

Development of the Visual-Type Airway Radio-Beacon System

The object of the research reported in this paper was to provide a system of navigational aids by which aircraft could be flown on a course in fog or in any condition of visibility or no visibility. After World War I civil aviation had become a serious enterprise with mail, express, and passenger flights. Weather and conditions of visibility hampered regular schedules that had now become highly desirable for the new industry to be commercially successful. The requirements of airmail service necessitated night flying to meet the "next day" delivery schedules the Post Office wanted to establish across the nation. This research paper [1] summarizes the work done at the Bureau of Standards between 1926 and 1929 for the purpose of making possible blind flying and landing of aircraft.

Navigational instruments available at that time were the altimeter, the bank-and-turn indicator, the rate-of-climb indicator, and the compass. With these instruments it was possible to continue to fly in fog, but it was only by radio means that the pilot could be certain of staying on course and finding the landing field when the ground was invisible. Accurate as a compass may be, it cannot tell the pilot that the aircraft has drifted off course. The altimeter (simply a barometer) gives only an approximation of the height above ground and cannot warn of obstacles in the flight path.

The Bureau of Standards began work on radio navigation for the military during World War I. Since military aircraft did not fly on fixed airways, they required direction-determination service on independent courses. The radio direction finder, using loop antennae and sensitive receiving sets aboard airplanes, was chosen as a homing device well adapted to military needs. However, the method was not useful for nonmilitary aviation because great difficulties were experienced with this type of receiving apparatus. There were two reasons for non-acceptance by civilian aircraft: the expense and weight of the receiving equipment, and the inherent slowness and complexity of operating the radio direction finder. Although the direction finder could not tell when wind drift had shifted the aircraft off-course, the method eventually brought the aircraft home to its destination, often by a circuitous route.

A new method was developed with the direction finder based on the ground. Every plane in commercial transport service carried a radiotelephone transmitter and receiver, used with a trailing-wire antenna. Perma-

nent direction-finding stations were located at certain principal airports. For an aircraft to find its position, it transmitted a radio request to the airport, whereupon two or more direction-finding stations each observed the radio waves transmitted by the airplane; triangulation yielded the airplane's position, which was then transmitted to the pilot. But this system required an airplane to carry both receiving and transmitting equipment, and it was not effective when a large number of airplanes simultaneously requested position coordinates since the ground station could serve only one plane at a time.

The Bureau's first crude radio guidance system for aircraft was tested in 1921 when a pilot flew along a course designated by signals from two transmitters on the ground. A prototype radiobeacon produced two years later by the Bureau for the Army Air Service was put aside in favor of further work on the radio compass. Without passengers, flying the mail was considered "high adventure," and the pilots liked it that way. Thus the prevailing attitude of pilots discouraged further refinements of navigational systems, and work on the beacon did not resume until 1926.

The radiobeacon system described in this paper was an outgrowth of the project undertaken by the Bureau of Standards for the Army Air Service in 1920. The Air Service had requested the Bureau to devise a method whereby a directional transmission would serve as a guide to airplanes along a chosen course. Army Air Corps engineers added further refinements to the Bureau prototype. In July of 1926 the Department of Commerce decided to establish an Aeronautics Branch, which requested its research division at the Bureau of Standards to carry out necessary experimentation and development to provide civilian aircraft with navigational aids. The work over the next three years led to very major improvements, the results of which are reported in this paper.

In order to engage in blind flying and blind landing—that is, flying under conditions of no visibility—the pilot must know the position in three dimensions at all times. This can be achieved with indicators on the aircraft instrument panel that record the signals from a small direction beacon, giving the pilot the longitudinal or approach position, plus an inclined ultrahigh frequency radio beam that continuously reports the height above ground. For such a scheme to work, an important

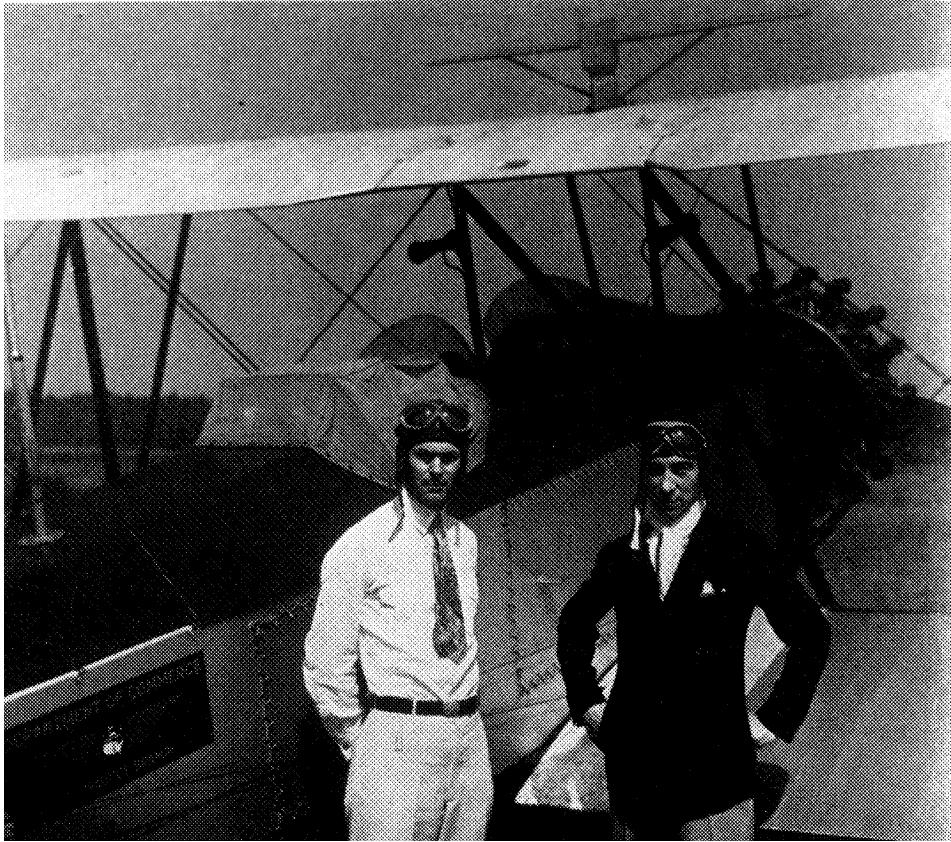


Fig.1. The early blind landing experiments conducted at College Park, MD, used a plane with a canvas hood over the pilot's seat. The copilot took over if plans went awry (from Ref. 3).

difficulty still remained because the Commerce Department transmitted weather information to planes on a different frequency. This meant that the pilot had to keep switching frequencies and also contend with interference from marine radios. Adding a device allowing voice communication about weather conditions without interruption to the range service (radiobeacon) solved the difficulty. It was fortuitous that the inventive talents of Harry Diamond and his team made possible the assembly of the first visual-type radiobeacon system that enabled a pilot to keep on course and to know his approximate position at all times while in flight.

In the paper on the assembly of the visual-type radiobeacon system, the authors describe the property that "direction service could be given to any number of planes flying the course, and that each airplane only had to carry a receiving set, with no other special equipment whatsoever. The pilot would obtain the necessary information pertaining to magnitude of course deviations hands-free and without having to rely on earphones. The means to accomplish this was the development of vibrating-reed indicators that alerted the pilot to any off-course condition. The system had to

be also entirely free from errors due to wind drift. Finally, all heavy radio equipment would have to be on the ground, the receiving set on the plane to be light of weight and simple."

In 1919, Francis Dunmore and F.H. Engel [2] had already developed a radiobeacon system that mapped out "highways" that a pilot could follow by listening to the signal pattern on a radio receiver. But the landing of an aircraft after arrival at an airport is three-dimensional, as shown in Fig. 2. The pilot must have lateral guidance to stay within the confines of the runway during the approach to the field, and the pilot must also have longitudinal guidance in the approach to the landing field in order to know the distance from the landing point. Finally, the pilot must have vertical guidance to decrease the altitude gradually as the plane glides towards the field.

A major step forward came with the replacement of the voice communication system (radiotelephone) by a visual indicator in the cockpit. The means to accomplish this was a set of tuned reeds that would tell the pilot by how much he was off course and whether to steer left or right to get back on the right course. A test of

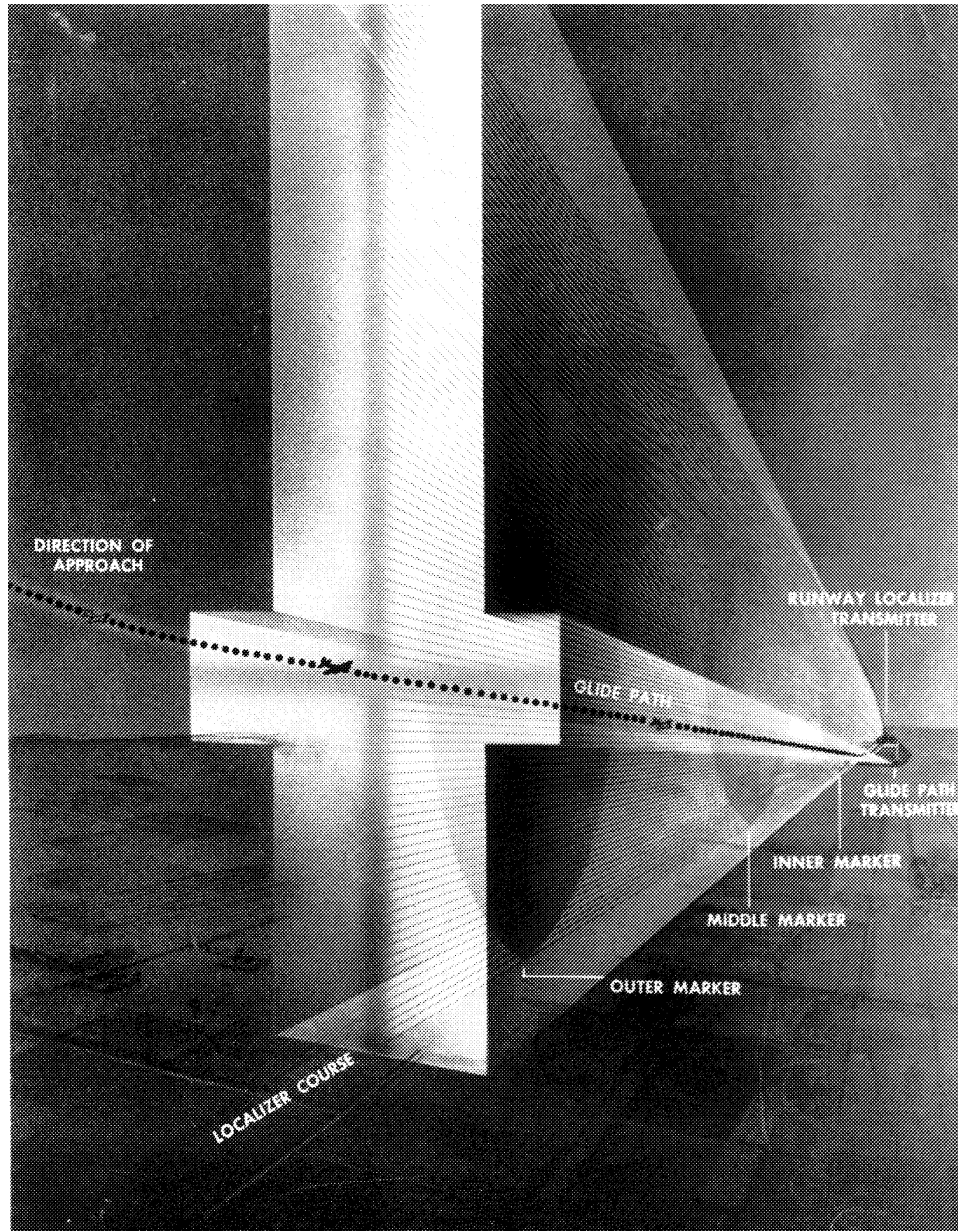


Fig. 2. Definition of the glide path consists of a localizer course for lateral guidance, an outer and middle marker to tell the pilot the *distance to the runway*, and a glide path (UHF) transmitter for the *vertical guidance* (from Ref. [3]).

the *direction finder system* came in 1929 when a pilot took off from Philadelphia on a day of low visibility and was told to fly to College Park, Maryland—120 miles away. The pilot, unfamiliar with the route or the landmarks and with no maps, had to follow solely the guidance given by the beacon indicator on the instrument board. He not only flew in a straight line to Washington, but when over the College Park field, the location of which he did not know, the sudden drop in the reed deflections signaled that he was at the journey's end, and he completed the flight with a visual landing.

However, a pilot needed more precise longitudinal guidance in order to prepare for a blind landing. For that purpose, Diamond and Dunmore devised a “distance indicator” instrument for the airplane based on measuring the field strength of the incoming radio signal. The instrument would calibrate itself by two marker beacons, one located about 2000 feet from the runway and the other at the edge of the runway. The authors describe in great detail various systems and techniques that would meet these requirements: the receiving equipment they developed for use on board the aircraft,

the marker beacons that inform the pilot when passing over one of the locations, and considerations for fog landings.

The next phase of the problem—providing vertical guidance for the pilot in the descent for landing—was solved by another transmitter antenna located near the runway localizer transmitter. Using ultra-high frequencies this time, the second antenna would send out a radio wave pattern, parabolic in shape and sharply enough defined to form an invisible ramp that the pilot would follow as the plane glided down to earth. (This was probably the very first practical use of ultra-high radio frequencies).

In 1930 Diamond added a 15-pound unit to the radio range beacon and radiotelephone in the cockpit that made possible the first blind landing of an airplane entirely by radio guidance [4]. The test came on September 5, 1931, when an airplane, on loan from the Bureau of Air Commerce with pilot Marshall S. Boggs at the controls, made the first blind landing in the history of aviation using only radio signals for lateral, longitudinal, and horizontal guidance. (A previous blind landing had been accomplished in July 1929 when Lt. James Doolittle brought down a hooded plane using a sensitive barometric altimeter and a gyro-stabilized horizon indicator, together with a radio lateral course indicator and marker beacon, also supplied by the Bureau.) This blind-landing system was turned over to the Department of Commerce in 1933.

Diamond and Dunmore admitted that, for a time in 1933, they thought that they had sold the system to the Commerce Department for adoption. They believed it was inherently simple and practicable and could be mastered by a pilot in five hours of practice. Their hopes for adoption were not fulfilled until the beginning of World War II.

After 1933, the U.S. Civil Aeronautics Administration (CAA) continued to experiment with other systems. The difficulty remained with the definition of the glide path. The Lorenz A.G. of Germany in 1934 announced a blind landing system similar to that of Diamond and Dunmore, but that system failed to provide a smooth glide path and hence fell short of adoption there. France became the first nation to adopt the Diamond-Dunmore system in 1935.

In 1937, a U.S. committee proposed the standardization of the best features of all systems that had been tested up to that time. Indianapolis was to be the test site, but satisfactory results did not come until Diamond's ultra-high-frequency antenna system was employed to obtain a straight "equi-signal" glide path. Diamond and Dunmore also improved the stability and sharpness of the runway localizer course and suggested further improvements in equipment and instrumentation. In 1939 a committee of the National Academy of Sciences, meeting at the request of the President, recommended the adoption of the system, called "Indianapolis" and later the "CAA Instrument Landing System (ILS)." Installation of ten such systems at key airports began.

However, World War II stopped the commercial development of blind landing systems and the armed forces took over the ILS, labeling it "SCS-51." It was used by the Allies throughout the war and was put to a crucial test during the Berlin airlift from June 1948 to September 1949. But even before that, in 1946, the CAA began installing the ILS on a wide scale for commercial use throughout the United States.

Now, 60 years later, the principles of this blind landing system are still the basis for air traffic control systems worldwide. The introduction of the global positioning system (GPS) was a major technological innovation able to guide airplanes across the vast oceans

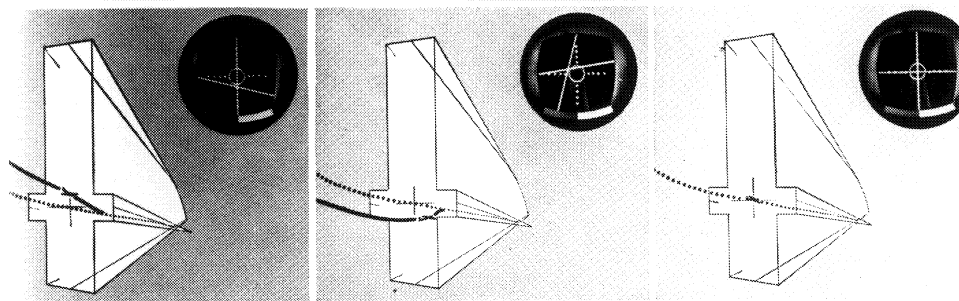


Fig. 3. By watching the pointers on the combined instrument, the pilot follows the glide path and runway localizer course to a safe landing. LEFT: He is on the runway course but above the glide path. CENTER: He is below the glide path and to the right of the runway. RIGHT: He is "on the beam." (From Ref. 3)

which were previously inaccessible to standard radio-navigation methods, thereby closing some big “black holes” in global air traffic control. Furthermore, radar provides the means to control the movement in the vicinity of most major airports today. Summary reports about this phase of NBS Research appear in [5] and [6].

Francis W. Dunmore and Harry Diamond were both born and raised in the vicinity of Boston. Dunmore got his degree in physics from Penn State in 1915, while the younger Diamond graduated from M. I. T. with a degree in electrical engineering in 1922. He worked for General Electric and B.F. Sturtevant Companies in Boston, taught electrical engineering and picked up another degree from Lehigh University. Diamond came to the Bureau of Standards’ radio laboratory in 1927, not long after it was handed the responsibility for the research and development work of the Commerce Department’s newly organized Bureau of Air Commerce. Diamond would soon become the chief of the Aeronautics Branch there. Prior to World War II, Diamond, Dunmore, and Wilbur Hinman developed methods for remote weather measurements with the first practical “meteorological radiosonde.” In 1939 they had developed the “remote weather station,” a ground-based radiosonde for automatic telemetering in remote and inhospitable locations. During World War II Diamond was transferred into the newly established Ordnance Division where he materially contributed to the development of the radio proximity fuse. In 1940, he received the Washington Academy of Sciences Engineering Award for his work, and the IRE honored him with its Fellow Award in 1943 for his efforts in radio-meteorology. The successor organization, IEEE, has renamed that award in honor of Harry Diamond. The NBS organization chart listed him as Chief of the

Ordnance Development Division in 1945. Diamond was personally presented with Navy and War Department Certificates for Outstanding Service in 1945 [7]. His untimely death in 1948 was a profound loss for the National Bureau of Standards, which had relied heavily on Diamond’s visions and plans for the post-war development of civilian technology. To honor him, NBS named the newly constructed electronics laboratory the Harry Diamond Laboratories. That organization was turned over to the U.S. Army in 1952 and continues to operate under that name to this day.

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