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PROVISIONAL NOTE

ON THE

ACOUSTIC GONIOMETER
MILITARY TELEGRAPH TYPE 1

INCLUDING AN EXTRACT ON THE USE OF SEARCHLIGHTS; AND NOTE ON THE APPLICATION OF THE ACOUSTIC GONIOMETER TO FIRING BY SOUND AND TO THE ORIENTATION OF SEARCHLIGHTS

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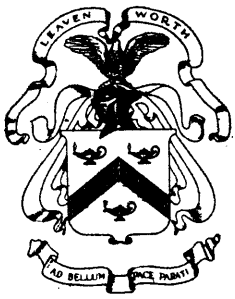
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WAR DEPARTMENT,
WASHINGTON, *October 29, 1917.*

The following pamphlet, entitled "Provisional Notes on the Acoustic Goniometer, Military Type 1," is published for the information of all concerned.

[062.1 A. G. O.]

BY ORDER OF THE SECRETARY OF WAR.

JOHN BIDDLE,
Major General, Acting Chief of Staff.

OFFICIAL:
H. P. McCAIN,
The Adjutant General.

WAR DEPARTMENT,
THE ADJUTANT GENERAL'S OFFICE,
Washington, June 19, 1917.

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BY ORDER OF THE SECRETARY OF WAR:

H. P. McCAIN,
The Adjutant General.

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I. Notice Provisoire sur la Goniometre Acoustique.

PROVISIONAL NOTE ON THE ACOUSTIC GONIOMETER.

Military Telegraph, Type No. 1.

REVIEW OF THE PRINCIPLES OF THE BINAURICULAR METHOD.

If the sound waves issuing from a source S reach both ears of an observer at the same time, he experiences the impression of hearing the sound by both ears at once. If, on the contrary, one ear is struck before the other, the listener has the impression of hearing the sound by this ear alone. By turning the head from right to left and vice versa, from one side to the other of the direction of the sound source, he will have a very distinct impression of the passage of the sound from one ear to the other. At the moment of passing the source of sound will be equidistant from both ears; that is, in front of the observer.

It is partly by virtue of this physiological phenomenon that we have the sense of direction for azimuthal sound.

This effect will be greatly strengthened if, instead of the ears alone, two horns are used, the apices being connected with both ears respectively by tubes of equal length.

To obtain a direction, the combination of the two horns will be rotated to and fro around a point of the straight line which joins them so as to give the impression of the passage of the sound from the right ear to the left. The angle made by the line joining the horns with the direction North–South at the moment of the passage of the sound from one ear to the other is read on a graduated scale. If the two horns are movable on a horizontal plane, the azimuthal of the source will be obtained from the reading of the circle.

We have just said that the impression of the passage of the sound from one ear to the other is produced when the same wave strikes both ears of the observer at the same moment, or, in other words, when the difference δ of the paths followed by this wave before reaching one or the other ear is zero.

Really this is not exactly the case, and an impression is retained for the very small value of δ comprised between two

limits very near together. One may say that for an experienced observer are about ±1 centimeter.

It is clear that with such an instrument, as has just been described, the precision of the direction is proportional to the distance between the two receivers.

Remark.—The system of binauricular sound perception makes possible obtaining the azimuthal orientation of a sound source by means of the ear unassisted, but does not make possible orientation in elevation since both ears move only in a horizontal plane. However, if receivers other than the ears are used, they may be turned in any plane desired, and particularly in the vertical plane passing through the source. The binauricular method of sound perception will then permit the determination of both the azimuth and the elevation of this source.

ACOUSTIC GONIOMETER FOR AZIMUTH AND ELEVATION (MODEL A).

The Military Telegraph Service has devised an apparatus based on this principle (the acoustic goniometer) intended for listening for aircraft. It permits the separate measurement of their two coordinates, as has just been described.

It consists of four receivers, having by pairs the same orientation. The first two are supported by the same horizontal arm capable of moving on a vertical axis passing through its center. The two others turn on a horizontal axis, forming a single piece with the preceding combination. The symmetrical axes of these two receivers move in this rotation in the same vertical plane.

While the line joining the first two is kept constantly perpendicular to the direction of the aircraft, the two others are movable in the instantaneous vertical plane of this aircraft.

The receivers forming the first pair are connected by two tubes of equal length with the two branches of an earpiece; they are used for measuring the azimuths. The two others are connected by two tubes of equal length to the two branches of a second earpiece. They are used to determine the elevations.

DESCRIPTION OF THE APPARATUS.

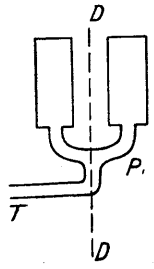
Receivers.—The receivers are formed of a series of cells of pyramidal form, all having the same apex, and the axes of which are in the same plane. These cells are arranged in a quadrant. At the common apex there is an opening where the listening tube must be attached.

The two receivers for determining the azimuth are placed at a distance of 2 meters, 50 centimeters from each other, so that the axes of the corresponding cells are parallel and that the diametral planes of the receivers are vertical and perpendicular to the line joining the apices. The extreme partitions of each of them are vertical and horizontal, respectively. They permit the application with excellent results of the binauricular method of listening to the determination of the azimuth of an aircraft. In fact, there will always be one of the cells of each of them the axis of which will have approximately the same angle of elevation as this aircraft.

The two receivers for determining the elevation are in all respects similar to these for the azimuth. The axes of the corresponding cells are still parallel with each other. The distance between the two apices is 1 meter.

NOTE.—*The experiments made with this instrument have led to the decision of introducing into it in future the two following improvements:*

1. Each receiver will consist of a pair of horns like those described above. The diametral planes of these two horns will be parallel and 30 centimeters apart. Their apices will be connected with the listening tube by two tubes of equal length. When the diametral plane D D of the combination of the two horns passes through the sound source sought, the sound waves received by each will come in contact at the common point P, and the sound in the listening tube T will reach a maximum of intensity.



With this arrangement the maximum intensity of sound will be obtained simultaneously with the impression of the passage of the sound from one ear to the other. This is attended with a very notable augmentation in the magnifying power of the instrument.

The mouth of the instrument will be drawn back, an undoubted advantage in itself. Furthermore, if several aircraft fly over the station at the same time, the maximum intensity of sound will be noted whenever the instrument is pointed at one of them. Thus all confusion between the sound produced by this and by the other aircraft will be avoided.

2. In the acoustic goniometer type "I a" the distance between the receivers for elevation will be increased in future to 2

meters. For this purpose the circular movable disk will be lowered 20 centimeters and the horizontal axis will be raised 30 centimeters. This modification is very important. It will result in a precision of the same order in aiming for elevation and for direction.

The symmetrical axes of these two receivers are parallel with each other, perpendicular to the line joining the apices, and they are situated in a same plane perpendicular to the horizontal axis of rotation.

These two receivers are held firmly together by three parallel arms of steel tubing, perpendicular to their diametral planes and to the horizontal axis of rotation.

The apparatus consists of three distinct pieces:

1. *The stand*, composed of a horizontal circular cast-iron plate, resting on three steel tubes. This plate is pierced in the center by a circular opening prolonged by a vertical socket 30 millimeters in diameter. This socket is closed at its extremity by a steel plug which is screwed into its side. It is intended to offer passage to the vertical axis of rotation.

2. *The fork*, composed of a cast-iron horizontal arm forming a single piece with the vertical axis of rotation, with the receivers for the azimuth, and with the two vertical uprights on which the horizontal axis rests. The horizontal cast-iron arm has the form of a circular plate prolonged along one diameter by two projections on which two arms of angle iron 75 centimeters long are bolted. To the extremities of these two arms are bolted the receivers for the azimuth. The vertical axis is screwed to the center of the plate perpendicularly to its plane. It bears at its extremity a ball bearing on which it turns. The diameter of this plate is the same as that of the fixed plate of the stand over which, moreover, it is exactly superimposed. The edge of the fixed plate of the stand is graduated to 10 mils. An index traced on the edge of the moving plate moves in front of this graduation. Finally, the two supports of the horizontal axis of rotation are each formed of two vertical steel tubes united at their top by a U piece in which is screwed a bolt, the extremity of which is pointed. It is around the points of these two bolts that the rotation of the horizontal axis takes place. A hole at the center of the movable plate allows for the oiling of the vertical axis without dismounting the apparatus. It is generally closed by a little copper screw which will only have to be

removed whenever it is desired to oil the vertical axis of rotation.

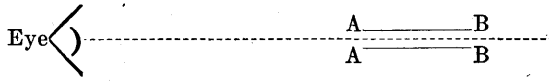
3. *The combination of the two receivers for elevation.* The two elevation receivers are, as has been said, connected rigidly by three steel tubes which are parallel and perpendicular to the diametral planes of the receivers. One of these three fixed tubes is fastened to the two receivers near their apex. The points where the two others are fastened are placed symmetrically on the two outside partitions near the opening of the receivers. These last two tubes form a single piece with the horizontal axis of rotation to which they are perpendicular. Finally, at the two extremities of the horizontal axis there are two conical holes intended to allow passage for the two points about which this axis should turn and of which mention has already been made. A quadrant graduated in degrees forms one piece with this system and moves with it.

COLLIMATOR.

A collimator intended for the optical verification of the acoustic aimings forms a single piece with the receiving equipment for angles of elevation.

This collimator is formed of a single copper tube 1 centimeter in diameter and 5 centimeters long, the axis of which is parallel with the symmetrical axes of the receivers.

To find the line of sight the eye should be 20 centimeters behind the collimator so as to see the two extreme sections of this tube as two concentric circles. The point sighted should be seen at the center of these circles. If this is the case, the right line passing through the retina and the point sighted coincides with the axis of the tube.



This collimator will be serviceable for the instruction of the personnel. It will enable the observers to control visually the precision of their acoustic aimings.

It will enable the instrument to be oriented.

Care should be taken that the axis of the collimator is parallel with the diametral planes of the receivers. If they are not parallel, the acoustic aimings and those made with the collimator on a same sound source will not coincide. A locking

screw makes it possible to correct the error of orientation of the collimator.

EARPIECES.

The earpieces are of the model employed for the stethescopes for mine listening. They consist of two nickeled tubes terminated at one extremity by two nipples of galaith and vulcanized rubber for insertion in the ears of the listener. The two other extremities are connected by a spring. They are connected with the two listening tubes by two rubber tubes of equal length. The extremities with the nipples are curved so as to penetrate easily into the ear channel. The two nipples are of different colors; the black one should be placed in the right ear; the other, which is white, should be placed in the left ear. It is important not to invert them, for the transmission of sound would then become poor. One should also let the spring alone press the nipples into the ears. This pressure should be gentle, and it can readily be proved that by pressing the nipples against the ears with the hands the unserviceable sounds developed in the interior of the instrument are increased, the listener is fatigued. and there is no gain in intensity of sound perception.

Important recommendation.—It is essential that the two rubber tubes of the same earpiece should have the same length. A variation of the length of one of these tubes would involve the displacement of the zero. If any reason (as for instance the wearing out of the rubber) leads to the shortening of one of the tubes the other must be shortened an equal amount.

FOREIGN NOISES DEVELOPED IN THE INTERIOR OF THE INSTRUMENT.

The greatest importance is attached to the preservation of the purity of the sound.

Unless precautions are taken the receivers and tubes transmit to the ears, under the influence of the foreign waves, a continuous noise, which obscures the significant sound. This may be called the interior sound of the instrument.

These foreign waves strike the exterior surfaces of the tubes and of the receivers and make them vibrate, producing a noise in the earpieces. On the other hand, a part of these noises penetrate directly or by diffraction into the interior of the tubes or of the horns, and after a series of reflections on their interior surfaces are transmitted to the earpieces. Experiments have

shown that tubes of small diameter vibrate very little. The interior sound in this case seems to be due to the reflections of the foreign waves in the interior of the tubes, the intensity and pitch of these foreign noises varying with the length of the tubes.

NOTE.—*Recent investigations have shown that the foreign noises can be very greatly reduced by introducing into the interior a very light material which would entirely obturate the tube without forming an acoustic stopper.*

For this purpose use is made either of wadding, which has first been rendered very flaky, or simply a cigarette paper stretched across the interior of the tube perpendicularly to the axis.

Experience has taught that the most favorable conditions are realized when the deadening membrane divides the tube into two unequal parts in the ratio of 4/5, the smaller one being next to the receiver.

The foreign noise is then greatly reduced without loss of intensity of audition.

In the most recent types of instruments provision has been made for the introduction of a sound-deadening membrane, based on this principle, into the listening tube. The membrane of paper is stretched in the interior of a copper tube 6 centimeters long and of the same diameter as the listening tube.

The latter is formed of two tubes with lengths in the ratio 4/5. The sound-deadening tube can be inserted between the two parts of the listening tube. By means of screws the three sections are united into a single tube.

If the membrane is to be replaced the sound-deadening tube will be released by removing the screws. The membrane will be changed and the tube replaced in position.

The sound-deadening tube can also be replaced by an ordinary tube of the same diameter and length, which will be delivered for this purpose with the instrument. The officers commanding in the artillery command posts can therefore use the instrument with or without the sound deadener as they prefer.

On the other hand, the receivers, of which the walls present a large surface, vibrate under the influence of the sound waves which strike them on the exterior, and the resulting noise forms the greater part of the foreign noises of the instrument.

Accordingly, the desire to reduce as much as possible the foreign noises has led, on the one hand, to the reduction of the listening tubes to a minimum, on the other to the envelopment

of the exterior surfaces of the receivers with a felt sheath protected in turn from the inclemency of the weather by a rubber cover. This felt sheath suffices to protect the exterior surfaces of the horns from the action of the foreign waves.

The same result has also been produced by adopting receivers of paper paste. This material vibrates very little under the influence of the sound waves. The interior surfaces are varnished with ripelin in such a way that the sound waves are reflected from them in the most advantageous manner.

There are three different types of receivers:

Those of thin wood covered with felt.

Those of iron covered with felt.

Those of paper paste not covered with felt.

Experience will show which should be preferred for future models.

INDEX.

It has already been said that the azimuth circle was graduated in mils and the quadrant for elevation in degrees. The indices of these circles are themselves capable of receiving small displacements and of being clamped by a vise.

The index of the azimuth circle is formed by a circular copper plate applied to the edge of the horizontal plate and capable of moving around the latter. A mark is engraved on the lower border of this copper plate, opposite the graduation in mils of the stationary plate. It serves as index for this graduation. Furthermore, the copper plate bears on its upper border a graduation in mils. The regular displacement of the index is read on this graduation by means of a reference mark engraved on the movable plate.

The index of the elevation quadrant is formed by a mark engraved on a needle which is made fast at the moment of observation, but which can receive small angular displacements read on an auxiliary graduation.

The displacements provided for in the indices of the circles of azimuth and elevation enable the station commander to correct the readings of the error due to the movement of the aircraft during the time consumed by the sound in reaching the listener.

Lighting.—The lighting of the indices is provided by two little electric bulbs, each mounted in front of a reflector. The current for each is furnished by two batteries borne by the movable

plate. A screw placed over each bulb serves as cut-off. The current is closed by tightening the screw in the opposite direction. Two extra bulbs are delivered with each instrument.

MOUNTING THE APPARATUS.

The apparatus is delivered, dismounted, in six parts:

1. The stand.

2. The movable plate and the combination of two receivers for elevation.

3 and 4. The two receivers for the azimuth, mounted on the angle iron, which connects them with the movable plate.

5 and 6. The two earpieces with their rubber tubes.

To mount it, it is only necessary to bolt the pieces of angle iron pertaining to the receivers for azimuth onto the projections of the movable plate, and to place the movable plate on the stand by inserting the vertical axis in the socket of the stand. Each of the two earpieces will then be attached to the corresponding listening tube.

Cover.—A canvas waterproof cover is delivered with each instrument.

Spare parts.—The military telegraph service can supply the following spare parts:

Receivers (specify whether for azimuth or elevation).
Felt sheath for receivers with rubber cover.
Earpieces with rubber.
Elbows of copper tubing (specify diameter).
Bulbs and batteries.

USE OF THE ACOUSTIC GONIOMETER.

EMPLACEMENT OF THE APPARATUS.

The acoustic goniometer ought to be placed in the open, as far as possible, on an elevation. It ought especially to be installed far from any noise. If it is considered necessary to place it in the immediate vicinity of a gun, the station commander ought to insist upon the greatest silence on the part of his men during an investigation.

ORIENTATION AND LEVELING OF THE INSTRUMENT.

The collimator will be kept in aim on a reference point of the horizon situated at an angle of direction known beforehand, and tentative adjustments will be applied to the stand until the index, previously placed opposite the zero graduation of the

movable disk, marks on the graduated disk the azimuth required.

The horizontality of the axis of rotation of the receivers for elevation for two rectangular azimuths must be tested by means of a level. This operation will be greatly simplified by placing the legs of the instrument on ground leveled in advance.

After these operations of adjustment and orientation have been performed once for all, the stand of the instrument will be imbedded in the soil.

PERSONAL EQUATION.

The impression of the passage of the sound from one ear to the other will not necessarily be registered at the same instant by all the observers. The intensity of sound perception is, in fact, for a great many people, greater in one ear than in the other. It will be necessary, therefore, for each observer to determine carefully his own personal equation, by which he will correct once for all his observations by giving a corresponding displacement to the index.

To determine this personal equation, a stationary sound source will be placed on a known point α of the azimuth, and the instrument will be aimed acoustically at this source. If $\alpha+\epsilon$ is read on the azimuthal circle, ϵ is the personal equation of the observer. If the instrument has been improperly oriented, this quantity would be the sum of the error of orientation and of the personal equation of the listener. The readings of both will be corrected at the same time. It is advisable to perform these operations on a windless day.

INSTRUCTION OF THE LISTENERS.

The determination of the position of aircraft by the acoustic goniometer is much more difficult than that of stationary sources of sound. Listeners can not succeed in making accurate measurements before they have completed a course of graduated exercises to familiarize themselves with the instrument and the methods of observation.

They must be trained at the same time to determine the position of a sound source with the ear unaided and with the instrument. It is more difficult to perform the determination without the instrument, and those who can do it will surely be very good observers with the goniometer.

The best exercise without the instrument seems to be the following:

The observer, with eyes bandaged, assumes the position of "attention." Two assistants take positions in front of him. By moving his entire body in accordance with the indications of the sound the observer seeks a position directly opposite one of the two assistants, who remains motionless and cries, "Hep, hep, hep," until the observer makes a sign for him to cease. In connection with this proceeding the observer moves his head to and fro in order to make sure that in the position of his body he receives the impression of the passage of sound from one ear to the other directly in front. If this situation has not been realized, he alters his position and repeats the same experiment.

When this experiment has been completed the first assistant, without moving, cries, "Hep." The other assistant replies, "Hep." The observer determines whether the second is on the right or left of the first and makes a sign with his hand whether he should move to the left or right. The movements of the second assistant should always be short (a single pace, for instance).

The assistants will then cry "Hep" alternately, and the observer will make a second determination of his direction, and the same operation will be repeated in succession.

When he judges that the two assistants are both directly in front of him, the observer takes the bandage from his eyes. If his judgment has been correct he should find the two assistants in the same direction.

For the successful performance of this experiment the first assistant should remain motionless during the entire operation. The observer should also remain motionless, so as always to face the first assistant. For this reason he must remain during the entire exercise in the position of "attention."

Reference should be made to the notice on "The Perception of Aerial Sounds by Means of the Methods Devised by the Military Telegraph Service for the Instruction of Listeners."

The instruction of the goniometer observers should be carried out in three stages:

1. *On a fixed terrestrial sound source* (klaxon, drum, rattle, etc.).—The instructor will verify the exactitude of the aimings made by the observer with the collimator mounted on the instrument.

2. *On a movable terrestrial sound source.*—The sound source will be shifted to and fro in front of the observer, and he must undertake to follow it acoustically by means of the instrument in accordance with the rules concerning the observation of aircraft which are given later (page 20).

3. *On aircraft.*—The following exercise relative to the observation of a movable sound source deserves being especially recommended:

The assistant carrying the sound source moves across the field some distance in front of the goniometer. The observer follows him acoustically with this instrument.

The instructor selects a certain number of reference points on the terrain, and whenever the sound source passes in front of one of them he cries "top." An assistant reads the circle at the moment of the signal. Every time the sound source passes a same reference point the reading made should be the same.

The instructor can thus judge of the precision of the aimings and of the progress of the observers.

Very good observers should be able to keep the margin of error down to about 10 mils.

As regards the instruction of the observers on the goniometer the note relative to the development of the sound observers for the antiaircraft posts included in the present note (extract from the Provisional Instruction on the Use of Projectors, p. 46) can be read with profit.

The observers should be trained every day systematically, either to follow the aircraft when they fly over the post, or to follow movable terrestrial noises by means of acoustic goniometers.

Furthermore, they should practice daily the exercises in determining position by sound without the aid of instruments.

This daily practice is absolutely indispensable. The officers commanding the posts must regard it as an important part of the maneuver.

If they should allow it to lapse, the observers would quickly lose the efficiency acquired.

ANGLE OF SENSATION.

If the observer moves the instrument very slightly from the direction in which he has the feeling of the passage of the sound, he has the sensation that the source of sound moves from right to left or from left to right very quickly.

At a certain point he will have the sensation that it passes completely to his right or to his left. The angular deflection required to produce this sensation is extremely small (a few degrees) ; let α represent this angle.

As long as the observer moves the instrument to right or left of the direction of the sound source to an extent less than the angle α he has the sensation that the source moves, but if he turns it to an extent greater than the angle α he retains the impression of hearing the sound at his right or left, as the case may be, but he no longer has the feeling that the sound source moves.

For this reason the angle α has been called the angle of sensation.

This angle seems to be determined by the condition that when the observer begins to have the impression of hearing the sound absolutely on his right or left, the difference of the courses traversed by the same sound wave to reach one ear or the other is equal to the distance of the two ears.

The angle of sensation is therefore inversely proportional to the distance of the two receivers (base) and for this reason the precision of the aimings is proportional to the base.

But the oscillations which the observer applies to the instrument should be smaller the larger the base. If he revolves the instrument to right or left of the direction of the sound source to an extent exceeding the angle greater than α he will no longer have the sensation that the source moves. He must then use his reason to find again the direction of the source of the sound. He will advance the receiver on the right or the receiver on the left, according as he hears the sound on the left or right.

This explains why beginners sometimes cease suddenly to follow acoustically the source and subsequently have great difficulty in replacing their instrument in the proper direction. For this reason also they generally find it easier to follow the source with an instrument with short base than with one of long base. Proficient observers will readily acquire the ability of keeping the range of the oscillations applied to the instrument within the limit of the angle α on one side or the other of the direction of passage.

These observations should suffice to show the great importance of maintaining the regular and systematic training of the observers without interruption.

By reason of the existence of the angle of sensation, skilled observers will succeed in getting their directions in spite of the simultaneous presence of several aircraft above the post. An aeroplane at which a goniometer is aimed ought to be in a direction within the angle of sensation, and consequently the observer will have the impression that the aeroplane is moving. The case will be different with the other aeroplanes.

Proficient observers will not be disturbed by noises perceived directly by the ears. In fact it will be sufficient for them to fix their attention on the movement of the sound from right to left or from left to right, and only the sound perceived through the receivers will give him this sensation.

OBSERVATION OF AIRCRAFT.

The determination of the direction of a sound of a motor will be performed by the two listeners operating together, each with one of the earpieces in his ear.

They will determine uninterruptedly, one the azimuth of the aircraft, the other its elevation. The first will take a position for this purpose behind the instrument, opposite the line joining the two receivers for the azimuth. He will hold in the left hand the horizontal arm and with the right hand the vertical upright on the same side, and he will manipulate them in such a way as to give the combination of the two receivers the suitable angular displacements.

NOTE.—*The terms "right" and "left" are here applied to the receivers according as they are connected with the right or left ear, respectively.*

An assistant stationed at his right will read the azimuth and will give to the index the deflections corresponding to the velocity of the sound. The observer for elevation will take position facing the plane of the rotation of the elevation receivers, either behind the apparatus, on the right of his comrades, or in front of the instrument on their left. (In the latter case he will stand between the left azimuth receiver and the elevation receivers.) He will give the elevation receivers the displacements required by moving the steel tubes which join them.

An assistant placed in front of the instrument between the right azimuth receiver and the elevation receivers will read the

elevation angles and give the index the displacements corresponding to the velocity of the sound.

To follow an aircraft, each of the two observers will proceed by bracketing. They will move the appliance slightly back and forth to right and left of the position sought so as to hear the noise of the motor pass successively from one ear to the other.

The direction and elevation of the aircraft, as has been seen, can only be accurately determined if the instrument is made to oscillate within the limit of the angle of sensation. The aim must be, therefore, to bracket the aircraft within an angular range of oscillation of very small extent.

During the course of a single oscillation the aircraft moves on its trajectory. If the goniometer is aimed a little in front of the aeroplane and then maintained in an immovable position the impression of the passage of sound from one ear to the other, as from the right to the left, will be produced in consequence of the continuous movement of the aeroplane. After the passage of the aeroplane it will only be necessary to turn the goniometer slightly to have the impression of the passage in the opposite direction (from left to right). If immediately after the passage the instrument is left immovable, the impression of the passage of the sound from the right ear to the left will be produced by the movement of the aeroplane, and so on in succession. In this manner the operator will succeed in obtaining extremely short brackets, and the movement of the goniometer will be practically almost continuous.

These considerations lead to the adoption of the following rules for the observations:

When an aeroplane has been reported the azimuth observer immediately turns completely toward the sound heard, moves his head two or three times to right and left to be sure that he has the sensation of the passage of the sound at approximately the position where the line of his ears is parallel with that of his shoulders. If the case is otherwise he will modify his position.

Then he gives the goniometer an approximate orientation in which the horizontal rod supporting the azimuth receivers will be parallel with the line of his shoulders.

Then he inserts the earpieces in his ears.

It is indispensable that the above-mentioned operations be performed very rapidly. Their purpose is to give the instrument a general orientation in the aiming direction.

For the observer of elevation this preliminary investigation of the target without the use of an instrument is impossible, as has been said on page 41. But this is not a serious impediment, since the angle of elevation of an aeroplane is generally slight (included between 10 and 30 degrees) when it is first heard.

The observer of elevation will therefore place the earpiece in his ears at the same time as his companion.

He must be sure that the listening tube connected with the upper receiver is always attached to the right ear and the listening tube connected with the lower receiver to the left ear. It is indispensable that the observer should always conform with this rule. In these conditions, when he hears the sound on the right, he will advance the lower receiver. When he hears it on the left, he will advance the upper receiver. This operation should be performed automatically. It is clear that if the observer should invert the listening tubes the sensations of right and left would be inverted, and since he would not be accustomed to operate in this manner, he would follow the source of the sound with much less accuracy.

The method of observation will therefore be the same for both observers.

If the observer hears the sound on his right or his left, he will turn the instrument by advancing, in the first case, the receiver on the left (or lower receiver); in the second case, the receiver on the right (or upper receiver), so as to make the sound pass from one ear to the other.

He will then restore the goniometer as nearly as possible to the direction in which he has noticed the passage of the sound, and he will keep it stationary in this direction for a short time.

Four situations are possible:

First situation.—In consequence of the movement of the aircraft, the observer will have the impression that the sound passes to his right.

He will accordingly turn the instrument a little by moving forward the receiver on the left (lower receiver). He will then have the impression of the passage of the sound to left. He will keep the instrument motionless until he has heard the sound on his left. In consequence of the movement of the aircraft, the sound will then pass to his right. As soon as he has received the impression of the passage of the sound he will turn the instrument a little in the same direction as before, and proceed by a succession of the same operations.

He will continue, therefore, by this method of progressive bracketing by making the instrument turn intermittently and always in the same direction, as has been stated above.[1]

Second situation.—The observer has the impression that the sound passes to his left.

This is the opposite of the preceding. It is only necessary to reverse the terms right and left in the preceding directions.

Third situation.—The orientation angle of the aircraft is zero. The azimuth is constant.

If the observer for azimuth has oriented the instrument in the direction in which he has the exact impression of passage, and if he keeps it motionless in this position the sound will pass neither to right nor to left.

He will have the impression of always hearing it in front of him. He should then produce the impression of passage by giving the instrument slight oscillations on both sides of the neutral direction (oscillations less than the angle of sensation).

He will make the instrument oscillate as long as the azimuth of the aircraft remains constant.

If the angle of orientation of the aircraft changes he will have the feeling that the sound becomes more distant on the right or the left. He will then follow the aeroplane by bracketing as explained above (first and second situations).

Fourth situation.—The orientation angle of the aircraft is 90 degrees. In this situation the elevation of the aeroplane is constant.

This situation leads back to the preceding. The observer for elevation will proceed as has been explained for the observer of azimuth in the preceding situation.

It may happen that the variations of the coordinates of the aircraft change direction suddenly during the observation.

For instance, the observer having heard the sound on the right turns the instrument a little, so as to make the sound pass to the left. Then he keeps the instrument motionless. The sound does not pass to the right. If the angle at which the instrument has been turned is clearly less than the sensation angle, the observer will have the feeling that the sound source does not

[1] This manner of observation is entirely successful with the acoustic goniometer and insures a high degree of precision in the aimings. It should be remarked that the fact that the aircraft can be followed almost continuously in the two coordinates is largely due to the very great independence of the receivers of elevation and direction attained in this instrument.

move, then that it recedes. If the instrument has been turned at an angle greater than the sensation angle, he will await in vain for the sound to pass to the right. Furthermore, if after a few seconds he does not have the impression of the passage it is to be inferred that the aeroplane has changed its course. To verify this conjecture, the observer will make the instrument oscillate a few degrees so as to give him the impression of the passage and the indication of the position of the aeroplane and on the direction of its displacement. He will then follow it as has been said before.

ORIENTATION OF SEARCHLIGHTS.

The listening instrument is kept acoustically fixed on the target. An attendant follows the line of sight[1] so as to estimate the deviation of this line from the direction of the rays; he orders "higher," "lower," "to left," "to right," so as to reduce this deviation to its theoretical value. (The rays ought to be bracketed in advance of the position indicated by the listening instrument to a distance varying from 100 down to 50 mils, according to the speed and transversal movement of the target.)[2]

Thus he explores a surface of several square degrees in case the target is not immediately found.[3]

ACOUSTIC GONIOMETER FOR THE AZIMUTH (MODEL B).

The Military Telegraph Service has also undertaken the construction of instruments based on the same principle, but recording only the azimuth of the aircraft. These instruments are especially intended to be used in the lateral observation stations for antiaircraft fire.

They differ slightly from the preceding in construction. The distance between the two receivers is two meters.

NOTE.—*In the instruments with factory number higher than 18 the receivers will be of the twin type described in connection with the acoustic goniometer, type I, model E* *(p. 26)*.

[1] This line is determined by the axis of the collimator.

[2] An aiming wheel mounted in accordance with the principles set forth in the Instruction on Anti-Aircraft Fire on the axis of sight enables the observer to make an exact estimation of the value of this deviation.

[3] The preceding is an extract from the Provisional Instruction on the Use of Searchlights in the Search for Aerial Targets, published by the Practical School for Anti-Aircraft Fire at Arnouville.

Furthermore, in these instruments the distance separating the two receivers will be increased to 2.50 meters. Finally, sections of tubing for deadening foreign sounds like those described on page 13 of the present note will be inserted in the listening tubes.

The two arms which hold these receivers are of angle iron and are maintained in a horizontal position by two iron braces, which connect the base of the receivers with the extremity of a vertical cylindrical tube forming a single piece with the movable horizontal plate. Through this cylindrical tube passes the stationary vertical axis which forms a single piece with the stand. The rotary motion is effected on ball bearings.

As this instrument is much lighter than the preceding, it has been possible to design the stand as a vertical iron column terminating below in four horizontal iron branches with angles of 90 degrees between them.

The movable portion of the instrument supporting the receivers has a socket at its center into which the axis of rotation is inserted. This forms a single piece with the horizontal graduated circle and can be bolted onto the standard. This locks the axis and the circle on the standard.

ORIENTATION OF THE INSTRUMENT.

To orient the instrument the bolt will be slowly unscrewed. The instrument will be aimed at a known azimuthal reference sound. The circle will then be turned on the vertical axis until the graduation indicated by the index corresponds to this azimuth. The orientation will be completed by the displacement of the idex.

PERSONAL EQUATION.

Corrections for the personal equation will be applied to the readings by adjustment on the index.

Provision has been made for a possible displacement of 50 mils on the index for the correction for orientation and for personal equation.[1]

On the other hand, no provision has been made for a displacement of the index for a correction relative to the velocity

[1] In all instruments with a factory number higher than 18, provision has been made for a possible displacement of 500 mils on both sides of the mean position, which enables the observers to apply the corrections for the velocity of the sound to all their readings.

of the sound. These instruments should therefore be operated as provided for in the Maneuver Regulations for Building Platforms, Model 1915. (Regulations of Jan. 28, 1917, par. 71.)

Lighting.—The lighting of the index is effected by a little electric bulb of the same type as those used for the acoustic goniometer—Model A. The current is likewise furnished by two batteries inclosed in a wooden case borne by the movable plate.

Case.—A case is delivered with each instrument. It includes an envelope for each of the receivers and also an envelope for the central part (axis and circle). It is important to keep the instrument covered when not in use, in order especially to avoid the clogging of the ball bearings by dust.

MOUNTING.

The instrument is delivered dismounted in three parts:

1. The stand.
2. The movable appliance mounted on the rotation axis and the two receivers.
3. The earpiece mounted on rubber tubes.

To mount it the appliance must be clasped onto the stand and the receivers must be attached to the two extremities of the movable horizontal arm. As in the case of the goniometer, Model A, the stand should be set firmly in the ground as soon as the instrument has been oriented.

Spare parts.—The Military Telegraph Service can deliver the following spare parts:

1. Receivers (indicate whether for the instrument Model B).
2. Felt sheaths for the receivers with waterproof covers.
3. Earpieces with rubber tubes.
4. Elbows of copper tubing (indicate in this case, also, whether intended for the instrument Model B, and indicate diameter of the tube).
5. Bulbs and batteries.

OBSERVATION OF AIRCRAFT.

The apparatus is intended for use in the lateral posts for acoustic telemetry on a wide basis. The observer will follow the aircraft acoustically in a continuous manner in accordance with the rules given for goniometers, Model E. An assistant will make the readings. The same aircraft will be followed acoustically by an instrument at the central station and by the instru-

ments B in the lateral posts. At the same instant as indicated by the call "top" transmitted by telephone to the lateral posts the attendants of the different listening instruments will make readings which they will immediately transmit to the central station.

DIRECT CONNECTION OF THE ACOUSTIC GONIOMETER AND THE SEARCHLIGHT.

Finally, in the antiaircraft stations at Paris they have tried to attach the receivers onto the searchlight itself. The axes of the listening instrument are then the same as those of the projector, and the operation commands are the same for both instruments.

The displacement of the indices is effected by little trombones attached to the listening tubes. The displacement of zero is obtained by the lengthening of one or the other listening tube, effected by drawing out one of the trombones.

Since the experiments were not completed at the time of publishing this note it is impossible to give the details of the results. Nevertheless, it may be said that such an arrangement presents a priori the advantage of eliminating the loss of time in maneuvering.

If the experiments now in progress yield satisfactory results, the Military Telegraph Service will be able to construct receivers furnished with trombones with adjustment pieces and listening tubes intended for different types of projectors used by the Antiaircraft Service.

II. Extract from the Provisional Instruction on the Use of the Searchlights.

[Published by the Practical School for Anti-Aircraft Fire at Arnouville.]

APPENDIX III. TRAINING OF SOUND OBSERVERS.

Extract from the Provisional Instruction on the Use of Searchlights—Annex III: Instruction of the Sound Observers.

A. EAR TRAINING OF THE LISTENERS.

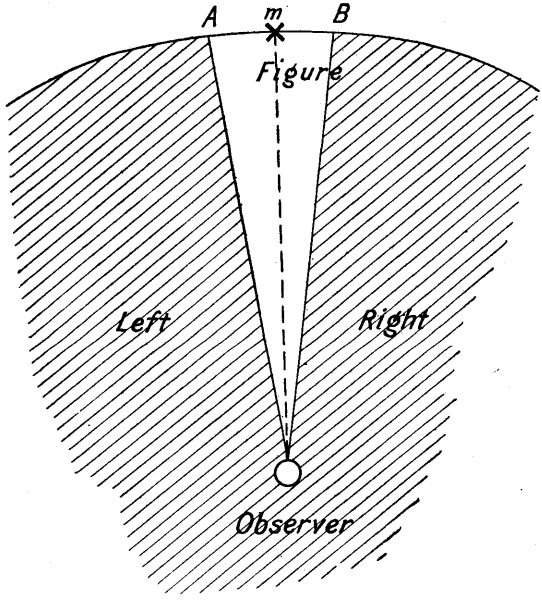
To determine accurately the direction of a sound source, the capacity of observing the passage of the sound from one ear to the other, when the head is turned from one side to the other of the direction sought, is of essential importance. The instruction of listeners consists chiefly in developing this sense of the passage of the sound, the nature of which will be explained immediately.

When an observer hears a noise proceeding clearly from a point on his right or left, he recognizes the side on which it originates without hesitation. But if the source of the sound is only slightly to one side, the sense of direction is not very clear, and a novice will declare that the sound comes from the front and (if he is listening without an instrument) that he is facing its origin. In reality there is an angle A O B, within which the sensation of right and left disappears. The smaller this angle the more accurately will the listener adapt his position to one facing in the direction of the sound. The extreme directions O A and O B may be brought very close together, if the head is carefully turned toward O A and O B alternately, the source of the sound being at M. The comparison of the sensation transmitted along O B following immediately the sensation transmitted along O A makes noticeable the difference between them. The passage of the sound from left to right and from right to left by alternate movement of the head is the phenomenon of the passage of sound from one ear to the other

mentioned above. Its importance consists (1) in exaggerating the sensation of right and left; (2) in bracketing the position sought between two adjacent known limits, bounding the range of possible error.[1]

The following exercise should be performed as often as possible for the training of the personnel:

1. An attendant takes a position about 50 meters from the plotting board and claps his hands or counts in a loud voice continuously; the observer lowers his eyes so as not to see (if



necessary open a newspaper as screen between him and the assistant); he faces exactly the center of the plotting board and moves about this point until he faces the sound. At this moment he orients the alidade in the assumed direction; then

[1] The preceding is an extract from the Provisional Note on the Preliminary Instruction of the Listening Personnel for Aerial Sounds of December, 1916, published by the Military Telegraph Service. The personnel of the searchlights may profitably seek instruction from the study of the methods there set forth.

he turns his eyes toward the assistant and tests the accuracy of his aim.

Perform this exercise preferably in calm weather to avoid the deflection of sound by the wind.

2. Every time an aeroplane passes within the range of sound the observer determines the direction of the sound on the plotting board, taking care not to look at the aeroplane; subsequently he verifies the exactitude of his determination by looking at the target and taking into account that the aim obtained must have been 50–100 mils behind the aeroplane.

B. TRAINING OF THE OBSERVERS OF THE ACOUSTIC GONIOMETERS FOR BINAURICULAR LISTENING.

The instruction should be conducted in five stages:

1. The observer practices in the observation of a distant fixed sound source at a hundred meters (assistant counting in a loud voice, clapping the hands, or sounding a horn).

After each determination of azimuth the assistant moves sidewise and the observer endeavors to indicate the direction of the displacement. The extent of the displacements is diminished progressively. The observer endeavors to reduce the time necessary to orient the instrument.

These experiments bring out the eccentricities in the sense of sound which may be exhibited by the student listeners.

There will thus be an opportunity of eliminating those whose acoustic aimings deviate too conspicuously from the symmetrical plan of the goniometer.

2. The exercises are resumed and the assistant moves continually at the rate of 1 meter per second at a distance of 150 to 200 meters.

The instructor keeps in a position between the assistant and the observer and whistles from time to time.

At this signal the observer ceases moving the acoustic instrument, while the assistant halts immediately and maintains silence; it is then an easy matter to verify the exactitude of the acoustic aim.

3. The observer is trained in following an aeroplane in direction, the elevation being given by an assistant who aims at sight a little behind the target.

The observer must follow the aeroplane by moving from one side to the other of the supposed position so as to maintain the sensation of the passage of the sound from one ear to the other.

This sensation is a far more reliable guide than that of "the aeroplane in front."

4. The observer is trained to follow an aeroplane in elevation, the direction being given by an assistant.

5. Two observers are trained to follow an aeroplane simultaneously, one operating for direction, the other for elevation.

For optical aimings on an aeroplane a sighting instrument with aiming wheel is used, which enables the operators to take account of the movement of the aeroplane during the transmission of the sound. The front sight of this instrument is formed by a peephole 4 millimeters in diameter.

The aiming circle has a radius of 70 millimeters and is placed at a distance of 670 millimeters from the peephole; it is held in a horizontal position by a perpendicular, the right line passing from the center of the peephole to the center of the circle is parallel with the acoustic axis of the instrument.

When the listeners follow accurately the target, an observer who keeps his eye at the peephole ought to see the aeroplane on the aiming circle with the tail toward the center of the circle.

III. Note on the Application of the Acoustic Goniometer to Firing by Sound, and to the Orientation of Searchlights.

[Published by the Practical Training School for Antiaircraft Fire at Arnouville, January, 1917.]

USE OF THE ACOUSTIC GONIOMETER.

The acoustic goniometer serves to determine the direction of the source of a sound.

It is in no wise serviceable for the determination of the nature of this sound. Only the ear unassisted can distinguish the sound of an aeroplane from that of a dirigible. No instrument, whatever its nature may be, ever renders accurately the timbre and intensity of the sound, and the use of any instrument with this in view is liable to create confusion.

The acoustic goniometer can be used either to direct the observations of the searchlight, or to direct the fire by sound on an invisible target, the presence of which has been noticed, without an instrument, by the artillery commander, who alone is responsible for the opening of fire.

(*a*) *To direct the observations of a searchlight.*—This is the normal use on cloudless nights. In this case the target is as a rule an aeroplane, since the approach of dirigibles is improbable on account of their great vulnerability.

The instrument may be attached to the searchlight. This manner of use will be considered in a special note.

When it is mounted on a separate standard it is furnished with graduations both for azimuth and elevation corresponding to similar graduations on the searchlight. The reading is made by means of an index which can be moved a definite space on a scale on which each interval is 10 mils.

The purpose of this deflection is to take into account the displacement of the target during the time T, the sum of the time required by the sound to arrive and of the time θ, which may be estimated as five or six seconds, required for transmitting to the searchlight the indications of the acoustic goniometer. Without this precaution the direction given to the searchlight would be that for a position of the target which it had already left.

It is not necessary to take the wind into account. It influences the indications received by the instrument to exactly the extent required for accounting for its influence on the course of the target (exclusive of the time θ, which is unimportant).

Let δ_h and σ_h be the corrections to be given to the direction and elevation, respectively, v the velocity of the target, h its altitude, A_o and A the positions of the target at the departure of the sound wave and at the instant when the target is to be illuminated, D_o and D the distances of these points from the instrument, S_o and S their angle of elevation, α_o and α the orientation of the instrument at these two points; we have the formulæ:

$$(1)\quad \sin \delta_h = \frac{vT}{D_o \cos \delta_o} \sin \alpha$$

$$(2)\quad \sin \sigma_h = \frac{vT}{D_o} \sin \delta \frac{\cos \frac{\alpha + \alpha_o}{2}}{\cos \frac{\alpha - \alpha_o}{2}}$$

The principal difficulty in the application of these formulæ arises from the fact that α and α_o are unknown. Enlightenment may be sought by comparing the rapidity of variation of the direction and elevation, but it is hardly possible in the present state of the instruments to use them as "acoustic goniometers for orientation" like optical telescopes. It need only be said that well-trained operators can quickly attain a degree of certainty in respect to the direction of variation of the azimuth and elevation.

This being the case, one should not attempt to derive precise rules from the formulæ (1) and (2), but only approximate ones, which are sufficient, however, in view of the usual dispersion of the searchlight rays.

PRACTICAL RULES.

The two aimers follow the sound source, and as soon as they are in a position to do this with accuracy they give their indications concerning the direction of movement with the expressions "to right," "to left," "stationary" for the observer of direction, and "higher," "lower," "stationary" for the observer of elevation.

Two assistants then move the two indices in the direction of the movement indicated and for distances of which the maxima

correspond to the orientations 0 for σ_h and $\pm 90°$ for δ_h and are given by the following table:

Elevation.	δ_h.	σ_h.
0—30°	15	5
30—50°	20	10
50—70°	30	15

They move one of the indices the maximum indicated in the table, if the indication "stationary" which has been given by the aimer has caused him not to move the other; in the contrary case the movement is reduced by a third.

Then they read the azimuth and the elevation and report them to the searchlight.

If the aircraft is not overtaken by the rays of the searchlight, the aimers continue to follow it with the acoustic goniometer. One of the assistants accustomed to account for the deflection which exists for the direction of the movement of the target, which has been reported to him, between the direction given by sight and the direction given by sound, surveys the line of sight determined by the telescope and directs the movements of the searchlight by the orders "right," "left," "higher," "lower." The operation can also be undertaken by orienting the searchlight by sound without the goniometer and only using the goniometer to direct the movements, as just described, after the searchlight has once been turned on.

FIRE BY SOUND.

PRELIMINARY REMARKS.

I. The firing of a round when the listeners are engaged with the acoustic telescope would deafen, if not wound them, and would render them incapable of continuing their service.

To avoid this misfortune, it is indispensable that periods of firing be broken up by listening intervals. During the alternate intervals of fire in this combination the personnel attached to the service of the goniometer remove the appliances from their ears, while during each listening period they seek to gain data of importance for the next firing period.

II. It is necessary for firing to account for the displacement of the target during the time T, including—

1. The time required for the sound to reach the instrument.
2. The time consumed in manipulations from starting operations with the instrument to the firing of the round.
3. Half of the period of fire.
4. The time of flight of the projectile.

Thus it is possible to obtain corrections much superior to those expected in operating with the first method.

III. In view of the errors likely to be committed, it is necessary to distribute the fire of each period over an extensive zone so as to be sure of delivering some rounds near the target which will at least produce, failing any material effects, a certain moral effect.

When tracers are used, shell fire is dangerous over a wide extent. It is only necessary, therefore, for battering an extensive zone in all directions to vary the direction and inclination of the gun.

These remarks throw light on the paragraphs 29 and 71 of the Service Rules for Platforms, Model 1915, which deal with firing by sound.

The goniometer, as considered in these service rules, is without index capable of deflection for taking account of the corrections for azimuth and elevation. But with goniometers furnished with such indices the operations there regarded as incumbent upon the commander of fire and the reader of the telemeter for altitude will be very readily performed by the assistant employed in connection with the goniometer.

Since the correction for elevation is no longer reckoned in degrees, the table in paragraph 71 should be replaced by the following:

Distances.....	3,000 meters.	5,000 meters.	7,000 meters.
Orientation.			
Coming.....	25	20	35
Transversal movement.	0	10	25
Departing.....	25	0	20

EXTRACTS FROM THE SERVICE RULES.

Paragraph 29. Firing by sound.—When the target is not visible it may be advisable to fire by sound.

The direction and inclination of the gun are then given by the commander of fire and transmitted to the piece in terms of the graduations discussed in paragraph 26. The direction is given by the aimer for direction on instructions of the chief of section who has his eye on the suitable graduation.

The inclination is given in the same way by the aimer for elevation on instructions from the assistant for elevation. Regulators for the deflection allowance are not necessary.

The commands are given for six shots in the form "azimuth 52, inclination 40; increase by three points," for example. The indication of direction (azimuth 52) applies to the six rounds. The indication of inclination (40) applies to the first round. The indication "increase by three points" means that after each round the aimer ought to turn the winch control wheel three points in the direction which increases the inclination of the gun.

The fuze setter gives the distance as mentioned in paragraph 26. This distance is indicated by the commander of fire.

Paragraph 71. Firing by sound.—When the sound shows clearly the proximity of an invisible target there is an occasion for firing by sound.[1]

The rules for firing against dirigibles and aeroplanes are fundamentally different.

(A) DIRIGIBLE.

If tracers are available, in view of the large dimensions of the target and the effectiveness of the projectile, the chance of obtaining definite results is by no means inconsiderable. In consequence, moreover, of the importance of the destruction of such a target, the position commanders must not hesitate to open fire even in unfavorable conditions, and to fire, if the target remains long within effective range, as many projectiles as would be used against a visible aeroplane.

To reduce as much as possible the element of chance, the following rules should be followed:

1. Try to determine approximately the direction and, if possible, the elevation of the target by means of the acoustic instruments (interference or binauricular instruments; the latter are more effective for following the movement of the aircraft). It is requisite with any instrument for obtaining good results that there should not be too much noise in the vicinity, and that the operator should be carefully trained. Experiments made

[1] The commander of the post should base his order to fire solely on the observation of sounds heard without the instrument. The acoustic instruments here discussed render reliable data for the direction but do not accurately transmit the nature of the sound, for they are liable to modify the timbre and the intensity.

When the commander of a post is thus sure of the presence of an aerial target, and knows that it is an aeroplane or dirigible, he takes into account, in making his decision, the information available in regard to the approach of friendly aircraft and the special orders which he has received.

by day with the eyes of the observer bandaged will serve to indicate the degree of precision obtained; remember that the direction revealed by the sound is behind the direction as given by sight.

2. While following the target at an interval of about 10 seconds, notice the direction of the sound movement (whether coming or going, to right or left).

In accordance with the indication made by the observer and the azimuth read on the acoustic apparatus, the commander of fire gives the azimuth for the first six rounds of each piece by the application of the following rule:

To take into account the displacement of the target during the transmission of the sound and the time consumed in manipulations (reckon to the mean point of fire) and the time of flight, he makes in the suitable direction the following corrections in the azimuth as read on the instrument:

25, if the observer reports a transversal displacement with the distance apparently remaining constant.

15, if the observer reports a transversal displacement and a variation of elevation at the same time.

(With these figures the supposition is that the azimuths are graduated from 0 to 640, each interval having consequently a value of 10 mils.)

They are applicable only for small elevations and must be increased by half for elevations of 15–20 and doubled for elevations of 60.

In the case of two-piece positions the first piece increases the indicated azimuthal deflection angle by 5, the second diminishes it by 5 (substitute 10 for 5 if experience has shown that great accuracy can not be expected from the instrument or the observer).

3. As a rule the commander of fire gives as distance—

3,000, if the dirigible flies almost over the post (elevation indicated by the instrument greater than 45 degrees).

5,000, if the sound produces the impression that the target is near without flying over the post (the elevation in this case must be included between 25 and 50 degrees).

7,000, if the impression is of a distant target, but one heard without instrument (elevation between 15 and 30).

Do not forget that the indications derived from the elevation depend on the altitude, and that this will usually be less for a dirigible approaching than for one departing when relieved of

the weight of the explosives which it carried (altitude probably 2,000 to 2,500 for the approaching target, 2,500 to 3,500 for the departing target).

Every possible effort will be made to determine accurately the position of the target on the basis of the information furnished by the distant observer. Whether or not he has an acoustic instrument, ask him for the approximate azimuth of the target and deduce the distance with the help of the telemetric apparatus.[1]

If the dirigible is clearly in the direction of the observation station deduce the azimuthal angle of deflection received only in case the aircraft flies over the observation station or if the dirigible appears to the observer on the side of the command post or on the opposite side.

In any case give the distances in multiples of 1,000 meters, for, in view of the nature of the projectile, it is not necessary to seek greater precision, which, moreover, would be illusory.

4. The inclination of the gun is transmitted to the pieces in the form " so many degrees," " increase by intervals of 3." [2]

The command is given by the noncommissioned officer who is the normal reader of the telemeter for altitude; he obtains the number of degrees by adding to the elevation indicated by the acoustic instrument the quantity given by the following table:

Distances.....	3,000 meters.	5,000 meters.	7,000 meters.
Orientation.			
Coming.....	15	10	20
Transversal flight.....	0	5	15
Departing.....	15	0	10

[1] The idea is to obtain a rough indication. Consequently it is not necessary to take into account the fact that the time required for the sound to reach the observation station and the command post is not the same.

It is possible, after a first operation of this sort, to estimate whether the target is nearer the command post or the observation station. If, for instance, the target is thought to be two kilometers nearer the observation station than the command post, give two " tops " separated by six seconds; at the first read the azimuth at the observation station and give no attention to the command post until the second " top."

[2] See paragraph 28; revise this paragraph by substituting " six rounds " for " four rounds " and " increase by intervals of 3 " for " increase by intervals of 2."

5. When the firing data are transmitted to the pieces the commander of fire gives, by whistle, the signal for opening fire. At this signal, or even at the moment when he gives the expected directions, the observer at the acoustic instrument removes the connection from his ears (he would otherwise be deafened or even injured by the detonation), and the fire begins.

At the termination of fire the commander gives the order "cease firing" by two short blasts of the whistle. No round should be fired after this signal under any pretext; the projectiles with fuzes set, which in consequence of the accidents of fire have not been fired, are preserved for the subsequent period of fire (it not being necessary to set the fuzes with great accuracy, they will be suitable for subsequent fire).

At the command the observer resumes observations as for the first fire. The comparison of the azimuths and of the elevations obtained with those of the first fire furnishes a test for the accuracy of his estimation of the direction of the movement of the target. A second period of firing follows in the same conditions as the first, and so on successively.

REMARK I.—The dirigible protects itself against this sort of fire by stopping the motors, reducing ballast, and mounting rapidly. Therefore, if the sound of a dirigible, after being clearly heard, stops suddenly, it may be assumed that it has stopped its motors and is somewhat in front of and considerably above the last position reported (at most, 5,000 meters above). Firing can be tried again, nearly in the same direction as before and with an inclination of the gun increased by 5 degrees. After this fire no further fire is undertaken unless the target has been heard again.

REMARK II.—The preceding method, which has not yet received the sanction of experience, is given tentatively and subject to modification. Especially, in view of the necessity of setting off an interval of pause between two firing periods, and for increasing the mean velocity of fire, it may be found advisable to allot eight rounds per piece to the periods of fire and mount by intervals of two.

(B) AEROPLANES.

In view of the effectiveness of fire by day against aeroplanes, the practical effectiveness of fire by sound is inconsiderable. But a moral effect may be expected.

APPENDIX TO THE NOTE ON THE ACOUSTIC GONIOMETER.

MILITARY TELEGRAPH, TYPE I.

INFLUENCE OF AN ERROR OF LEVEL ON MEASUREMENTS MADE WITH THE ACOUSTIC GONIOMETER.

If the goniometer is incorrectly leveled, its axis is not precisely vertical. Let n represent the angle which it makes with the vertical. Let α and s be the true azimuth and elevation of the aircraft, α_1 and s_1 the azimuth and elevation read on the instrument (it is assumed for simplicity that the origin of the azimuths is the vertical plane containing the axis of the goniometer).

1. INFLUENCE ON THE AZIMUTH.

It can readily be shown that—

$$\delta g(\alpha_1-\alpha)=-\frac{n\delta gs\sin\alpha}{1+ntgs\cos\alpha}$$

or approximately, n being small,

$$\delta g(\alpha_1-\alpha)=-ntgs\sin\alpha$$

Therefore for $\alpha=0$ the error of level is without influence on the azimuth. For the same elevation it has a maximum effect when $\alpha=\frac{\pi}{2}$. Furthermore, the error committed increases in proportion to the approximation of the elevation to $\frac{\pi}{2}$. For $s=\frac{\pi}{2}$ we have: $\alpha-\alpha_1=\frac{\pi}{2}$.

The following table gives in mils the values of α, α_1 varying with the elevation for $\alpha=\frac{\pi}{2}$ and for $n=\frac{4}{1000}$ (which corresponds in the goniometer of 2.50 meters base to a difference of level of 1 centimeter in the azimuth receivers).

s	0	30	45	60	70	80	88	90
$\alpha-\alpha_1$	0	2^m	4^m	7^m	11^m	22^m	118^m	1600^m

2. INFLUENCE ON THE ELEVATION.

Furthermore, it is easily shown that $S_1—S$ is at its maximum when α is zero; that is, when the source is in the vertical plane of the axis of the instrument.

We then have, whatever S may be, $S_1—S=\eta$.

In the preceding case, $S_1—S=\mu$.

Conclusion.—The error committed is clearly greater for direction than for elevation, but it should never be regarded as negligible.

It is therefore essential that the instrument should be leveled with care, and, furthermore, that it should be sufficiently stable that no displacement of the ensemble of the receivers should be possible during the course of the observations. The acoustic goniometers of the military telegraph have been designed with this requirement in view.

ON THE PRECISION OF THE OBSERVATIONS FOR VARIABLE ELEVATIONS.

An observer not otherwise informed has the impression that the position of an aircraft is less accurately determined acoustically by the goniometer when the elevation increases. This, however, is not the case.

1. OBSERVATIONS FOR AZIMUTH.

Let Δa_0 and Δa_s be the errors that may be committed in respect to the azimuth of an aircraft of elevation zero, and on that of an aircraft of elevation s, situated at equal distance from the observation station.

It is shown that $\Delta a_s=\frac{\Delta a_0}{\cos\sigma}$.

The error of angle committed depends therefore on the elevation. But it is easy to see that these angles Δa_0 and Δa_s correspond to equal linear displacements of the airship. For the same distance from the observer the error committed in the position of an aircraft in space is therefore numerically the same, whatever its elevation may be.

2. OBSERVATIONS OF ELEVATION.

With the two horns for elevation constantly moving in the azimuth of the aircraft, the angular precision of the aimings does

not vary with the elevation. At an equal distance the position of the aircraft is determined with a precision independent of the elevation.

In fact, when an aircraft passes near the zenith the necessity of giving the instrument large angular displacements to follow it is an embarrassment, but by always keeping the acoustic axis of the instrument within the angle of sensation the observer will be almost certain of not losing it, since he will be constantly aware of the direction of the sound displacement. The angle



Acoustic goniometer, military telegraph, type 1, Model A.

of sensation will be extremely large near the zenith, and this will make the operation very easy.

ON THE ADVANTAGE OF THE INTERPOSITION OF A SCREEN BETWEEN THE RECEIVERS.

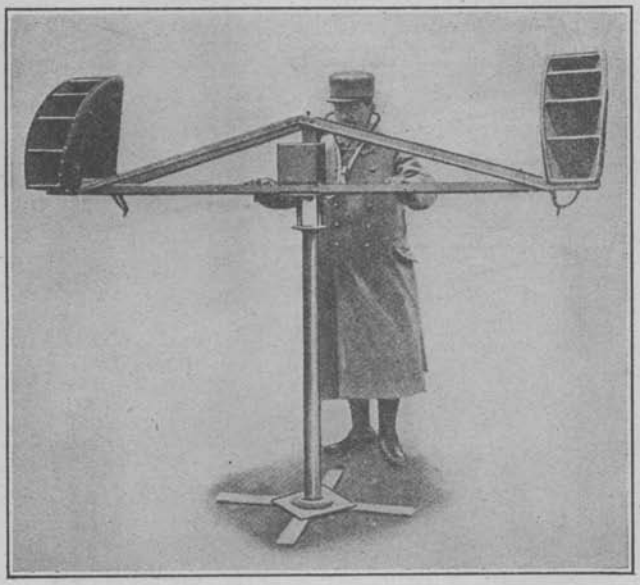
Experience shows that if a screen is interposed between the two receivers the acoustic aimings are greatly facilitated.

This can as yet be only partially explained. It will be observed that a very effective screen is interposed between the human

ears, the head (cheeks, nose, etc.), which is a very real factor in listening without an instrument. The idea of placing a screen between the two receivers of the instrument would naturally suggest itself therefore.

APPLICATION TO THE AZIMUTH RECEIVERS.

The shield consists of two penthouses in the form of a quarter circle with a radius of 1 meter set up in a position to cover



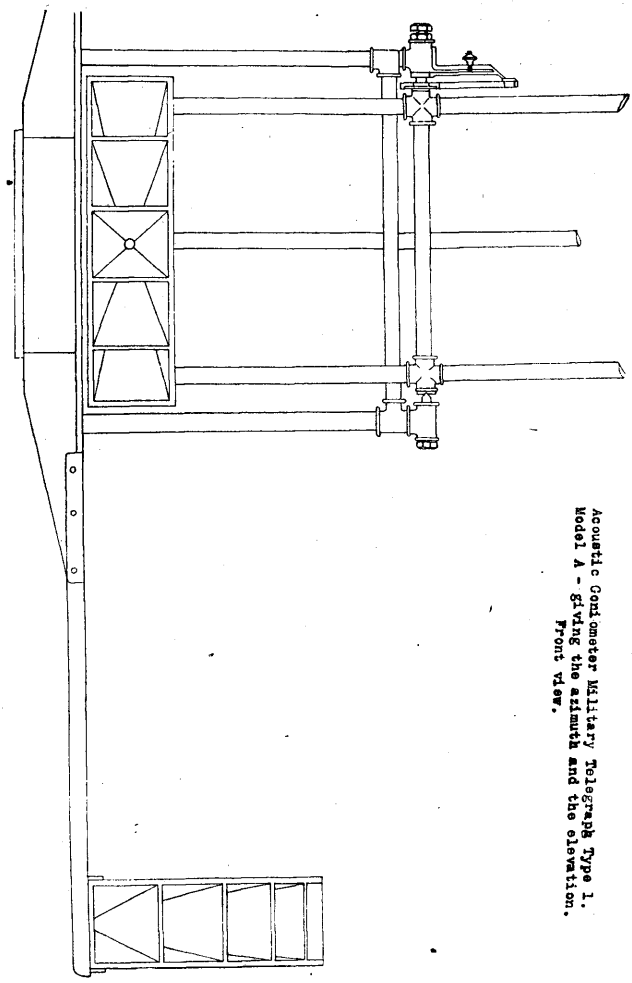
Acoustic goniometer, military telegraph, type 1, Model B.

each of the receivers, respectively, and parallel to the diametral plane of the latter, as shown in figure 1.

APPLICATION TO THE RECEIVERS FOR ELEVATION.

The arrangement is the same, except that the two penthouses forming the screens are cut off in such a way as not to impede the movement of the receivers about the horizontal axis (fig. 2).

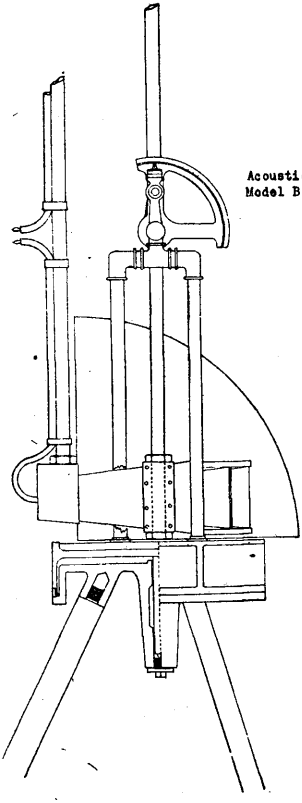
This arrangement will have a particularly important application in the goniometers of type 1*a* with factory numbers less than 30.



Acoustic Goniometer Military Telegraph Type 1. Model A - giving the azimuth and the elevation. Front view.

In these instruments the space separating the receivers is only 1 meter, and experience shows that observers experience greater difficulty in this case in following the sound source correctly

than in azimuth. The insertion of the screens seems to make the feeling of right and left clearer, so that the observer will more readily follow the course of the aircraft, and will thus more surely obtain good aimings.



Acoustic Goniometer Military Telegraph Type 1. Model B - giving the azimuth and the elevation. Side view.

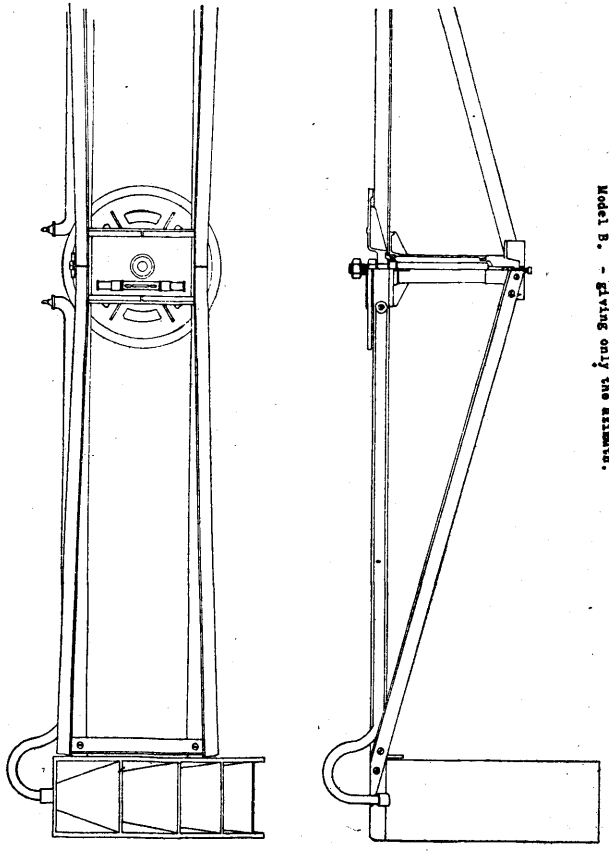
Vue de profil.

It is even possible that the precision of the aimings will be increased, but the experiments thus far made are not sufficient for a categorical statement to this effect.

NOTE ON THE DETERMINATION OF THE DIRECTION OF AN AIRCRAFT BY SOUND WITHOUT THE AID OF INSTRUMENTS.

It was stated in the remark on page 8 that the binauricular method of listening, while enabling the observer to obtain an

orientation of a sound source in azimuth without the use of instruments, can not be used for elevation, since the two ears move only in a horizontal plane.



Acoustic Goniometer Military Telegraph Type K. Model B. - giving only the azimuth.

Strictly speaking this is not exactly the case. For it appears in practice that the sensation of the direction of a sound source is closely associated with the difference δ of the lines of propagation traversed by a same sound wave issuing from this source before reaching the two ears, respectively. The impression that

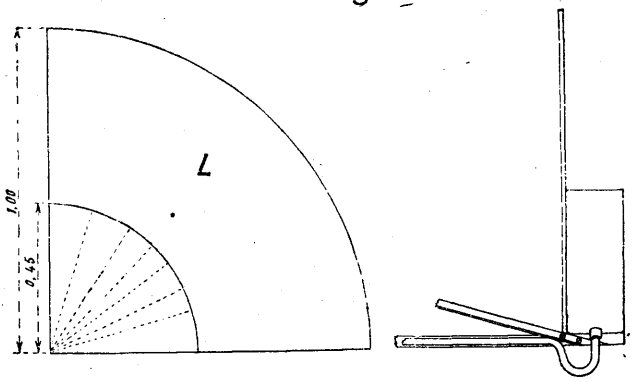
the source is directly in front is produced when δ is zero, and the source seems to move toward the right or left when δ varies one way or the other.

The variation of δ is caused by the rotation of the head on its axis. Since this axis is vertical, the impression of the movement of the sound source is naturally in the horizontal plane. This is the general rule.

But it is possible to vary δ by turning the head on a horizontal axis.

If the observer reclines on the ground facing the sound source and turns his head on its axis back and forth, he will have the

Fig. 1.



impression of the passage of the sound from one ear to the other when the line of his ears makes an angle with the vertical equal to the elevation of the sound source. But this proceeding is too laborious to be recommended.

There is an easier way of turning the two ears on a horizontal plane, which is simply to incline the head to right or left and turn it about the neck as a hinge. To produce a variation in the difference δ in this movement, it is only necessary to make the line of the ears conform with the azimuth of the sound source.

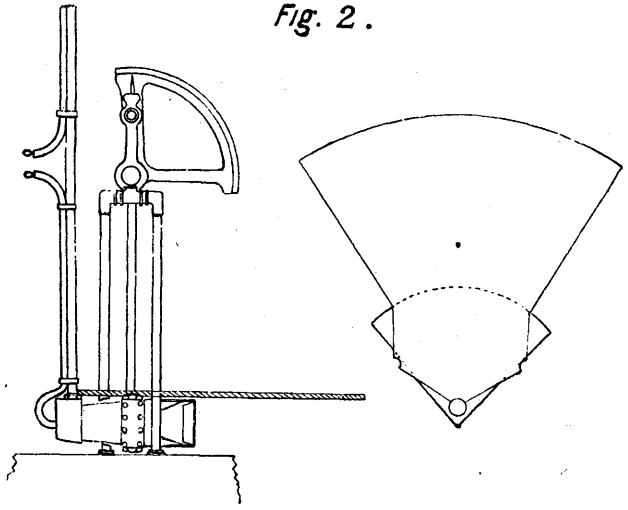
The method of auricular observation of an aircraft without listening instruments will be as follows:

(1) *Determination for azimuth.*—The observer, assuming the position of "attention," moves his head to and fro on its axis

from one side to the other of the direction of the sound source. Thus he obtains the impression of the passage of the sound from one ear to the other. He decreases progressively the extent of the oscillations and stops in the position in which he has the impression of the passage of the sound. At this moment his head is oriented in the same azimuth as the source.

(2) *Determination for elevation.*—The observer faces to the left. He inclines his head to the right until he has the impression of the passage of the sound. The line of his ears then makes with the vertical an angle equal to the elevation of the source of the sound.

Fig. 2.



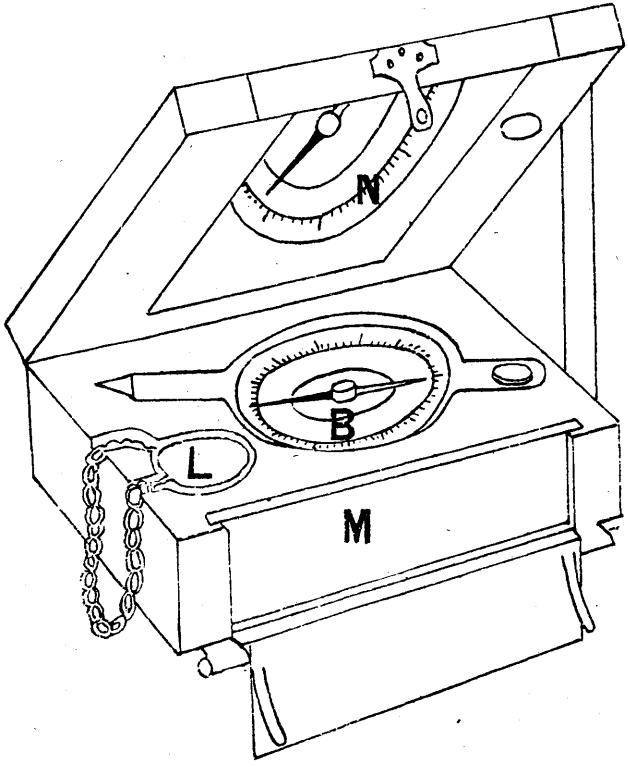
INSTRUMENTS FOR DETERMINING THE POSITION OF THE HEAD OF THE OBSERVER IN THE TWO PRECEDING CASES.

(1) *In azimuth.*—The acoustic goniometer military telegraph Type III (acoustic sight) will be used.

The instrument consists essentially of a flat mirror M and of a compass B, the dial of which has a graduation in degrees (fig. 3). The mirror serves to orient the instrument, and the compass to determine this orientation with respect to the magnetic north.

The observer facing the sound orients the sight held in his hand at the level of his face so as to see the complete reflection of his face in the mirror M, each of his ears appearing in the same way. The simple reading of the needle of the compass will furnish the azimuth of the sound source.

Fig. 3.



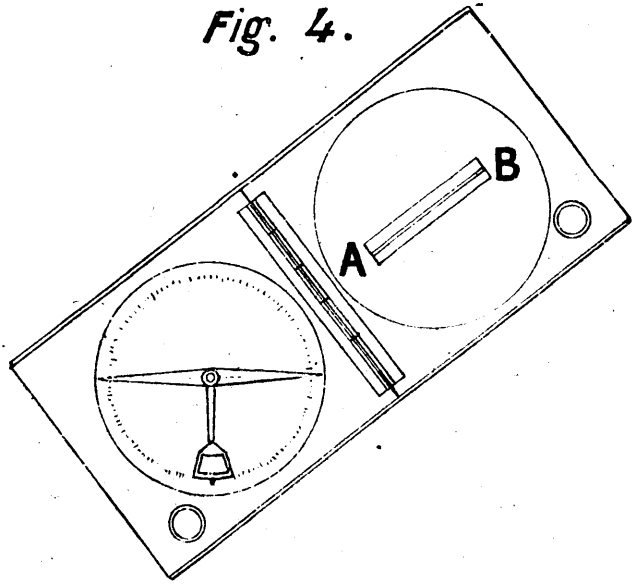
(2) *In elevation.*—The compass of Gen. Peigné may be used. The cover of the case of this compass is fitted in the interior with a flat mirror pierced by a rectangular opening A B. When the case is entirely open this mirror is parallel with the dial of the compass.

A small perpendicular moves on the axis of the magnetic needle and its extremity moves in front on a graduated circle (fig. 4).

The case of this compass is kept open during the entire operation.

When the observer has inclined his head to the right at an angle at which he has the sensation of passage he will orient the mirror opposite so that the line of his ears coincides with the axis of the opening A B. The reading made opposite the extremity of the perpendicular will give him the elevation of the sound source.

Fig. 4.



Such a method of observation is necessarily a rough one and should only be used when the acoustic goniometer Type I is not available or when only a moderate degree of correctness is required. The latter case is presented in the service of the anti-aircraft defense lookout stations where the observers have to identify the noises which they hear. They can easily determine by sound observation for the elevation without instruments whether the sound heard is that of an aircraft or of an automobile, for instance.

The military telegraph has had constructed for the lookout stations of the antiaircraft defense a class of very light, inexpensive goniometers which can be used for this purpose. These are the acoustic goniometers military telegraph, Type I, model E. (See special note.)

