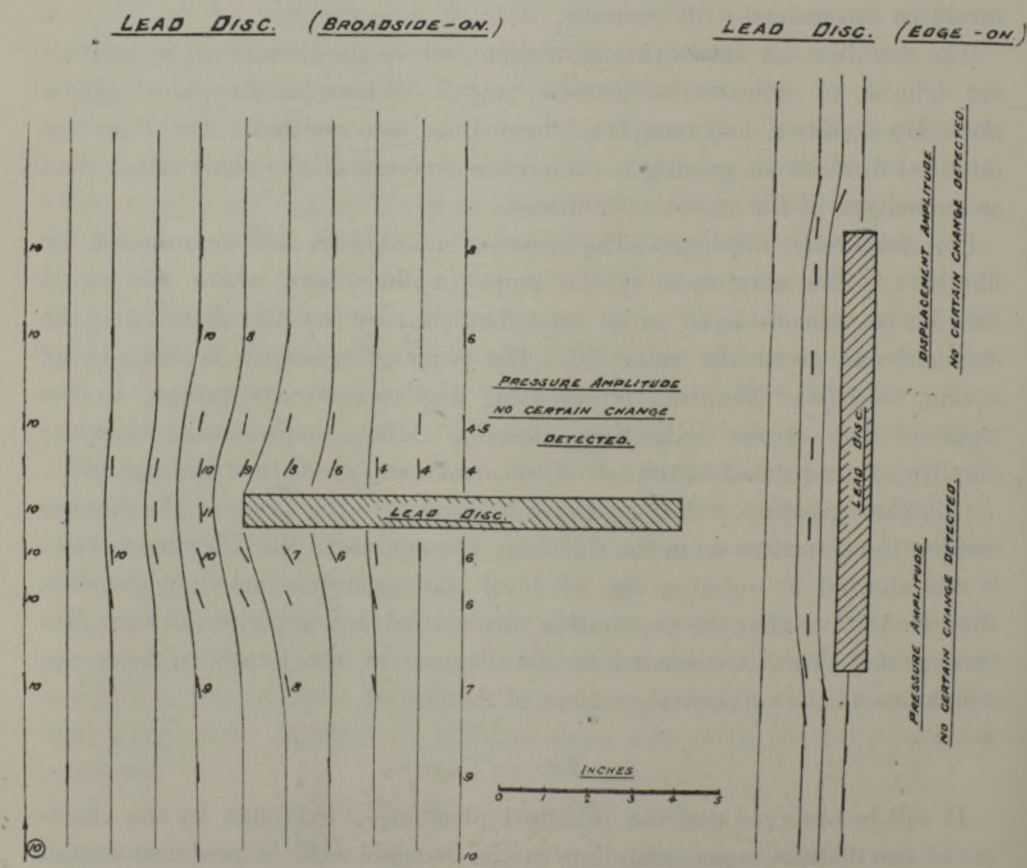


CHART 1.

water as that water contracts and expands, thus giving rise to secondary vibrations in the same phase as the primary. Considered as a double source, it virtually oscillates in opposite phase to the adjacent water, tending to give rise at the near surface (*i.e.*, the surface facing the source) to vibrations in the same pressure phase as the primary waves, and at the remote surface to waves in the opposite pressure phase. In the latter case, however, if the dimensions of the disc are small compared with the wave-length, the motion results principally in lateral oscillations of the water round the edges of the disc. The form of the "stream lines" in the charts is adequately accounted for if they are considered to represent the resultant of the primary oscillations and the secondary lateral oscillations. The absence of any appreciable effect due to the rigidity of the disc is of course to be expected from its small thickness compared with the length of the sound waves.

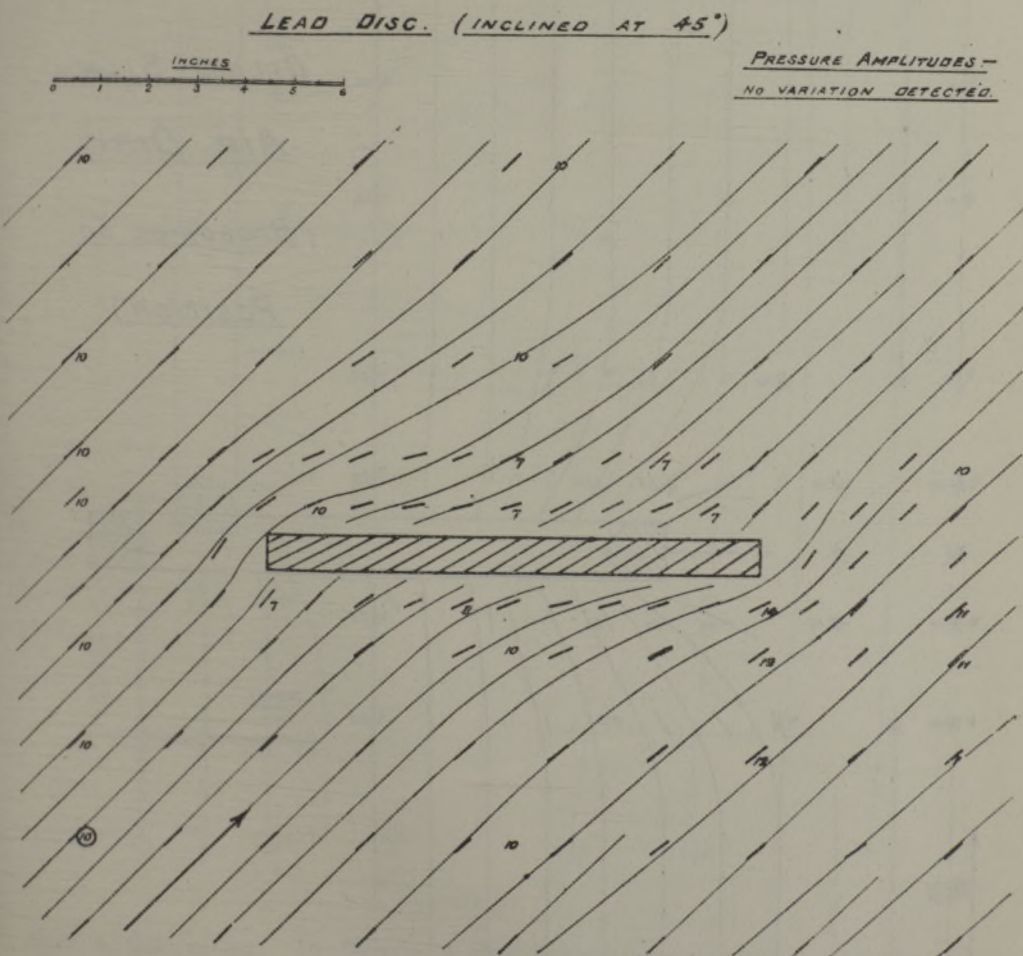


CHART 2.

The disturbances produced by the lead disc are comparatively slight, and, as would be expected, those produced by similar discs of lower density are still slighter. Discs of wood, rubber, and paraffin wax produced no definite disturbance, but appeared completely transparent to the sound waves.

It is reasonable to suppose that if a solid disc of rigid material having a density far below that of water were obtainable, the effects (i) and (ii) would be inverted, *i.e.*, the lines of direction would bend into the disc and an increase of amplitude would be produced near each face. In practice, however, no highly rigid material of sufficiently low density is available.

(2) *Hollow Bodies.*—The oiled silk disc may be taken as the simplest type of hollow body. It consists of a light wooden ring, over the faces of which are stretched two sheets of oiled silk, so that it is therefore little more

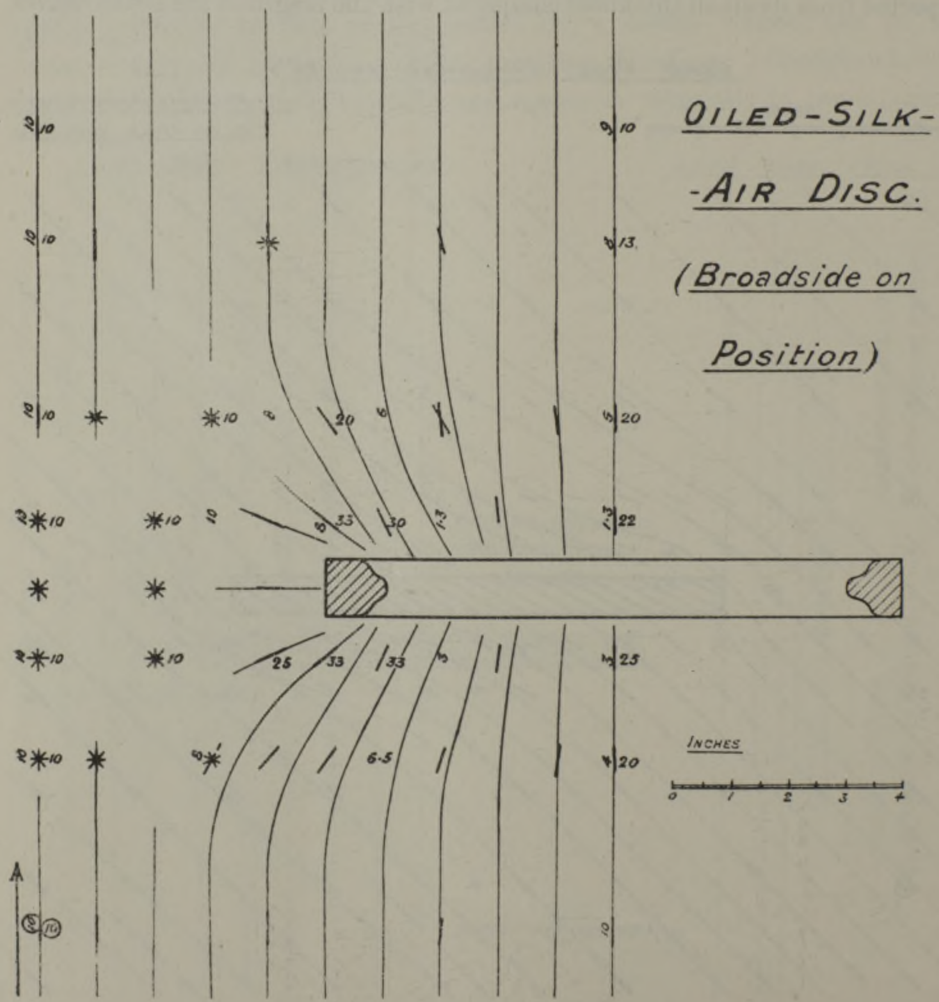


CHART 3.

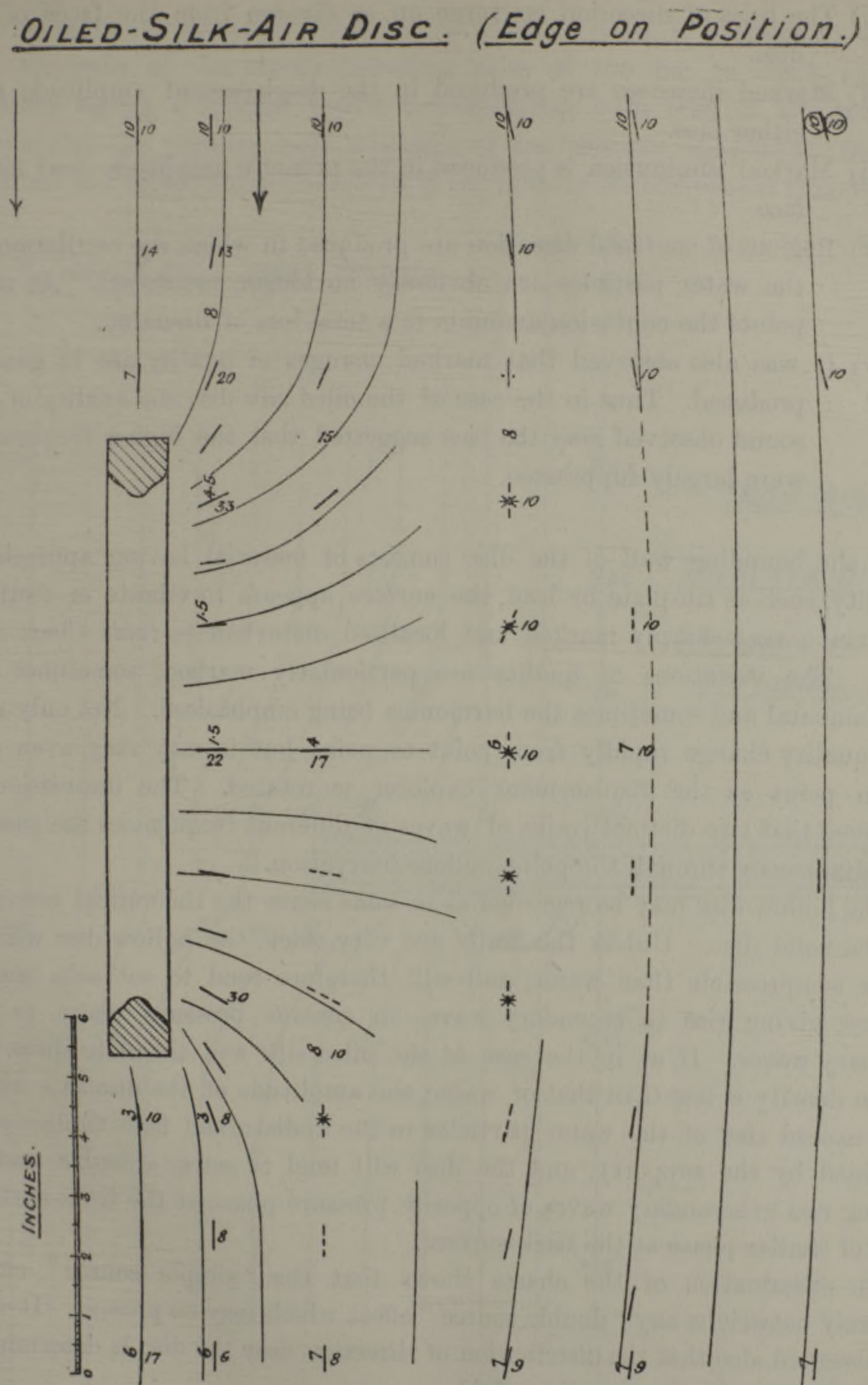


CHART 4.

than a disc of air. In Charts 3 and 4 the following characteristics are exhibited:—

(i) The lines of direction converge on, or diverge from, the faces of the disc.

(ii) Marked increases are produced in the displacement amplitude near either face.

(iii) Marked diminution is produced in the pressure amplitude near either face.

(iv) Regions of confused direction are produced in which the oscillations of the water particles are obviously no longer rectilinear. At some points the confusion amounts to a total loss of direction.

(v) It was also observed that marked changes of quality are in general produced. Thus in the case of the oiled silk disc the quality of the sound observed near the face suggested that the higher frequencies were largely suppressed.

If the bounding wall of the disc consists of material having appreciable rigidity, such as tin-plate or lead, the surface appears to vibrate in sections producing very sharply marked and localised disturbances (*vide* Chart 5, *et seq.*). The variations of quality are particularly marked, sometimes the fundamental and sometimes the harmonics being emphasised. Not only may the quality change rapidly from point to point, but it may vary even at a given point as the displacement explorer is rotated. The impression is received that two distinct trains of waves of different frequencies are passing simultaneously through the point under observation.

The hollow disc may be regarded as in some sense the theoretical converse of the solid disc. Unless the walls are very thick, the hollow disc will be more compressible than water, and will therefore tend to act as a simple source, giving rise to secondary waves in *opposite* pressure phase to the primary waves. If, as in the case of the oiled silk and tin-plate discs, the mean density is less than that of water, the amplitude of the disc as a whole will exceed that of the water particles in the undisturbed field (unless constrained by the support); and the disc will tend to act as a double source, giving rise to secondary waves of opposite pressure phase at the front surface and of similar phase at the back surface.

An examination of the charts shows that the "simple source" effect entirely outweighs any "double source" effect which may be present. It will be observed also that the distribution of direction near the disc is determined predominantly by the secondary field.

The regions of confused direction would be the resultant of the primary and secondary waves, occurring where these waves cross one another with a phase difference other than 0° or 180°.

The sectional vibration exhibited in Charts 5 *et seq.* is presumably due to the tendency of the elastic bounding plate of the disc to break up into sections having a natural period corresponding with that of the primary sound, and the peculiar local emphasis of the primary components may be ascribed to a difference in the sectional response to the component frequencies.

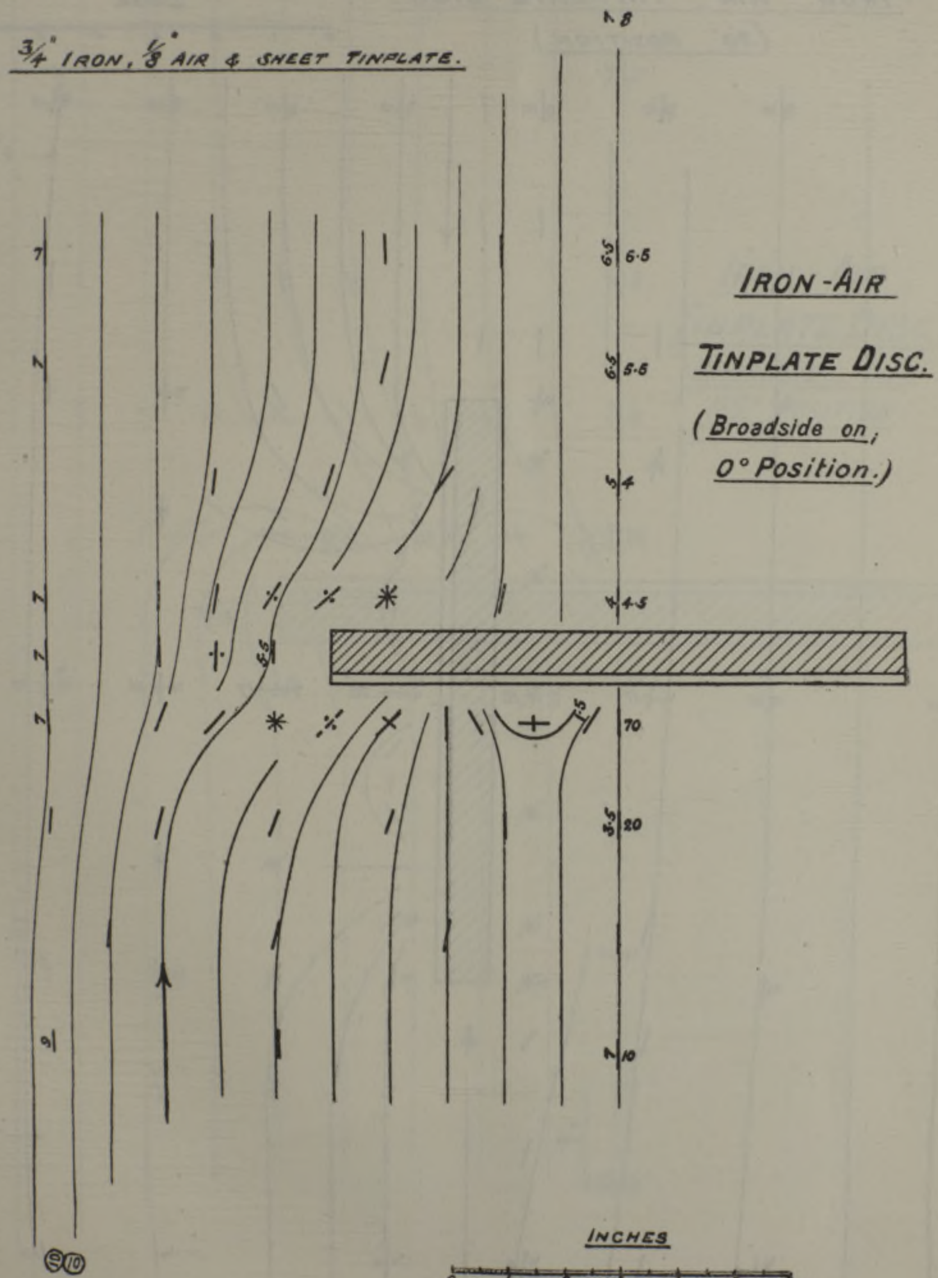


CHART 5.

(3) *Combinations of Types* 1 *and* 2.—As would be expected, various compromises between the characteristics of solid and hollow bodies may be produced by suitably constructed screens, though the more pronounced hollow body characteristics naturally tend to predominate.

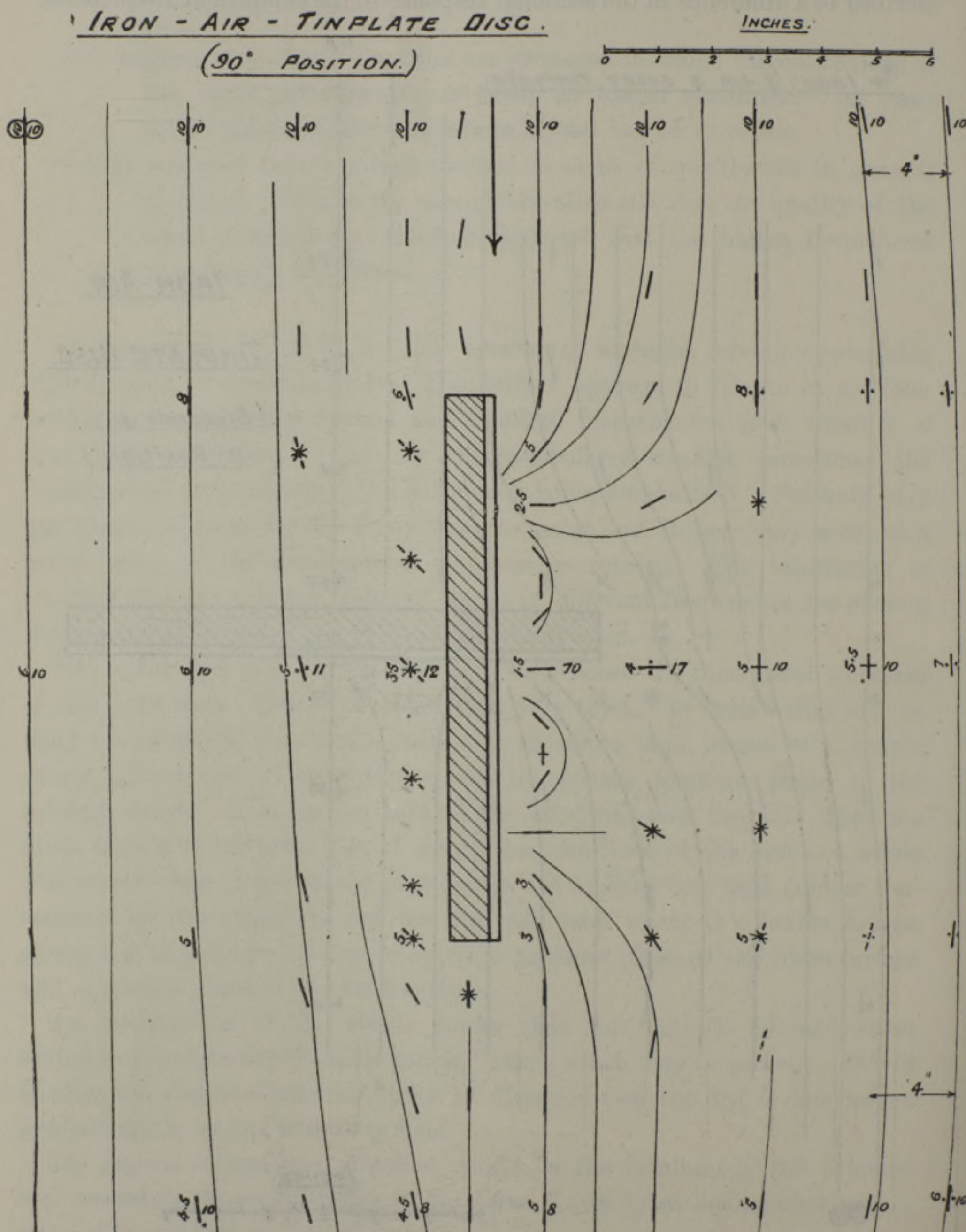


CHART 6.

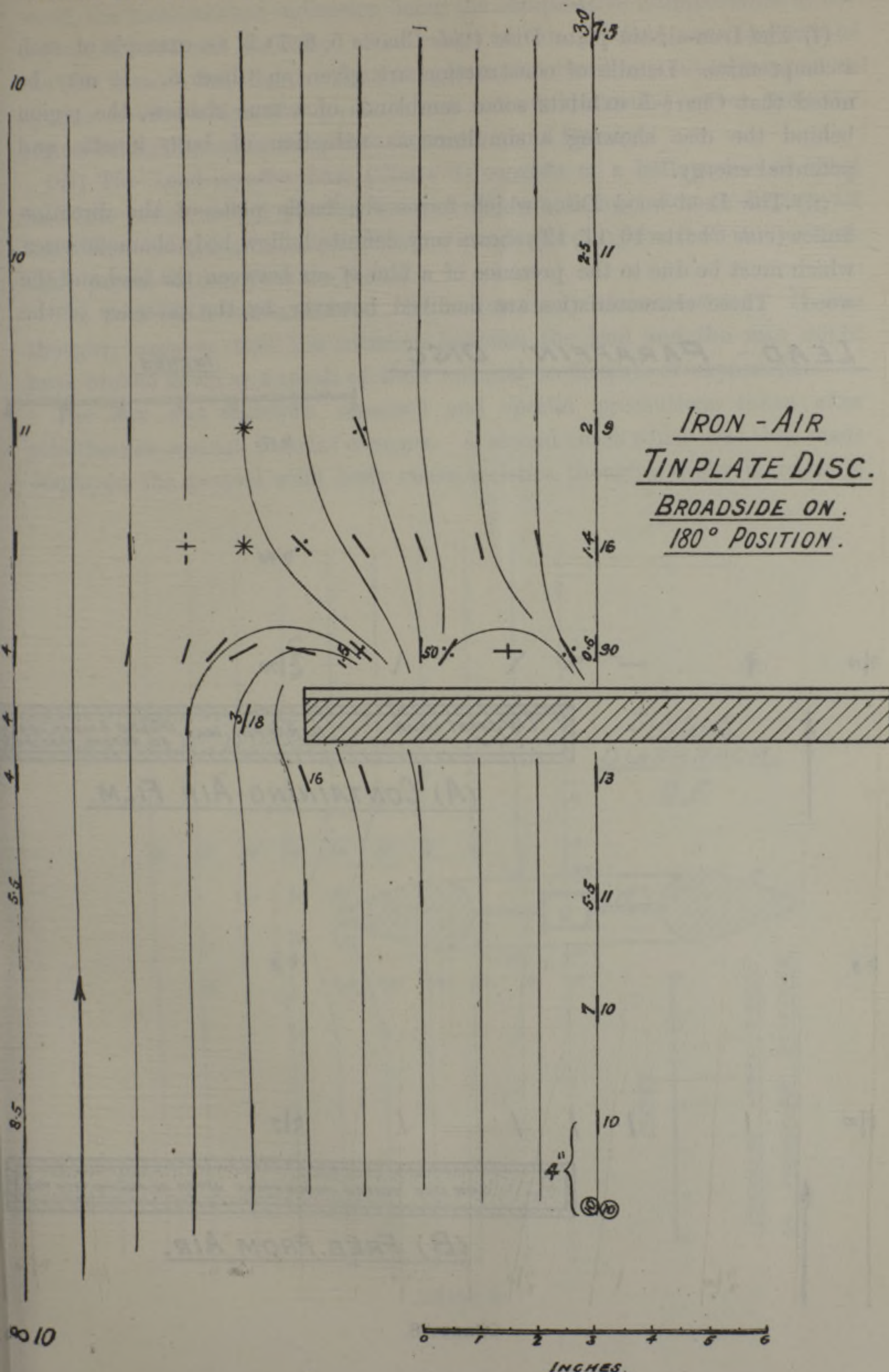


CHART 7.

(i) The Iron-air-tin-plate Disc (*vide* Charts 5, 6, 7) is an example of such a compromise. Details of construction are given on Chart 5. It may be noted that Chart 5 exhibits some semblance of a true shadow, the region behind the disc showing a simultaneous reduction of both kinetic and potential energy.

(ii) The Lead-wood Disc, which forms the baffle plate of the direction finder (*vide* Charts 10, 11, 12), shows very definite hollow body characteristics, which must be due to the presence of a film of air between the lead and the wood. These characteristics are modified, however, by the presence of the

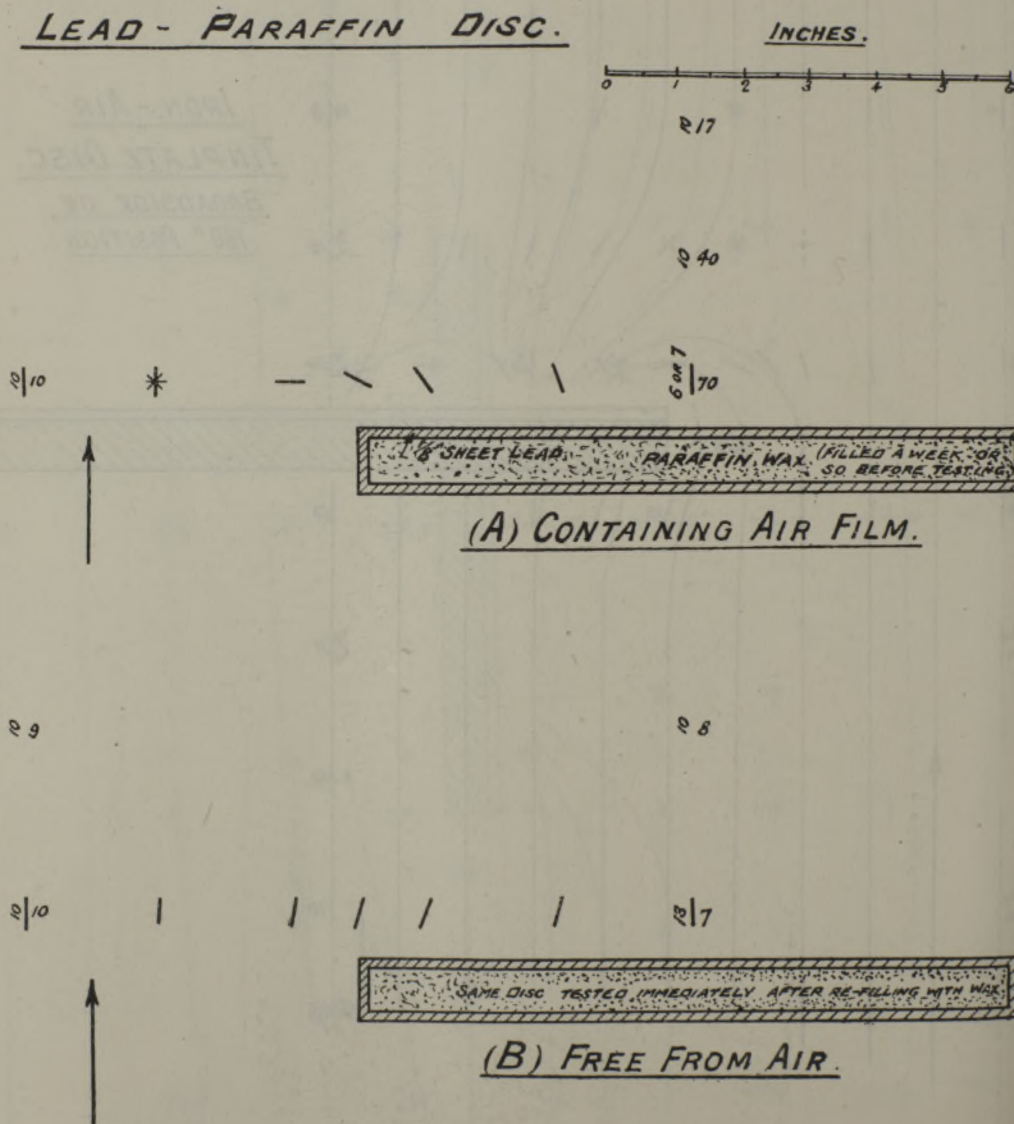


Chart 8.

wood, the most marked indication being the comparative unimportance of the regions of confused direction. As a result of this, the field near the edge of the disc is more definite and clearly suggests that the disc is functioning as an opaque screen, which, though it cannot cut off the sound waves from the region behind it, forces the pulses to travel round its edge.

(iii) The Lead-paraffin Disc (Chart 8) consists of a hollow disc of sheet lead into which molten paraffin was poured, care being taken to displace all air. The object was in fact to obtain a composite disc free from air cavities. Only partial explorations are shown.

The first chart made showed the hollow body characteristics. It was thought, however, that the cohesion between the lead and the wax might have broken down as a result of their unequal coefficients of expansion.

The wax was therefore remelted and special precautions taken after solidification against thermal changes. A second chart which was then made displayed the general solid body characteristics, though a slight increase in

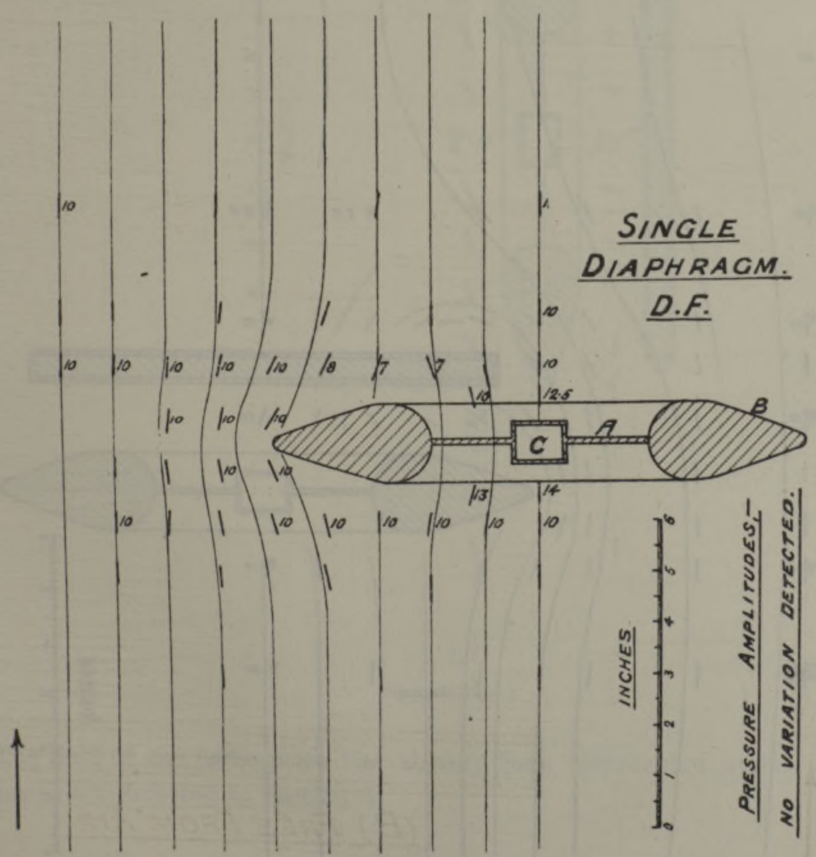


CHART 9.

the pressure amplitude is shown at the back of the disc, of which no explanation can be offered.

The two charts illustrate the important effect produced by even a small trace of air.

(4) *Single Diaphragm Direction Finder.* (i) Direction Finder without Baffle (Chart 9).—This instrument is briefly described in Section 1. The field does not differ essentially from that which was obtained for a single metal ring (chart not shown). It appears as if the bronze diaphragm does not appreciably modify the sound distribution. As in the case of the lead disc, the pressure amplitude is sensibly uniform throughout the field.

(ii) Baffled Direction Finder (Charts 10, 11, 12).—Charts are shown for the instrument in the position of maximum, the position of minimum, and the

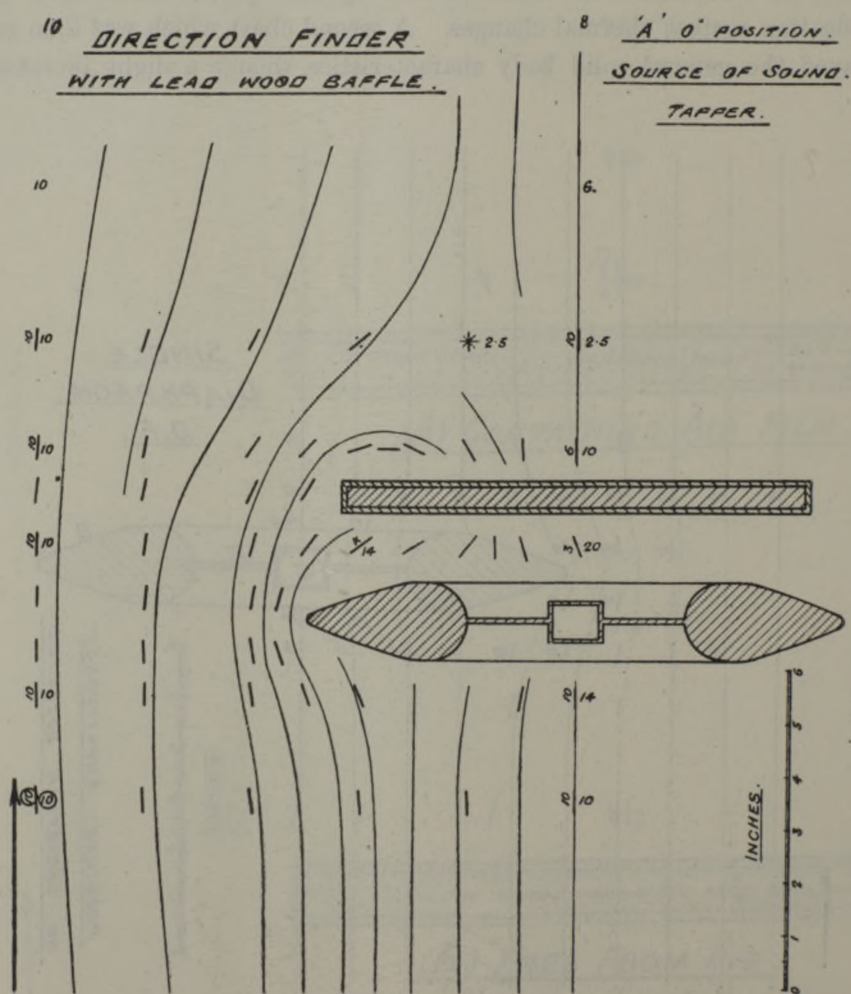


CHART 10.

edge-on position. The exploration is confined to the immediate neighbourhood of the diaphragm and baffle.

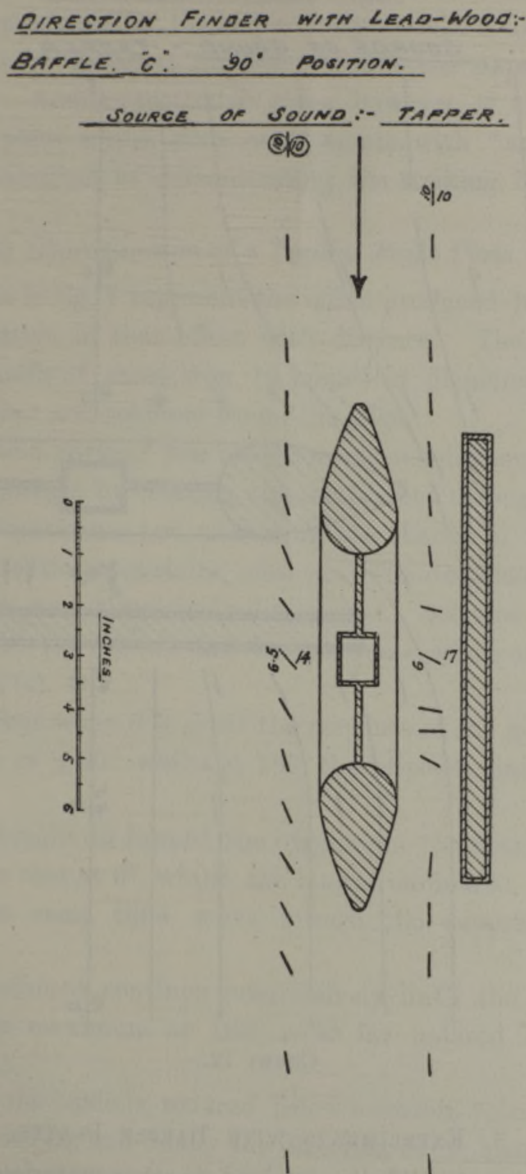


CHART 11.

The field of the baffle plate has already been commented upon. Further remarks are deferred to Section 4.

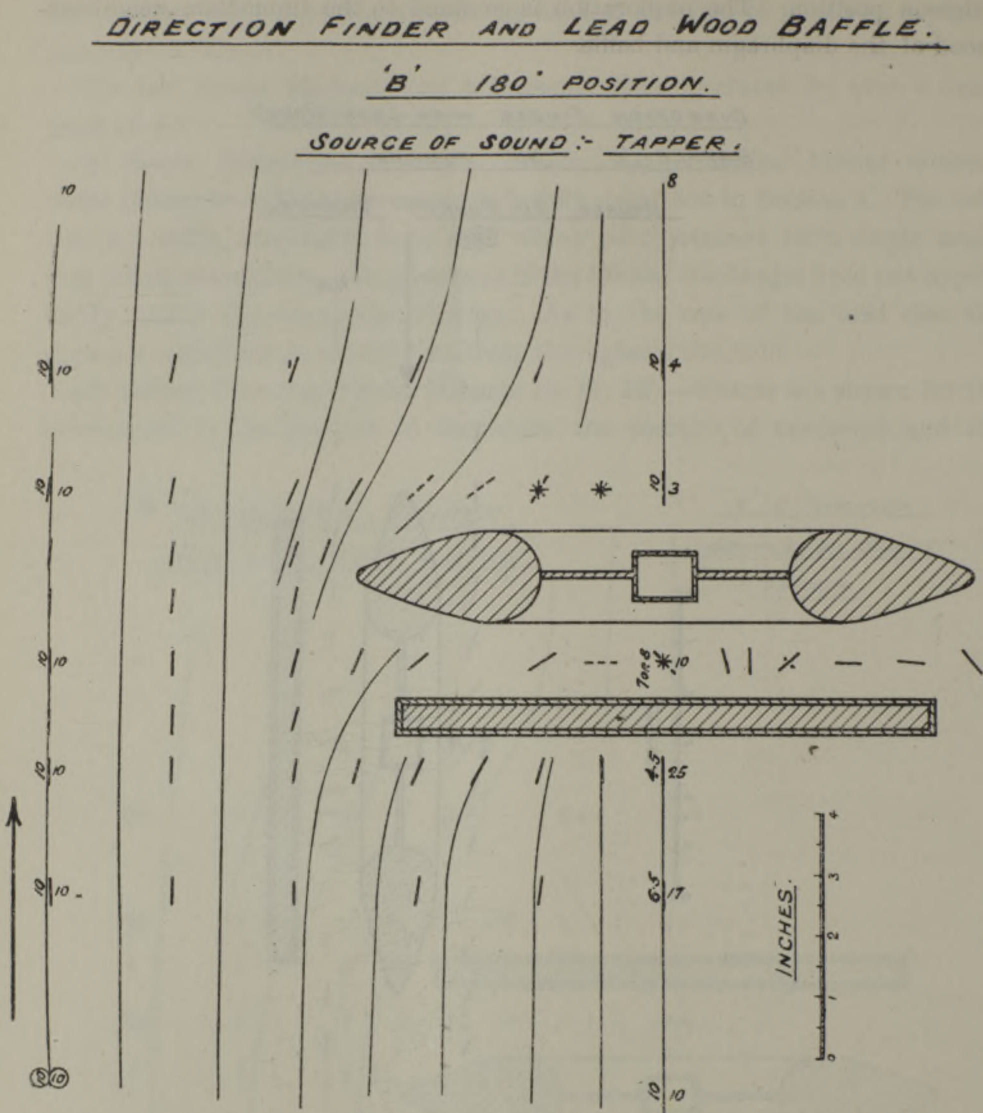


CHART 12.

3. Experiments with Baffle Plates.

As previously stated, solid discs of lead or other materials had been found to be practically ineffective as baffle plates, whilst the lead-wood discs gave the instrument a definite bias. Since the chart indicated that the most important difference between these discs lay in the air films enclosed in the composite disc, the conclusion was drawn that this air film plays an essential part in the baffle.

This conclusion was verified by a number of experiments with "air-film"

baffles consisting of two plates of metal pressed into contact and soldered around the edge. Many baffles thus constructed gave very good bias.

The various patterns of baffle, however, shared with the lead-wood baffle the defect of lack of reproducibility, baffles carefully made to the same specification giving results of very different quality. Hence the experiments are not described in detail. A short account is given, however, of the characteristics of a typical baffle plate, whilst some experiments with "stream-line" baffle plates are briefly described as demonstrating the striking influence of small traces of air.

(a) *Characteristics of a Typical Baffle Plate.*

The curves shown in fig. 5 represent the effect produced by a typical baffle plate and the variation of that effect with distance. The baffle employed consisted of two plates of sheet iron 10 inches in diameter and 1/20 inch thick, pressed together and soldered round the edge.

A series of "rotation curves" was made for various distances, *d*, of the baffle plate from the diaphragm by rotating the instrument through various angles from its position of maximum and measuring the change in the amplitude of response by the potentiometer shunt method. The distance, *d*, of the baffle from the diaphragm was successively diminished. Selected rotation curves are shown in fig. 5 (*a*), (*b*), (*c*), (*d*), and the complete series of observations is recorded in diagram (*e*).

Curve (*a*) shows that when *d* is great the response of the instrument passes through a minimum at $\pm 90°$, whilst at 180° the response rises to a maximum equal to that at 0°.

As the baffle is brought in toward the diaphragm the maximum at 180° is reduced relatively to that at 0°, whilst the lateral minima at 90° become less marked and at the same time move toward the suppressed maximum (curve (*b*)).

The changes mentioned continue progressively until the lateral minima fade out, whilst the maximum at 180° is so far reduced as to become a minimum (curve (*c*)).

If the distance of the baffle is reduced below a certain value the minimum at 180° begins to fade out, and finally the direction finder loses its directional properties entirely, responding equally for all orientations (curve (*d*)).

Diagram (*e*) represents the progressive changes as the distance of the baffle is altered. The curve "amp. 180°" indicates the amplitude of response at 180° and the curve $l/0$ the amplitude of response at the lateral minimum relatively to that at 0°.

In diagram (*e*) the amplitude of response at 0° has been taken as standard. By arranging the baffle so that it could quickly be swung into or out of

action at will, it was found that this amplitude is not constant but increases as d is reduced. The variation of amp. 0° with d is shown in diagram (f), which

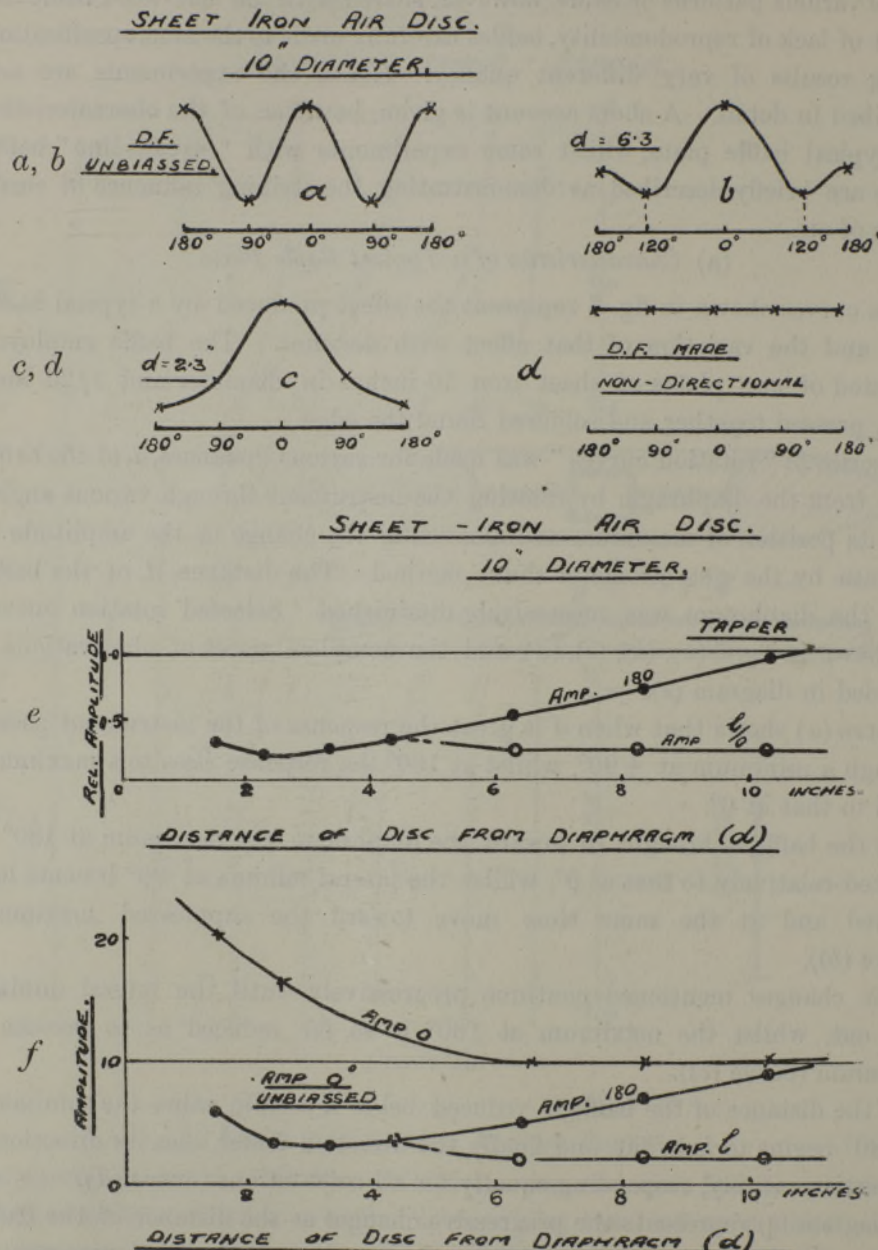


FIG. 5.

shows also the true variation of amplitude at 180° and at the lateral minima.

Though diagram (f) gives the fuller information, diagram (e) is of greater

practical significance, since the increase in sensitivity produced by the baffle is of less importance than its effect upon the ratio amp. 180°/0°. From (*e*) it is seen that the correct setting for the baffle employed is at about 2·3 inches from the diaphragm. At this distance amp. 180/0 is about 1/5.

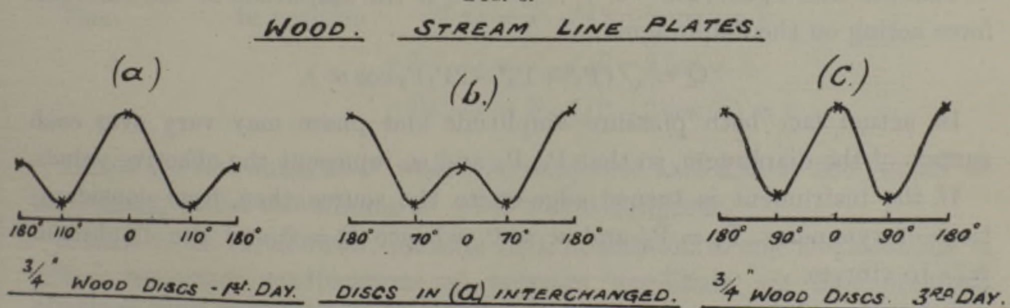
The diagrams shown are representative of those obtained with good baffle plates. The chief practical consideration is that the curve amp. 180/0 shall have as low a minimum as possible; and this appeared to depend upon a critical adjustment of the air film. In the case of the lead-wood baffle (which was the earlier service form) the desired adjustment was secured largely by a process of selection.*

The position and value of the minimum in the curve amp. 180/0 was found to vary not only from baffle to baffle, but also to a smaller extent in the same baffle with sounds of different quality and pitch.

(b) "*Stream-line*" *Baffle Plates.*

When a direction finder is employed in rough water or in a current, considerable noise is produced in the telephone receivers by the wash of the water. With a view to diminishing such disturbances wooden discs were secured flush with the ring of the instrument to enclose the diaphragm between them, small holes being left for the escape of the air. It was found that, though the directional properties of the instrument were not impaired, a marked bias was produced. The effect is recorded in fig. 6 (*a*),

Fig. 6.



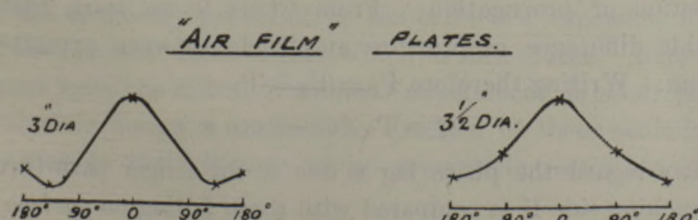


Fig. 7.

* A more reproducible design of baffle was later produced by Dr F. L. Hopwood.

where the curve represents the change in the amplitude of the response as the instrument was rotated in either direction from one of its broad-side on positions. By interchanging the discs the direction of the bias was reversed (curve (*b*)). The strength of the bias diminished as the wooden discs became sodden, and after a day or two disappeared (curve (*c*)).

The bias was attributed to the presence of air in the pores of the wood, which was differently distributed in the two discs. Attempts were made to reproduce these discs in more permanent form. The wooden discs were replaced by discs of tin-plate, to the centre of one of which a smaller tin-plate disc was soldered by the edges only, so that an air film was enclosed. As shown in fig. 7, very good bias was obtained with selected air films, 3 to $3\frac{1}{2}$ inches in diameter.

These experiments demonstrate the predominant importance of the air in a baffle plate, and the unimportance of the mass of the plate.

4. Notes on Theory of Single Plate Direction Finder.

A complete theory of the unbiassed direction finder would involve a consideration not only of the movements of the diaphragm but also of the ring. An approximate explanation, however, may be attempted by supposing that the heavy ring remains practically at rest whilst the diaphragm is driven to and fro by the resultant action of the pressure pulses arriving at the two faces, A and B. Let the pressure pulses arriving at these faces be respectively $P_1 \cos 2\pi nt$ and $P_2 \cos(2nt - \alpha)$; then if Q is the amplitude of the resultant force acting on the diaphragm

$$Q = \sqrt{(P_1^2 + P_2^2 - 2P_1P_2 \cos \alpha)}.$$

In actual fact both pressure amplitude and phase may vary over each surface of the diaphragm, so that P_1, P_2, and α represent the effective values.

If the instrument is turned edge-on to the source, then, from considerations of symmetry, $P_1 = P_2$ and $\alpha = 0$, whence $Q = 0$ and the diaphragm fails to vibrate.

Let surface A be turned toward the source of sound and at right angles to the direction of propagation. From Chart 9 we learn that there is no appreciable difference of pressure amplitude between opposite faces of the diaphragm. Writing therefore $P_1 = P_2 = P$,

$$Q = P\sqrt{(2 - 2\cos \alpha)}.$$

We may regard the phase lag as due to the longer path travelled by the pulses reaching side B as compared with those falling on surface A.

The overall radius of the instrument is 5 inches, whilst that of the diaphragm is 2 inches. We may take 4 inches as the rough average distance of the

diaphragm from the edge of the clamping ring. If the frequency of the sound is 580 ∼/sec., the wave-length is about 100 inches.

Hence $$\propto = \frac{2\pi \times 4}{100}, \text{ or about } 14^\circ,$$

and $$Q = P\sqrt{(2-2\cos 14^\circ)} = P \times 0{\cdot}25 \text{ nearly.}$$

Now, if the water were excluded from side B, the amplitude of the force acting on the diaphragm would be P; hence the ratio $Q/P = 0{\cdot}25$. Tests made by Dr. F. L. Hopwood on the effect of thus excluding the water showed that the sensitivity is actually increased thereby from three to five times.

The action of the baffle plate is more obscure. The foregoing theory of the unbaffled instrument suggests that this plate, when interposed between the diaphragm and the source, may tend to bring the pressure pulses arriving at the surfaces A and B into phase by increasing the length of path to surface A. Such a theory would explain the suppression of the maximum at 180°, but fails to account for the observed reinforcement of the maximum at 0° or the obliteration of the minima at −90°.

The general effects of the baffle plate might be explained on the assumption that the baffle introduces a constant phase lag near the adjacent face of the diaphragm, and that for the ideal unidirectional setting of the baffle this lag is equal to $\propto$.

Then in position $0^\circ, Q = P\sqrt{(2-2\cos 2\propto)}$.

" $\pm 90^\circ, Q = P\sqrt{(2-2\cos \propto)}$.

" $180^\circ, Q = P\sqrt{(2-2\cos 0^\circ)} = 0$.

Hence the maximum at 0° would be reinforced and that at 180° would be suppressed, whilst the minima at ±90° would disappear.

Charts 10 to 12, however, indicate that, in addition to any modifications of phase, important modifications of pressure amplitude are also produced which are too great to be disregarded as incidental disturbances. It is possible that the symmetry produced by the baffle is a somewhat fortuitous resultant of the various disturbances which it introduces. Such a view receives support from the difficulty hitherto experienced in securing a baffle of good reproducible design, a considerable fraction of those made having to be rejected, owing to their failure, for no perceptible reason, to give good baffle action.

Appendix.

Exploration of the Acoustic Field produced in the Reservoir by a small Source of Sound.

Though the large area of the reservoir rendered negligible the disturbances due to reflection from the banks, it was desirable to determine to what extent the primary acoustic field was affected by reflections from the surface and bottom.

For this purpose a dead calm day was chosen. By means of a graduated rope stretched from the raft to the shore, a boat was hauled to measured distances from the source of sound. A Submarine Signal Company's hydrophone, suspended on a graduated cable, was employed as a "pressure explorer."

(a) *Exploration with Buzzer* (*vide Section* 2) *as Source.*—The buzzer was supported in the water at a depth of 8 feet, as for the experiments of Section 2. As the hydrophone was lowered steadily to the bottom, it was observed that, in general, variations of intensity occurred, the sound received passing through a number of maxima and minima. The depth at which each minimum occurred was recorded. Special attention was paid to the first minimum below the surface zone, this being followed continuously from point to point as the boat was moved, so that the zone was completely traced. The results are plotted in fig. 8.

Comments.—(1) The zone AB, which was clearly marked, coincides approximately with the theoretical position of the interference zone, which is produced by reflection, with change of phase, from the surface.

(2) The zone BC, also clearly marked, is remarkable in its form, and cannot be accounted for by surface reflection only. This zone, together with the others (of which points only have been recorded), was probably produced as the result of multiple reflection from bottom and surface.

(3) Close to the bottom (which was in general of soft mud) there was usually observed some diminution of intensity. At some points, however, a reinforcement was observed, and in certain of such cases the instrument struck hard rock on reaching the bottom. The diminution may have been due to gases trapped in the mud, which would tend to produce reflection with change of phase.

(4) The intensity close to the surface was consistently very low, as would be expected from theory.

(5) The acoustic field seemed to tend toward uniformity as the distance from the source increased, the limits of the zones observed, from 66 feet to 160 feet, being increasingly indefinite.

(b) *Exploration with "Tapper" (vide Section 2) as Source.*—An attempt was made to carry out an exploration with the tapper as source in the same manner as with the buzzer. No definite maxima or minima were, however, observable, and only certain variations of quality could be distinguished. Regarding the tapper as a "noise source," this result would be anticipated.

From the diagram it will be seen that, at the working distance of about 20 feet, and at the same depth as the buzzer, it would be unsafe to assume the "undisturbed" field to be uniform. That practical uniformity existed, however, may be inferred from the marginal readings of the majority of the charts, which indicate uniform distribution, except in cases in which the disturbance due to the disc under examination is obviously of wide extent.

SUMMARY.

The experiments described were undertaken primarily with the object of elucidating the action of the "single plate direction finder" and "baffle."

By means of a pair of miniature exploring hydrophones, the acoustic field was plotted around a number of discs placed in the path of plane waves propagated through the water of a reservoir, so large that reflections from the sides could be disregarded.

The characteristics displayed by the charts varied according as the discs were solid or contained air cavities. The *solid* bodies created comparatively

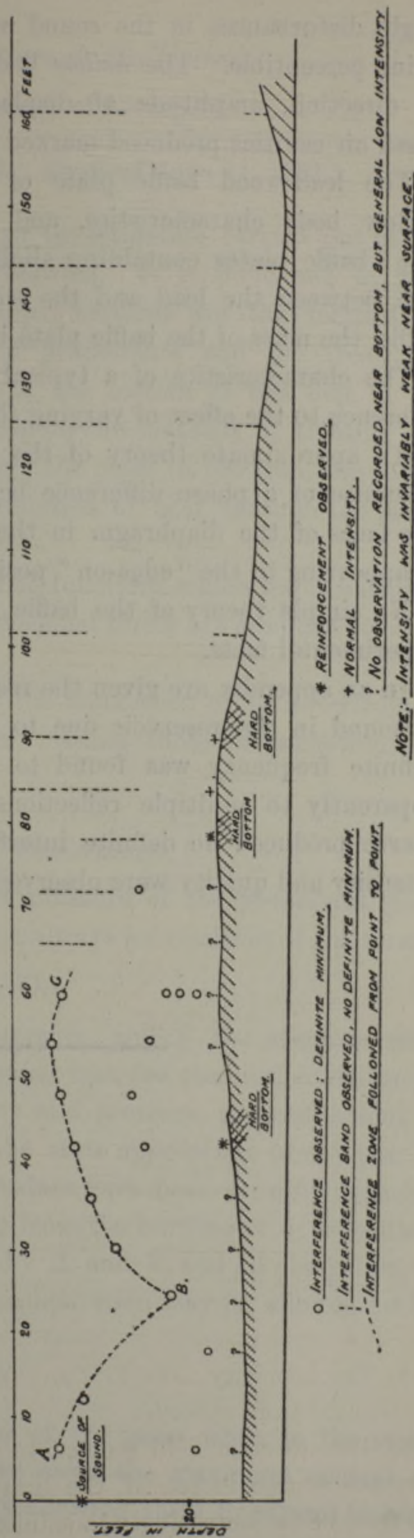


FIG. 8.

slight disturbances in the sound waves, no variations of pressure amplitude being perceptible. The *hollow* bodies created very pronounced disturbances of direction, amplitude of displacement, and pressure amplitude. Very small air cavities produced marked effects.

The lead-wood baffle plate of the direction finder showed pronounced hollow body characteristics, and, from experiments made with "stream-line" baffle plates containing slight air films, it was concluded that the air film between the lead and the wood constitutes the essential part of the baffle, the mass of the baffle plate being of minor importance.

The characteristics of a typical baffle plate were examined with special reference to the effect of varying the distance between diaphragm and baffle.

An approximate theory of the unbaffled instrument can be based on the existence of a phase difference between the pressure pulses arriving at the two faces of the diaphragm in the "broad-side on" position, this difference disappearing in the "edge-on" position.

No simple theory of the baffle plate can be offered which covers all the experimental facts.

In an appendix are given the results of an exploration of the distribution of sound in the reservoir due to a small submerged source. A source of definite frequency was found to produce marked interference zones, due apparently to multiple reflections from surface and bottom. A "noise" source produced no definite interference zones, though certain variations of intensity and quality were observed.