(seconds rather than microseconds), but there is no 'coding delay' and logically enough the centre line is marked zero. Thus if the sound reached A and B simultaneously the gun would be somewhere on the centre line of that pattern and if it reached B exactly 1½ seconds before C, the dotted 1·5 second line in the 'plus' half of the BC pattern would be the other position line. The fix is plotted by interpolating to 1/100 second as illustrated.

Sound ranging was started, on both sides, in the first World War. The Allies used a different microphone layout and resolved the time differences without recourse to a pre-drawn family of constant-time-difference lines. The Germans tried various techniques including the one shown here and are said to have used coloured lattice overprints, of which I hope to find an example. Sound ranging is still used, but the lattice method of plotting was short-lived; in a wider context, however, it was strikingly prophetic.

It was through the kindness of the late Sir Lawrence Bragg, himself one of the pioneers of sound ranging, in allowing me access to his papers, that I learned of the German work. I am grateful to Oberstleutnant A. Pilgram of the School of Artillery at Idar-Oberstein, West Germany, for supplying a photostat copy of the 1918 handbook.

# Distance by Vertical Angle

Charles H. Cotter

THE note by V. L. Bosazza (on page 112) raises a number of interesting points. First it must be noted that there is no indication in Ryder's book[1] that the *horizon method*, viz. 'To observe from the cross-trees or other convenient place the angle subtended between the horizon and the enemy's waterline', was used before it was introduced by Ryder in 1845. Ryder remarked that in not a single man-of-war which he visited before the time of the publication of his book did he find any method in use that would denote satisfactorily the range of a ship at sea; and it was to meet this deficiency that he suggested his horizon method.

Ryder described the methods in general use before the introduction of the horizon method, and in so doing drew attention to their defects from the gunner's point of view. Any of these methods may well have had their applications in maritime surveying during the nineteenth century; but of course surveying was not the immediate concern of Ryder.

The method devised by Sir Howard Douglas, in which the vertical angle between an enemy's masthead and waterline was measured with a sextant, was useless unless the height of the enemy's mast was known. In connection with Douglas's method, Ryder suggested the use of a micrometer telescope and mentioned that the hydrographic department of the Admiralty then supplied Rochon's micrometer telescopes to surveying vessels. Moreover Ryder informs us in a footnote that:

> 'Mr. Blakey, a master in the Royal Navy, has made a telescope without glasses, but with fine wires, by means of which the distance from ships of known height can be readily ascertained.'

Ryder goes on to say:

> 'I have been informed by an officer who placed great dependence on the observation that he was in the habit of estimating the portion of the field glass of his common telescope occupied by any ship or lighthouse of known height, whose distance he was desirous of obtaining, and then multiplying the height by a coefficient, which of course varies with each telescope, and must be ascertained by experiment'.

The method of determining the range of an enemy suggested by Sir Edward Belcher required two observers, one at each end of the ship, to observe simultaneously the respective angles subtended between the enemy and the other observer. This method had obvious defects, such as the difficulty of measuring the angles simultaneously, and the possible large effect on the computed distance through a small error in one or both of the measured angles, especially when the enemy was not abeam or broad on the beam.

Sir Edward Belcher's method was sometimes applied vertically, that is to say, the simultaneous observations were made respectively from the deck and aloft instead of from the ends of the ship. But results from this method, especially when used in rough or even moderate or slight seas, were generally not dependable.

The so-called *vertical method*, viz. 'To observe at the cross-trees the angle subtended by the enemy's waterline and a point perpendicularly under the observer', was more rigidly confined in its application than the horizontal or vertical methods suggested by Sir Edward Belcher.

It is interesting to note that Murdoch Mackenzie, Senior, made no reference in his treatise on surveying[2] to a method for finding distances using vertical angles; although according to Admiral Ritchie[3] Alexander Dalrymple, whose *Essay on Nautical Surveying* was published in 1771, indicated a simple method of finding the distance off one's ship from the sounding boat by observing the vertical angle between the ship's masthead and a horizontal line painted on the ship's side at a known distance below the masthead. It is also of interest to note that Admiral Shortland, who had seen service on the North American Survey in 1842 under the command of Captain W. F. Owen, made no mention in his book[4] of any method for finding distance by vertical angle; although by this time (1890) it had no doubt long been a standard surveying technique.

Captain A. B. Becher's *Tables of Masthead Angles* (1854) is referred to by Lecky in his *The Danger Angle and Offshore Distance Tables* (1890) who points out that the angles computed by Becher and used in his tables are based on an arbitrary mile of 6000 feet. Although well-suited for the purpose for which they were essentially designed, viz. for station keeping, they were not suitable for navigational or surveying purposes.

In 1856 Staff-Commander James M. Share, R.N., published his *Tables for ascertaining a Ship's Distance from High Land*. In these tables the Earth's curvature and atmospheric refraction are taken into account. It seems that Captain Lecky utilized and extended Share's tables for his *Off-Shore Distance Tables*.

The tables designed by Share, and Lecky's tables, may have their foundation in Raper's 'Method for finding the distance of an object seen above the Sea-Horizon, for the purpose of taking a departure'.

Raper's method[5] required the use of a table giving, against height above sea level in feet, the theoretical dip in minutes ($1{\cdot}06\sqrt{\text{height in feet}}$) and also the square of the dip. The table is designed with uniform 1-minute intervals of dip against unequal intervals of height. The method involved measuring the altitude of a summit; one-twelfth of the estimated distance in miles (an allowance for atmospheric refraction) was to be subtracted from the correct altitude in minutes to give the true altitude. From this the theoretical dip (or *depression* as Raper called it) was to be subtracted to give a 'remainder'. The square of the depression corresponding to the height of the summit was then to be added to the square of the 'remainder'. The table was finally entered with this sum in the column giving depression squared, and the corresponding depression lifted. From this the 'remainder' was to be subtracted to give the required distance of the summit in miles.

Raper's *Practice of Navigation*, considered by many to be a classic of its kind, is a thoroughly practical manual. Its author intended publishing a companion volume dealing with the theoretical background to practical navigation, but death overtook him before his intention could be realized. No doubt Raper would have explained his method of finding distance by vertical angle in his proposed book. As it is we are left with many 'Rules' which, in some cases, are not at all easy to demonstrate. Thomas Ainsley, a well-known North-east Coast teacher of navigation during the nineteenth century, was a friend of Raper's, and indeed assisted him in compiling his *Practice of Navigation* and became his literary executor. It is curious, therefore, that no mention of any method for finding distance by vertical angle appears in Ainsley's very large and comprehensive *Extra Master's Guide Book*, first published in South Shields in 1867.

Using the formula[6]: $D = (0{\cdot}565H)/(\phi - d - 0{\cdot}423D)$, or that used by Cluett[7] to compute curves for the determination of distance by vertical angle, viz. $\phi = D^2 + D(2{\cdot}339\phi - 2{\cdot}3\sqrt{h} - 1{\cdot}3225\ (H-h)$, both formulae being quadratics in $D$, in which $D$, $\phi$, $H$, $h$ and $d$ denote respectively distance off in miles, vertical angle in minutes, height of summit above sea level in feet, height of observer's eye above sea level in feet, and dip in minutes, the solution for $D$ is practically equivalent to that obtained using Raper's method.

Raper, however, makes no reference to a method for finding the range of an object such as a buoy, ship, rock or lighthouse, from a measured vertical sextant angle between the sea horizon and the object.

## REFERENCES

1 Ryder, A. P. (1845). *Methods of Ascertaining the Distance from Ships at Sea*. London.
2 Mackenzie, Murdoch, Senior (1774). *Maritime Surveying*. London.
3 Ritchie, G. S. (1967). *The Admiralty Chart*. London.
4 Shortland, P. F. (1890). *Nautical Surveying*. London.
5 Raper, H. (1840). *The Practice of Navigation*. London.
6 Cotter, C. H. (1964). *The Complete Coastal Navigator*. London.
7 Cluett, S. L. (1935). Determination of offshore position by sextant altitude of mountain peak. *U.S. Naval Institute Proceedings*. Annapolis. (See also *International Hydrographic Review* (1936), 13, 142.)