ARTICLES

BINAURAL SOUND-LOCATORS[1]

By E. T. PARIS, D.Sc., F.Inst.P.

The instruments known as binaural sound-locators have been developed in Anti-Aircraft Defence for finding the direction of aircraft at night by sound. The development of such locators began about the year 1917 when the dropping of bombs from aircraft at night had become a regular feature of warfare.

The problem of anti-aircraft sound-location may be divided into two parts, the first being the determination of the direction from which sound-waves from an aircraft arrive at some point on the earth's surface. This direction may conveniently be called the " line of sound " to the aircraft. Since sound-waves travel in air at about 1,100 ft./sec., while the speed of bombing aeroplanes is generally between 150 and 250 ft./sec., the " line of sound "—if we ignore refraction effects due to wind and temperature-variations in the atmosphere—is always the direction to some past position of the aircraft. Also this past position is at a considerable distance from the position occupied by the aeroplane at the time it emitted the sound received by the sound-locator. For example, the average time taken by sound to travel to a sound-locator from an aeroplane at 10,000 ft. is about 15 seconds and during this time the aeroplane moves along its course for a distance of about half a mile. Thus the " line of sound " is a line from the sound-locator to a point half a mile behind the aeroplane. The second part of the problem of sound-location is therefore the deduction of the present line of sight from a past line of sight. This " prediction " from the past into the present can be accomplished if the course of the aircraft and its speed along the course are known. The process of finding the present line of sight is called colloquially " correcting for the lag of sound." We shall in this article be concerned mainly with the design of sound-locators for finding the line of sound, but some mention

[1] Much of the information concerning sound-locators in this article has come to me through official channels, and I am indebted to the Royal Engineer Board for permission to publish it and to reproduce the photographs in Figs. 3 and 4.—E. T. P.

will be made of the principles on which devices for applying the lag-of-sound correction can be designed.

The design of sound-locators for anti-aircraft defence began in this country in the Anti-Aircraft Experimental Section of the Munitions Inventions Department. This Department was a war-time organisation and is, of course, now defunct. Simultaneously experiments were also carried on at the National Physical Laboratory. It was in the A.A. Experimental Section, under the direction of Prof. A. V. Hill, that the design for the first binaural sound-locator used in the British Army was produced. At the time when experimental work was begun, there was a binaural apparatus in the French Army known as the Claude " orthophone," and tests were made with one of these instruments. The orthophone was intended for the location of guns and machine-guns by sound and, although it appears never to have attained much success when used for the purpose for which it was designed, it seems to have provided the starting-point for the development of a binaural locator for use in anti-aircraft defence.

The Claude apparatus was the simplest type of binaural sound-locator that could be devised. It was designed to make use of the natural binaural faculty of a listener, that is, the faculty which enables him to determine whether a sound is coming from left or right or straight ahead. This faculty is dependent on the simultaneous employment of both ears, and the sensations experienced are probably due to an appreciation of a difference in the time of arrival of a sound at the right and left ears. If sound from a certain source reaches the right ear of a listener before it reaches his left ear then he judges the source to lie to the right, and conversely if the sound reaches his left ear first he judges the source to be to the left. If the sound reaches both ears simultaneously then the source of sound appears to be straight ahead. Since the distance from ear to ear round the back of the head is only about six inches, and since sound travels this distance in about one two-thousandth of a second, the time-differences which give rise to the binaural sensation of direction must be very small. The idea underlying the Claude apparatus was that if there were a virtual extension of the distance between the ears, such as can be secured by the use of two listening tubes leading from two points some distance apart, one to the right and one to the left ear, it should be possible, by a rotation of a stand carrying the tubes, to make accurate determinations of the angular bearings of sources of sound, because, if a suitable distance between the open ends of the two tubes is chosen, a small angular rotation of the stand would produce an easily apprehended time-difference at the ears of the listener.

The Claude apparatus took the form shown diagrammatically in Fig. 1. There were two horizontal metal tubes T_1 and T_2, bent into the shape shown in the figure. The sound was picked up through the open ends at O_1 and O_2, these being bent forward for a short distance towards the direction from which the sound arrived. The tubes were continued downwards alongside a vertical shaft X, and to their other extremities, at t_1 and t_2 in Fig. 1, was attached a stethoscope head-fitting, so that the sound entering at O_2 was led to the right ear of the listener while that entering at O_1 was led to his left ear. The tubes T_1 and T_2 could be rotated in a horizontal plane about the vertical axis X by means of the hand-control *h* until the sound that was being located appeared to the listener to be straight ahead. When this happened the line of sound was at right angles to a line joining O_1 and O_2 and the bearing could be read on a scale with which the instrument was provided. The whole instrument was designed to be supported in the roof of a dug-out from the inside of which the listener made his observations.

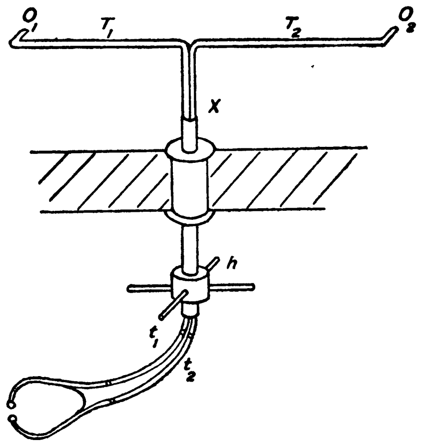

FIG. 1.—The Claude Orthophone.

With the help of this instrument the azimuthal bearing of a source of sound could be found. To define the direction of an aircraft from a point on the earth's surface it is, however, necessary to determine a second angular co-ordinate. Thus, in the binaural sound-locator as finally developed there were two listeners, one of whom found the azimuthal bearing by the rotation of a horizontal cross-arm about a vertical axis as in the Claude orthophone, while the other found the elevation in a vertical plane. The second, or elevation, listener rotated an arm in a vertical plane about the horizontal axis provided by the cross-arm operated by the azimuthal listener. This method of building a sound-locator is the altazimuth method and is shown diagrammatically in Fig. 2. The vertical axis is X and A_1, A_2 are the two points where the sound heard by the azimuth listener is picked up. The cross-arm A_1 A_2 is horizontal and can be rotated about its point of support at O. The sound heard by the elevation listener is picked up at E_1 and E_2 and the arm E_1 E_2 can be rotated about A_1 in a vertical plane. When both listeners are " on sound " all four points A_1, A_2,

E_1 and E_2 lie in a plane the normal to which is the line of sound.

For aircraft location it is found insufficient to employ only the open ends of tubes for picking up the sound, and sound-collectors are mounted with their centres at A_1, A_2, E_1, E_2. In some sound-locators these collectors are conical trumpets with tubes leading back from the narrow ends of the cones to the stethoscope worn by the listeners. The cones act in the same way as the ordinary ear-trumpet and serve to magnify faint sounds and make them easily audible to the listener; they also assist a listener to concentrate his attention on the sound coming from one direction by screening off sounds coming from other directions.

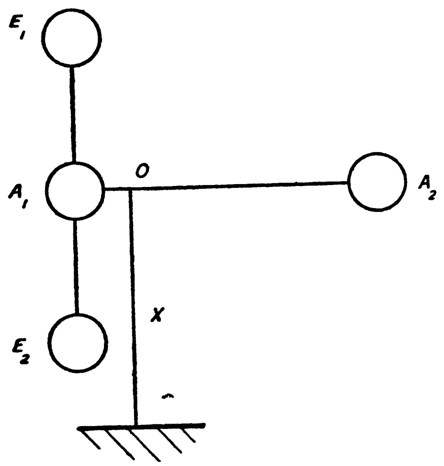

FIG. 2.—Altazimuth Sound-Locator Mounting.

A sound-locator with four conical trumpets on an altazimuth stand is shown in the photograph reproduced in Fig. 3. The trumpets, which are made of thin metal, are encased in pyramidal wooden sheaths of square cross-section, and there is an air-space between the wooden sheaths and the cone. This construction is intended to prevent the incidence of sound on the walls of the cone and to minimise the disturbing effect of sounds coming from lateral directions (*e.g.* the sound of road traffic).

We may now enquire into the accuracy with which the direction of a source of sound can be found by listeners using a sound locator. In discussing this question we shall ignore effects due to the refraction of sound in the atmosphere. Both the temperature lapse-rate in the atmosphere and the variation of wind strength and direction with height above the earth's surface refract the rays of sound from an aircraft, so that even when the lag of sound has been corrected for, the line of sound does not in general coincide with a past line of sight. These refraction effects are calculable by methods that have been described [1] and will not be considered here. When they are left out of account, there remains the question as to the accuracy with which a locator can be used to determine the normal to the wave-fronts arriving at the point of observation. It is

[1] E. A. Milne, *Phil. Mag.*, vol. XLII, p. 100 (1921).

necessary as a preliminary to consider the nature of binaural hearing.

As stated above, the binaural sensation of direction is probably due to a difference in the time of arrival of sound-waves at the two ears. At one time, however, it appears to have been held that the perception of direction was attributable to a difference in the amplitude of the vibrations affecting the two ears, this difference being caused by the sound-shadow thrown by the listener's head. It was shown by Rayleigh[1] that this hypothesis did not adequately explain the phenomena of binaural hearing. For example, the head-shadow formed by sound-waves of frequency 128 cycles per second produced a barely perceptible difference in amplitude at the two ears, but the perception of direction was as clear as at higher frequencies, when the head-shadow was more definite. Rayleigh's hypothesis was that up to frequencies of 512 cycles per second, and perhaps higher, a phase-difference between the sound occurring at the two ears could be recognised and that a listener's judgment of the direction of a sound was founded on an appreciation of this phase-difference. The emphasis laid by Rayleigh on phase-difference as distinct from differences in amplitude or intensity, led to the belief that his hypothesis implied that the apparent direction of a source emitting a continuous tone was determined only by the phase-difference (measured as an angle or as a fraction of a period) between the vibrations stimulating the two ears, and not by the time-difference to which the phase-difference corresponded. It is difficult to believe that any such implication was intended ; there would be obvious difficulties in the case of complex sounds, for the various component tones would be associated with different apparent directions. Also a source of varying frequency would appear to be continually changing its direction. Hornbostel and Wertheimer,[2] in 1920, advocated the view that time-difference was the determining factor in localisation, and in a recent publication Shaxby and Gage [3] describe experiments which appear to show definitely that a given localisation can be associated with a certain time-difference. Shaxby and Gage conclude from their experiments that " for ordinary sounds, at any rate for frequencies lower than about 1,200 vibrations per second, the physical phenomenon on which localisation in the median plane depends is the interval of time elapsing between the arrival of the sound-waves at the two ears."

[1] *Phil. Mag.*, vol. XIII, pp. 214–32 (1907) ; *Sci. Papers*, vol. V, pp. 347–63.

[2] *Sitzungber. Preuss. Akad. d. Wissensch.*, vol. XX, pp. 388–96 (1920) ; see also Hornbostel, *Phys. Soc. Discussion on Audition*, p. 120 (1931).

[3] *Studies in the Localisation of Sound*, by J. H. Shaxby and F. H. Gage, *Med. Res. Council Special Report Series*, No. 166 (1932).

It appears, therefore, that, except in the case of sound of high frequency, current opinion favours time-difference as a principal factor in binaural localisation in everyday life. What is more important, however, is that it has been demonstrated that time-difference alone provides a sufficient basis for a judgment of localisation. That time-difference alone is sufficient can be confirmed by the use of an apparatus designed by G. W. Stewart [1] and called a "Phaser." This apparatus is so made that alternating currents of the same frequency and amplitude pass through two telephone receivers on the ears of a listener. The relative phase of the currents can be altered at will and it is found that a binaural sensation of direction is experienced by the listener, and that when the phase is changing he is conscious of a moving "sound-image." Since in any particular experiment with the phaser the frequency of the sound remains constant, every phase-difference corresponds to a definite time-difference. With this apparatus there is no variation in the amplitude or quality of the sounds at the two ears and therefore localisation is due to time-difference alone.

In a sound-locator such as the Claude orthophone the listener finds direction solely by time-difference, for this is the only thing that changes as the instrument is rotated. Owing to the small size of the openings through which the sound enters the apparatus there can be no change either in the amplitude or in the quality of the sound reaching the listener's ears. It is true that, except when the listener localises the sound in the median plane, one of the openings will be farther from the source than the other and that there is theoretically a difference in amplitude on this account; but in practice, unless the source is very near the locator, the difference is quite negligible. Let the locator be initially placed so that the openings O_1 and O_2 (Fig. 1) are equidistant from the source of sound, and then let the stand be rotated through an angle α. If L is the length of each arm of the locator, and a cm./sec. is the velocity of sound in air, the time-difference consequent on the rotation is $(2L \sin \alpha)/a$ seconds, or for small values of α approximately $2L\alpha/a$ seconds. If Δt is the smallest time-difference that can be appreciated with certainty by a normal listener and we write $\lambda = a.\Delta t$ then the greatest angular error that would be made in laying the locator is given by $\sin \alpha = \lambda/2L$, or $\alpha = \lambda/2L$ radians approximately. The distance $2L$ is called the base-length of the locator and we see that the accuracy of laying should be inversely proportional to the base-length. According to the experiments of Hornbostel and Wertheimer (*loc. cit.*) the value of λ is about 1 cm., so that even with base-

[1] *Phys. Rev.*, vol. XV, p. 433 (1920).

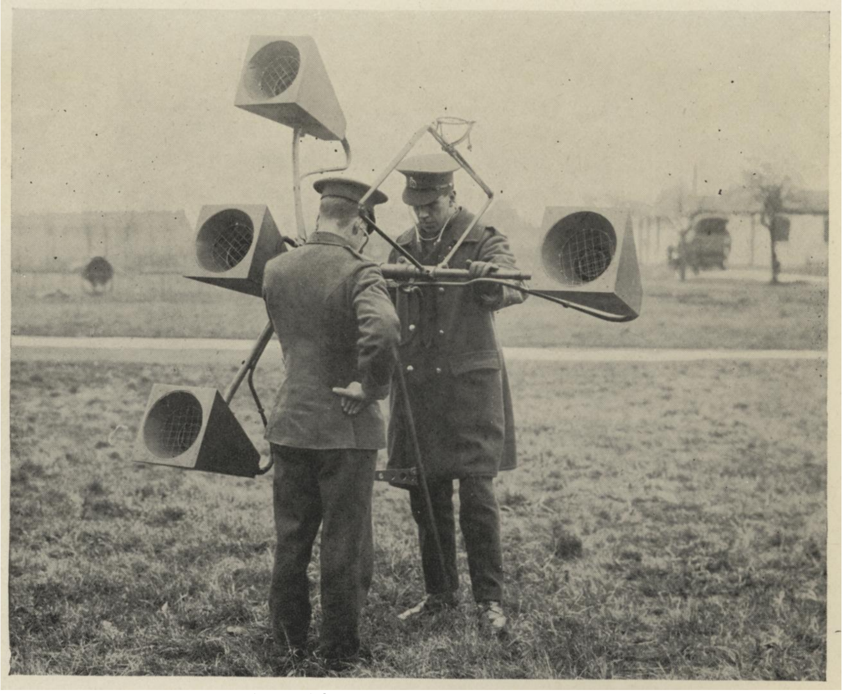

FIG. 3.—A FOUR-TRUMPET SOUND-LOCATOR.

FIG. 4.—THE GOERZ SOUND-LOCATOR.

lengths of quite moderate dimensions, say L = 1 metre, the greatest error should not be more than 1/200 the radian, or between a quarter and a half of a degree.

In a sound-locator such as that shown in Fig. 3, in which the sound is received by conical trumpets, the principal effect on which localisation depends is still probably time-difference. The use of sound-collectors is, however, accompanied by other effects which may be of assistance to the listeners. These other effects are associated with the directional properties of the sound-collectors. Conical trumpets have different polar curves of reception for sounds of different frequencies, but in all cases the received sound is a maximum when the axis of the cone is pointing towards the source. When the axis of the cone is moved away from the direction to the source, the loudness of the received sound falls off and the higher the frequency of the sound the more marked is the falling off for a given angular movement. It follows from this that, in addition to time-difference two other effects occur which may be of help to listeners. Firstly, the sound is loudest when the trumpets point towards the source. In the construction shown in Fig. 3, the trumpet mouths are coplanar and are arranged to lie in the plane of the wave-fronts of the received sound when the time-difference is zero, and hence zero time-difference and maximum loudness occur together. Secondly, if, as is the case with aircraft, the sound to be located is very complex, there is a change of quality as the sound-locator is moved round through different angles from the direction to the source.

It is not possible to say what parts are played by these loudness and quality changes or even whether or not they are important in comparison with time-difference. It may be significant, however, that most users of sound-locators agree that they find localisation easiest when they can hear the high-pitched sibilant constituents of aeroplane sound. The frequencies of these constituents are very high, far above those for which the time-difference theory has been found to be satisfactory. On the other hand, it must be remembered that the sound from aircraft suffers considerable and rapid variation in amplitude (due to meteorological hazards) and it is conceivable that there may be some mechanism of hearing whereby localisation can be made by an appreciation of the time-difference between the arrival at the ears of the beginnings (or ends) of trains of waves of different amplitude.

The base-length in the locator shown in Fig. 3 is 54 inches. On the assumption that localisations are made entirely by time-difference and that the minimum perceptible path-difference is 1 cm., the determination of direction (on a fixed source) should be possible to within one degree. This is about the accuracy that can be obtained if trained listeners are used. The accuracy on a moving source is of course not so good.

The selection of listeners for sound-locators is a matter of great importance if accurate results are to be obtained. It has been customary to test the binaural powers of individuals by observing the accuracy with which they can lay a sound-locator, in azimuth only, on a fixed source of sound. It was discovered, in the early days of sound-location, that certain listeners would lay the locator very consistently but that the mean of the directions found would not coincide with the theoretical direction, *i.e.* the direction which would make the length of path of the sound to both ears equal. This deviation from the theoretical direction was called the "personal error" of the listener and sometimes amounted to as much as one degree with a locator having a base-length of

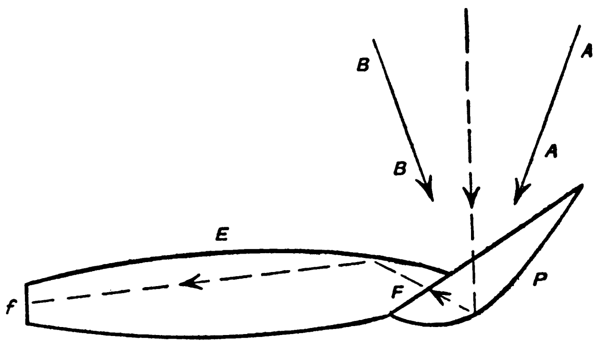

FIG. 5.—Goerz Paraboloid-Ellipsoid Combination.

about five feet. The corresponding path-difference is about 2·5 cm., and is considerably greater than the minimum path-difference which the listener could detect. Shaxby and Gage (*loc. cit. supra*), using a laboratory method, have recorded the personal errors of a number of observers. In an examination of forty individuals they found that (expressed as path-differences) the personal error varied from 0·02 cm. to 5·03 cm. (about equally distributed right and left), the average being about 1·2 cm. At the same time they recorded the scatter of the listeners' observations and found that it might happen that an observer with a large personal error had a small scatter, or *vice versa*. They use the convenient terms "bias" and "uncertainty" to define the quality of a listener. The "bias" is the personal error of the listener expressed as path-difference, and the "uncertainty" is the standard deviation of his observations. A good listener must have a small bias as well as a small uncertainty.

In recent years a sound locator has been manufactured by the firm of K. P. Goerz in Bratislava, Czechoslovakia, which presents novel features in the design and arrangement of the sound-collectors. A view of the instrument is reproduced in Fig. 4; a detailed description of it, including theoretical considerations, has been given by C. v. Hofe.[1] The sound collecting units are paraboloid-ellipsoid combinations, and one of them is shown in section in Fig. 5. The sound is received first of all on the paraboloidal reflector P, which brings the rays to a focus at F. From this focus the sound is led to the listener's ear by the elongated hollow ellipsoid E. The theory is that the rays of sound after passing through the focus F, which is also one of the focal points of the ellipsoid, will be reflected once more from the inner surface of the wall of the ellipsoid and again brought to a focus at *f*. The end of the ellipsoid near *f* is cut off and a porous rubber ring attached to the circular opening. This ring fits over the listener's ear, and when the ear is held in place the entrance to the meatus is approximately at the focus *f*. The rays incident on the paraboloidal reflector can of course only be brought to a focus when they are parallel to the axis of the paraboloid. The paraboloid and the entrance to the ellipsoid are shaped in such a way that when rays are incident from the right (looking forward towards the source), as from AA in Fig. 5, more sound enters the ellipsoid than when the rays come from the left as from BB in Fig. 5. In this way a differential intensity effect is obtained, the sound being louder on the side to which the source lies.

The azimuth listener uses two sound-collecting units similar to that shown in Fig. 5. For the elevation listener the elongated ellipsoid is divided at its widest part and the two halves set at right angles with a "flat-elbow" joint. The arrangement is shown in Fig. 6. It will be noticed that although the arrangement of the sound-collectors is such that one listener finds the azimuth angle and the other finds the elevation, the stand is not of the altazimuth type shown in Fig. 2, but a variation of it in which the elevation collectors are "staggered." The elevation and azimuth parts of the locator are mounted on opposite sides of a tripod stand with a large round top on which is a seat for the operator of a mechanism

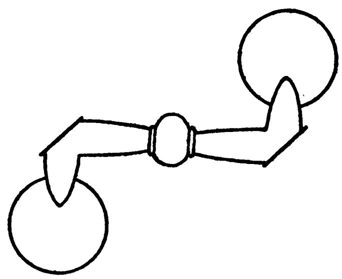

FIG. 6.—Arrangement of Elevator Sound-collectors in Goerz Locator.

[1] *Zeitschr. f. Instrumentenkunde*, vol. XLIX, p. 331 (1929); other descriptions of the locator and accessory apparatus are contained in various articles which have appeared in the *Rivista di Artigleria e Genio* from 1928 to 1931.

for applying the lag of sound correction. The azimuth and elevation collectors are linked mechanically in such a way that the axes of all four paraboloidal reflectors are always parallel to one another.

The instrument is interesting because it is designed to produce a difference in amplitude at the two ears of the listener, and the intention of the designers is that the listener should locate the sound by rotating the instrument until the sound appears equally loud in both ears. At first sight it seems improbable that a "ray" construction could give any useful results when applied to the reflexion of sound in the paraboloid-ellipsoid combination, since the dimensions of the reflecting

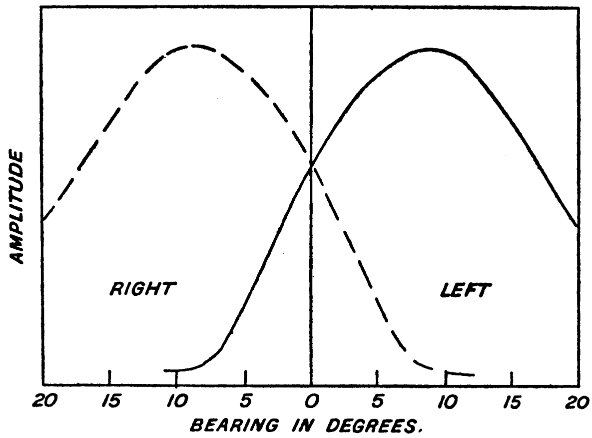

FIG. 7.—Differential Sound-amplitude Effect in Goerz Locator (Frequency 1,000 cycles).

surfaces are comparable with the wavelength. Experiments show, however, that quite well-marked differences in amplitude can be produced at the listeners' ears. The curves in Fig. 7, for example, show the variation in amplitude for sound of 1,000 cycles per second as the listening unit is rotated. The curves were obtained by placing a condenser microphone at the end of one of the azimuth ellipsoids in the position that would be occupied by one of the listener's ears. The source of sound was a loud-speaker emitting a steady and fairly pure tone of 1,000 cycles per second at some distance from the locator. The response of the microphone is proportional to the amplitude of the vibration affecting the diaphragm and this was plotted against the angular bearing of the locator. The full curve shows the amplitude of the sound affecting the right ear and the broken curve the amplitude that would simultaneously affect the left ear. When the bearing is 0° the amplitude at the two ears is of course equal. If the instrument is moved to the left the amplitude at the right ear increases and that at the left ear decreases until when the bearing is about 5° from the central position the amplitude at the right ear is about twice that at the left ear. This corresponds to a difference of 6 decibels between the stimuli at the two ears and the difference in loudness would be easily perceived. In this locator the listener has three aids for localising the sound in the median plane; these are (i) the usual time-difference effect, (ii) a differential loudness effect—which will obviously be more apparent in the high-frequency components of the sound, and (iii) a differential quality effect.

There are, as pointed out above, loudness and quality effects in the sound-locator with conical trumpets shown in Fig. 3, but they are the same for both ears. The point about the Goerz locator is that unless the instrument is placed so that the sound appears to be directly ahead, the loudness and quality of the sounds heard by the two ears will be different.

Two other types of sound-locator may be mentioned. These are the Exponential Sound-Locator [1] of American origin and the French Telesitemetre.[2] The former is equipped with four large exponential trumpets (each about 15 feet long) as sound-collectors, two being used for finding the azimuth angle and two for elevation. The locator is the same in principle as the four-trumpet locator shown in Fig. 3, but the base-length is greater, being in the neighbourhood of 9 feet. The Telesitemetre is also a large locator with four sound-collectors of a type designed by Prof. J. Perrin of Paris. They are nests of small conical trumpets (forty-two trumpets to each collector) and are called "myriaphones."

The locators described and mentioned above include the principal types at present made. With the exception of the Goerz locator, they rely ostensibly on the perception of time-difference by the listeners. In the present state of our knowledge it is not possible to say whether time-difference is the only factor of importance, or what are the advantages—if any—of the Goerz method of introducing loudness differences. Nor is it known what part is played by changes in quality. The experiments already mentioned demonstrate that localisation can be made from time-differences; they do not demonstrate that time-difference is the only factor relied on in the

[1] The exponential locator is made by the Sperry Gyroscope Co. Photographs have appeared recently in the daily press. There is a description and a good photograph in the *Coast Artillery Journal* for November–December 1931. See also P. R. Bassett, *Coast Artillery Journal*, **75**, 200 (May–June 1932).

[2] A photograph of the telesitemetre has appeared in the *Illustrated London News* and is reproduced in the *Scientific American* for December 1930.

use of sound-locators and in everyday life. It is, in fact, probable that localisation in everyday life is made largely by means of extra-auditory clues. An admirable account of the factors affecting binaural localisation with some reference to the possible effect of depriving a listener of extra-auditory clues has recently been given by H. Banister.[1] It seems possible that although a sound-locator can be made with time-difference alone as a basis, yet better results may be obtained when additional clues, such as those provided by differences in loudness and quality, are presented to the listener.

It was remarked at the beginning of this article that the second part of the problem of sound-location was the deduction of the present line of sight to an aircraft from observations on the line of sound. This is a relatively simple problem if acoustical refraction effects are ignored and the track of the aircraft is supposed to be straight and at constant height. The line of sound at any instant is of course a past line of sight and all past lines of sight will be in a plane which is, in fact, the plane containing the track of the aircraft and the point of observation. Thus in Fig. 8 let O be the position of the sound-locator and OT_1 OT_2 two successive lines of sound. The triangle OT_1T_2 lies in the plane containing track and point of observation and the intersection of this plane with a horizontal plane gives the course of the aircraft. Let t seconds be the time taken by the sound to travel from T_2 to O, then $OT_2 = at$, and if v is the velocity of the aircraft along its track its position at the instant the sound is received at O is at T_3 such that $T_2T_3 = vt$, so that $T_2T_3/OT_2 = v/a$. Since the directions of OT_2 and T_2T_3 are known, the direction of the line of sight OT_3 can be determined, if v is known. In practice it is usual to rely on an estimated or guessed value for v.

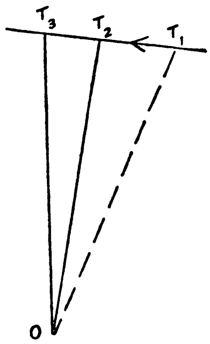

FIG. 8.—Deduction of Line of Sight from Line of Sound.

A very elegant and simple device for applying the lag-of-sound correction to a sound-locator was designed in the A.A. Experimental Section. The device was called a " ringsight " and the theory of its working can be explained by reference to Fig. 9. Let O represent the position of the sound-locator and let T_1 be some point on the line of sound to the aircraft. Let the length of OT_1 be l and with centre T_1 draw a circle of radius r in a horizontal plane and let $r/l = v/a$. Then the line of sight from O to the aircraft will always pass through some

[1] " The Basis of Sound-Localisation," *Phys. Soc. Discussion on Audition*, p. 104 (1931).

point on the ring. Also as the aircraft moves along its track the ring as a whole will move on a parallel course and it is easily seen that the line of sight to the aircraft will be from O through a point on the front edge of the aircraft, judged from the direction in which the ring is moving. The ringsight itself consisted of a bead backsight and a ring foresight, the latter balanced horizontally by means of small weights. The whole sight was mounted rigidly on the sound-locator stand in such a way that the line from the backsight to the centre of the ring was always parallel to the line of sound found by the locator. The ringsight can be seen on the locator shown in Fig. 3. An observer looks at the ring over the backsight and notices the direction in which the ring moves as the locator follows the aircraft; he then selects the leading edge of the ring and a line from the backsight to the leading edge gives him the line of sight to the aircraft. The ratio r/l can be varied, to correspond with different estimated values of v, by increasing or decreasing the distance from the backsight to the centre of the ring.

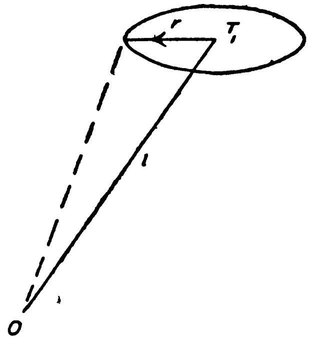

FIG. 9.—Theory of the Ring-sight.

It is curious that the development of sound-locators appears to have taken place solely for military purposes. In view of the difficulty of navigating ships in fog (even with the assistance obtainable from wireless) it might reasonably have been expected that some development of the sound-locator for navigational purposes might have occurred. Perhaps the lack of confidence, frequently expressed by mariners, in the directions found by sound in fog may be partly responsible. For example, a writer in a recent number of the *Nautical Magazine* (February 1932) says that "one of the great nerve-straining things about fog and the signals given by ships is that it is almost impossible to tell from what point of the compass a sound is coming." But another writer in the same number of this periodical describes how ships were habitually navigated up narrow water-ways by timing the echoes of the ship's fog-siren from the left and right banks of the channel. So that there seem to be at least two opinions on the value of directions found by sound in fog. It is difficult to believe that a properly designed sound-locator would fail to give accurately the directions of sound-signals in fog.