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METHODS FOR FACILITATING THE BLIND LANDING OF AIRPLANES

By M. Heinrich Gloeckner

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METHODS FOR FACILITATING THE BLIND LANDING OF AIRPLANES*

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Since the introduction of blind flying, the accomplishment of blind landing on prepared fields has become one of the most pressing problems, and many attempts are being made to solve it. The methods employed, in so far as they have been published, are summarized in the present report.

I. THE DETAILS OF BLIND LANDING

The economy of air traffic depends largely on its regularity and reliability. Regularity necessitates blind flying. Special arrangements are necessary, however, to insure the safety of the airplane and its occupants. These measures concern "inside" navigation, i.e., the instrumental control of the course, and "outside" navigation, i.e., the determination of two or more bearings of the airplane. Although reliable aerial-navigation methods and excellent ground organization now enable the trained pilot to reach his destination, there are still many difficulties in making a blind landing. The shrouding of the field in fog has hitherto meant the omission or change of destination of the proposed flight. No traffic enterprise can yield with impunity to such dependence on the weather.

That blind landing is not impossible, has been demonstrated on several occasions when airplanes, caught in unexpected bad weather, have landed without harm on fog-enveloped fields with the standard blind-flying equipment and radio direction-finding apparatus. It has also been demonstrated by the frequently mentioned flights of the American, Mr. Doolittle. (References 1 and 2.) In all these cases, however, the successful outcome must be attributed more to the exceptional skill of the pilots and to the excellent cooperation between them and the ground personnel, than to the adequacy of the auxiliary equipment and methods.

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*"Verfahren zur Erleichterung von Blindlandungen." Z.F.M., June 24, 1932, pp. 347-355.

Even in clear weather the landing is the most difficult part of a flight. An accurate knowledge of the airplane's characteristics and of the wind conditions is necessary, in order to land in the desired manner. While, in clear weather, the controls are operated according to impressions received from direct observation of the ground, in foggy weather the requisite information must be obtained from auxiliary apparatus. In so far as possible, devices are employed to improve the visibility and enable the pilot to see through the fog. Such "fog glasses" cannot be realized, however, in the present state of science. Likewise, according to recent data, it is hardly feasible to adopt the proposals of R. Mandl and E. M. Torkelson (reference 1), to cast real images on a screen by means of infra-red rays. (References 3 and 4.) Hence, blind landings on unprepared fields still remain entirely problematical.

Since the use of known methods for increasing the visual range in blind landings on prepared fields offer little prospect of an early satisfactory solution, the method has been generally adopted of dividing the whole complex problem into its principal component problems, in order to formulate technical hypotheses. In this attempted solution, the methods of high-frequency electrical engineering occupy a promiment place, while the exchange of radio communications also plays an important role. The determination of the ground wind, of the barometric-altitude correction, of the order of landing and the mutual reports of the courses and altitudes of airplanes in the vicinity are among the essentials of blind flying and are important helps in making blind landings safely.

As in blind flying, so also in blind landing, a thorough knowledge of "inside" navigation is assumed. The pilot must always know whether the airplane is in a climbing or diving attitude, whether it is in a sideslip or bank. As regards "outside" navigation, blind landing requires considerably more accurate bearing checks, whereby the altitude ordinate is especially important.

The fixed reference point for the spatial coordinate system is the spot where the airplane is intended to land. The problem is therefore, within the possible limits of flight, to follow a spatial curve, to which the horizontal plane in the coordinate origin is tangent. In practice, according to the size of the field, more or less deviation of the actual from the intended landing point is permissible. Hence there is an abundance of spatial curves for the landing, which leaves the pilot considerable leeway in the final landing.

The previously known methods for facilitating blind landing require certain restrictions, however, in so far as they prescribe definite landing limits, whereby it is left to the skill of the pilot to keep within the prescribed limits with the aid of the steering controls and the regulation of the revolution speed of the engine.

The particular problems of blind landing consist in finding the airport and in getting one's bearings at close quarters. The latter requires both horizontal and vertical navigation. Horizontal navigation involves the determination of the direction of landing and the boundaries of the landing field, while vertical navigation involves the determination of the altitude and the freedom of the gliding path from obstacles. It is important for the corresponding instruments and methods to furnish reliable data and especially for the instruments used on board to be light and of small dimensions and to require the least possible attention.

II. FINDING THE AIRPORT (LONG-RANGE BEARINGS)

Blind landing includes the blind finding of the airport. This problem has been satisfactorily solved by numerous radio direction-finding methods, which will not be described here in detail. (References 5 and 6.) In Europe the determination of the radio bearings from ground stations is preferred, while a mixed method predominates in the United States.

The former method employs stationary direction-finding apparatus, which can determine the direction of the radio waves emitted by a moving aircraft. It is especially advantageous for the apparatus to be located on the airport which the craft is seeking. After establishing radio communication, the aircraft sends bearing signals. The receiving station then usually radioes the aircraft the result in the form of its deviation from the correct course. The bearings can be repeated as often as desired and thus constitute a check on the correctness of the course. The direction-finding ability of the airplane is retained till it reaches the vicinity of the ground station, so that, e.g., an airplane approaching at an altitude of 150 m (492 ft.) can obtain its bearings up to a distance of about 100 m (328 ft.). Even in direction finding on board, the conditions are similar during the approach of the aircraft. (Reference 7.) This method has, in addition to its continuous indications, the advantage of immediate results. The special antennas and the extra weight must, however, be regarded as disadvantages.

In the mixed method, the directional function is assumed by the ground station. On the airplane there is a suitable receiver connected with a nondirective antenna. In so far as the flight course, prescribed by the sending method, is not limited to hearing (A-N method), the objective indications may be produced by special devices.

The best-known method for determining the course by a so-called "directive beam" employs two crossed vertical loop antennas, whose emissions can be specially characterized. In the original form this is accomplished by coordinated keys, so adjusted that the signals from one antenna fall in the pauses of the other. For the purpose of objective indications, the emissions from the loop antennas are characterized by special modulation frequencies, whereby, instead of alternate emissions, there is simultaneous excitation.* In all cases the directive beam, corresponding to the double circular sending characteristics, is defined by the zone in which the signals from both loops have the same amplitude. (Fig. 1.) An airplane following such an electrically designated route recognizes every lateral deviation through the reception amplitude of the coordinated antenna characteristics. At the moment of flying over the radio beacon the reception strength passes through a minimum, after which the lateral characteristics are reversed.

All these briefly sketched methods are essential and tested components of modern radio beacons. With their help it is possible to guide an airplane toward the airport and to bring it within range of the special aids for blind landing.

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*An objective directive-beam method according to Kramar has an intermediate position. (Fig. 6.)

III. AIDS TO BLIND LANDING

1. Horizontal Navigation Methods

a) Finding a safe route.- Near the airport, horizontal navigation methods are required which will indicate accurately, at any time, the location of an approaching airplane. These methods become more necessary in proportion to the height of the obstructions.

The simplest method consists in guiding the airplane, by means of a radio beacon at the airport, within a sector suitable for low flying. In this way many airplanes, which have to fly blind on account of low clouds, are enabled to descend safely through the clouds. This method assumes, however, that the ground will become visible before the landing is effected. The process is similar with the aid of a radio beacon on board and mixed direction finding.

A further step is indicated by the use of cross beacons. In Figure 2 the approaching airplane F continually receives its bearings from two or three beacons A, B, C. The bearings at any moment are indicated by the intersection of the radio beams with the north-and-south lines. All the radio beacons can be provided with automatic direction-indicating devices, whereby the result of each auxiliary beacon is transmitted to the central beacon. The auxiliary beacons can be marked on a landing chart, so that the results are immediately perceptible and the changes in the bearings can be followed (Berndorfer-Dieckmann method). The bearings can be radioed to the airplane by indicating the squares on the chart. This method can be used both in direction finding on board and in mixed direction finding. Although we have thus far sketched only the application of long-range methods to nearby uses, there is no lack of other methods.

J. Valoris utilizes the dependence of the intensity of the reception field on the distance of the transmitter for determining the bearings. In order to obviate the necessity of absolute field-intensity measurements, the ratio of the reception-field intensity of each corresponding pair of signals is determined. In Figure 3, A and B are two nondirective transmitting stations which, with the same radiant energy, are alternately used on equal waves. The modulation frequencies of the two transmitting stations differ. In the output circuit of the airplane receiving set there are two filters which separate the signals A and B from each other, so that there are coordinated deflections of the two instruments corresponding to the distances of the transmitting stations. The two instruments are combined as shown in Figure 4. The scale can be calibrated so that the intersection point of the pointers will indicate the distances from both stations. If the flight charts are provided with curves of like distance ratios, the bearings can be determined from the reception data of stations A and B. If another pair of stations A C is utilized, the bearings are then obtained from the intersection point of the two lines. One disadvantage of this method is the difficulty of keeping the operating conditions of the transmitting station constant. Moreover, in practice, neither the circular-radiation characteristics nor the uniform resistance to spreading can be guaranteed for the individual radiations.

Another base-line method, which utilizes the spatially stationary interference picture of two coherent oscillating beacons, is proposed by M. Harms for radio-bearing purposes. Since this is of little use, however, for short-range beacons, it is not necessary to consider it further here.

In addition to the base-line methods, which enable the determination of the position of the airplane and leaves the pilot free to attend to the navigation, there is the further possibility of accurately indicating the route to the pilot. This is done by means of the directive-beam and directive-course methods. From the navigation standpoint, these methods require that they shall not only indicate any deviation from the prescribed route, but shall also indicate the side toward which the deviation occurs.

The directive-beam methods serve chiefly to determine the landing direction. Use is generally made of the same methods as developed for long-range beacons. The difference between the beacons consists simply in the lower electric power and the smaller dimensions of the loop antennas. A device described by H. Diamond and F. W. Dunmore (reference 8) consists in principle, at the sending end, of two vertical loop antennas, which are placed at right angles to each other and which are excited with the same phase and power for the same wave length, but are modulated with distinguishable low frequencies. (For example, with 65 and 86.7 cycles.) Such a beacon then has a radiation diagram as shown in Figure 5. The directive beam is the locus of all the points at which the reception amplitudes are equal from both loops. The receiving set is provided with a filter for separating the frequency mixture. In an older arrangement, each of these low frequencies causes the vibration of a suitably tuned reed. The pilot's task is to steer so that the amplitudes of the vibrating reeds will be equal. Unequal reed vibration amplitudes indicate that the airplane has deviated toward the side of the greater amplitude. (Fig. 5.) A more recent arrangement (references 9 and 10), which is a further development of the reed frequency meter, functions with the interpolation of an electromechanical resonance filter on a dial indicator. This arrangement is especially insensitive to disturbances.

A method developed in Germany by E. Kramar (C. Lorenz Co.), which functions with an indicator, is likewise based on the amplitude method, but also involves the use of a new, simultaneous use of the alternating-current and direct-current methods. The radiations from the two frame antennas, placed at right angles, are differentiated by the fact that the modulation of the high frequency ensues according to a saw-tooth curve in which, by the use of a high-frequency choke or inductance coil with an iron core, both loops are simultaneously and symmetrically but inversely excited. (Fig. 6.) After double rectification on the low-frequency side in the counterphase method, a laterally correct indication is obtained at the reception end from the unsymmetrical course of the curves according to the ratio of the reception amplitudes of the two antenna radiations.

While the directive beam always defines a rectilinear route, W. Loth's method (reference 11) makes it possible to guide an airplane along a curvilinear route. Under certain conditions this is important for airports surrounded by many high obstacles, as, for example, in a mountainous region.

The basic principle of these arrangements lies in the fact that revolving beams are emitted from two fixed points, the rate of rotation of the beams being so adjusted that their intersections follow the desired route. These beams may differ greatly. Since they must penetrate vapor, fog, snow, etc., all vibrations are eliminated which do not meet this requirement. High-frequency electric vibrations largely fulfill the requirements.

If the beams from the two beacons are suitably distinguished, the observer can tell whether he is on one side or the other of the prescribed route according to which signal is first perceived. The time interval between the beams indicates the distance from the prescribed route, if the rotational velocities of the beams are such that, over the whole route, equal lateral deviations are coordinated with equal time intervals. In Figure 7, let AB represent the route prescribed by the beacons S_1 and S_2, and A'B' represent a parallel path. An airplane at F receives the beam S_1 when this beam intersects the beam S_2 on the prescribed route at a. According to the preliminary assumption, the second beam will be perceived on the parallel route by a constant time interval Δt after (or before) the first beam is perceived. After the interval Δt, the beam S_2 must therefore pass through F. Simultaneously it intersects the prescribed route at b. According to the conditions, the beam S_1 must also pass simultaneously through b, since the route is indicated by the intersection point of the two beams. While S_2 is passing from F_0 to F and also from a to b, S_1 simultaneously passes from a to b and from F to F'. Accordingly the distances F_0 F and F F' on the parallel route correspond to equal time intervals Δt but to unequal angular velocities. From this it is easy to determine graphically for a given route the law governing the angular velocities of the beams S_1 and S_2, since, for Δt as the time unit, the angles a S_2 b, b S_2 c, etc. (and also a S_1 b, b S_1 c) furnish a direct measure for the velocity. It is also easily seen that the beam S_2 will be perceived on the parallel route A" B" two Δt time units after the beam S_1 is perceived. Hence the position line on a previously prepared route chart can be accurately determined by observing the time intervals. The limits, within which a given pair of beacons can accurately indicate a route, are determined by the fact that a beam must neither be tangent to the route nor intersect it twice.

Since the rotational velocities of the two beams are dependent on each other, they can both be adjusted from a central station. For this purpose, according to W. Loth, the rotations are made with the aid of a timing switch. The impulses are imparted by means of keys controlled by a perforated strip, each hole corresponding to a current impulse. The holes are at different intervals and determine the rate of rotation of the beams corresponding to the predetermined law of motion.

The production of the directive beam is effected by the amplitude method or by the use of ultrashort waves by special antenna arrangements. If the antennas do not permit direct rotation, this may easily be accomplished with the aid of a goniometer. (Bellini Tosi.) The airplane receives the nondirective signals.

The above-described transmitting systems assume a definite azimuthal course. For the central approach to an airport from any direction, there are numerous methods of direction finding on board, especially the long-range methods of J. Robinson (reference 12), Berndorfer-Dieckmann (reference 13), R. Hell (reference 14), and H. Busignies (references 15 and 16). These methods will not be considered here.

Light beams in the infra-red portion of the spectrum can be utilized for steering toward a given point. Their ability to penetrate fog depends largely on the size of the drops in proportion to the wave length. (References 3 and 4.)

Of the many ways suggested for using infra-red beams for short-range direction finding, that of F. W. Westendorp (General Electric Co.) is of special interest. As transmitter a neon lamp is used, which is based on an alternating electromotive force of the frequency of sound. This modulation frequency is important in reception, in order to determine accurately the source of the light. The receiver consists, in principle, of a photo-electric cell over which a mirror, inclined at about 45°, rotates at about 100 r.p.m. On both sides of the airplane fuselage there are windows which are explored by the mirrors. The photo-electric currents generated by the incoming light are compared. When these currents are equal, the source of the light is directly ahead; when unequal, it lies on the side corresponding to the stronger current. This arrangement should therefore give good results even in relatively diffused light. No flight-test results have yet been published.

The "leader cable" was one of the first means used to guide airplanes into port along definite routes. This cable is generally charged with an alternating current whose field acts on the airplane receiver. The position of the airplane with reference to the cable is then determined from the strength and nature of the signals received.

The use of such cables for guiding aircraft into port will be limited in comparison with the above-mentioned methods, due to the necessity of acquiring additional land outside the landing field. It was found impracticable, according to the D.V.L. experiments (reference 17) to endow leader cables with radio frequencies, since extensive regions are affected by the overlapping of the waves with those of other cables. Change of terrain also involves changes in the reception field, which permit no conclusions regarding the position of the airplane with reference to the leading cable. These phenomena compel limitations in the frequency and in the adoption of the audible spectrum, whereby the lower portion is less favorable for reception than the upper portion. The working frequencies are therefore mostly between 10^3 and 10^4 cycles. Many of the published methods have not been practically tested. In most cases, the conclusions were drawn from model tests.

One of the first devices for guiding an airplane by cable, for the purpose of facilitating blind landing, is described by C. Cooch. (Reference 18.) The arrangement of the cable is shown in Figure 8. The cable A serves to guide the airplane to the landing field proper, while the actual landing is effected with the aid of cable B. These cables are charged with currents of different frequencies, cable A, for example, with 34 periods and cable B with 68 periods. For guiding the airplane along the cable A, the airplane is equipped with loop antennas or "search coils" arranged symmetrically with respect to the longitudinal axis of the airplane. According to Figure 9 the same e.m.f. is induced in both coils when the airplane is in the position a. In the positions b and c, the greater electromotive force is induced in the coils nearer the correct track, i.e., more nearly over the leader cable O.

We will now assume that we have a second pair of coils placed vertically between the wings but sloping at 45° to the plane of symmetry, as shown in Figure 10. If the airplane is on the track and flying parallel to it, the port and starboard coils present equal effective areas to the magnetic field. As the airplane turns to starboard, the effective area of the port coil is increased and that of the starboard coil is decreased. As the airplane turns to port, the effective area of the starboard coil is increased and that of the port coil is decreased. The coil which presents the greater area, and so picks up the greater electromotive force, indicates the direction to turn in order to get parallel to the track again.

For these reasons the two starboard and the two port coils are each combined with one another and connected with the corresponding indicator. The latter shows the position of the airplane with reference to the track. The indications are given by means of dynamometric instruments. Each instrument is provided with a small mirror which reflects a beam of light. The reflected beams of light play on a common transparent scale as represented in Figure 11. The zero position is at the top of the scale. From left to right the columns signify the port scale, height scale, starboard scale, and an "indicating" scale. The latter indicates to the pilot when he is over the landing track and his progress along it. The spot of light on this scale oscillates at four periods per second and is therefore quite distinct from the other two.

The latest model frequency reducer has three sets of reversing contacts, one each for the port and starboard search coils operating at 32 periods per second and one for the indicating search coil operating at 64 periods per second. When the search coils are over the landing section, they are in a magnetic field of 34 periods, on which is superimposed another field at 68 periods per second. Since the leading cable has a frequency of 34 periods and the frequency reducer reverses the circuit at 32 periods, the resultant current at two periods is applied to the instrument. It is easily seen that the spots of light on the port and starboard scales oscillate at the same phase and amplitude, when the electromagnetic field is horizontal, i.e., when it is approximately over the cable.

The arrows at the top of Figure 12 represent the relative amplitude of movement of the P and S spots of light on the instrument, when the airplane is flying parallel to the track. Arrows in the same direction indicate that the oscillations of the two spots are in step, but when the arrows are opposite the oscillations are out of step. When the airplane is on the correct track H, the two spots of light are equal and in step, as shown in positions 4 and 12. If the airplane is on the port side of the track, the starboard light remains about the same, but the port light is reduced. When the airplane gets over to X_3 on the port side, the port light drops to zero and the starboard light is about the same as at H. If the airplane moves farther to port, the port light begins to oscillate again, but out of step with the starboard light, as shown in position 9. When the airplane is in the center of the area enclosed by the track, the magnetic lines are vertical and the two lights are equal and out of step, as shown at 8. Positions 1 to 7 represent airplanes coming in the opposite direction. The same rule holds good, namely, that the side showing the greater amplitude is toward the correct track.

The dash lines H represent the positions where the field is horizontal, while the lines X_1, X_2, X_3, and X_4 represent the positions where the field is inclined 45° to the horizontal. When the airplane is over the leading cable, i.e., on the line H, its height above the ground can be determined from the amplitude, with constant transmission characteristics.

Banking increases the electromotive force in the search coil on the depressed wing of the airplane. This effect is usually offset, however, by the turning of the airplane, so that the instrument reading is not much affected.

When the airplane comes within the effective range of the landing cable B (fig. 8), it is indicated on a special scale (fig. 11). The corresponding instrument is connected through a reversing device with an indicating search coil, whose plane is parallel to the longitudinal axis of the airplane. This is operated at 64 periods per second, while the cable has 68 periods. The spot of light then oscillates at 4 periods per second. Since all the instruments are excited in their natural frequency, it follows that the indications are practically independent of one another. Therefore noticeable oscillations occur on the landing scale I, only when the airplane is in the vicinity of the landing cable.

So far as known, this method has been used only in model tests on a scale of 1/200. It is a disadvantage to have to follow rather sharp curves in landing.

b) Marking the limits of the landing area.- Tests have been made at the Ford Airport (reference 19), Lansing, Illinois, with an invention by Earl C. Hanson, for indicating the limits of the landing area along with the direction of approach. (Fig. 13.) The device consists of two single-turn loops extending almost 4,000 feet out from the airport boundary. The coils are about 200 feet apart at the field ends, but diverge to 1,500 feet at their outer ends. Each coil is impressed with a 1,000-cycle audiofrequency impulse generated at a ground station. A device is used to open and close alternately the circuits in the two loops, so that one coil emits dashes and the other dots. A pilot flying a middle course between the two coils hears an unbroken sound in his headphones.

At right angles to the inner ends of the coils there is a six-turn loop of No. 8 weatherproof solid copper wire 600 feet long and 200 feet wide. The sound in the headphones materially increases when the airplane is over this loop, informing the pilot that he is in position to land. Mr. Hanson has devised an induction altimeter which is said to indicate the height of the airplane above the landing loop to one-quarter of an inch.

W. Loth (reference 20) uses a cable charged with currents having mean frequencies of 7.5 to 10 kc, in order to communicate to the pilot of an airplane certain data on his bearings with respect to the landing field and his height above the ground. The device, as tested in model form, consists essentially of a circular cable as shown in Figure 14. It is connected with the generator G through the switch S and the transformer T. The timing mechanism is omitted for the sake of clearness. The circular cable represents a vertical loop antenna whose plane is rolled together in the form of a cylinder. The current generated in such a loop produces an electromagnetic field which, for a cross section through the middle of the loop, has about the course shown in Figure 15. The circular cable, as a whole, forms an open antenna, which is laid over the excitation coil b on the ground. The device operates, therefore, as a condenser, one of whose plates is connected with the cable and the other with the ground. If the direction of the current is reversed through the switch S, the phase of the magnetic field produced by the cable current is changed 180° with respect to the electric field produced by the open antenna, since the electrostatic displacement is practically unaffected by the reversal.

The airplane has a horizontally placed loop antenna and an open antenna, both being connected with the same receiving circuit. The induced electromotive forces can be made to offset one another by suitable adjustments, while they are added in other cases. If, as in the case of the guiding beam, complementary signals are used, then conclusions can be drawn from the behavior of the receiving system regarding the direction of the magnetic field and consequently regarding the position of the aircraft. The conditions are further illustrated in Figure 15, which represents the magnetic field of a circular cable of 1,000 m (3,280 ft.) diameter. An airplane will generally be able to fly safely, according to the readings of its barometric altimeter, at heights of 150 to 200 m (492 to 656 ft.). Left of the line OS, the field will have a relatively inductive effect on the receiving antennas. If the two tuning characteristics, coordinated with the polar fields of the circular loop, are the signals D(- ..) and U(.. -), then, e.g., in the first part of the flight the signal D will be received, if it is assumed that the electromotive forces induced from the two fields here oscillate in phase in the airplane receiver. Within the field T O T', the horizontal antenna receives practically nothing, due to the plane-parallel components of the strength of the magnetic field. Also the electric field has, vertically over the circular cable, a minimum which is more pronounced with the use of an open vertical antenna than with a trailing antenna. In the field T O T', accordingly, the distinguishability of the signals D and U ceases, which fact serves to indicate the field boundaries. The time required to fly across the center of the circular cable gives a rough basis for the flight altitude. Finally, after reaching the line OS, the airplane begins to glide. Beyond the line OS' the signal U is received. As the ground is approached, the signal becomes continuous, because the receiver is affected by the magnetic field. Finally, within a few feet of the ground, the signal D is heard, and the airplane levels off. (Fig. 16.)

Although this method also yields theoretically correct results, there are serious doubts as to its universal applicability. (Reference 20.) In the first place, the circular fence with posts about 10 m (33 ft.) high constitutes a serious menace to low-gliding airplanes. Then the field arrangement is considerably more complicated than here shown in order to make the principles clearer. Even the loop antenna has an electric field, which likewise changes phase with the reversal of the loop. The electric field of the open system is, moreover, differently distributed in space than the magnetic field of the landing loop. Since, however, the critical data for the pilot result from the cooperation of both fields, it is difficult to make the best adjustment of the receiving set. From the short distance between the loop wires there follows a slight distance effect, since, for every farther point, the fields work against one another and the field intensities are almost equal. This is particularly disadvantageous in landing. It is only near the ground that the fields are stronger. If it is sought to remedy these disadvantages by using more power, special measures are necessary to safeguard the receiver against excessive indications near the ground.

Recently a further development of this method has been announced by the American Loth Corporation, (reference 21), which is being tested on Wright Field. In this system the open cable is replaced by concentric cables in the ground. An approaching airplane first hears the signal D and then, as it crosses the boundary of the landing field, a continuous sound. Inside the landing field, the signal U is heard. At a height of about 20 feet above the ground, this is replaced by I(..). This is the signal for the pilot to level off for landing. The receiving apparatus on the airplane consists of a vertical loop antenna for guiding it toward the landing field, as well as a horizontal loop for receiving the bearings. While the latter ceases, the course is controlled by an indicator. The guiding may begin at a distance of about five miles from the landing field, whereby the cable is supplied with about 15 kw.

Another method for indicating the landing-field boundaries was developed by H. Gromoll and H. Johannson of the D.V.L. and confirmed by laboratory tests. (Reference 22.) The outer and inner fields of the airport are plainly marked by visual beacons, whereby, in flying across the boundaries, the direction of the indicator needle is reversed. The reliability of the indications depends on the use, in the reception field, of unsymmetrical curves with respect to the time axis.

A cable, surrounding the landing field, is endowed with a sound-frequency current of the form $I\ (\sin \omega t + k \sin 2 \omega t)$, so that the induced electromotive force in the horizontal loop R of the airplane has about the course shown in Figure 17. This electromotive force is transmitted to a two-way rectifier in the output circuit of which a differential instrument is interpolated. The rectification produces unequal directive currents, due to the unsymmetrical electromotive forces. These currents determine the direction of deflection of the pointer. On flying across the landing-field boundary O (fig. 17), the magnetic field changes its direction with respect to the horizontal receiving antenna of the airplane and correspondingly also the induced electromotive force. This deflects the indicator pointer in the opposite direction. An automatic amplifier was used to render the reception of the flying altitude largely independent.

The directive transmission methods can be used for partial and rectilinear landing-field boundaries. Such, e.g., are the loop antennas used in America under the name "gun coil," in which the sectors of minimum radiation serve usually as the corresponding criterion. (Reference 8.) As compared with the circular cables, these methods have the disadvantage of providing only one landing direction.

2. Vertical Navigation Methods

a) Barometric altitude determination.- Ordinary barometric altimeters are generally unsuited for blind-landing purposes.* It is true that the altitude correction can be communicated to the airplane by radio, so that the height above the ground can be determined, but it is generally difficult to overcome the effect of pressure variations in the pilot's cockpit due to changes in the attitude of the airplane, the propeller r.p.m., etc., as also the mechanical lag of the instrument. Thus the accuracy of the indications, so important near the ground, is lost, and it becomes necessary to find more suitable methods. These are sought in acoustic, electric, and optical fields.

b) Altitude determination by reflection.- The "Behm Lot" (references 23 and 24) is the oldest and best known of the acoustic methods. With the firing of a pistol mounted on the aircraft, a ray of light is set in motion which casts a point of light on a vertical transparent scale so marked as to indicate the distance corresponding to one-half the velocity of sound. The sound reflected from the ground excites a microphone mounted on the airplane and generates a current impulse which deflects the point of light laterally, thereby indicating the height above the ground.

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*The American, Mr. Doolittle, in blind landing, used a special instrument, the Kollsmann precision altimeter, on which one scale division of 0.2 mm corresponded to an altitude difference of 3 m (about 10 ft.). (Reference 2.)

For blind landing, this method has the serious disadvantages that no continuous indication is shown and that a particularly attentive observation of the scale is required in order not to miss the instant of the indication. Confusion may result regarding the height above the ground, due to reflections from obstacles.

There have therefore been attempts to develop electro-acoustic methods with continuous indication of the flight altitude. Sounds are given off at short intervals (e.g., by compressor pipes) which, as well as the reflected waves conducted through suitable filters, activate the indicating instrument. All acoustic methods require a comprehensive analysis of the engine and other noises produced on the airplane, as well as a study of the changing conditions of reflection, in order to choose suitable working frequencies. According to flight tests the lowest heights which can be reliably indicated are about 2 m (6.56 ft.). (Reference 25.)

For determining the altitude, reflection methods have also been proposed which employ high-frequency oscillations. Short waves are reflected better than long ones. Among the published methods that of W. L. Everitt is of special interest. (Reference 1.) In Mr. Everitt's altimeter the frequency of the carrier wave is varied by the rotation of an air condenser. For a certain rate of frequency change, the beat note set up by the transmitted and reflected waves has a pitch which is a direct function of the altitude. Only a single loop is used for transmitting and for receiving the reflected waves. As compared with other radio altimeters, Mr. Everitt's instrument is simpler and has the advantage of indicating altitude directly instead of within a nodal distance. (Reference 26.) The practical value of the radio altimeter cannot yet be judged, since we do not have sufficient data on the reflection conditions of different terrains.

<u>c) Altitude determination from capacity variations</u>.- The approach of an airplane to the ground can be determined from the capacity changes in a suitably constructed condenser. All capacity methods can be based on the principles illustrated by Figure 18. The condenser consists of two metal plates a and b attached to the fuselage and connected with a measuring circuit c. The capacity of this condenser is determined principally by the size of the plates and the dielectric effect of the surrounding air. The capacity of the conductors is joined in parallel

to the measuring instrument d. On approaching the ground the capacity increases, due to the reduction in the plate distance, as well as to the generally greater dielectric constants of the ground. Since the dielectric constant of the air varies with the humidity and barometric pressure, the capacity altimeter is especially suitable for low altitudes, where the effect of the air is small with respect to that of the ground, and for the accurate determination of the leveling-off altitude of the airplane for landing. Corresponding instruments have been proposed in Germany by H. Wigge and List and tested at the expense of the Junkers Airplane Company. All these instruments differ simply in the form of the measuring circuit c. Bridge methods, beat methods, and resonance methods have been used. (References 27 and 28.)* The arrangement of the condenser plates on the fuselage, as used in experiments by R. Gunn (reference 29) is shown in Figure 19. Altitude measurements can be made by the capacity method from about 100 feet downward. This method is only conditionally reliable, since the dielectric constant of the ground varies with the atmospheric conditions.

d) Altitude determination by field-intensity measurements.- The flight altitude can also be determined by measuring the strength of the reception field. As already mentioned, use is often made of this method in connection with the leader-cable methods (Coock, Hanson, Loth, etc.). It is assumed, however, that the airplane is in a location where the field distribution is fixed and also that it remains over the cable with uniform field distribution along the cable. Another assumption is that the field is neither directly nor indirectly affected by the weather. In general the field distribution along the cable does not actually correspond to that sought, so that adequate accuracy of altitude determination for landing purposes is attainable only under certain conditions.

3. Gliding-Path Method

A method which provides a gliding path for the airplane was developed in America by H. Diamond and H. W. Dun-

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*Another method for measuring very small capacities, which is based on the "interruption method" in a tube circuit, was used by H. Löwy (reference 27) for measuring flight altitudes.

more. (Reference 9.) The gliding path was identical with a curve of constant reception-field intensity. For this purpose a directive beam was generated, as shown in Figure 20. This figure shows how the intensity of the reception field is affected by the angle of elevation, when the airplane moves in the vertical plane passing through the axis of the beam in an arc about the position O of the transmitter. By the angle of elevation ϑ is understood the angle at which the airplane is seen from O. Similar directive characteristics are received at various distances from the transmitter. The absolute values of the field intensities of these groups of curves are connected by the law of distribution for equal angles of elevation. In close approximation the field intensities are inversely proportional to the distance for ϑ = constant.

Since the angle of elevation ϑ is introduced into Figure 20 as an independent variable, it can overlap, in the representation with polar coordinates, a Cartesian system in which the abscissa is the distance d and the ordinate is the flight elevation h. It should be noted, however, that the plotted beam characteristic is valid only for a definite distance d, for example, for d = 1,500 m (4,921 ft.).

If an airplane flies from A at a height of about 200 m (656 ft.), the deflection in an instrument connected with the receiver will increase according to the degree of the increasing reception-field intensity. There are two reasons for the increase in the field intensity, namely, the increase due to the approach to the transmitting station (ϑ = constant) and that due to the approach to the axis of the beam characteristic ($\Delta\vartheta > 0$ for $\vartheta < \vartheta_m$). If the instrument has reached a certain deflection, say half the scale, the airplane is then steered so that the pointer indication remains constant. This then corresponds to keeping the reception-field intensity constant. Correspondingly, the airplane must so move that the increase in the reception-field intensity due to approaching the transmitting station is equal to the decrease in the reception-field intensity due to increasing the distance from the beam axis OP (diminishing the angle of elevation ϑ). This yields a gliding-path curve, which flattens out strongly in approaching the ground.

The practical solution of the problem is based on the use of ultrashort waves, since these greatly facilitate the bunching due to the small antenna dimensions and since the airplane antennas can also have small dimensions. Wave lengths of 3.2 m (93,700 kc) were used in the experiments at College Park. For energy concentration, eight horizontal dipole antennas of the length of a half-wave were used in depth arrangement. (Fig. 21.) The rearmost one formed the reflector, while the forward six served as directors. The seventh antenna was connected directly with the transmitter, all the others being excited by radiation coupling. The principal axis OP of the characteristic was inclined 8° to the horizontal. A transmitting power of 500 watts was used for a distance of 10 km (6.2 mi.).

The receiving apparatus consisted, as shown in Figure 22, of a horizontal dipole antenna connected directly with a detector-amplifier-rectifier unit in a streamline housing on the wing of the airplane. The modulated frequencies were rectified by a copper-oxide rectifier in the output circuit of the receiving set. The resulting direct current operated the indicating instrument.

This apparatus has the advantage of great simplicity. It requires no attention while landing. The correct landing path can be followed through variations in the sensitivity of the indicating instrument and through diminution of the intensity. In connection with this method, still other devices are required to insure the direction of approach and to keep the aircraft in the vertical plane in which the axis of the landing beam lies. These devices have already been described.

In connection with the work of Diamond and Dunmore, the gliding-path method of the D.V.L. was investigated and further developed in Germany. The flight tests with 4.7 m (15.42 ft.) waves were fundamentally satisfactory, but the practical application of this method still requires various modifications on which work is now in progress.

IV. SUMMARY

The extraordinary importance of safe blind landing for aircraft led to the development of numerous methods for facilitating it. The methods described represent partial solutions of the complex problem of blind landing. There are special methods for insuring the flight path, for indicating the boundaries of landing fields, for determining the flight and leveling-off altitudes and for establishing the gliding path.

It lies in the nature of the case that blind landing with the aid of instruments, as compared with visual landing from direct observation, makes much greater demands on the skill of the pilot. In judging the different methods, therefore, the ingeniousness of the signals and their freedom from ambiguity are of surpassing importance. They must be reliable. All the apparatus on board must be light and of small dimensions. It must require only the simple operation of a switch to throw it on or off.

In several of the above-described methods, no flight tests have yet been made. Though no satisfactory solution of the problem has been attained, valuable preliminary work has nevertheless been done.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

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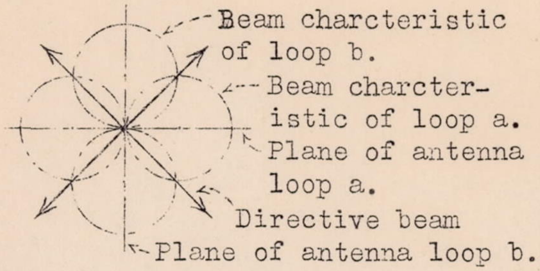


Fig. 1 Principle of a directive-beam transmitter (amplitude method).

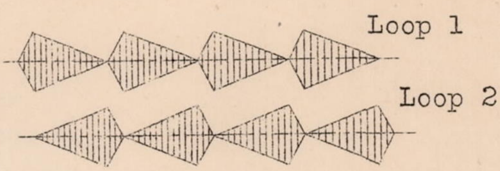


Fig. 6 Kramar method for directive-beam transmission. The two loops are symmetrically but inversely excited.

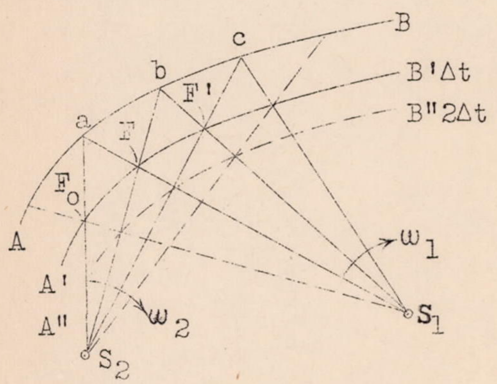


Fig. 7 Loth method.

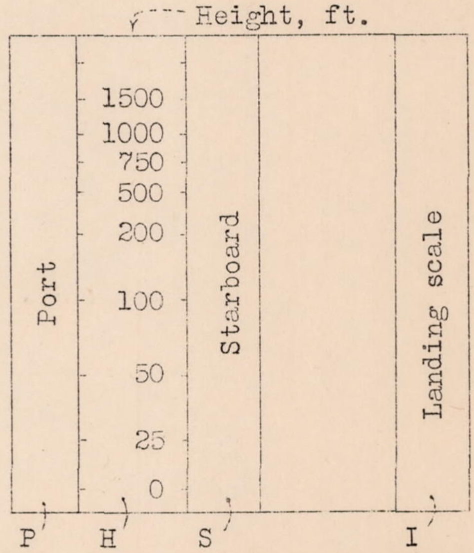


Fig. 11 Scale of Cooch indicator.

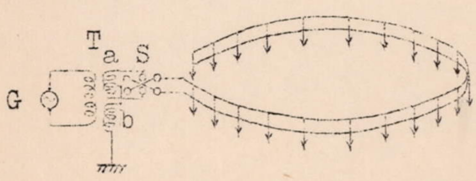


Fig. 14 Loth method for indicating field boundaries.

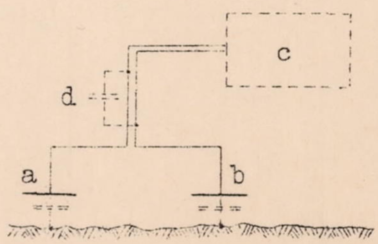


Fig. 18 Altitude determination from capacity variations.

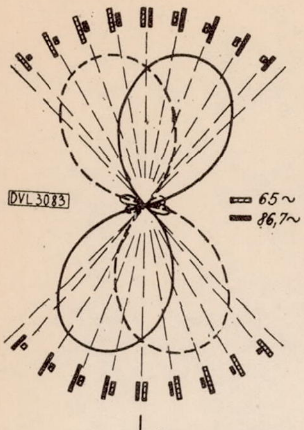
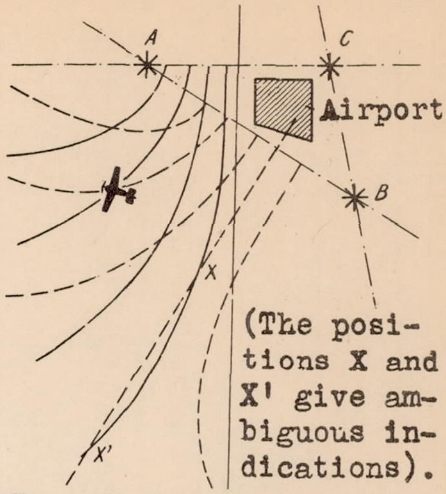


Fig. 5 Polar diagram showing relative reed deflections as a function of angular deviation from the runway localizing beacon course



(The positions X and X' give ambiguous indications).

Fig. 3 Direction finding by the Valoris method.

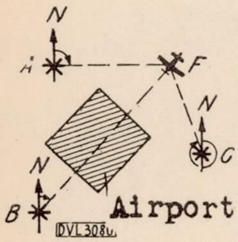


Fig. 2 Cross beacons.

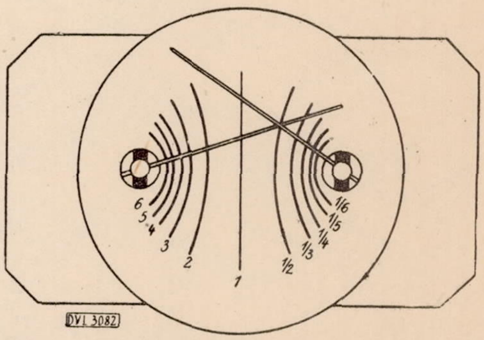
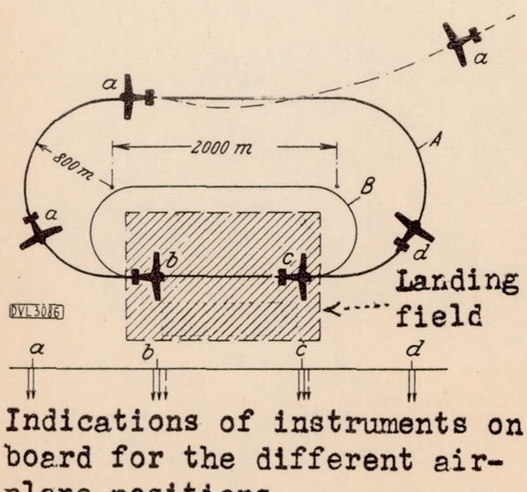


Fig. 4 Valoris bearing indicator. The numbers give the ratio of the distances from the two transmitting stations.



Indications of instruments on board for the different airplane positions.

Fig. 8 Cooch leader-cable method. A, leader cable for approach to airport. B, leader cable for landing.

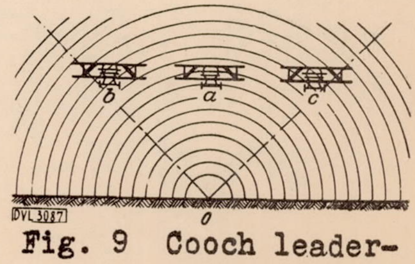


Fig. 9 Cooch leader-cable method. Arrangement of loop antennas for determining lateral position with respect to cable.

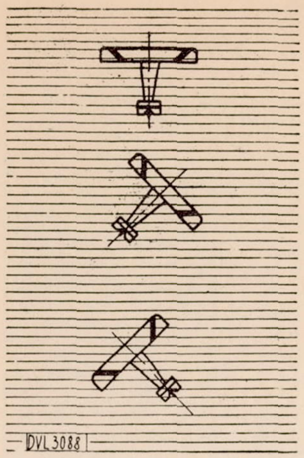


Fig. 10 Cooch leader-cable method. Arrangement of loop antennas for determining angular position with respect to cable.

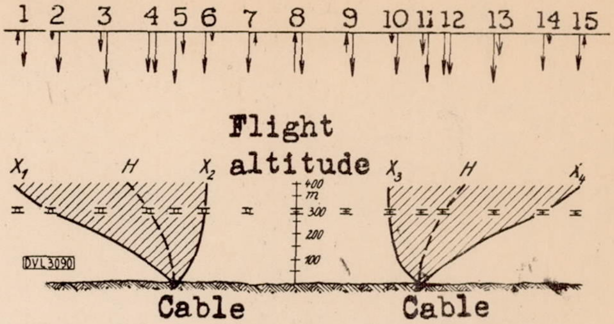


Fig. 12 Principle of Cooch leader cable. (A in Fig. 8)

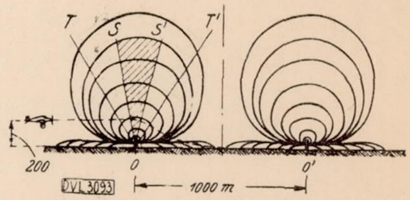


Fig. 15 Field distribution of circular cable.

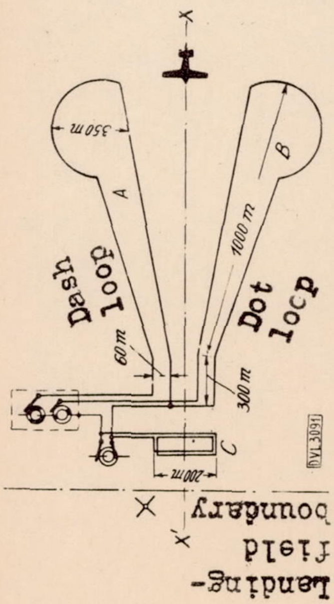


Fig. 13 Hanson leader-cable method.

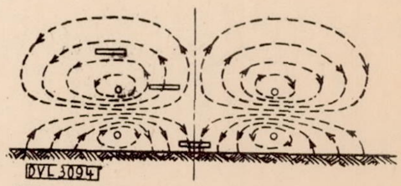


Fig. 16 Leveling-off altitude

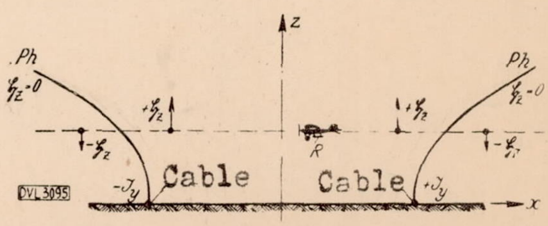


Fig. 17 Gromoll-Johannson method of indicating landing-field boundries. Field is bounded by the phase-varying area Ph. The signals are received by the horizontal loop antenna R.

Fig. 20 Gliding-path method.

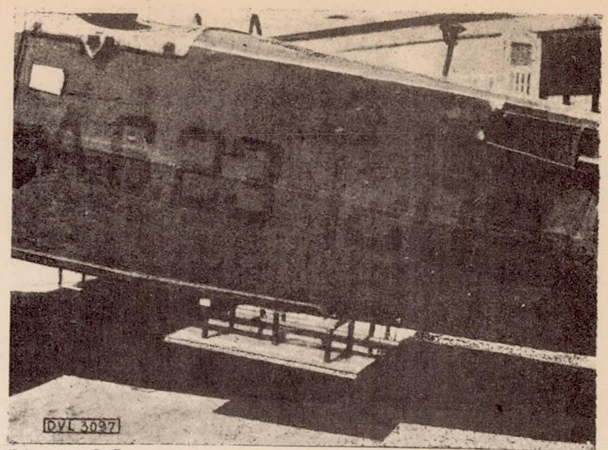


Fig. 19 Arrangement of condenser plates for determination of altitude by capacity method.

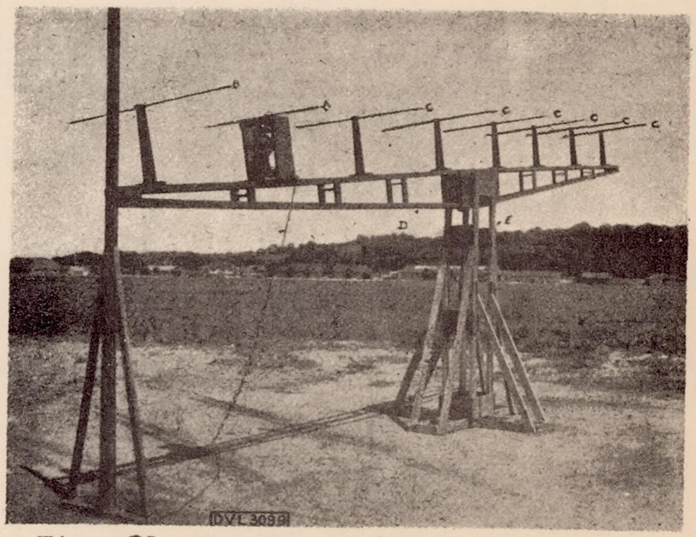


Fig. 21 Landing beam transmitting system, showing electron-tube oscillator and directive-antenna array.

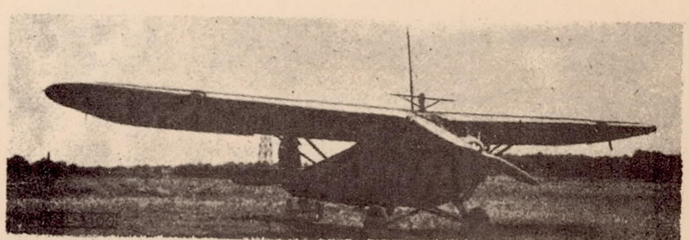


Fig. 22 Bureau of Standards' experimental airplane showing horizontal doublet antenna used for receiving the landing-beam signals.