SOUND TRANSMISSION AND METEOROLOGICAL CONDITIONS

(Extracted from an article prepared by E. W. BARLOW - *The Marine Observer* - July, 1929, page 150.)

The following extracts are reproduced here, for information, in connection with the preceding articles on the same subject in *Hydrographic Review*, Vol. V, N° 2, p. 25 and 185.

General Remarks on Meteorological Conditions. — It must be understood that natural air conditions are usually complex and are often so in the highest degree and it would be beyond the power of anyone to set out all possible variations of the actual paths of waves of sound. Not only have the conditions near the ground to be taken into account, but also those in the upper air, in some cases to a very great height. Thus, every change in speed or direction of wind with height in the uppre air will affect the path of sound and so will every change of temperature or humidity. All ttha can be done in the present article is to consider the effect of wind, temperature, etc., separately in the form of general principles and to give simple illustrations, remembering that in nature the various factors are acting together at the same time. Also, the further we are from the source of the sound, the greater the probability that the meteorological conditions along the path of the sound will be variable. The transmission of sound in air is a more complex problem than its transmission in water.

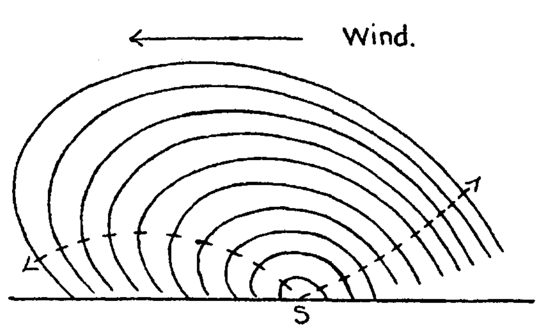
In the years 1921-22, Mr. E. S. PLAYER carried out a series of experiments on the audibility of the sirens of the North Goodwin and other neighbouring light-ships. He was stationed at Joss Gap, near the North Foreland, and the sound was received by electrical and photographical recording instruments as well as by the ear. The Elder Brethren of Trinity House granted the privilege of special blasts on certain days of the week so that the transmission of sound could be studied in different types of weather. The result of one set of observations is given in Table I and is very interesting as showing the great variation of the intensity of the sound received in successive minutes. The light-ship bore 122° at a distance of 7 miles and the wind was 215°, 12 m.p.h. The galvanometer deflections for 44 blasts with one minute between each are shown in the table, the figure 0 indicating inaudibility.

TABLE I.

VARIATIONS IN INTENSITY OF SOUND RECEIVED FROM THE SIREN OF THE NORTH GOODWIN LIGHT-VESSEL, March 12th, 1921, 3.50 p.m to 4.34 p.m. (B. S. T.).

Blast.	*Galvanometer Deflection.*	*Blast.*	*Galvanometer Deflection.*
1	1	19	2
2	4	20-28	0
3	1	29	5
4	0	30	9
5	0	31	3
6	5	32	9
7	1	33	3
8	1	34	3
9	6	35	5
10	1	36	3
11	1	37	7
12	1	38	2
13	4	39	1
14	3	40	0
15	3	41	8
16	1	42	1
17	3	43	1
18	1	44	2

The effect of wind on Sound Transmission. — The effect of wind is to distort the spherical sound waves as is shown diagrammatically in Figure below, where the source of sound is at *S* and the direction is as shown by the arrow. We are considering here the wind near the ground, which increases in velocity with height above the ground. On the leeward side of the source the sound



Vertical section through sound waves distorted by wind. The source of sound is at *S*. The dotted lines represent two rays of sound.

waves advance more rapidly above than below, while on the windward side the reverse is the case. There are thus two reasons why sound is better heard to leaward of the source. The first is that the sound waves received at a distant point to leeward of the source have come down from above and so have lost less energy than waves travelling nearer the ground on the windward side. Also, as shown in the diagram, the waves to windward very soon leave the ground altogether. The second is that the waves to leeward are more likely to pass over obstacles than the waves on the windward side on account of the greater upward curvature of their paths. It may also be remarked that, in the direction in which the wind is blowing, the speed of sound is increased by the speed of the wind; directly against the wind the speed is decreased by the speed of the wind. Since the speed of sound is about 650 knots, it is obvious that only very strong winds have much effect on its speed. Pitch is not affected by the speed of the wind. From the effect of wind in distorting sound waves, it may easily happen that a sound, such as a gun firing, made at a place A, is heard at a place B to leeward of A, while the sound or a similar gun fired at B is quite inaudible at A. The statement that sound is heard better to leeward than to windward only applies on or close above the land or sea surface; at greater heights the sound will be better heard to windward. Thus, in a ship to windward of a source of sound, the sound would be better heard at the masthead than on deck.

There are other wind effects. Sound waves can be refracted and reflected like light waves. In considering the paths of sound in these cases it is easier to think of rays of sound rather than the waves themselves. Thus, with our original undisturbed spherical waves, any radius of the sphere represents a ray of sound because sound travels equally far along any radius in a given time. In the diagram of waves distorted by wind, shown in Figure 2, two of the sound rays are indicated by dotted lines showing the downward curve of the path of sound to leeward and the upward curve to windward. Now let us suppose that the wind near the surface is calm or light and that the rays of sound proceeding upwards meet a definite wind current in the upper air. In such a case the sound ray is refracted, continuing upward but making a smaller angle with the horizontal. If, in the upper air, the sound ray suddenly enters a region of less wind, it is also refracted, continuing upward but making a larger angle with the horizontal. If the sound rays pass into a region where wind speed is gradually increasing with height, the result is similar to that of Figure 2, where the rays are bent successively downward to leeward and upward to windward. If the wind speed gradually decreases with height, the paths would curve upward to leeward and downward to windward. Thus, endless variations of the path are possible with successive wind changes in the upper air. Also, whenever there is an abrupt change of wind and refraction occurs, a small proportion of sound will be reflected downward towards the ground. In certain conditions the whole of the sound will be reflected downwards by total reflection at a stratum where the wind speed abruptly increases.

These effects of wind provide one means by which the phenomenon of zones of silence may be explained. It has long been known that sound, for example that of gunfire, may be heard up to a distance from the source, then be inaudible for a further distance and heard again at still greater distances. Maps have been constructed from a number of observations of a particular sound which show very clearly these more or less irregularly shaped areas of inaudibility, and the great explosions of surplus ammunition dumps in France and elsewhere since the war have been utilised in studying the subject. It is easy to see that the total reflection of sound from a height in the air could direct a ray downwards which might ultimately reach the land or sea surface. When this is the case, it may give rise to audibility at a point beyond which the direct rays from the source, travelling more or less horizontally, could affect the ear. The longer path is the easier one and the sound therefore arrives at the ground with less loss of energy.

The effect of Temperature on Sound Transmission. — Generally speaking, temperature decreases with height above the ground and this results in the upward deflection of sound rays. Hence, the normal state of affairs is for sound to be heard at greater distances upward than horizontally along the ground. Thus FLAMMARION, in a balloon in the neighbourhood of Paris, heard the chirping of crickets at a height of 2,620 feet and the croaking of frogs at 2,950 feet. When there is a temperature inversion, that is when temperature increases with height for some distance above the ground, sound is deflected downwards, and as on these occasions there is usually little or no wind, conditions are very favourable for audibility in all directions along the sea or land surface. When different air currents are superimposed, there may be considerable sudden changes in temperature with height. In such cases, refraction occurs as in the case of wind currents, and it is quite possible for total reflection downwards to occur in suitable circumstances. Generally speaking, variations of wind speed and variations of temperature are acting at the same time in the deflection of sound rays, but they may be working together or in opposition. The irregularities introduced by temperature differences may therefore also have their place in the explanation of zones of silence. Recent research into the subject of meteors goes to show that at a very great height in the earth's atmosphere, about 40 miles, there is a large and rather sudden rise of temperature. It has been pointed out by Dr WHIPPLE that reflection of sound waves from this layer would give a zone of audibility on the earth's surface whose nearest point to the source would be about 90 miles. Such a zone was actually observed on the occasion of the Oldbroek Explosion of 28th October, 1922.

The Effect of Humidity and Fog on Sound Transmission. — PLAYER'S observations of the sirens of light-vessels, previously referred to, show that humidity has a definite effect on the distance over which sounds can be heard. Thus, on 21st April, 1921, with little variation of temperature during the day, variations in audibility followed those of humidity almost exactly. Audibility decreases with lowered humidity and increases with rising humidity. On this day the *Tongue* Light-Vessel's fog signal, distant 9 miles, was inaudible with relative humidity 70 per cent. or less, faintly heard with humidity 70 per cent. to 75 per cent., moderate from 75 per cent. to 80 per cent. and loud above 80 per cent. Effects of refraction and reflection will also be obtained if the sound rays encounter strata of abrupt or gradual change of humidity, and the same applies to nearly horizontal waves which meet such changes of humidity near the sea or land surface at varying distances from the source. The path of the sound rays therefore depends on the combined effects of strata or patches of different wind speed, temperature and humidity. As it is known that the humidity of the air may on certain occasions change appreciably almost from minute to minute without change in temperature or apparent change in other conditions, it is probable that the rapid variations of audibility in Table I are mainly due to humidity changes.

It is well known to navigators that in foggy conditions at sea the sound signals are unreliable and, while they may be heard further from the source, are not always heard at shorter distances. It is also well known that sounds normally inaudible may be heard in foggy weather and that frequently the presence of fog definitely increases audibility. These statements appear at first sight contradictory, but there is quite a simple explanation. If the source of sound and the observer are in a continuous stratum of fog, audibility will be increased. The presence of the temperature inversion normally associated with land or sea fog refracts the paths of the rays downwards. Also, the high humidity, as we saw above, is advantageous, and finally the almost complete absence of wind (which applies, howevei, more to land than to sea fog) allows the sound to spread equally well in all directions. If, however, the fog is patchy the conditions are quite different. Suppose the source of sound and the observer are both in fog with clear air in between. There may then be large reflections of sound at the two surfaces between the fog and clear air so that little or no sound comes through to the observer. The same applies if the source and the observer are both in clear air with a fog bank between them. Even in stretches of continuous fog there are usually patches of variable density and these may cause a loss of sound which may wholly or partially neutralise the advantages of the fog to audibility.

Audibility on "Oppressive Days". — On what are usually called "oppresive days", with little or no wind, high shade temperature and a cloudless sky with a slight but definite haze which slightly dims the sun, PLAYER found that the worst conditions prevailed for audibility along the land or sea surface, although sounds coming downwards as from an aeroplane were transmitted well. This type of weather does not necessarily imply thundery conditions, and it has been noticed that exceptional audibility may precede a thunderstorm. Rain, hail and snow appear to have little or no effect on audibility.