CIVIL AERONAUTICS AUTHORITY

Technical Development Report No 1

THE STATUS OF INSTRUMENT LANDING SYSTEMS

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Formerly Report No 1, Safety and Planning Division, Bureau of Air Commerce, Department of Commerce, Reprinted by the Civil Aeronautics Authority

OCTOBER 1937

UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON . 1940

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FOREWORD

The author wishes to acknowledge the able assistance and cooperation of many people in the airline companies, radio laboratories, and other Government and commercial organizations, without whose valuable contributions this report and the results described therein would not have been possible

REPORT ON THE STATUS OF INSTRUMENT LANDING SYSTEMS

SUMMARY

During the past 10 years a large number of instrument landing systems have undergone development and tests and a considerable fund of information has been accumulated concerning the short-comings and advantages of each The major air lines of the United States, the Federal Communications Commission, the Bureau of Air Commerce, and the subcommittee on Instrument Landing Devices of the Radio Technical Committee for Aeronautics have reached an agreement as to the fundamental elements which should be incorporated in a practical instrument landing system and have also outlined a program of projected development Having this agreement, it is now possible for all interested organizations to proceed with the perfection of a practical system by combining the superior features of the systems which have been tested and to carry on development which will further augment this system At present, the major air lines are planning to install a number of instrument landing systems, having the fundamental elements agreed upon by the abovementioned organizations, to be used on an experimental and pilot training basis It is recommended that the Bureau of Air Commerce sponsor further development of instrument landing equipment until it meets the approval of all concerned with regard to operation, reliability, and ease of maintenance as well as fundamental elements When this condition is reached, it is recommended that the Bureau of Air Commerce purchase, install, and operate a number of these instrument landing systems at various airports throughout the United States on an experimental basis

INTRODUCTION

About the time that directional radio facilities were being considered as an aid to the navigation of aircraft under conditions of restricted or zero visibility, it became apparent that, with further modifications, directional radio transmission could be utilized to assist a pilot in landing an airplane where a low or zero ceiling prevailed Although some work was done as early as 1919, no especially promising results were obtained until about 1929 when the Bureau of Standards produced a complete instrument landing system Following this, several solutions to the problem have been proposed, all of which can be grouped as follows First, those which employ radio transmission merely as a means of enabling an airplane pilot to orient himself in a horizontal plane, after which he must depend on an altimeter in making the final landing maneuver; second, arrangements in which radio transmission supplies the pilot with both lateral and vertical guidance using the altimeter only to check the radio indications, and third, methods employing a medium other than radio for the transmission of landing information to the pilot In this report, progress in the development of systems falling under the first two classifications will be outlined Study and development of methods falling under the third group is progressing and will be made the subject of a later report.

DESCRIPTION AND DISCUSSION OF DEVELOPMENT

National Bureau of Standards Developments.

In 1919 the National Bureau of Standards developed experimentally a radio system to aid airplanes landing during poor visibility The system comprised the use of a direction finder on the airplane in conjunction with a marker beacon to localize the landing field (*1*) The marker beacon employed two horizontal loop antennas, one above the other It produced a vertical distribution of intensity, including a cone of silence, which effectively indicated a position with respect to the landing field The transmitter used was a half kilowatt spark transmitter operating on approximately 300 kc

In 1928 the National Bureau of Standards developed for the Aeronautics Branch of the Department of Commerce (now the Bureau of Air Commerce) a blind landing system comprising a radio range in conjunction with marker beacons In this system, the radio range is placed near the landing field and one course is alined with the runway on which it is desired to land One or more marker beacons are located on the course at suitable distances from the desired point of landing to give the pilot an indication of his distance therefrom and thereby to assist him in suitably controlling the altitude of his airplane as indicated by either a barometric or an absolute altimeter A report outlining this system was submitted to the Daniel Guggenheim Fund for the Promotion of Aeronautics in 1928 A runway localizer (radio range with course alined with runway) and marker beacon were installed by the Bureau at Mitchel Field in 1929 for blind-landing experiments (*2*) Using the runway localizer and its cone of silence as a marker beacon, pilot Lt J H Doolittle of the Guggenheim Fund made the first successful instrument landing in history on September 24, 1929 Other landings were made in later months, using both the marker beacon and the runway localizer This type of system, comprising only the radio range and marker beacons, is sometimes called a radio approach system

Lieutenant Doolittle did notable work on the development of the nonradio instruments required in making an instrument landing, and on their grouping on the instrument panel to facilitate use by the pilot He was one of the first to recognize the need for an artificial horizon instrument and a directional gyroscope and cooperated with the Sperry Development Co in their design Both of these instruments and many of his ideas for instrument grouping have since been generally adopted in aviation

These systems provided the pilot with lateral and longitudinal guidance The important step of providing guidance in the vertical plane, thus achieving a complete three-dimensional system, was conceived by the National Bureau of Standards in 1929 (*3*) To the equisignal runway localizer and the marker beacons was added a beam in the vertical plane which provided a constant-intensity glide path of convenient shape for easy landing The equipment was set up and the system developed at College Park, Md The glide path was obtained from an ultra-high-frequency transmitter utilizing a horizontally polarized directive array operating on 90 8 mc The runway localizer utilized small multiturn loops which operated on 278 kc The marker beacons used long low-transmission line antennas and operated on 3105 kc A complete monitoring system was added The first blind landing with this system was made by pilot M S Boggs at College Park, September 5, 1931 A second installation was made by the National Bureau of Standards at Newark, N J, in 1933, where over a hundred blind landings were made (*4*) A third installation was made by the National Bureau of Standards at Oakland, Calif, in 1934 The system was planned to require a minimum of manipulation of radio controls by the landing pilot and to simplify the interpretation of the radio signals received To this end, visual runway-localizer and landing-beam course indications were provided on a single crossed-pointer instrument, the need for volume-control manipulation was eliminated, and distinctive modulation of the approach and boundary marker beacons was employed

During 1933 and 1934, test flights of the Newark installation by air transport pilots in airplanes equipped for the purpose by the United Air Lines and Transcontinental Western Air served to indicate the practicability of the fundamental principles of the system and pointed to desired improvements Reduction of cost of the ground station equipment, elimination of the slight bends in the runway localizer course caused by the presence of railroad tracks, power lines, etc, and increase of the slope of the landing path were desired The Bureau of Standards cooperated in the tests and, at College Park, continued its work on improving the system Tests were made on a combined runway localizer and landing beam operating on a single ultra-high frequency, and on a method for placing the landing beam (or the combined system) in a pit at the center of an airport in order to increase the slope of the landing path and to afford service for all wind directions (*5*) The simplification of the combined system when using vertically polarized waves led to a study of the relative advantages of horizontal and vertical polarization, this study revealed that horizontal polarization was preferable for safe use of the landing beam, inasmuch as the glide path would drop with snowfall when using vertically polarized waves, whereas the glide path would rise with horizontally polarized waves under similar conditions Reverse directional effects in the runway-course indications when using horizontally polarized waves led to the development of special nondirectional receiving antennas to overcome this effect

Airways Division Development

In 1933 the Airways Division of the Department of Commerce developed and installed at Newark, N J, what is probably the simplest instrument landing system (*6*) It used the conventional radio range augmented by an omnidirectional radio marker and a Kollsman altimeter on the airplane In this system the radio range is located about 2 miles from the airport and has one course alined with the runway on which instrument landings are to be made The marker transmitter and its antenna are located on the radio range course 1,000 feet outside the airport boundary A carrier frequency differing from that of the radio range by 1 kilocycle is used for the marker transmitter In addition, it is modulated by an audio frequency several hundred cycles below the range modulating frequency.

In order to make a landing through the use of these facilities, the pilot approaches the airport flying at 1,000 feet on the course which is the reciprocal of that projecting along the runway As the airplane passes over the radio range, the pilot observes the cone of silence and immediately reduces the speed of his engines and puts the airplane into a normal glide As the let-down is continued, the airplane is held on the radio range course using a directional gyrocompass bearing as a check When the marker beacon signal is detected, the airplane should have descended to 100 feet, and this provides the pilot with a check on his progress in the letting-down maneuver If the airplane has been gliding at the proper angle, this altitude will have been reached and the pilot can proceed to land on the runway Otherwise, he must climb to 1,000 feet and repeat the procedure, making such corrections in the airplane speed as appear necessary to compensate for wind velocity

A variation in this system was installed at Washington, D C, in 1933 and is described in detail in the reference (*7*) It utilizes an additional radio marker, installed 2½ miles distant from the airport boundary on the course selected for instrument landings It operates on the same radio frequency as the boundary marker and is modulated by two audio frequencies keyed alternately The modulation frequency of the boundary marker is not keyed and differs from both of the outer marker modulations Also, the radio range beacon is located on the side of the airport opposite that on which the markers are situated The procedure followed is different from that of the first system in that the pilot makes his approach flying toward the range station rather than away from it and the signal from the outer marker instead of the radio range cone of silence is used to warn the pilot that he should begin his glide Much of the success of either system depends on the accuracy of the barometric altimeter, none of which at the present time can be relied upon to give a reading having a tolerance of less than plus or minus 40 feet For this reason, instrument landings with either system are not considered feasible since the possibility of undershooting or overshooting the landing area is too great. However, these facilities do assist the pilot to fly in under a 100-foot ceiling and make a contact landing.

Early Development of the Lorenz System

In 1933, Kramar described a blind landing system which had been tested in Europe. It consisted of an ultra-high-frequency transmitter operating on a frequency of 43 mc., which was so located with respect to the airport that an instrument landing could be made. A pilot making a landing with this system first flew over the cone of silence at an altitude of 650 feet. At this elevation, the cone of silence lasted approximately 4 or 5 seconds, depending on the speed of the airplane. Immediately after passing through the cone of silence, the glide to the airport was begun and the airplane was maneuvered along a radio range course at a gliding angle which would permit it to contact the runway at the proper point (*8*).

Army Development.

In 1932 and 1933, the Air Corps at Wright Field under the direction of Captain Hegenberger developed an instrument landing system which was unique in its simplicity of operation and the flexibility with which it could be used under varying wind conditions. This system was adopted by the Bureau of Air Commerce and installations were begun at 36 airports throughout the United States (*9*). This program was never completed due primarily to the fact that a majority of the air lines felt that it did not give sufficiently precise indications for safe commerical use. This system is described in the Air Commerce Bulletin, volume 6, No. 5, and by Jackson in the National Safety News (*10*) and by Jackson and Hromada in Pender's Handbook (*6*). The major disadvantage of the Army approach system was that it did not give a precise absolute altitude indication, since that furnished by the Kollsman sensitive altimeter could only be relied upon within plus or minus 40 feet under all practical conditions. Furthermore, it did not provide a well-defined lateral path, but gave a radio compass heading which would continually change with any cross-wind component. The major advantage of the Army system was that it was simple to fly, which made it possible for the pilot to quickly orient himself and placed no extra burden on the pilot as he followed the radio compass indicator.

Washington Institute of Technology Development

In 1933, the Washington Institute of Technology was organized for the purpose of further developing and commercializing the Bureau of Standards instrument landing system.

In 1935, this organization produced an experimental set-up utilizing the I–A visual indication method developed by the Bureau of Air Commerce, but, after a short period of flight testing by the United Air Lines, the use of the I–A indicator for the localizer was abandoned. This system consisted of a glide path operated on approximately 93 mc., the visual runway localizer operated on a frequency of 278 kc. and an aural marker beacon on the same frequency as the runway localizer. All of the ground equipment, except the marker beacon, was mounted in an automobile trailer to permit the operation of the system in any direction. Concrete platforms and power outlets for the trailer were provided at the end of each runway. The trailer could be towed to the position best suited for the particular weather condition at the time of landing.

The localizer transmitter had a frequency of 278 kc. and a power output of approximately 400 watts transmitting into small multiturn loops enclosed within the trailer. The keying used was that of the I–A system, that is, an "I" transmitted into one loop while an "A" was transmitted into the other loop. The small loops gave very poor radiation efficiency so that the maximum distance over which the range could be used was approximately 15 miles under favorable conditions and less than 2 miles under heavy static conditions.

The glide-path transmitter operated at a frequency of approximately 93 mc. and had an output of approximately 400 watts. The antenna array utilized horizontal polarization and consisted of four half-wave antennas fed in phase and four reflectors. This entire antenna array was mounted on the trailer The only difficulty obtained in connection with the glide path was that, because of the short runway at College Park, it was necessary to adjust the path so that it was relatively steep and the point of contact fairly close to the transmitter, giving only a few hundred feet for the plane to roll after contacting the ground This would be eliminated on a larger airport by using either a higher sensitivity setting on the receiver or more power at the transmitter Under these circumstances the path would be identical to all systems using horizontally polarized waves

The marker beacon consisted of a transmitter having a frequency of 278 kc and a maximum power output of approximately 4 watts The carrier was modulated at 1200 cycles The antenna system consisted of a single insulated wire laid on the ground

A complete monitoring system was provided whereby the equipment could be turned on or off at a remote point. Monitor lights were provided which indicated when the transmitters were on or off. In addition, each transmitter was provided with a cut-out relay which was designed automatically to remove power from the transmitter if its output varied appreciably from normal, thus precluding the possibility of radiating incorrect signals A visual indicator device used in the aircraft to indicate the right or left of the course was similar to the I–A indicator, originally developed by the Bureau of Air Commerce

After these tests, the Washington Institute of Technology then continued the development of a double-modulation localizer based on the principle originally employed in the National Bureau of Standards system, that is, one loop was modulated at a frequency of 65 cycles, while the other was modulated at 86 7 cycles A novel method of accomplishing this modulation was adopted which resulted in a great improvement over the earlier scheme Originally the transmitter had dual output radio-frequency amplifier channels, each of which was modulated at one of the two frequencies mentioned above Each power amplifier independently excited one of the loops. The most serious objection to this arrangement was that any change in emission of the tubes in either channel caused localizer course variations To overcome this difficulty, a single power amplifier was used with direct-current plate supply Modulating means, not including any vacuum tubes, were connected to the output of the tank circuit and the output of each of these was supplied to one of the loops One loop was then modulated at 65 cycles, and the other at 86 7 cycles This arrangement had the advantage that variations in emission varied each of the figure-of-eight patterns simultaneously, and the course alinement was not affected The course indications were furnished to the pilot by means of a conventional cross-pointer type of meter, using a reed converter similar to that originally used by the Department of Commerce

The original converter has been somewhat redesigned mechanically and a major improvement in calibration procedure developed which gives the device a high degree of service reliability

Another type of converter unit has been developed, interchangeable with and even lighter than the reed converter, which is known as the torsional type of converter This type of indicator will be adopted if extensive flight tests prove its superiority over the original reed type of converter

Although only one trailer platform was established at College Park during the tests with United Air Lines in 1935, extensive tests conducted since then have shown that not only will the equipment stand up under usage far more severe than that to be encountered on any airport, but also that stable and reproducible courses are obtained by means of the positioning platforms used to locate the trailer Improvements in the trailer and the method of coupling make possible the change from one position to another a matter of a few minutes

The present equipment for conducting service tests incorporates a 91-mc glide-path transmitter, a medium high-frequency localizer, and a marker beacon on the localizer frequency, all crystal controlled The major disadvantage with this system and all other systems using runway localizers operating on relatively low radio frequencies is the fact that the use of these frequencies is apt to give numerous bends and multiple courses which make it difficult, if not impossible, for the pilot to land on an airport consistently under blind conditions As soon as sufficient data is accumulated on the operation of an ultra-high-frequency localizer, this equipment will be substituted

Transcontinental & Western Air Development

In 1935, TWA developed a combination glide path and localizer unit at the Kansas City Airport using a frequency of 85 mc The equipment was crystal controlled and a satisfactory straight path was obtained However, considerable difficulty was encountered due to variations in the altitude of the glide path when crossing over a river and a dike near the river's edge This discontinuity in the path was considered to be a serious objection and it was not until later that it was determined that vertically polarized waves were responsible for the discontinuity

Bureau of Air Commerce Developments.

In 1935, the Bureau of Air Commerce of the Department of Commerce conducted further tests at Newark, N J, on a glide-path system on 93 mc and on a localizer system on 227 kc The localizer was modified to operate on single side band with a symmetrically disposed vertical antenna continuously excited by a carrier 1020 cycles lower than the single side band With this system, automatic volume control operated from the carrier could be used and it also permitted simultaneous operation of the radio compass in addition to making it possible to transmit voice communication from the carrier antenna The course indications were obtained by keying the single side band with "I" and "A" and obtaining a visual indication by energy derived from the transient power An objectionable feature of this system was that it gave a kicking indication to the pilot This caused considerable eyestrain and required an unnecessary amount of concentration to determine whether the plane was gradually approaching or leaving the course Another difficulty was that static caused the visual indicator to give erroneous course indications, thus making it difficult to fly an accurate course during atmospheric conditions A further objection to the use of transient type of visual indicator was the inherently broad course indication which made accurate flying impossible

Due to the concentration of traffic at the Newark Airport, the entire equipment was moved to Indianapolis, at which point further tests were conducted on this system After a considerable number of tests, it was determined that it was unnecessary to transmit voice over the carrier antenna, and, furthermore, that the courses obtained were 41 percent wider when using this type of transmission than when using the two loops without the vertical antenna In addition to this, there were the kicking difficulties outlined previously and the kicking meter was abandoned

Modifications were then made which made use of extremely high-speed dots on one side of the course and dashes on the other, each dash having a length five times that of one of the dots It was then possible to obtain a smooth on-course indication This proved to be much more satisfactory than the kicking needle type used with the I–A system However, due to mechanical imperfections in the fast keying of the dots which were at the rate of 600 per minute, random transients were produced by key clicks caused by the link circuit relay contacting both sides or because of spaces occurring between the dots and dashes tending to give occasional course indicator fluctuations which were annoying to the pilot Furthermore, flight tests indicated that the pair of courses in line with the runway were free from key clicks and coincided aurally and visually whereas the pair of courses normal to the runway were found to be located properly aurally although key clicks were apparent, but rotated 8° clockwise on the visual indicator This error was caused by a key-click figure-of-eight pattern, the axis of which was normal to the runway This parasitic key-click pattern combined with the normal figure-of-eight patterns to produce a visual course 8° off the true course Due to the difficulties involved in maintaining the link circuit relay adjustment in a mechanically perfect condition, it was decided to abandon the high-speed keying system in favor of a visual system using a mechanical modulator which produced 65-cycle modulation in one loop and 86 7-cycle modulation in the other loop. A mechanical modulator has been constructed and tests with it are about to be conducted It is anticipated that the mechanical modulator will overcome all the faults found in previous visual localizer transmitters

Another improvement made at Indianapolis was to locate the glide-path antenna so that the axis of the beam was projected across the runway at an angle of approximately 13° Tests indicated that this method was entirely practical in pushing the point of contact out farther on the field and at the same time preventing the structure housing the antenna array from being a hazard

Tests on the low-frequency runway localizer at Newark indicated that both multiple courses and bent courses prevailed, whereas at Indianapolis, using the same frequency, under ideal conditions no vagaries were observed Based on these observations together with the experience gained from other instrument landing installations and radio range stations located throughout the United States using these low radio frequencies, it would appear that these frequencies are not well suited to provide a straight localizer course However, experience indicates that the solution to this problem is the use of ultra-high frequencies, provided care is exercised in properly locating the localizer with respect to reflecting objects such as hangars, gas tanks, towers, and buildings Tests are now being conducted at Indianapolis to determine the feasibility of replacing the low-frequency localizer with an ultra-high-frequency localizer

Later Development of the Lorenz System.

In 1934 and 1935, Dr E Kramar, of the Lorenz Co in Germany, developed a unique and simplified blind landing system *(11)*, *(12)*, *(13)* This system consisted of the same elements originally used by the National Bureau of Standards; that is, glide path, runway radio range localizer, marker beacons, and monitor system The glide path and the localizer were combined into one transmitter and radiating system. The transmitter was operated on 33.3 mc , and excited a vertical halfwave radiator. On each side of the vertical radiator, a reflector was located with a relay at its center. One reflector was keyed by dots while the other reflector was keyed by dashes By interlocking the dots and dashes, two elliptical patterns were obtained, the major axes of which were parallel to the on-course Only one pattern was present at a time, inasmuch as a single source of energy is used to supply the energy in both patterns These alternately keyed patterns produced an equisignal zone, which gave two courses The carrier energy was modulated at 1150 cycles, and the usual type of aural radio-range courses were obtained with an interlock signal Visual indication was obtained by means of a rectifier circuit and amplifier which produced off-course indications either to the right or the left, depending upon whether dashes or dots were the predominant off-course signal This indicator, however, gave a kicking needle indication The glide path was produced by the presence of a field pattern in the vertical plane A field intensity line of constant amplitude was selected and followed directly to the airport The outer marker was located approximately 1 9 miles from the airport The inner marker was located approximately 0 19 miles from the airport Each of the markers transmitted on a frequency of 38 mc. The outer marker was modulated at a frequency of 700 cycles and keyed with dashes four-tenths of a second long The inner marker was modulated at a frequency of 1700 cycles and keyed with dots one-fifteenth of a second long Each marker gave an aural indication in the headphones of the pilot in addition to lighting an individual light on the instrument panel A complete remote control apparatus was provided which constantly checked the operation of all units

Tests at Indianapolis of Lorenz System.

Through the courtesy of the International Telephone & Telegraph Co , one complete set of equipment was installed at the Indianapolis airport for test purposes Receiving equipment was also furnished to the Bureau of Air Commerce and to several of the air lines

These tests indicated that approaches could be made to the field under conditions of low visibility and low ceilings with good reliability However, there were several limitations to the use of this equipment First, it was found that the radio range could be flown better aurally than visually This was attributed to the fact that the needle indications were of the kicking type rather than of the smooth visual type, which was originally used in the National Bureau of Standards installation It was also found that if the transmitter was keyed with the "N" and "A" that pilots who were familiar with this form of keying could fly the radio-range localizer much better than with the dot-dash signals When the equipment was originally installed, the course was approximately 6° broad, which it is understood is the width desired in Europe However, the consensus among all the pilots in this country who flew this equipment was that the courses were too wide A considerable amount of work was done in an effort to sharpen the course When the course was narrowed to approximately 3°, the results obtained were greatly improved By further manipulation of the position and length of the reflectors, the course width was reduced to approximately 2° Even though this very definite improvement of course width was made, the consensus was in favor of a further reduction in the width of the course It is felt that the difference in magnitude of the two patterns should be at least one db at a point 1½° off the center of the course for adequate course sharpness with aural operation, however, with visual operation the difference in pattern magnitude at the same position needs to be only 0 5 db provided the instrument is sufficiently sensitive to give a 10° pointer deflection 1 9° off the center of the course

Another serious difficulty observed was the fact that the glide path was smooth down to a point just beyond the end of the cement runway, at which point the glide path took a definite dive into the ground Further tests indicated that this was primarily due to the fact that the radiation was vertically polarized and that probably the reinforcing steel in the runways caused a very definite change in the conductivity which affected the reflection coefficient sufficiently to give a very pronounced discontinuity in the glide path This feature is considered a serious factor, inasmuch as a highway at the end of an airport would probably cause a discontinuity in the glide path An opportunity has not yet been afforded to confirm this assumption However, it is definitely known that, in the glide path at Kansas City, using vertically polarized waves at 85 mc, there was a discontinuity present in the glide path at the point where the waves crossed over the river The Bureau of Air Commerce glide-path antenna at Indianapolis which was normally horizontally polarized was rotated so that vertically polarized waves were radiated This system tuned to 91 mc definitely gave the same phenomena which was obtained on the Lorenz system using a frequency of 33 3 mc From the data which is at hand, it is felt that horizontally polarized waves should be used for glide-path purposes

The frequencies which were used in the Lorenz equipment, namely 33 3 mc and 38 mc, are not believed to be satisfactory for a blind landing system which would be used universally due to the fact that reflection from the Heaviside layer would occasionally cause interference between stations separated by several thousand miles Further, these frequencies cannot be used in the United States, inasmuch as this part of the spectrum is already crowded with police and forest-fire-patrol services Another difficulty which was encountered with the Lorenz equipment was cross-modulation in the audio-frequency amplifier which amplified both the marker-beacon frequencies and the radio-localizer, glide-path frequency It was noted that when the ship was flown over the inner and outer marker beacons, energy from the marker beacons caused erroneous indications in the glide-path meter and the right-left indicator This, however, was only for a short-time interval and could easily have been eliminated by having separate audio-frequency amplifiers It is understood that this difficulty will be eliminated in later equipment

This system is unique in that it gives simultaneous visual and aural lateral indication Furthermore, the simplicity with which the visual indication is obtained should not be overlooked It is felt, however, that the advantage of having both the visual and aural indication is not sufficient where it is necessary to sacrifice the effectiveness of either indication for the purpose of obtaining both indications Experience indicates that a visual indicator which operates smoothly and informs the pilot which side of the course he is off and the rate at which he is approaching or leaving the course is the type of indicator which is essential This type of indication not only gives minimum eye fatigue, but has the advantage that automatic flight control may be readily attached to the meter circuits Although experience has indicated that a fairly good instrument landing can be made with the aural N–A signals, it is not believed that this type of indication will be ultimately used

Tests conducted with both the Lorenz and the Bureau of Air Commerce installations indicated that, for a given power, receiver sensitivity, and receiving antenna height, the point of contact using vertically polarized waves was at a distance considerably farther away from the antenna structure than when using horizontally polarized waves This is a definite advantage in that one of the major limitations of the present system is that the point of contact must be so close to the transmitting antenna that insufficient room is left on the airport for the airplane to roll to a safe stop Another obvious advantage of the Lorenz system is that a single vertical antenna on the aircraft is used for both the glide-path indications and the localizer indications In addition to this simplification, only one receiver is required for both of these indications

One of the most interesting features of the Lorenz system, pointed out by Dr Kramar, is the fact that it is possible to calibrate the receiver by observing the glide-path indication at the moment the outer marker is received For example, let it be assumed that the airplane approaches the outer marker at 700 feet and observes the glide-path indicator at the moment the outer marker light on the dash operates It is only necessary to maintain the same amplitude of the glide-path meter and follow the glide path down until contact is made It is possible to determine the altitude at the outer marker by means of a Kollsman altimeter with an error of not more than plus or minus 40 feet and at this point select one of the constant amplitude field intensity lines and fly from the outer marker to the point of contact with the ground All of the points of contact with the ground will be relatively close to one another for all absolute altitudes between 660 and 740 feet From this, it may be seen that it is only necessary that the transmitter output be constant and the receiver sensitivity remain constant for a period of a little over a minute and a half This simplicity in operation eliminates the necessity of maintaining the receivers with absolutely constant sensitivity adjustments and also eliminates the necessity of checking the receiver with a signal generator before making a landing Experience has indicated that this method of operation is entirely practical Another outstanding feature of the equipment is that it is operated entirely on ultra-high frequencies which are free from the annoying effects of atmospheric interference

United Air Lines and Bendix Development.

In 1934, the equipment originally installed at the Oakland Airport by the National Bureau of Standards was turned over to United Air Lines for further tests and improvements Early in 1936 the Bendix Radio Corporation agreed to cooperate with United Air Lines in carrying on an extensive program of tests and improvements The major improvements which were made with the assistance of the Bureau of Standards in an advisory capacity were the elimination of bends and multiple courses by using an ultra-high-frequency localizer; the use of electrical filters instead of vibrating reeds to separate the modulating frequencies, the use of a single transmitter for both the glide-path and course indication, and the use of a mechanical radio-frequency modulating device, which eliminated the possibility of course variations caused by emission differences in dual radio-frequency channels.

The improved system developed by Bendix and United Air Lines consisted of a crystal-controlled transmitter operated on 91 mc., which was used to simultaneously excite two horizontally polarized Yagi arrays. The major axes of each of the patterns produced by these two arrays were displaced by an angle of approximately 40°. The field pattern radiated by each array was modulated by keying the director next to the antenna on one of the arrays at 70 cycles, while the corresponding director on the other array was keyed at 90 cycles. This arrangement produced a combined glide path and localizer course. One of the major difficulties to be overcome in this system was the fact that different headings of the ship would tend to give varying receiver outputs due to receiving antenna directivity. This problem was solved by using a horizontal loop which had a nondirectional characteristic for horizontally polarized waves.

Another contribution was the utilization of the automatic pilot in blind landing. The method of application consisted essentially of getting on course with the plane headed in the proper direction, flying over the outer marker beacon at the proper altitude and permitting the automatic pilot to fly the airplane as it descended to the runway. This arrangement greatly relieved the strain on the pilot inasmuch as it was not necessary for him to maintain the plane in the proper attitude while making a landing. The pilot was able to concentrate and interpret the indications of the cross pointer instrument, making only slight adjustments to the controls of the automatic pilot as required. In effect, the airplane was flown down the glide path at approximately 90 miles per hour. After contact was made, the automatic pilot maintained the proper heading of the airplane while the throttles were slowly closed and the airplane was brought to a stop by brakes. Later in 1936 TWA combined their efforts with United Air Lines and the Bendix Corporation to further the development of the system outlined above. During 1936 and 1937 approximately 3,000 hooded landings were made on this system in a Boeing 247 and a Douglas DC-3 airplane by pilots from the various air lines, Army, Navy, and Bureau of Air Commerce.

Fundamental Elements and Projected Development

From the foregoing, it is evident that a considerable fund of knowledge has been gained from the numerous systems which have been described. Each of the systems has its limitations although some are better than others for making completely blind instrument landings consistently under service conditions. In general, it may be said that there are three essential elements in an instrument landing system: Localizer, glide path, and markers. A monitor system is necessary in order to inform the landing system operator that all elements are operating satisfactorily. An adjunct to the system, which is not described in this report is the use of approach lights for the purpose of providing the pilot or copilot with a double check in aligning the airplane with the runway under most conditions of poor visibility. These lights however, should be considered only as a supplemental aid to the instrument landing system using radio facilities. Approach lights are now being installed by the Bureau of Air Commerce at a number of airports.

Based on knowledge accumulated as a result of the experience described, the air lines, the Bureau of Air Commerce, the Federal Communications Commission, and the subcommittee on Instrument Landing Devices of the Radio Technical Committee for Aeronautics have agreed on the fundamental elements which are necessary for a uniform instrument landing system. These elements are as follows:

1. Runway localizer.
   (a) The runway localizer should operate on an ultra-high frequency, preferably in the band 92–96 mc. or, if the localizer trans-

mitter is operated as a separate unit, in the band 108–112 mc

(b) Straight course, i e, one which has no bends or multiple courses perceptible to a pilot flying in still air

(c) The difference in the magnitude of the two patterns of the localizer should be 0 5 db at 1 5° either side of the center line as measured with a linear detector

(d) The vertical needle of the cross-pointer indicator should give a 10° deflection indication for a 1 9° angular deviation from the center line of the runway

(e) The range of use as a runway localizer should be 20 miles at 3,000 feet

(f) Freedom from interference pattern effects perceptible to the pilot both in elevation and azimuth.

2 Glide path

(a) The glide path should operate on an ultra-high frequency, preferably in the band 92–96 mc

(b) A smooth glide path should be provided, i e, one which is free from interference pattern effects perceptible to the pilot when on the localizer course.

(c) The system should be capable of adjustment to provide a suitable glide path

3 Markers

(a) The markers should operate on 75 mc

(b) It should be possible to positively identify each marker both aurally and visually by modulation and keying Modulation frequency of the inner marker should be 1300 cycles and that of the outer marker should be 400 cycles

(c) A normal arrangement of markers would be

(1) At the normal intersection with the glide path

(2) Near the boundary of the airport, the exact location to be determined by local conditions

(d) The marker beacons should have an array adjustable so that when installed in the boundary position the beam will cause useful indications of a visual device within 700 feet either side of the on-course path and for 300 feet along the glide-path trajectory Indications from this marker should be receivable to an altitude of 2,000 feet

(e) The outer markers should have sufficient power to accomplish a similar visual indication with the same beam pattern at 2,000 feet

4 Monitor system.

(a) Satisfactory means for indicating visually the operation of all equipment should be provided at a central point.

(b) Whatever form of visual indication may be employed should be smooth in performance and have no irregular characteristics

5 General characteristics

(a) Frequency of emission of all of the elements of the system should be equivalent to that obtained with a low-temperature coefficient quartz crystal.

(b) The number of fixed or portable equipments required will depend on conditions prevailing at individual airports.

(c) The installation of the foregoing equipment should not constitute an obstruction to a normal approach to a runway

6 Approach lights

(a) The installation of the best known type of approach and runway lights appears to be a most desirable measure in combination with instrument landing facilities.

7. Projected development

Additionally, certain desirable features should be provided depending upon the state of the art and experience obtained. These represent improvements over and above the performance to be obtained from the fundamental equipment and are in no sense a substitute for such equipment nor do they require the redesign or replacement of such equipment

These are

(a) The inclusion of suitable emission for the operation of a radio compass either by—

(1) The utilization of the ultra-high-frequency runway localizer if practicable, or

the installation of a low-powered low-frequency transmitter adjacent to the runway localizer

(*b*) The equipment provided should be so designed as to facilitate possible ultimate utilization (with accessories) in a fully automatic landing system in conjunction with a gyropilot

(*c*) Consideration should be given to possible separation of localizer and glide-path transmitter functions in order to—

(1) Permit alteration of glide path

(2) Accomplish independence of horizontal and vertical indication

(*d*) Study should be made of the possibility for obtaining a straight line constant rate of descent glide path

Work is going forward in a number of agencies, including the Bureau of Air Commerce, along these lines

DISCUSSION

It is believed that instrument landing systems installed at a number of the major air terminals would add materially to the safety of airways operations At present, the major airlines are planning to install a number of instrument landing systems having the fundamental elements previously outlined These systems are to be used on an experimental basis primarily for pilot training While the equipment which can be produced at this time is considered satisfactory for this purpose, it is believed that a year's further development would add much in the way of reliability and ease of maintenance Because of the considerable expense involved and also to serve the ends of standardization and coordination, it is believed that eventually instrument landing systems should be installed and operated by the Bureau of Air Commerce In view of this, it is believed that the Bureau of Air Commerce should sponsor further development in the industry along the lines indicated under "Projected Development"

Another point to be considered is that with the increasing number of aircraft being dispatched to and from airports under conditions of restricted ceilings and visibility, the air-traffic problem is becoming more acute Under present conditions at a well-regulated traffic-control center, each airplane is allowed a maximum of 15 minutes for landing under the worst possible conditions It is believed that an instrument landing system would contribute to the solution of the airways traffic control problem by reason of the fact that more ships could be landed and dispatched per hour at a busy terminal during bad weather conditions An instrument landing system would relieve the present "bottle neck" by reducing the time required for landings as it would furnish the pilot with precise indications of the proper course and glide path down to the point of contact with the runway

CONCLUSIONS

The most satisfactory system is one that uses ultra-high frequencies for each of the three elements outlined in the foregoing Ultra-high frequencies have the outstanding advantages of being practically free from atmospheric disturbances and of utilizing smaller and more efficient antennas for both plane and ground With ultra-high frequencies, it is possible to obtain straight courses without bends or multiples by properly locating the localizer with respect to reflecting objects In the majority of cases, it is impossible to obtain straight courses with low frequencies, particularly in the vicinity of irregular terrain, railroads, high buildings, and transmission lines Straight localizer courses may be obtained using ultra-high frequencies with either vertically or horizontally polarized waves With the glide path, however, it is necessary to use horizontally polarized waves in order to obtain a relatively smooth path to the point of contact with the runway The markers should use horizontally polarized waves and the antenna array should have sufficient directivity to give a width-to-thickness ratio of at least 4 to 1

RECOMMENDATIONS

It is recommended that the Bureau of Air Commerce sponsor further development work in the industry along the lines outlined in "Projected Development" under "Fundamental Elements and Projected Development" to bring the equipment to a point of perfection which will preclude the possibility of early obsolescence

When the above work has been carried to the point where the equipment meets with the approval of all concerned with regard to both operation and ease of maintenance, it is recommended that the Bureau of Air Commerce purchase, install and operate a number of these instrument landing systems at various airports throughout the United States on an experimental basis

It is further recommended that when this has been accomplished the Bureau carry out a long-range program of blind landing development and improvement similar to the program which has been followed with regard to development and improvement of radio ranges.

REFERENCES

(1) The Field Radiated from Two Horizontal Coils, by Gregory Breit, Bureau of Standards Scientific Paper No 431, 1922 H S patents—Loop Antenna, #1,898,474, filed June 26, 1919, and Aircraft Landing System, #1,555,345, filed January 19, 1929

(2) Pamphlets by the Guggenheim Foundation for Aeronautics Solving the Problem of Fog Flying, October 1929 Equipment Used in Experiments to Solve the Problem of Fog Flying, March 1930

(3) A Radio Beacon and Receiving System for the Blind Landing of Aircraft, by H Diamond and F W Dunmore
Bureau of Standards Journal of Research *5*, 897–931 (1930) (RP238)
Proceedings of the Institute of Radio Engineers, *19*, 585–626 (1931), and in brief, in Air Commerce Bulletin *2*, 79–87 (Aug 15, 1930)

(4) Performance Tests of a Radio System of Landing Aids, by H Diamond Bureau of Standards Journal of Research 11, 463–490, (1933) (RP602), and, in brief, the following
Air Commerce Bulletin
4, 441–7 (March 15, 1933)
4, 525–7 (May 1, 1933)

(5) Experiments with Underground Ultra-High-Frequency Antenna for Airplane Landing Beam, by H Diamond and F W Dunmore. Bureau of Standards Journal of Research *19*, 1–19 (1937) (RP1006)

(6) Blind Landing Aids, Electrical Engineers' Handbook, by Pender and McIllwain (Communication and Electronics), p 16–48

(7) Radio Approach System Assists Airmen to Land Under Low Ceilings, Air Commerce Bulletin, January 15, 1934, p 165

(8) A New Field of Application for Ultra-Short Waves, by E Kramar, Proc I R E, November 1933, p 1519

(9) Army Air Corps Radio Blind Landing System Adopted as Standard by Bureau of Air Commerce, Air Commerce Bulletin, Vol 5, No 6, p 107

(10) Modern Aircraft Radio, by W E Jackson, National Safety News, October, 1935, also published in Shell Aviation News, February 1936, and Revista De Aeronautica, April 1936

(11) The Present State in the Art of Blind Landing of Airplanes Using Ultra Short Waves in Europe, by E Kramar, Proc. I R E, Oct., 1935, p 1171

(12) Lorenz Blind Landing System, Wireless World, p 332, April 5, 1935

(13) Landing Aircraft by Sound, Wireless World, p 627, June 26, 1936.