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THE PRESENT STATE OF DEVELOPMENT OF RADIO INSTRUMENT AIRPLANE LANDING SYSTEMS IN THIS COUNTRY AND ABROAD

BY

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During a number of years it has been possible and practical for a trained instrument pilot to take off in an airplane and, by means of radio facilities, fly with a high degree of accuracy and comparative safety to the vicinity of a distant airport. Weather conditions along the route occasionally prohibit such flights but poor visibility by itself is never a controlling factor. The real problem and the most difficult part of an instrument flight is the landing of the ship when a low ceiling and poor visibility prevail at the destination.

At the present time in the United States, the pilot has means of knowing when he is over the airport radio range station by observing the so-called "cone of silence" corresponding to a vertical null in the radiation diagram of the radio range antenna. With a ceiling of 300 feet or better and a minimum of 1 mile visibility, a safe landing can usually be made from the "cone of silence" by altimeter, compass and knowledge of surrounding terrain. While it is sometimes possible to make landings by this procedure with ceilings below 300 feet, the operation is considered risky and is only permitted in cases of emergency. The procedure is definitely hazardous for ceiling heights of less than 100 feet.

Based on these facts and a desire to ensure the safety of air transportation in the United States, the Bureau of Air Commerce has specified a minimum safe ceiling requirement for every commercial airport in the country, varying between 300 and 800 feet according to the size of field, surrounding terrain, neighboring obstacles, radio facilities, etc. No flight can be undertaken to a destination where the ceiling at the time of the proposed flight is below the established minimum. At present practically all flight cancellations on scheduled air transport lines in the United States are due to this single flight limitation. Therefore, further improvement in the regularity of commercial air transport service is contingent on a safe reduction or elimination of the ceiling limitation and this can be made possible only by the provision of adequate "poor visibility" landing facilities.

The problem is not a new one. During the past ten years experimenters have devised various aids to poor visibility landings. Some utilized radio waves while others were based on the use of infra-red radiations. Various types of high power visible light beams have been tried and artificial fog dissipation has been achieved experimentally over limited areas. Perhaps the most promising, from a technical and economical standpoint, is the radio method and considerable progress has been made in this direction. It is conceivable, however, that the future system may be a combination of several types of facilities. In fact, it is already determined that high-power runway approach lights are a desirable supplement to a radio landing system inasmuch as they provide additional assistance during the last 50 feet of descent, even in the heaviest fog, which is precisely the time the aid is most needed.

The requisites for a complete radio instrument landing system are the following:

(1) A radiation pattern for the purpose of establishing

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the vertical plane of approach, usually called the localizer beam. The localizer beam provides the necessary directional guidance.

(2) A radiation pattern for the purpose of defining the line of descent in the vertical approach plane, generally known as the glide path beam.

(3) Several sharply defined vertically directed radiation patterns at suitable points along the line of approach for the purpose of providing spot indications of the distance from the airplane to the airport. These radiation patterns are produced by marker beacons and while not absolutely necessary from a theoretical point of view, these beacons serve useful, practical purposes which will be described later. Fig. 1 illustrates the essentials of a complete radio landing system. The vertical approach plane for directional guidance is indicated by the shaded area. The white line in the approach plane represents the path of descent to the airport at the right. The marker beams are indicated by the two pear-shaped shaded areas.

The earliest experimental work on a radio landing system was started in 1929 by Diamond and Dunmore of the Bureau of Standards on appropriation from the Aeronautics Branch of the U. S. Department of Commerce. The first experimental radio instrument landing under the hood took place in September, 1931 at College Park, Maryland and trial installations were completed at Newark, New Jersey and Oakland, California in 1933 and 1934 respectively.

The Newark installation consisted of a runway localizer beam, a glide path beam, two marker beacons, and a centralized monitor unit for the control of the various transmitters.

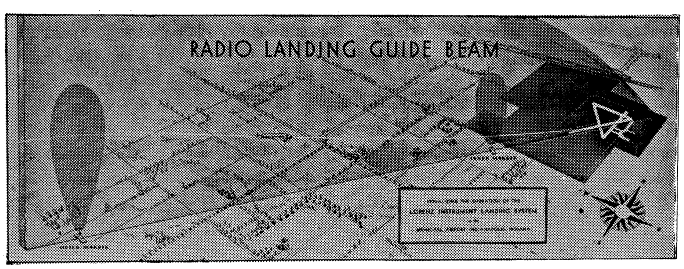

FIGURE 1
RADIO LANDING GUIDE BEAM

The localizer beam was obtained by utilizing the well-known radio beacon principle whereby one of the equisignal zones of two directive and overlapping radiation patterns determines the direction of approach. Two small multi-turn crossed loops operating on 278 kc. were used to produce the necessary radiation patterns. Fig. 2 illustrates how equisignal zones are formed by the radiation patterns of two crossed loops. The two loops were supplied with energy of the same carrier frequency, but with different modulation frequencies. After detection in the aircraft receiver, the two low frequencies were separated by means of filters and following rectification, the two DC outputs were applied differentially to a zero center microammeter. A predominance of one signal over the other would cause the needle to indicate right or left of center, thus providing a positive and quantitative off-course indication. Automatic volume control took care of the increasing signal as the plane approached the airport.

RADIATION PATTERNS OF TWO CROSSED LOOPS SHOWING EQUISIGNAL ZONES

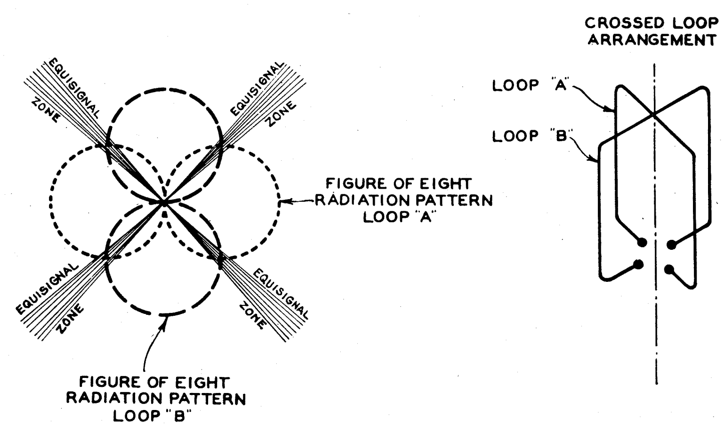

FIGURE 2
RADIATION PATTERNS OF TWO CROSSED LOOPS SHOWING EQUISIGNAL ZONES

The first scheme for defining the line of descent or glide path was also based on the beacon principle. In this case, the two loops were turned on their sides in an effort to establish two radio beams making different angles with the ground, the equisignal zone serving as a straight line descent path. This method of attack was abandoned because of the difficulties caused by ground reflection at the frequencies used.

The next step was to utilize lines of constant field strength for glide path definition. While these lines are parabolic in shape, it was found that a region could be selected where the curvature is sufficiently broad and of suitable slope for normal glides. Fig. 3 shows a number of lines of constant field strength. The heavy line is chosen as the best approximation to the average glide angle. Actually an infinite number of constant field strength lines make up the complete pattern.

In the Newark installation, horizontally polarized waves were used on a frequency of 90.8 megacycles per second. The signal was detected and rectified in a fixed gain receiver. The DC output was applied to a microammeter turned on its side in such a way that the needle assumed a horizontal position for midscale deflection. To

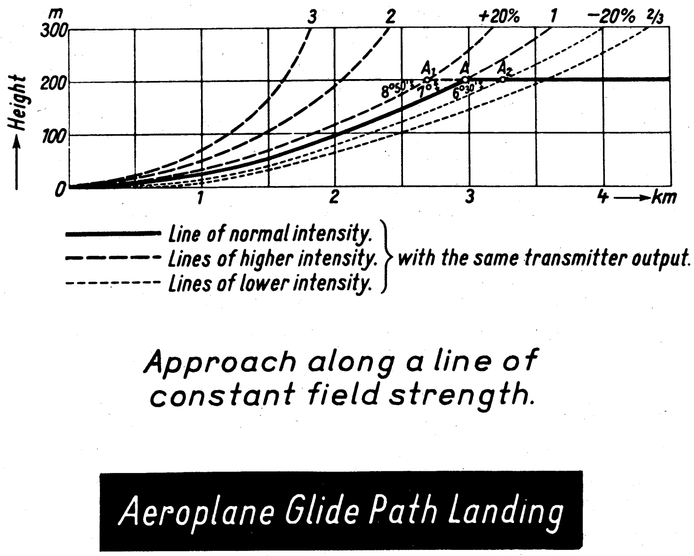

FIGURE 3
AEROPLANE GLIDE PATH LANDING

follow the glide path, the pilot flew the ship to keep the needle at a constant reading, usually in the horizontal position. An increase in reading indicated that the airplane was flying above the glide path while a decrease in reading indicated that the airplane was flying below the glide path.

In the final arrangement, the localizer and glide path microammeters were combined in a single instrument having two crossed pointers. With this device, the point of intersection of the two needles gives the position of the airplane with respect to the glide path. For example, when the pointers intersect in the upper right hand quadrant of the instrument dial, the pilot knows that the airplane is above and to the right of the landing beam. To correct his position, the pilot must increase the rate of descent of the plane at the same time bearing left until the pointers intersect at a small circle in the center of the instrument dial. Fig. 4 shows three typical instrument indications and their interpretations.

Two marker beacons operating on the aircraft communication frequency of 3105 kc. per second were installed along the line of approach, the first at 2000 feet from the airport boundary, and the second at the boundary. The marker antennas consisted of long wire horizontal radiators (3500 and 2500 feet long respectively for the outer and inner markers) stretched about 2 to 8 feet above the ground transversely to the direction of flight. The marker transmitters were modulated at 1000 cycles per second and a sharply defined minimum signal in the pilot's earphones indicated the passing of a marker. The outer marker was not provided in the earlier installation at College Park.

The technique of landing by the Bureau of Standards—Department of Commerce system was for the pilot to locate himself about 1000 feet over the airport radio range station which he could do by utilizing his barometric altimeter and observing the "cone of silence." At this point, the pilot retuned the receiver for the landing beam and proceeded by compass and knowledge of local geography to intercept the localizer beam at a distance of 5 to 10 miles from the airport. The localizer beam was then followed at an altitude of 1000 feet until the glide path indicator needle reached mid-scale, which was the signal to reduce speed and start the glide. The pilot then flew the ship to keep the glide path indicator at midscale position and the localizer needle at center. Upon reaching the outer marker, an altimeter reading of about 150 feet served as a check that the glide path had been followed correctly. Also at this point the pilot throttled down to landing speed. Finally, the inner marker indicated that the boundary of the airport had been crossed.

The work at College Park and Newark demonstrated that a localizer beam operating in the low frequency band was not entirely satisfactory due to the presence of multiple and bent course effects. These appeared to be caused by reflections from utility lines, buildings, hills, and other obstacles.

Working along parallel lines, the Lorenz Company of Berlin, an associated company of the International Telephone and Telegraph Corporation, completed in 1932 an experimental radio instrument landing installation at the Berlin-Templehof Airport. A number of important improvements were incorporated in this system.

The first advancement was the utilization of ultrahigh frequencies for all services including localizer, glide path, and marker beacons. At the higher frequencies the localizer beam was found to be practically free from multiple and bent course effects. Greater freedom from atmospherics and other types of electrical disturbances also proved to be advantageous, while the limited range of effective propagation permitted operation at many airports on the same frequencies resulting in a simplification of receiver design and operation.

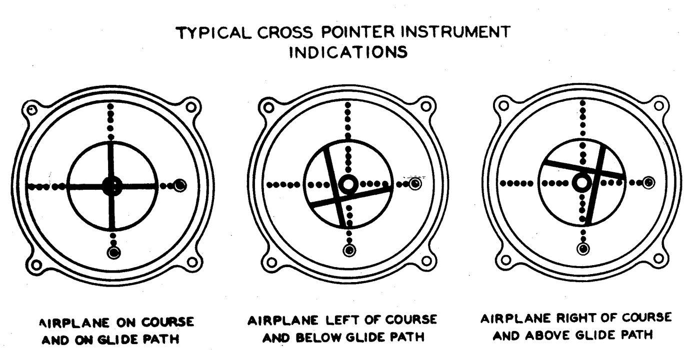

FIGURE 4
TYPICAL CROSS POINTER INSTRUMENT INDICATIONS

Secondly, the localizer and glide path transmitters and antennas were combined in a single transmitter and antenna. The saving in equipment cost was considerable since the separate glide path transmitting arrangement was a major item of the cost of the earlier system.

The third major improvement was the relocation of the outer marker at a point about 2 miles from the airport where its purpose is to indicate the starting point of the glide. With this arrangement, it is not necessary for the pilot to observe a gradual build-up of signal to a predetermined value to know when to start the glide; the necessary warning is received from the marker beacon at which time the pilot sets the glide path indicator needle at a convenient reading which is then held constant by flight manipulation during the descent. An important advantage of this arrangement is that changes in the electrical characteristics of the system such as shifting of the glide path due to ground variations or a change in receiver gain will not alter the starting point of the glide and moreover the shape of the glide path will remain substantially unchanged. With the earlier method, where the glide is started at a predetermined signal strength, a raising of the glide path or a loss of receiver gain resulted in a late start and a steeper glide to the airport. A lowering of the glide path or an increase in receiver gain advanced the starting point and the glide path would be flatter and more hazardous from an obstacle standpoint.

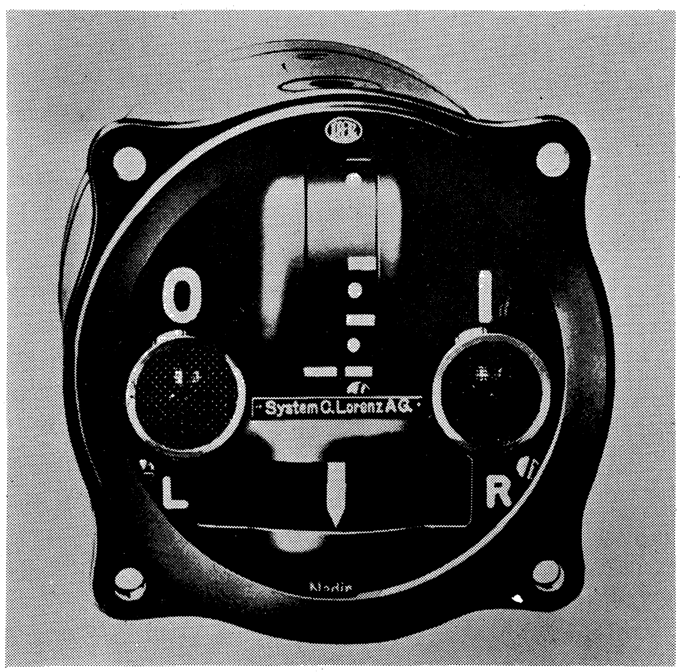

Figure 5
Lorenz Radio Landing Instrument

Other improvements by Lorenz included positive indicating marker beacons of simple design and construction and the incorporation of the marker beacon signal lamps in the aircraft landing instrument thus concentrating all landing indications in a single instrument.

A later advancement of considerable merit was the selection of very effective marker modulation frequencies and keying rhythms. The outer marker is modulated at 700 cycles per second and keyed at the rate of one dash per second. The inner marker is modulated at 1700 cycles per second and keyed at the rate of five dots per second. The psychological effect on the pilot appears to be correct. The low pitched slow dashes at the outer marker call for calm, deliberate preparation for the descent. While the high pitched fast dots at the inner marker suggest diminishing time intervals and put the pilot on his toes for the actual landing.

It may be well at this point to complete a brief description of the Lorenz radio instrument landing system.

All pilot indications are reproduced both aurally and visually for reliability and safety. As already mentioned, the visual indications are concentrated in a single instrument having a vertical glide path scale, a horizontal localizer scale and two marker lamps of the neon type, capable of following the keying rhythm of the markers. Fig. 5 is a view of the most recent type of Lorenz radio landing instrument.

Vertical polarization is used for the combined localizer-glide path transmitting system. A unique antenna arrangement is employed as illustrated in Fig. 6. The carrier power modulated at 1150 cycles per second is fed into a vertical dipole, S. Two parasitic reflector dipoles, R_1 and R_2, spaced about one-quarter wavelength on each side of the exciter are keyed alternatively, the first with dots and the second with dashes at intervals of 1 second. Each reflector produces an elongated radiation pattern as

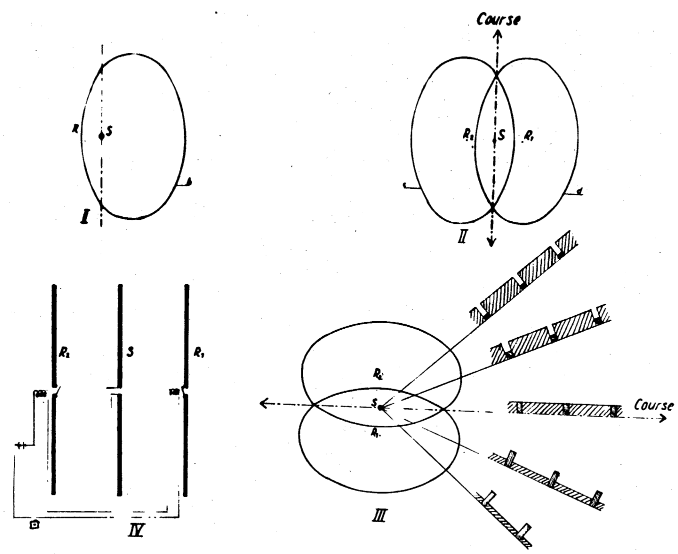

Figure 6
Lorenz Localizer-Glide Path Antenna Arrangement and Corresponding Radiation Patterns

illustrated in Fig. 6 and the two patterns are symmetrically arranged about the equisignal axis. Along the equisignal or on-course zone, the dots and dashes blend to provide a continuous tone whereas in an off-course position one signal or the other predominates and is easily distinguished audibly. A visual indication is obtained by utilizing the differential in time duration of the two signals.

A view of a practical antenna installation with transmitter house is reproduced in Fig. 7 Fig. 8 is a view of the combined localizer-glide path transmitter. The marker beacon antenna arrangement and equipment are shown respectively in Figs. 9 and 10. Fig. 11 is a view of the monitor equipment which provides facilities for starting and stopping the equipment from the airport control tower and for checking the output powers and keying rhythms of the various transmitters. Aural monitoring facilities are also provided.

During 1932 and 1933, an instrument landing system utilizing radio waves for directional guidance and barometric instruments for determining the glide path was developed and tested by the U. S. Army. This system,

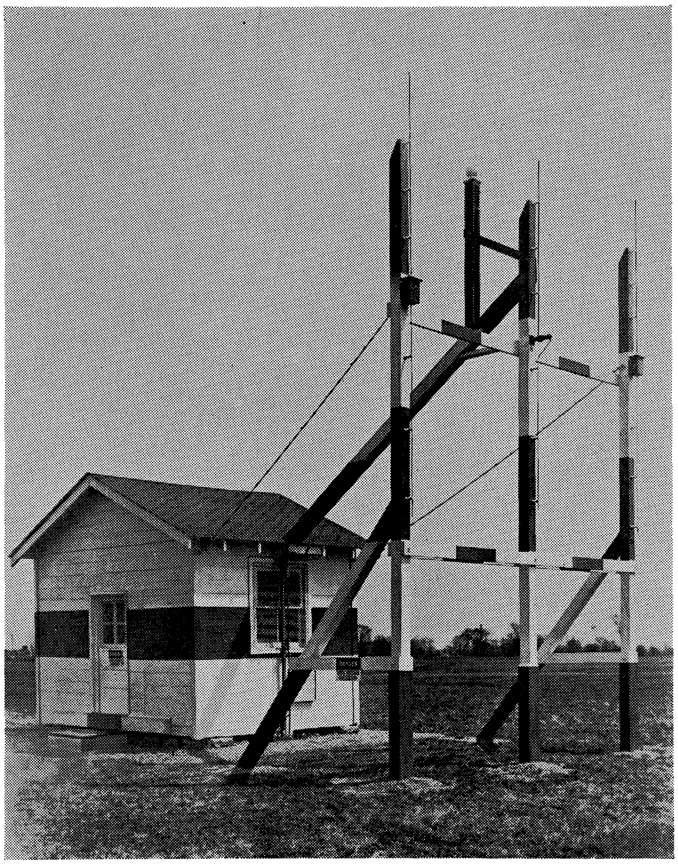

FIGURE 7
LOCALIZER-GLIDE PATH TRANSMITTER ANTENNA AND TRANSMITTER HOUSE AS INSTALLED AT INDIANAPOLIS

known as the Hegenberger System, utilized two low frequency ground transmitter stations, located about 1500 feet and 2 miles respectively from the edge of the field. The pilot, wishing to land, flies the airplane to the inner station, utilizing a visual homing type of compass for this purpose. An ultra-high frequency marker also located at the inner station causes a lamp on the airplane instrument panel to light when the ship arrives over the inner station. The low frequency receiver is then tuned to the frequency of the outer stations. The arrival of the plane at the outer station is also signalled by an ultra-high frequency marker. One or more trips between the two stations enable the pilot to establish the approach

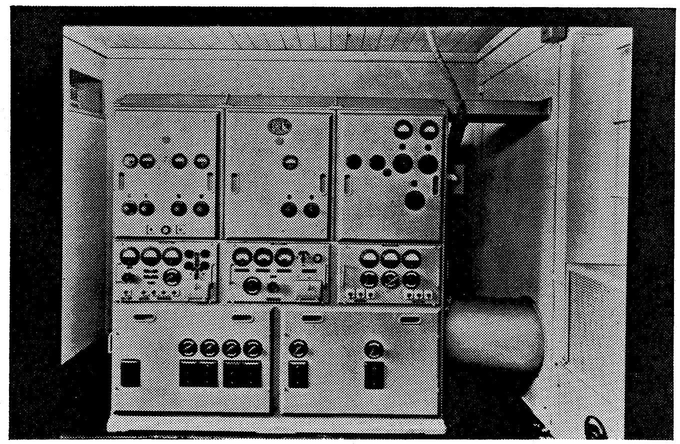

FIGURE 8
LORENZ 500-WATT LOCALIZER-GLIDE PATH TRANSMITTER

heading on the directional gyro compass making allowance for cross wind components. For the final approach, the pilot lets down to 800 feet as indicated by altimeter and heads towards the landing field on the established course. Upon passing the outer station, the engines are throttled and a power glide of a predetermined angle is followed bringing the ship to an altitude of about 150 feet at the inner marker. After the inner station is passed, the pilot must rely on his directional gyro for course holding the same rate of descent until the wheels touch the ground.

The two ground stations were also mounted on automobile trucks thereby permitting the orientation of the system to meet different wind directions. In addition, the portable arrangement made it possible to take care of any desired glide angle by a proper selection of the distances between the two stations, and between the inner station and the airport.

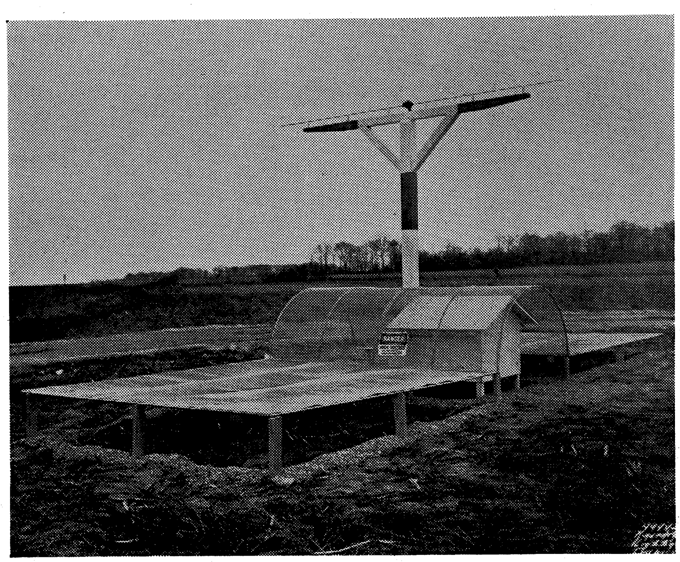

FIGURE 9
MARKER BEACON ANTENNA ARRANGEMENT AND EQUIPMENT HOUSING

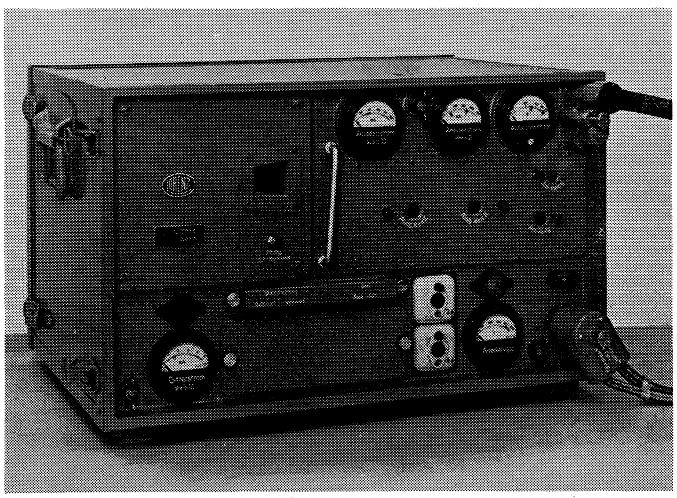

FIGURE 10
LORENZ 5-WATT MARKER BEACON EQUIPMENT

There appear to be two disadvantages to the system. Firstly, the pilot must rely on a barometric altimeter for altitude. Secondly, a heading established by radio compass may be subject to considerable error when variable cross winds are present.

In 1935, the Washington Institute of Technology completed the development of a radio instrument landing equipment for portable use. The elements were similar to those of the original Bureau of Standards system. The ground equipment, except the marker beacon, was mounted on an automobile trailer to permit the operation of the system in any direction. Concrete troughs for the trailer wheels and power outlets were provided at the end of each runway. The chief advantage of the W.I.T. development lies in the fact that one equipment (except markers) serves for landing into several wind directions. This advantage is somewhat offset by a higher initial cost in cases where a single landing direction meets requirements. The operation of the localizer on 278 kc. where multiple and bent course effects are troublesome, constituted the principal disadvantage.

In 1934, the equipment installed at the Oakland airport by the Department of Commerce was taken over by the United Air Lines for further tests and improvements. The following year, the Bendix organization entered into cooperation with the United Air Lines in matters of radio design. The joint experimental work and flight testing continued until August of this year. Basically, the United-Bendix installation followed the lines of the earlier Department of Commerce system. However, ultra-high frequencies were used for all services and the Lorenz combined localizer-glide path transmitter principle was adopted. Two horizontal Yagi antenna arrays, the axes of which diverge at an angle of 30° provided horizontally polarized localizer and glide path beams. The radiation patterns of the two Yagi arrays showed an angular displacement of about 40°. Motor driven contactors placed in the first director dipoles represented an ingenious method of modulating the two arrays at 90 and 70 cycles per second respectively. A rectifier-filter and differential microammeter circuit in the aircraft receiver provided a steady right-left course indication on an instrument of the crossed pointer type.

This year brought about renewed interest in the radio instrument landing problem in the United States. A study of the subject revealed that Europe had advanced considerably in the commercial application of instrument landings systems. While many experimental systems had been tested in this country over a period of ten years and major contributions had been made to the art, the air transport industry still lacked practical installations for use under service conditions.

In Europe, the Lorenz system had been adopted as standard and approximately 30 ground installations and 200 plane installations were in constant use. In addition, 10 installations were being operated and 2 more installations were in progress in other parts of the world, notably Australia, Japan, Argentina, and South Africa. Germany alone had 15 ground installations, and the German Lufthansa was using the Lorenz landing system to such advantage that flight cancellations were exceedingly rare, in spite of fog conditions comparable to those in the coastal regions of this country. To our knowledge, there have been no landing accidents in Germany during the period radio instrument landing has been in operation. The results were considered sufficiently satisfactory for the German government to remove all restrictions regarding

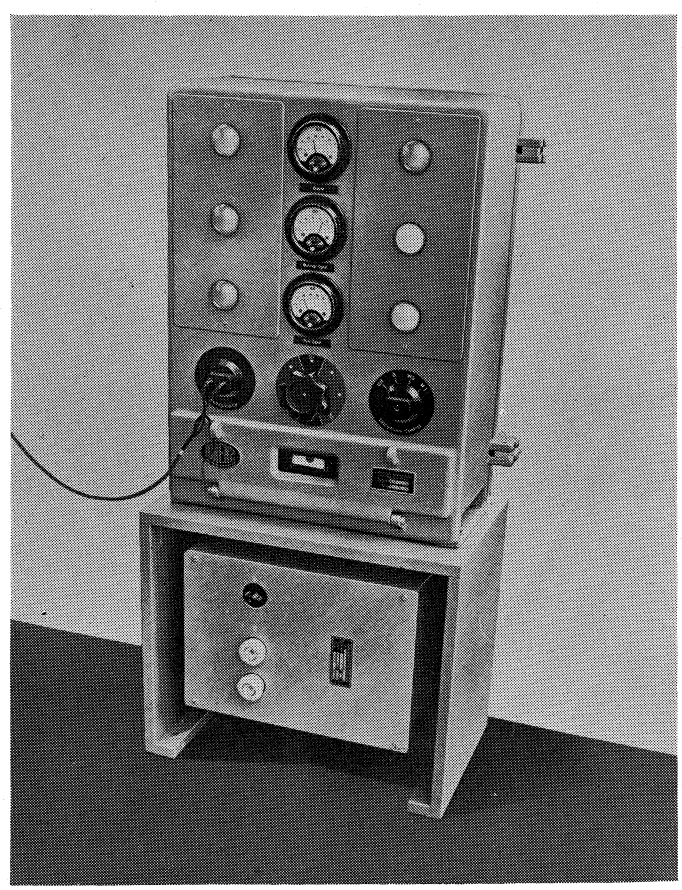

FIGURE 11
LORENZ RADIO INSTRUMENT LANDING MONITORING AND CONTROL UNIT

ceiling limitations, although a limitation of 50 feet is usually imposed by the airport control officer. Landings are frequently permitted with ceilings down to 30 feet where the pilot is known to be especially skillful and conditions seldom prevent the sight of ground at this altitude.

In view of the definite need for a radio instrument landing system in this country and the technical and commercial success of the Lorenz System in Europe, the International Telephone and Telegraph Corporation early this year offered to cooperate with the Bureau of Air Commerce in bringing over a Lorenz equipment for tests under American conditions. Arrangements were made with the City of Indianapolis to use the municipal airport for this purpose. The system was set up and flight tested in April and May by numerous representatives of the Government services and air transport companies.

To interpret the results, it is necessary to take into account an important difference between European and American airports. In Europe, uniformly sodded landing fields are the rule and a large area is available for landing in any direction. In the United States, on the other hand, it is the general practice to provide hard-surfaced runways, usually of concrete, for landing into six or eight wind directions. Except during the summer season, off-runway landings are frequently unsafe for transport ships. The runways are usually 100 to 150 feet in width and the problem of lateral navigation by radio instrument calls for extreme accuracy.

The precision of the Lorenz system, which was designed for open field landings, is sufficient for a hooded or absolute zero-zero landing along a 500-foot strip. At Indianapolis, it was evident that a considerable increase in sharpness of the localizer beam would be required for landing on the 105-foot runways provided at that airport. In fact, based on the results of several radio instrument landing systems, it now appears doubtful that zero-zero landings could be made consistently on anything less than a 200-foot runway. The ultimate solution will probably call for uniformly surfaced airports or special radio instrument landing runways having minimum widths of 200 or perhaps 300 feet.

Another interesting observation was made at Indianapolis. During the last portion of the descent, a rapid rise in field strength and consequently glide path indication occurred about 300 feet from the approach end of the runway. This was due apparently to a discontinuity in the electrical constants of the ground surface at the end of the runway. Parallel approaches 50 feet to the side of the runway were found to be free from this disturbance, the glide path remaining smooth to the point of contact. Further tests with horizontally polarized waves showed that this phenomenon only occurred with vertical polarization.

A number of pilots felt that the signal build-up at the approach end of the runway served as an effective marker to signal the start of the runway. However, the majority of pilots as well as all radio engineers felt that this type of indication is not reliable and should be definitely eliminated.

By August of 1937 the United Air Lines and the Bendix Radio Corporation were ready to demonstrate their development at Oakland, California. Their contribution from a radio design standpoint was the provision of a sharp, steady course indication. Landings were made consistently on a 200-foot runway and the occasional few that missed the runway because of heavy cross-wind conditions would have been safe on a 400-foot runway.

A considerable portion of the sharpness was obtained by utilizing a fairly high degree of directivity in the localizer transmitter system. This introduced a disadvantage in that the indications to the sides and rear of the approach direction become unusable and it is necessary to rely on the airport radio range and dead reckoning for the initial contact with the landing beam. The Lorenz System, on the other hand, permits self-orientation within a radius of 25 miles of the airport. It is believed that the feature of self-orientation can be retained with a sharp course indication by increasing the sensitivity of the receiving system.

A new flying technique for radio instrument landings was developed by the United Air Lines. First of all, high speed landings about 30% above normal provided better controllability of the ship and it was found that the beam could be followed with greater accuracy. Secondly, the Sperry automatic gyro pilot was used to keep the ship on a steady keel thus relieving the pilot of a number of operations and permitting increased concentration on the landing indications. Small manual adjustments of the gyro pilot settings kept the ship on the landing beam during the descent. It was found that once the pilot became accustomed to the procedure, more accurate landings were obtainable with the aid of the robot pilot. No attempts were made to couple the radio landing signals to the automatic pilot although it is felt that this will probably be accomplished at some time in the future.

A general agreement now exists between the various commercial airlines of the United States as to what should constitute a practical radio instrument landing system and it is expected that a number of installations will be available in the near future for commercial use. At meetings in Chicago in June, and Oakland in August, the representatives of the Bureau of Air Commerce, the major air transport companies, and several radio manufacturing companies, drew up tentative fundamental requirements, for a standardized United States radio landing system incorporating what were considered to be the best points of all previously developed systems. The opinion was expressed that the experimental ground had been adequately covered and that further experience could best be gained by the commercial use of the standardized landing system. It was the consensus of opinion that radio instrument landing facilities should be government-owned and operated.

It is expected that the U. S. System will not be interchangeable with the European System, principally because of the choice of operating frequencies. The established European frequencies of 33.3 and 38 megacycles/sec. respectively for the localizer-glide path and marker services are in extensive use throughout the world and a change now could be made only at great expense. It is unfortunate that the Federal Communications Commission has not found it possible to make these same frequencies available for instrument landing purposes in the United States. The selection of very much higher frequencies, namely 92 to 96 megacycles/sec. for the glide path and 75 megacycles/sec. for the marker beacons, to the exclusion of the lower frequencies in the United States, will probably work a hardship on airlines engaged in the future in transatlantic air transportation.

It is recognized that there is a technical basis for the selection of the higher frequencies on the grounds that they do not reflect from the Kennelly-Heaviside layer and therefore, do not travel far beyond the optical range. It is also universally agreed that transmissions at frequencies of the order of 30 to 40 megacycles/sec. are frequently receivable at great distances but it is interesting to note that, with one exception, no cases of perturbation in operation of the Lorenz System have come to the attention of the engineers responsible for this service. The observations are very complete and cover all distances of separation of installations up to approximately 10,000 miles. The exception was in the case of two installations in Germany located about 30 miles apart and within optical range. While this absence of interference may appear surprising on first thought, it can be explained by the fact that the field intensity, as used in the Lorenz System, is very high in the landing beam, being of the order of 300 to 500 millivolts/meter. The field intensity of the strongest signal arriving from a distant point by way of the Kennelly-Heaviside layer would be negligible in comparison.

One further point may be of interest. There is considerable objection both in Europe and the United States to the shape of the glide-path due to the fact that the start of the glide is steep while the end of the glide is very flat over a considerable distance. While a number of European air lines fly the glide path, the German Lufthansa prefers to descend at a constant glide angle by altimeter using the glide path radio indicator as a check on altitude at the outer and inner markers. This procedure is dictated by the German practice of locating their airports near the central part of the cities where buildings and other obstacles would prevent following the radio glide path to the ground.

Considerable experimental work has been carried out or is in progress in an attempt to provide a glide path having a steeper slope during the final part of the glide. In Germany, it is hoped that an absolute radio altimeter will be available providing the pilot with facilities for selecting his own glide angle depending on the characteristics of the type of ship he is flying. In the United States, the Bureau of Standards have succeeded in obtaining a steeper glide path for a given point of contact by placing the glide path transmitting system in a pit in the ground while others are attempting to obtain a straight line glide path by a double beam equisignal method utilizing frequencies of the order of 600 megacycles per second.

In this paper, it has been necessary to limit the discussion of radio instrument landing systems as space would not permit a detailed description of all the work accomplished by the many organizations and individuals engaged in this activity.

For the information contained in this paper, the writer is indebted to a score or more of individuals who are actively connected with the development, application and utilization of radio instrument landing systems in this country and abroad.

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