THE LOTH LEADER CABLE SYSTEM FOR ELECTRICAL STEERING OF AEROPLANES.

Paper read by Mr. John Gray, B.Sc., M.I.E.E., before the Institution on Friday, 14th December, 1923, at the Royal Society of Arts.

MR. WM. LOTH, the Author of the System, was present, and Mr. Fredk. R. Simms occupied the Chair.

MR. JOHN GRAY said :—

The question of guiding movable objects is complex and has necessitated a long and careful study extended over a period of ten years.

It is a science which is still in its infancy, as was wireless telegraphy twenty years ago, but the scientific and practical bases of this science are, however, now firmly established, and, by its numerous applications, it is destined to receive progressive development. If one or more guide lines are established, the old means may become unnecessary, and even wireless telegraphy is already surpassed in certain of its applications.

Many persons confound wireless telegraphy and the guiding of movable objects, and believe that both are based on the same principles, and that is why I want immediately to rectify this error and to show that not only the determination of the routes to be followed made by wireless telegraphy and by magnet guiding are, on principle, different, but that, even from a purely scientific standpoint, and apart from any application to the guiding of movable objects, the starting point in both questions is different.

I shall first consider the problem of the route to be created. To create a safe route means going from one point to another; for instance, from the point A to point B (fig. 1), without any risk, or with the minimum of risk. It will be noted that it is possible to go from A towards B, either according to a straight line or according to a sinuous line which can be considered, in an approximate manner, as being composed of a succession of elements of straight lines; but this time the points to be considered will be at A^1 and B^1 (for instance see fig.8).

Visual means will allow the route between A and B to be determined, if it is a straight line, by placing at each of these extreme points a source of light, or, if it is a sinuous line, by considering this route as formed of rectilinear elements and by placing at each bend a source of light (S_1, S_2, S_3, etc.), or infra red, or even ultra violet luminous sources.

If, instead of having recourse to visual sensations, use is made of sonorous sensations, the same result will be obtained, and the route A and B will be determined in a similar manner to those indicated by replacing the sources of light by sonorous sources. Instead of sonorous sources, it is also possible to use infra or ultra sonorous sources.

These methods give only an approximate solution of the problem. Not only do they not permit a route to be exactly determined, *whatever may be its sinuosities*, but yet they are a function of the qualitative variations of the medium separating the starting point from the point of arrival. In fact, if we admit that between A and B there is fog, clouds, rain, snow, etc., the methods of luminous or infra red or ultra violet radiations cannot be employed. If we imagine that between A and B there is air or a liquid mass, the non-homogeneity of these media, as well as the currents, are causes of errors which prevent the route between these two points from being exactly determined.

Now, the solution of the problem implies that it should be possible to go from A towards B by following any route, and in any weather.

It then immediately comes to mind to remedy the failures of the preceding systems by using hertzian waves and radiogoniometric methods.

Unfortunately, the latter, although based on the use of electromagnetic waves, only permit a route formed of elementary straight lines to be determined by placing emitting stations at the ends of each straight line.

On the other hand, experience shows that the errors of bearing are frequent. If one is at sea and receiving from coast stations, errors of a few degrees only will prevent ships from exactly following a channel, even if it is nearly rectilinear. Above the earth, however, these errors amount to several degrees, and vary with the time of day when the bearing is taken.

If the problem is completely studied, it is seen that its total solution can be obtained only if *each point of the route* between A and B, *becomes an emitting point,* and this in every case, whatever may be the arrangement of these points. The system, moreover, must be independent of the qualitative variations of the medium. If use is made of a magnetic system (a variable magnetic field, for instance) it will be possible to obtain actions at somewhat long distances. In fact, it is known that if we consider an emitting turn of simple geometrical shape (near which is placed another turn) and that a variable electric current is sent in the first turn, the variable current creates in the media surrounding the turn a variable magnetic field: at a point, at a distance (r) on the axis of symmetry of the emitter, the value, at a given moment, of this magnetic field (H) will be. $H = I\phi \frac{(I)}{r}$.

If at this point is placed a receiving turn, this variable magnetic field will produce through this turn a variable flux (ϕ) and the electro motive force induced in this second circuit by the passage of the variable current in the emitting turn will be: $E = \frac{d\,\phi}{d\,t}$

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It is thus possible to influence at a distance a receiver composed of several metal turns and which can be placed on a movable object. But at what distance can this be done? If we develop the function $\phi \frac{(1)}{r}$, it is seen that it contains only high powers of $\frac{(1)}{r}$. For a circle, for instance, the first term corresponds to the third power of $\frac{1}{r}$. But in reality the propagation is not instantaneous, as was thought when the formula was established. This must be taken into account. If the propagation is not instantaneous, the value of H is expressed otherwise. It becomes :

$$H = A_1 \text{ Sin } wt\, \phi_1 \frac{(1)}{r} + A_2 \text{ Sin } [wt - \phi]\, \phi_2 \frac{(1)}{r}$$

$\phi_1 \frac{(1)}{r}$ and $\phi_2 \frac{(1)}{r}$ are developed, and it is seen that $\phi_2 \frac{(1)}{r}$ contains, on the contrary, terms of the first degree.

If $H = H_i + H_r$, is written,

It is seen that at a great distance, owing to the rapid decrease of $\phi_1 \frac{(1)}{r}$, the field H_i disappears before H_r

At a small distance, and considering that $\frac{A_2}{A_1}$ is very small, it is on the contrary H_i which will produce the induced currents.

Thus, at a great distance, action by radiation (H_r) and small action, as $\frac{A_1}{A_2}$ is small, even by increasing the frequencies.

At a small distance, action by induction which is modified by acting on the ratio $\frac{A_2}{A_1}$. This ratio is a function of the frequency used, and increases with this frequency.

Now, what is required for solving the guiding problem? It requires the creation of an exact magnetic route, that is to say superposable, at each point of the material route. This is obtained, as indicated, by rendering each point of the route *an emitting point*. The magnetic route *must not be too wide,* but in its limits it must permit *easy determinations,* therefore, a reception of energy sufficiently large to obviate the need of constant attention. We shall therefore put aside Hr owing to the influence of the propagating medium.

We shall proceed in a manner contrary to that of wireless telegraphy. Hi will be used, and the range will be controlled by acting on the frequency.

These are the theoretical conditions to which we arrive. In what manner shall we now, on these principles, construct first the emitter, then the receiver, and finally, how shall we be able, by means of this receiver combined with this emitter, to determine at every moment the position of a marine or aerial movable object?

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CONSTRUCTION OF THE EMITTER.

We have seen that the system determining the route ought to be magnetic, and that each point of this route ought to be an emitting point. On the other hand, we have seen that a turn through which passes a variable current of medium frequency fulfils the conditions required for solving the guiding problem. The idea which comes to mind is, therefore, to determine, owing to a single turn, through which passes a variable electric current, the route to be followed. Now, if in an insulated cable or in a telegraphic or telephonic line is sent a variable electric current with return current, either through the sea or through the ground, it can be considered that an emitting frame of very large surface but with a single turn is realised. This same frame can obviously be realised by using, instead of the ground, a metallic return line.

For realising this emitter, in the case of the guiding of ships, for instance, a station producing a variable electric current is constructed on land, this station being connected to the insulated submarine cable. For generating the electric current, an alternator, or a station having oscillating valves, can be used (see fig 2). The current thus produced is sent in a circuit (1) on which is branched the primary circuit of a transformer (2). The secondary circuit of the transformer (3) is connected to the core of the cable (4) This cable is insulated and armoured with two thick wires.

At the end of the cable, at sea, the stripped end is connected to the armour by a special device avoiding the phenomena of electrolysis. The return of the electric current takes place through the sea. For aeroplanes, the line is either a metallic line, insulated on poles (fig. 1), or a line constituted by an armoured insulated cable buried in the ground. Without entering into details, it can be said that the emission on the cables and lines is effected in resonance.

OPERATION.

The variable electric current circulating in the cable produces in the media surrounding the cable a variable magnetic field of the same frequency. It is this magnetic field which can be made use of for guiding purposes. Will this field permit it? The first thing to do is to know this field, that is to say, to determine its shape, at the surface of the water, in the air and under water. Concerning the magnetic field of the guide lines on land, we shall proceed in the same way, but we shall have to know in addition the field at the surface of the ground and at varying altitudes.

For determining this field, it will be necessary to proceed methodically and to effect thousands of measurements. This has been done, and these thousands of measurements have permitted us to ascertain the shapes of the magnetic fields.

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The exploration of the field of a cable has been carried up to 15 kilometres from the cable. If this field is studied, it is seen that it is not a simple magnetic field, but a resulting field, formed of three elementary magnetic fields.

1. Magnetic field due to the current circulating in the cable (the less important for guiding purposes);
2. Magnetic field due to the return current in the ground or the sea;
3. Field due to the currents induced in the conducting mass surrounding the loop.

Now that this complex field has been analysed and we have found that its range is sufficient to allow movable objects to direct themselves parallel to the guide cable, we have next to find the plant which, with suitable combinations, will give the result we had in view. But before determining the guide plant, based on the special shape of the magnetic field created by the guide cable, we must know the conditions indispensable to guiding a movable object along any route. This is solely a problem of aerial or naval navigation. The data indispensable to any navigator for conducting his aeroplane or his ship being ascertained, we shall then see by means of what theoretical plant we can obtain them, and we shall subsequently examine if this plant can agree, in totality or in part, with that arrived at by taking as a basis the shapes of the magnetic field generated by the variable electric current circulating in the guide cable.

1.—DATA INDISPENSABLE FOR GUIDING A MOVABLE OBJECT.

If the problem of aerial or naval guiding is studied, solely as far as navigation is concerned, we arrive at the result that, for guiding a movable object with security, without visibility, along a route traced by a cable, it is necessary to know, at every moment, on board this movable object :—

1. The direction of the route and the perpendicular to this route by two different and independent operations, so as to control them one by the other.
2. The inclination of the movable object on the route to be followed determined by the guide cable (that is to say, the angle formed by the longitudinal axis of the movable object, or its axis of route, with the direction of the guide cable, at the point where this movable object is located).
3. The direction of this inclination towards the right or the left, and the number of degrees of this inclination, if possible.
4. The side of the guide cable on which the movable object is located.
5. The distance separating the movable object from the guide cable.
6. Concerning aircraft for which the third dimension intervenes, the problem is still more complicated, as it is, moreover, necessary

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to know, on board, at every moment, if the movable object navigates in the required position of stability (determination of the horizontal plane, on board), and if the guide cable, on land, ascends on the flank of a mountain or descends in a valley.

Two plants result therefrom, obviously based on the same principles, but both suited to different purposes.

II.—DETERMINATION OF THE GUIDE PLANT.

(A) Plant for Ships.

Let us refer to what has previously been said concerning the flux. We have seen that a turn through which passes a variable magnetic flux was the seat of a variable current of the same frequency as this magnetic flux. It is known that this current can be increased by suitably increasing the number of turns. This current will vary with the flux. Now, what are the variables acting on this flux?

It is seen that this flux will increase if the surface of the turns increases. But this surface is determined once for all. However, it will be immediately seen that the *surface presented* by the turns to the flux can vary, if the turns are caused to rotate.

If, for one position, the turns present, as apparent surface to the flux, their real surface, for a position at 90 deg. from the former position, they will present a null apparent surface. For the first position, the induced current produced by the same variable flux will be a maximum, for the second position it will be a minmum, the surface presented being null.

What is the other variable acting on the value of the flux? We have seen it previously—it is *the distance*. Therefore, the more the distance from the turns to the source of flux will increase, the less this flux will be intense, and the more the current induced in these turns will diminish. We have, therefore, immediately two data which seem to be obtained. Consequently, several turns will be wound on a wooden frame, and by causing this frame to rotate a maximum current will be obtained for one position and a minimum for a position at 90 deg. to the previous one. As the flux is produced by the guide line at right angles to the latter (see fig. 3 illustrating the shape of the magnetic field of the guide cable), the position of the frame giving the *maximum* of induced current will correspond to a *direction parallel* to the *guide line* itself, which it is no longer necessary to see for guiding one's self, and the other position, that of the *induced current*, will correspond to a position of the receiving frame *at right angles* to *the direction* of the guide line. On the other hand, if the movable object carrying the frame moves away from the guide line, the current induced in the turns will diminish and it will be possible, by means of a suitable graduation, to know the distance the movable object moves away from the guide line. Now new problems arise which must be solved. First, receiving

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at a great distance; I mean to say at a practical distance, say, a few kilometres, somewhat large frames are necessary (about $2\frac{1}{2}$m. by 1m.) Consequently, these frames must be fixed. A man cannot be employed on a bridge for constantly manipulating a large frame. In practice it is therefore necessary to use fixed frames. The solution adopted consists in arranging a frame in the axis of the ship and another one at right angles thereto (or both at 45 deg. from the great axis of the ship). Thus, the ship following the guide cable through one of the frames (the frame the vertical plane of which is parallel to the large axis of the ship), passes a maximum current, and through the other frame at right angles to the axis of the ship does not pass any current.

If the ship were moving at right angles to the submarine guide cable, obviously the reverse takes place, and the induced current trapped by the large frame parallel to the axis of the ship diminishes.

Two hypotheses are possible: either the ship moves away from the guide cable, or the ship no longer follows a route parallel to the cable, whether under the influence of a transverse current or whether it arrives at a bend of the cable. Now, it is absolutely necessary to discriminate between these two cases and to separate the variables: *moving away and inclination.* The operation is immediate: it is sufficient to see if the transverse frame receives. If this frame continues to receive nothing, this means that the ship moves away from the guide cable whilst progressing parallel to the same; if this transverse frame receives, this means that the ship does not progress parallel to the guide cable. But in what direction has the ship turned relatively to the guide cable? Did it incline towards the right or towards the left? In both cases the operations to be effected are different. If the ship inclines towards the right, it is in fact necessary to bring it towards the left so as to cause it to move again parallel to the guide cable; if the vessel has inclined towards the left, it is necessary, for the same purpose, to bring it towards the right. It will be seen that this knowledge of the direction of the inclination is of a capital importance, particularly for avoiding collisions.

We are again before a new problem to be solved. I cannot dwell on all the cases considered and on the manner in which the solution has been found. I will simply state it: this problem is solved by using the two previous frames at right angles to each other, and by successively connecting them in series with each other in two different manners.

For obtaining this result, they are connected terminals to terminals a first time and, immediately after, the terminals of one of them are reversed. It results therefrom that the currents induced in these two frames, if they were added to each other for the first connection in series, are separated from each other and can even annul each other for the second connection in series. If, on the contrary, they are separated from each other for the first connection in series, they will be added to each other for the second connection in series. Now, the first connection in series corresponds to the inclination towards the right, the second connection in series corresponds to the inclination towards the left.

If, therefore, the first connection in series gives a maximum of current and the second a minimum, this means that the vessel inclines towards the right and it is brought back towards the left. On the contrary, if it is the second connection in series which gives a maximum and the first a minimum, the vessel inclines towards the left and it is brought back towards the right. This information is therefore obtained by the simple operation of a switch, and in a few seconds.

The number of degrees of this inclination towards the right or towards the left can, moreover, be given by connecting each of these large receiving frames to a small corresponding frame arranged in the receiving cabin. These two small frames, each connected to a large frame, are at right angles to each other. Within these two small frames rotates a third small frame connected to the current detectors. The number of degrees of the inclination is thus obtained by a minimum of reception, but this well-known radio-goniometric device considerably diminishes the reception, and can be used only at a few hundred metres from the cable. It is very useful in narrow channels. We have therefore now obtained a number of data recognised as indispensable for navigation in foggy weather. We have all the elements for determining the position of our movable object relatively to the cable and progressing parallel to this guide cable. But, in addition, it is also necessary to know on what side of this cable we are navigating, so as not to enter into collision with vessels going in a reverse direction. Knowing at every moment on what side we are navigating, we can work the ship so as to always keep the guide cable on our left. The vessels going in a reverse direction will do the same. The usual rules will be observed, and all risk of collision will be absolutely removed. For solving this problem, we shall consider the magnetic field of a guide line. If we consider this field (see fig. 3), we see that its intensity diminishes somewhat rapidly with distance; that is to say, in proportion as the vessel moves away from the guide cable. Therefore, if a receiver (a turn) was placed at 300 metres from the guide cable, for instance, and another at 600 metres, through the turn nearest the cable would pass obviously a more intense current, and the difference of the currents generated in the two turns would be sufficiently great for being immediately determined. We shall admit that this system is transferred to the other side of the cable (movement of translation at right angles to the direction of the guide cable); the turn which previously was nearest the cable will be now the farthest away, and it will be possible, by comparing again the currents received by each of the two turns, to disclose that the system of the two turns has passed on to the other side of the guide cable. In the same way, at the moment the middle of the distance between the two turns will pass above the cable, the turns will be one to the right, the other to the left of the guide cable and at the same distance.

They will receive, at this moment, equal induced currents and we can thus say that at this moment the middle between the two turns (at 150 m.

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from each of them), is just above the cable. But in practice, it is not possible to imagine a vessel dragging two receivers, one on its right and the other on its left. It is therefore necessary to arrange the two receiving turns one to the right, the other to the left of the vessel, *on the vessel itself*. In this case, will the difference between the distances from these turns to the guide cable be sufficient for being perceptible owing to the difference of the receptions?

Yes, if we add to the difference of the distances the *magnetic screen* constituted by the *hull of the vessel*. Use will therefore be made of two receiving frames, similar to those previously employed, in order to have the data indicated, but this time they will be arranged one to the right, the other to the left of the vessel, and in such a manner that the hull of the vessel constitutes a screen for the farthest.

It will therefore be sufficient to compare the intensities of the currents received by each of these frames, for knowing if the vessel is on the right or on the left of the guide cable. If the vessel is on the right, it is through the left-hand frame that the more intense current passes, while if the vessel is on the left of the guide cable, always progressing in the same direction, it is through the right-hand frame that the more intense current passes.

But could these receiving frames be arranged in any manner? No. In fact, the study shows that they must be arranged in a special manner, otherwise false information would be given. I will not enter into the detail of the study effected concerning the position of the side frames, I will only give you an idea of the same. Let us examine again the magnetic field of the cable. If we place the side frames vertically, we see that the flux which passes through them will vary with the angle formed by the axis of the vessel and the direction of the guide cable. Now, this variation of intensity of the two receptions will have an influence on the comparison of the values of these two receptions. On the other hand, if the vessel progresses nearly at right angles to the guide cable, the receptions of the two frames will be approximately null, whilst if they were equal and not null, they would give an excellent indication. We are therefore compelled:—

1. For rendering the absolute receptions of the side frames independent of the inclination of the vessel;

2. For permitting to use these frames, when the vessel progresses at right angles to the guide cable, to arrange these two side frames horizontally.

However, the shape of the magnetic field itself must be taken into account, and it is necessary to ascertain if the shape of this field does not prohibit the placing of these frames in a horizontal plane. Let us consider again the magnetic field, and let us place, at a certain distance at one and the same point, on a straight horizontal line, a vertical turn and a horizontal turn. Let us bring together these turns closer to the guide cable. It will immediately be seen that one of the receptions varies as the cosine and the other as the sine of the angle formed by the lines of force at the point considered with the horizontal plane.

It follows therefrom that the horizontal frame will be much more sensitive to the moving away, than the vertical frame, and, owing to this position given to the frames, one will be warned much more rapidly of a movement of translation of the vessel in a direction at right angles to the guide cable.

Concerning the distance to the guide cable, we have seen that we ascertain it easily. It is determined quantitatively by connecting to the terminals of the telephone a shunt graduated in distances.

If we refer now to the data previously indicated as indispensable for navigation in foggy weather, we see that each of them is obtained. All the necessary indications are acquired and the problem of the receiving plant, based on the one hand on the special shape of the magnetic guide field (problem purely electric), and on the other hand based on the indispensable data to be obtained (problem of pure navigation), is solved.

PLANT FOR DETECTING THE INDUCED ELECTRIC CURRENTS.

These receiving frames arranged on board in suitable manners are of course devised for obtaining the maximum efficiency.

I will not enter into the details of construction. These frames are combined with switches allowing them to be connected separately or in series to the current-detecting apparatuses.

These instruments are composed of an amplifier of special construction, and tuned to the frequency to be received. At the terminals of the amplifier can be used either an apparatus giving visual indications, or an apparatus giving auditory indications. The most simple and most practical apparatus is a telephone which can be rendered suitable for selection. In the same way as the emission, the reception is effected by resonance. Finally, the plant can be used in wireless telegraphy.

(b) *Plant for Aircraft.*

Concerning aircraft, the difficulties are much greater than for ships. In fact we are in a space of three dimensions and, moreover, a metallic hull is generally not available to be used as a magnetic screen. The direction of the guide line and the perpendicular to the direction of the guide line are obtained by two vertical frames, one parallel to the axis of the aeroplane, the other at right angles to this axis.

The inclination and the direction of the inclination of the axis of the aeroplanes to the direction of the guide line are obtained by connecting these two frames in series in two successive and opposed manners, as previously indicated.

The examination of the plant and of the magnetic field have shown that the information indispensable for aerial navigation could be obtained simply by adding to the preceding frames *a third horizontal frame*. This frame must be compensated, that is to say, it must have equal reception under the same conditions as those of the two preceding ones (see figs. 6 and 7).

Drift, that is to say, the passage of the aeroplane from left to right or from right to left of the cable, is known owing to the combination of these three frames, by connecting them in series in the two ways indicated, the *longitudinal vertical* frame arranged in the axis of the aeroplane and the new *horizontal* frame. It suffices to refer to fig. 3 to see that if the admission faces of the flux change for the longitudinal vertical frame according to the position of the aeroplane, the admission face of the flux for the horizontal frame remains the same; successive additions and subtractions of current result therefrom, according to the position of the aeroplane, additions and subtractions which cause maximum or minimum receptions on different contact pieces, receptions which characterise the position of the aeroplane.

It is now necessary to know if the guide cable ascends on the flank of a mountain or descends in a valley; this is shown in fig. 4.

It is necessary that this be known by the pilot, as otherwise the aeroplane might, in a thick fog, strike against the mountain above which it must pass. This latter information is obtained by connecting *the horizontal frame* and the *transverse vertical frame* in series, in the two ways indicated. It is easily seen on fig. 4 that if the guide line is horizontal, the transverse vertical frame on board an aeroplane flying parallel to this line is not traversed by any current. Only the horizontal frame is traversed by a current. But if the guide line ascends on the flank of a mountain, the transverse vertical frame is immediately traversed by the magnetic flux of the guide cable, a current is generated in its turns, and this current is disclosed. If the guide line descends in a valley, it is seen that the flux passes through the same face of the horizontal frame, but this time it is the other face of the transverse vertical frame which is traversed by the same flux. It is not therefore the *same* connection in series which will give the *maximum* of reception in both cases. It is thus possible to know, without seeing anything, the ascents or the descents of the guide line on land. One feels, so to speak, without seeing anything, the ground rising and falling under one's self. The operation is simple; according as the pilot has read an ascent or a descent of the line, he inclines his aeroplane or his dirigible *to the same angle,* and thus, still blind, the aircraft ascends at exactly the same angle as the line on land, and that automatically. The purely electric plant—tuned amplifier and apparatuses for putting in resonance—is similar to that used on ships. The frames are made in two parts, by means of special pins which allow them to be removed without touching the aeroplane. These frames are arranged on the aeroplane or dirigible in such a manner that they are invisible. The longitudinal vertical frame is arranged either in the fuselage, or partly in the fuselage and partly in the fin. The transverse vertical frame follows the struts or the bracing of the fixed tail plane. The horizontal frame is made within the hollow fixed tail plane, and this plane is subsequently completely covered with fabric.

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Thus the entire plant is absolutely sheltered from weather conditions. The emission is effected at a frequency of current which can be raised to 3,000 or even 5,000 cycles. Everything depends on the length of the guide line to be used. Emergency aerodromes are provided at suitable distances from each other, on each guide line. These aerodromes are signalled to the attention of the pilots by a signal or a special frequency. The plant on these aerodromes can give higher frequencies (50,000 for instance) as well as the cable lengths of the guide lines. On short lines it is even possible to use higher frequencies. Very useful communications by guide-telephony can then be realised by using carrier waves of high ultra sonorous frequency, and give useful information to pilots whilst continuing to guide them. Finally, in the case of a line already made, for avoiding expense it is possible to use, at low or high frequency, telephone lines already constructed, or even telegraph lines. Thus, for aviation or aerostation, high induction sonorous and ultra sonorous frequencies, or even low frequencies of radiation, are used for the aerodromes and the cable lengths.

For the Navy, on the contrary, very low frequency of induction and even infra-sonorous frequency is used, owing to the phenomena of capacity of submarine cables, and the phenomena of absorption of the marine conducting medium.

One might think that aerial guide lines for aircraft may, in certain cases in war time, be destroyed or injured by bombardment.

In answer to this objection, the guide lines can be buried in the ground, as well as the landing lines passing round or surrounding the aerodromes. We shall see subsequently the applications of these underground guide lines.

Notwithstanding its importance and all the studies and experiments that had to be made, I shall not dwell a long time on the question of aviation or aerostation of the guide method, and of wireless telegraphy which is adjoined thereto. The guide plant for aircraft can also be used, as seen, for this latter application.

The problem of guiding movable objects as far as the emission and reception are concerned appears therefore as now solved. However, the end aimed at is not yet reached; a new problem has yet to be solved, and it can be said that if it had not been solved, the guiding would, in certain cases, have been distorted. In fact, the guide plants being arranged on board movable objects are placed near other electric apparatus which can create parasitic induced currents.

Among these apparatus the principal are the magnetos, coils and dynamos. On board ships, dynamos or alternators have particularly to be dealt with; on board aircraft the main disturbing source is created by the magnetos.

Thus, for example, in the first aviation experiments nothing was heard at 150 metres from the guide cable.

Now, we could not pretend to guide aeroplanes at 150 metres from this cable! It was therefore necessary to solve the new problem, which consisted in doing away with the parasites. For that purpose we have made a complete study of the magnetic fields of the magnetos. After thousands of experiments this shape has been found, because we have operated at low frequency. This study has shown why a receiving frame placed on board, at a certain place, was influenced, and why the same frame, after having been placed at another point and arranged nearer the source of parasites, was no longer influenced. This study has also particularly shown, concerning the magnetos, that it is necessary to differentiate between the case of magnetos the axes of which are parallel to the axes of the aircraft and the case of magnetos, the axes of which are at right angles to the axes of route of the movable objects. But, this study once made, the cause of the perturbations being clearly determined, these parasites themselves had to be done away with. For doing away with the parasites it was incredible to think of all the cages proposed, moreover, without success, considering the nature of the fields in question. But since it was not possible to do away with the effect itself, that is to say, the parasitic currents produced, one was led to think that it might be perhaps possible to use this effect, the free use of which was available, for destroying its own action on the guide plant. For that purpose, a small frame, specially devised, is placed near the sources of parasites, and is connected in series with one of the large receiving frames of the guide plant. Each large frame has thus its small frame, called the compensating frame. This frame has been so devised, as well as its distance to the disturbing source, that the current induced in its turns is equal to the current induced in the turns of the large frame connected in series with it. This being done, it now suffices to make provision so that the connection in series of the large frame and of the small frame opposes the currents induced in the small frame and the currents induced in the large frame. As these currents are equal, they annul each other, and parasites are no longer heard in the telephones. It is thus seen how scientific researches effected with a rigorous method have been useful, I would say indispensable, for the final success. During all last year the researches relating to these fields have been continued. Now, not only the law and high frequency parasites can, as seen, eliminate themselves by compensation, but we succeeded, last year, in eliminating even the high frequency parasites without altering the reception, by specially arranging the circuits which extend from the magnetos or coils to the sparking plugs, the return taking place either through the frame of the engine or, in the case of a sparking plug, with two or more electrodes, through a wire insulated from the frame of the engine. In low frequency, a special magneto was also tested last year, and we hope to devise a magneto which does not even create any parasites and, consequently, no longer necessitates any compensating frames at the reception.

From this moment, the solution of the guiding problem formed by a series of partial solutions was attained. You have seen by what simple method, by what researches, sometimes discouraging and very often thankless, it has been obtained. We first took the problem at the beginning and we saw that it could be solved in its broadest sense, for all movable objects, only by utilising induction. We then tried to create the necessary phenomena.

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The latter has been produced owing to a special magnetic field. We have studied it everywhere, in water, on the sea, on land, in the air. Once this field had been determined, it was necessary to utilise it for guiding purposes, and therefore to create a plant based on its very special shape. This plant based on this shape of field would allow of obtaining the information indispensable for navigating in foggy weather: direction of the route and perpendicular, inclination, direction of the inclination and degree, side of the guide cable on which one is located, distance to this guide cable. This study (purely of navigation) once made, then began the research of the plant necessary for having the preceding information recognised as indispensable for the solution of the problem, and taking only as a basis the special field we had obtained. We finally arrived at the necessary plants. At this moment, it is also necessary that this plant, capable of being influenced by the magnetic or electromagnetic fields, should be influenced only by that of the guide cable. The new study is further proceeded with.

The other disturbing fields are studied. The study once made, then many phenomena, incomprehensible up to now, are explained. For doing away with these parasites, their effect itself is employed, and this effect is used for annulling the prejudice it causes. The desired result is obtained. Thus the plant is no longer influenced by the fields on board the aeroplanes, and it can be influenced by the remote magnetic field which guides the movable object.

After having seen how the partial problems have been solved, one by one, we shall now see the results obtained.

RESULTS.

We have said the first trials were made 10 years ago (December, 1913). They related more particularly to the guiding of aircraft; then the researches in this direction were stopped by the war. In 1917 and 1918, we made some trials at Cherbourg, in the docks of the Arsenal. In 1919, experiments were made by us, on a larger scale, at Brest. In 1920, during several months, these trials were continued with the support of the Navy, who lent us the necessary ships and the help of officers. Thus, demonstrations of guiding were made on board the gunboat, "La Belliqueuse," and the armoured cruiser, "Gloire."

Other experiments were made on the Seine, near Paris.

The aviation experiments were effected at Villacoublay. They lasted fifteen months, and the demonstrations are still taking place (Fig. 10). After we had shown that the problem of guiding by guide cable was theoretically soluble, the Under-Secretary of State for Aviation and Aerial Transports asked us to continue the experiments so as to come to a solution which he considered as capital for the future of aviation.

The experiments have been made with a Nieuport Limousine and a Farman aeroplane (F. 50). When aerial guide lines are established between the aerodromes, the aviators will appreciate their usefulness and will have a great debt of gratitude towards M. Laurent Eynac, Under-Secretary of State for Aeronautics and Aerial Transports. In fact, M. Laurent Eynac did not hesitate to place at our disposal the necessary materials and "personnel," and did not cease, in the most difficult moments, during experiments often dangerous and always thankless, to encourage us and to stimulate our efforts. He has thus largely contributed towards the solution of the problem, and has spared many lives for the future.

These experiments, to which pilots such as Lasne, and managers of aerodromes, such as Weber, have co-operated, have led to the results beforementioned.

The experiments concerning dirigible balloons have been made at the Centre of Aerostation of Cuers, with aerial lines and also with buried guide lines. They have shown that it was easily possible to bring back a dirigible balloon to its aerodrome without visibility.

The officers and engineers of the Technical Department of Aviation, and those of the Navy, have mutually co-operated for these experiments.

The interest of guiding by means of guide lines buried in the ground is considerable. An immediate application of this guiding is found in the Sahara. In fact, it is not possible to establish in the desert an aerial guide line on poles. This line would be rapidly deteriorated and the poles thrown down by sand storms. On the contrary, a deeply buried line has nothing to fear from storms.

We have established two projects which will be carried out stage by stage.

The first one consists in establishing bases, transverse to the route followed by the aircraft, and placed at each aerodrome. Calculation shows that lines of 60 kilometres on either side, placed every 600 kilometres, will be sufficient for taking up the draft of the aeroplane. The second project, to be subsequently carried out, consists in connecting the aerodromes by a continuous line. The laying of the buried cables has been surveyed. Various machines have been studied by specialists, and we have chosen one of them capable of burying 500 metres of cable per hour.

Concerning the guide line themselves, the situation is as follows:—Our marine guiding has been adopted by the Navy, and our aerial guiding by the Under-Secretary of State for Aviation and Aerial Transports. The maritime installation of Le Havre has been foreseen, the project has been made, and I think that in a few months from now the work of installation can be undertaken. Other ports are under study.

In Belgium, demonstrations have been made for the aerial guiding at the aerodrome of Haeren We shall make an installation of maritime guiding at Ostend and another one at Antwerp, perhaps next year. After the demonstrations which have been made, it is possible that our system may be adopted by the Belgian State. Missions have been sent from several foreign countries, and demands made (America, England, Italy, Japan, China, etc.). It is seen that we arrive at a considerable development of the use of guide lines, which has just been created. Concerning the naval guide cables, a range of 2 to 3 kilometres on each side of the guide cable can be reckoned, resulting in a zone of reception from 4 to 6 kilometres. For aerial guiding, a line of only 3 kilometres in length gives on land a range up to 15 kilometres, with a current of frequency 800 per second, and in altitude, a range of 3 kilometres.

The French Government has budgetted for four guide lines to be put up in France. One of these will be with the object of guiding from Paris to London, another from Paris to Brussels, a third from Paris to Strasburg, and a fourth from Paris to Versailles. On the Paris to London line, the first section of which will be completed in 1924, namely from Lebourget to Leszarches—a distance of 20 kilometres, a sum of 200,000 francs has been voted. In the harbour at Havre, the town contemplates laying a Leader Cable of 52 kilometres. In Belgium a demonstration will be made on a 10 or 20 kilometres cable laid in Ostend Harbour. The current used at Villacoublay is 600 cycles.

For the lines of aerodromes and their cable sections, the frequency is increased (50,000, for instance, or more). A much greater range is then obtained, which is useful for signalling the approach of the aerodrome to navigators.

Concerning the hydroplanes, these machines, above the sea, can follow the guide cable resting on the bottom of the sea. In France, five cable sections of aerial guide lines are provided for this year in the budget of Public Works, and, in particular, the cable section of the line Paris-London. The first cable section will be 17 to 18 kilometres in length. Subsequently, this length will be increased. The line has been declared of public utility, and the necessary expropriations will be effected. All this is not accomplished without difficulties, certain mayors seeing with terror such a mysterious electric line passing over the territory of their parish.

The extended line will cease at Boulogne, the municipality of which, always active and understanding all the importance of the line in the future, takes interest in the work. At Boulogne the line will become submarine, owing to a cable which will emerge at Folkestone. From Folkestone to Croydon the line will again become an aerial line. Thus, aeroplanes or dirigibles starting from London or from Paris will be guided throughout their journey, at every moment, with entire security. Between Boulogne and Folkestone the submarine line will be followed, even without any visibility, as a kerbstone by the ships going from one port to the other, and by the aeroplanes or dirigibles of the line Paris-London, without danger of their going astray, and without fear of any collision. For giving an idea of the precision obtained, I can say the experiments have shown that a movable object passing above the guide cable determines its passage above the cable within ten metres. This is a precision greater than that of the visual alignments actually used.

OBJECTIONS.

Evidently, some people have said: What . . . you are going to cover France and other countries with lines on poles? We shall answer: Perfectly, in the same way as France and other countries have been covered with railway lines, telegraphic and telephonic lines. At the beginning, the railways, telegraphs and telephones raised the same objections from those who go forward while looking backward. Actually, there are railway lines everywhere; the most wild country places are conquered by the rail, and the beneficial electric lines which, from town to town, carry human thoughts, are no longer sacrificed to the scenery.

CONCLUSIONS.

Henceforth, we must no longer hear of ships lost in the fog, ignoring their position, wandering, blind, before harbours, sometimes quite near them without being able to enter to find shelter therein. We must no longer see ships, if the port is far in the interior of the country and connected to the sea by a river of insufficient depth, compelled, for having missed a tide, owing to the fog, to wait several days for the proper tide which will allow them to go up the river. No more collisions are to be feared as there will no longer be any ships progressing on any routes, either near the harbours or at sea, which are intersected without any possible regulations. Henceforth, every one will keep to the right of the guide cable. Even far out at sea where there is no longer any guide cable, there will be no more collisions, as the guide apparatus, from receiving apparatus becoming emitting apparatus, allow ships to locate themselves, to know their respective positions, and to progress with entire security by avoiding each other. This was quite understood by the Maritime and Colonial League when they expressed the desire that our apparatus should be rendered compulsory on board ship by the same right as wireless telegraphy apparatus or life-saving apparatus. But if wireless telegraphy (which however is powerless to give the exact position of the ships) is found useful and beneficial, since it allows the ships to ask for help after collisions, what must be thought of a system which prevents these catastrophes themselves and gives, finally, to the navigators, security in their work?

If wireless telegraphy is recognised as useful, should not the guiding and the security it gives be recognised as much more indispensable? Actually, we are in presence of this paradox: the ships are provided with wireless telegraphy which helps to save human lives threatened by the catastrophe it cannot prevent, but they are not provided with the apparatus which renders this catastrophe itself impossible! However, nothing must be said against those, who, having the responsibility of human lives at sea, allow their crews and passengers to navigate in these conditions. Fatally, one day, without effort of thought, they will be convinced. Perhaps there might be, alas! by that time, a few more collisions, a few more ships run aground in narrow channels or run ashore by foggy weather or by a dark night. It is to be feared, and it is that which rouses human conscience. To have done everything so that this should no longer happen, to think that these crimes of the sea should no longer be possible and see that nevertheless they are allowed to take place! At Rouen, a year ago, I told M. Rio, Under-Secretary of State, that the secret of those who discover is to wish to render a service, and I added that great inventions come from the heart. I might say that the same state of mind is as indispensable for rapidly realising discoveries or new inventions. As for us, our part ends there, where the part of those who must realise the inventions, begins?

By what genesis of the subconsciousness, independent, at the beginning, of any will, did this idea of guiding arise, grow, become precised and did it lead to the whole system which you know now? I think all is explained when I tell you that as a child I saw, on the coasts of Brittany and Normandy, so many sailors set out who have never returned! I think that all becomes clear, when I remember having seen, weeping, the wives and children of those who left for us, who remained behind. I recollect having said to myself that this injustice must not be, and solemnly declared to myself that it should no longer occur. Thus, this problem, little by little, set itself before me, ever present in my mind along the years of youth: Cause those who set out, to return! Each new catastrophe hastened our efforts and multiplied our work. Alas, the end so noble appeared distant, fugitive, and however, always tempting, as the mirage withdraws itself at each advance. And, now, it is realised and to-day we experience that sweet joy, to be able to say that these crimes of the sea shall never occur again, never! Doubtless, the ship might break asunder and the aeroplane might crash, but that does not depend on us; our task is accomplished, and, besides, these disasters are so rare!

I can tell you also, that it is the constant thought of your life and perils, you navigators of the sea and the air, that has always sustained us in our continuous and tenacious efforts. May this discovery, which our efforts joyously give you, cause those of you who depart henceforth, to set out having in your hearts the certainty of joyful homeward returns; may this invention also bring a little comfort to the hearts of the wives and children who, up to now, awaited your return, in anxiety, uncertainty and in tears.

Chairman (Mr. Fredk. R. Simms):

We have listened to a most interesting lecture, and I have much pleasure in calling upon some gentleman to open the discussion.

DISCUSSION.

Captain Sayers.—Mr. Loth's leader cable system has attracted singularly little attention in this country as far as I can gather, and it seems to me that the

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