BLIND FLYING ON THE BEAM: AERONAUTICAL COMMUNICATION, NAVIGATION AND SURVEILLANCE: ITS ORIGINS AND THE POLITICS OF TECHNOLOGY

PART III: EMERGING TECHNOLOGIES THE RADIO-RANGE—THE RADIO BEACON AND VISUAL INDICATOR

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ABSTRACT

Part III: Emerging Technologies—The third paper in the series analyzes the effect of the continued Federal oversight during the Great Depression and the progress of aeronautical telecommunications research and the deployment of such technologies in support of aviation. Herbert Hoover had become the President of the United States and continued to play an active role in the development of communication, navigation and surveillance. It was during his administration the aeronautical telecommunications infrastructure was defined and it became the cornerstone of modern communication, navigation and surveillance technologies.

"It seems clear that the radio beacon is the primary aid required for aviation," Radio Section chief John Dellinger reported to his boss, E. C. Crittenden, supervisor of the Electricity Division. The radio beacon was to be the radio aid around which the electronic airway was to be built. The Army and the Post Office had built working models and over the summer of 1926 the National Bureay of Standards (NBS) made trips to McCook Field for a more in-depth study the Army system. Based on the state of Army

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development and prior research, the Radio Laboratory set about developing an airworthy navigation system. Research and engineering questions to be answered included identifying the most efficient operating frequency, analyzing aircraft trailing wire antenna idiosyncrasies and deploying a visual cockpit-mounted indicator that would replace the aural system.

Army pilots thought that the aural system was preferable to the Army's visual indicator especially since the earphones had been built into a more comfortable flight helmet. Even so, Dellinger believed a visual indicator was important. His reasoning lay in the fact it was somewhat difficult to distinguish the subtle changes in the tones when the airplane was flying in the equi-signal zone of the beacon, especially in the presence of background noise such as static. While the pilot might become proficient in recognizing the signal, it nevertheless is a slight strain upon him, and the visual indicator would eliminate this problem. Pilots flying the mail agreed with Dellinger. The visual indicator would be a great advantage were they to be forced to deviate from the course to fly around weather. Interpreting an indicator seemed much simpler to them than the aural method.[1]

Preliminary research to produce the visual system was accomplished by Laboratory physicists F. Dunmore and E. Stowell. In a confidential report written in October 1926, they explained the success they had in powering two neon lights, labeled *Left* and *Right* with a 500 and 1,000 Hz signal broadcast by the beacon. When the 500 Hz signal was prominent, the left neon lamp would glow brighter; when the airplane was more in the 1,000 Hz area, the right lamp would glow brightest. When the airplane was on course, both lamps would glow with equal intensity. Dunmore and Stowell were on the right track. Their neon light indicator became the prototype for the vibrating reed visual indicator system. The system had other uses. Additional lights could be installed to signal the passing of a marker beacon or alert the pilot when being called on the radio.[2]

In August 1927, Dunmore devised a visual indicator employing a set of vibrating reeds. He mounted two tuned steel reeds, one tuned to 30 Hz and the other to 40 Hz, side-by-side with each placed in a magnetic field. The device worked much like a telephone receiver. The magnetic fields were energized by the two signals, one at 30 Hz and the other at 40 Hz, transmitted from the beacon. Further testing revealed that the two reeds required a separation of at least 20 Hz to reduce effects of interference. The two frequencies ultimately chosen were 60 and 85 Hz. The beacon broadcast on a carrier frequency of 290 kHz, and the low frequency tones were modulated on each antenna—60 Hz on one, 85 Hz on the other. The device could be plugged into the headset circuit, eliminating the need for a pilot to constantly listen to the signals broadcast by the beacon (see Figure 1).[3]

The results of the flight tests were encouraging. The reed indicator was not subject to aircraft ignition interference or static from storms. Additionally, it offered another advantage. If the pilot had to deviate from course the reed indicator provided the pilot with a fairly accurate idea of how many degrees the airplane was from course (see Figure 2). If the airplane were too far to the right of its course, the 60 Hz reed would vibrate with greater amplitude than the 85 Hz reed. Likewise, if the aircraft were off course to the left, the reverse would indicate that a course correction was needed back to the right. The pilot knew the airplane was on course when both reeds vibrated with equal amplitude. The instrument itself was small, lightweight and did not require batteries. The vibrating reed device was tested in February 1928 with the Bureau reporting that the design was adapted for practical use. Flight tests of both the beacon and visual device were made by National Air Transport in late 1927 and early 1928.[4]

The advantages of the visual system were touted in a Bureau press release on March 20, 1928. A flight demonstration was held for MacCracken, members of Congress and military and industry representatives at its College Park facility. According the press release, the vibrating reed device was now a demonstrated success, and the College Park beacon could support test flights by the commercial carriers. Bellefonte, operating on the aural system, would be converted by April 1928 for flight-testing.[5]

Night Errors

Radio Laboratory scientist Haraden Pratt discovered a serious flaw in the beacons during a test flight in August 1927. While flying *on the beam*, the aircraft's position was sometimes as much as 100 degrees off-course at night, not a comforting thought when negotiating mountains. The problem was not as pronounced within 20 miles of the transmitter, but was greatest when a pilot needed it most—at distances greater than 100 miles. Problems with the beacon were reported in the press. "Radio Beacon Gives Planes Inaccurate Guide By Night," reported *The Evening Star* (St. Louis, Missouri). Test flights of the system, the Associated Press story reported, revealed "serious errors" and a "continuous shifting of the course over a wide range."[6]

The cause of the error was the horizontal component of the signal, reflected from the ionosphere, which introduced errors in the aircraft's trailing wire antenna. Navigation errors were generally worse during sunrise or sunset hours and at night when the altitude of the ionosphere changed. This effect was termed night effect, and its solution, Pratt believed, could be found in a vertical antenna. Such an antenna would reject the horizontal component of the radio wave and eliminate the navigation errors it caused. A rigid, vertical antenna mounted to an airplane had to be short but reducing the size of an antenna would require a sensitive receiver. Experiments were conducted using a vertical, ten-foot antenna and special receiver. The antenna produced an error of only 2 to 5 degrees and had an effective range of 100 miles. Pratt and fellow scientist Harry Diamond solved the problem of sensitivity by constructing a small, lightweight receiving set that employed "three or four tuned radio-frequency amplifier circuits with gang variable air condensers"[7] for increased sensitivity and frequency selectivity. Additionally, it was a dual-purpose receiver—one that would receive both navigation and communication. Its description, engineering data and test flight results were published in the *Bureau of Standards Journal of Research* in 1928. "Without receiving sets of high sensitivity," Pratt and Diamond reported, "the elimination of the dangerous trailing wire antenna, and the reduction of night shift errors obtained with short vertical antenna, would not be possible."[8] Development of the shorter, fixed antenna, the Bureau reported to the press, mitigated course shifting in radio navigation and it now considered the technical difficulties associated with night effect as solved. Unfortunately, not all problems associated with the beacon and night effect were solved—more problems lay ahead.[9]

Confident that the design and engineering of radio beacons was sound, NBS Director George Burgess announced in *Aviation* that air route operations had entered a new era of regularity and safety. The beacons, Burgess explained, would allow for flights in weather that heretofore were unsafe, making air transport more reliable. He wrote that a new term *instrument flying* had been coined that described flights conducted totally by use of flight and navigation instruments. The new radio range beacons and marker beacons provided the electronic highways pilots needed to navigate without reference to the ground. Burgess described the system built around the beacons, the visual indicator and radiotelephony, and noted that, as soon as the Department of Commerce has completed its development and established the system, the beacon system would provide them constant position information.[10]

The technology was maturing and was ready to be applied in building airways. The Airways Division established specifications for radio beacons in 1928. The beacons, now called radio ranges, were to be 2 kW transmitters and capable of operating between 185 and 375 kHz ± 5 kHz. By 1928, the Airways Division had constructed a beacon at Hadley Field, New Jersey, and Cleveland, Ohio. The Bellefonte beacon was transferred to the division by the NBS in July 1928. These three aural beacons along with five marker beacons formed an experimental electronic airway between New York and Cleveland.[11]

The Radio Laboratory expanded research on the visual reed indicator system and Diamond introduced a polydirectional double-modulation beacon in late 1928. The four-course beacon was at a distinct disadvantage when used at larger airports where numerous airways converged. Only four courses were available to connect to courses leading to and from the airport. To solve the problem, Diamond suggested the development of a twelve-course beacon that could connect up to twelve courses. He proposed using a three-stator goniometer with coils displaced at 120 degrees and a third power amplifier. The three amplifiers would modulate each of the stator coils respectively at 65, 86.7 and 108.3 Hz. The pattern produced from such an arrangement formed twelve equi-signal zones around the beacon (see Figure 3). Diamond had intended the system to use a visual indicator, but by the end of 1929 had developed an aural method stating in his report that "the author entertains strong hopes that visual indication will finally be adopted for furnishing course navigation to airplanes flying the civil airways."[12]

Dunmore designed an ingenious vibrating reed system that worked with the twelve-course radio beacon. Three vibrating reeds in the indicator each were tuned to the three frequencies broadcast by the beacon. Each course, and its reciprocal, was represented by a color. Six colors were used in all: black, yellow, brown, red, green and blue. A set of any two reeds was selected by a shutter system on the face of the instrument. The two reeds corresponded to the two frequencies of the desired course. The box containing the reeds could be rotated. If the aircraft were flying towards the beacon the word *TO* would be displayed and if the aircraft were flying away from the beacon the word *FROM* would be displayed. Since only two reeds would be visible at one time the device worked exactly as it did for the two-course arrangement—on course was represented by both reeds vibrating with equal magnitude (see Figure 4).[13]

The physicists and engineers at the Radio Laboratory had, in just three years, developed a practical and useable electronic navigation system that had evolved from an aural to a more pilot-friendly visual device. They had solved the problems associated with a trailing wire antenna by developing a more sensitive receiver that could make use of a shorter fixed antenna.

Applying their newly developed technologies to the airway system fell to the Airways Division and its head Captain Fred Hingsburg. Hingsburg, not an aviator, had a reputation for lighting expertise and MacCracken, under pressure in 1926 to expand the lighted airways, hired Hingsburg from the Bureau of Lighthouses.[14]

Political Differences

The Airways Division was responsible for installing and maintaining aids to navigation within the Aeronautics Branch. Administrative oversight came from the Bureau of Lighthouses and policy from the Aeronautics Branch. The Aeronautics Research Division was operated within the NBS. Theoretically, radio aid research was to be conducted by the Research Division and, once developed and ready for use in the airway system, they were to be built and maintained by the Airways Division. Hingsburg and Airways Radio Engineer, H. J. Walls began in-depth preparations for constructing the Hadley Field radio beacon without consultation with the Radio Laboratory. Apparently Hingsburg had not been forthcoming about the Division's construction plans in what the NBS termed an apparent lack of cooperation. Laboratory personnel had believed the Hadley site was to be initially used for experimentation and the intentional lack of communication by the Division would result in a duplication of effort. The incident produced an agreement between Dellinger and Hingsburg that each administrative unit would respect the other's role within the Aeronautics Branch; unfortunately there would be other disagreements.[15] Future discord and funding issues would have an adverse effect on the deployment of the visual beacon system.

By the end of the fiscal year, the Radio Laboratory had established a blueprint for an aeronautical telecommunications system built around radiotelephony and electronic navigation with cooperation from the industry, military and manufacturers. Goals were established and research priorities assigned. A fully funded laboratory and test facility had been established at College Park where researchers had access to a double-beam radio beacon, radiotelephone transmitter and a test airplane.[16]

In its annual 1928 report, the Bureau announced that it now had a completely developed practical type of directive radiobeacon for use with a visual indicator and an aircraft receiver and antenna system that met the demanding flight environment. A complete system, including navigation and radiotelephony, was ready for service trials with the airmail contractors. Not only had the Radio Laboratory developed the basic communication and navigation system, it had convinced manufacturers to produce radios for the aviation industry. The close relationship the Radio Laboratory maintained with the radio industry had resulted in the commercial availability of aeronautical receiving sets by 1928.[17]

Dellinger and Pratt summed up the progress made during the first two years of research under the Air Commerce Act in a paper presented to the *Proceedings of The Institute of Radio Engineers*.

> The combination of directive and marker beacons with weather and other information broadcast to airplanes by radio telephone, properly organized, thus provides a complete set of radio aids for air navigation. They permit flying under conditions of no visibility, and should add materially to the safety and reliability of air transportation.[18]

The visual system, in the opinion of the Radio Laboratory, was superior to the aural radio ranges. Pilots only had to monitor the reed indicator to stay on course, a much simpler procedure than constantly listening to the interlocking A/N signal. The aural system was subject to static and interference from other stations, the visual radio range was not. It provided a safe course even in severe static conditions when the aural range was useless. An important consideration was its interoperability with radiotelephony. Course information continued to be displayed even when the pilot received weather reports. Most pilots who had flown with both aural and visual systems, the laboratory reported, very strongly prefer the visual type.[19] Clarence Young described the system in an article for *The New York Times* explaining the visual system would be tested on the New York to Cleveland route in order to determine its practicability under service conditions. The Bellefonte beacon was to be the test bed and National Air Transport would install visual indicators for tests in their aircraft.[20]

The tests slated to begin in 1931 were delayed, in part, due to dissention between the Radio Laboratory and the Airways Division. In confidential notes the Radio Laboratory was disturbed that Hingsburg was openly critical of the visual indication system. Hingsburg believed the visual beacon was too expensive and that pilots would have problems identifying which beacon should be followed because the identification feature would not be heard by the pilot. "It is, therefore, the intention of the Airways Division to install a system of aural radio range beacons," that were proven.[21] Aural beacons were cheaper and could be installed quickly while the visual system was prototyped. "The cost of the 40 aural radio beacon transmitters at $2,500 each is about the value of a modern passenger air liner," he pointed out.[22]

The Airways Division failed to cooperate with the planned testing of the visual system on the Bellefonte beacon. Hingsburg, who had been impressed with demonstrations of the twelve-course beacon and visual system, opted for construction of only seven visual radio beacon transmitters. But the most egregious offense occurred in a meeting with Assistant Secretary Young and air operator representatives where he did a complete about face. This left Dellinger and others in the Laboratory incredulous. The beacons had not yet been tested and therefore no data had been generated "upon which a change of position by the Airways Division could be based."[23] Of the seven beacons ordered, two had been installed but not tested for visual operation. The remaining five were to be converted to function as either aural or visual. Then in a memo to Liaison Committee for Aeronautic Research,[24] Hingsburgh recommended that further research on visual beacons be halted. The memo contained misleading statements as to cost of aircraft installation, claiming it to be between $1,000 and $1,200, when actual cost was between $100 and $125 according to the Laboratory. The "program has met with repeated obstruction originating in the Airways Division," wrote the Radio Laboratory.[25]

The Laboratory had heard persistent rumors that the Airways Division had determined the visual beacon system would never be used. Opposition from the Division, they asserted, had hampered their research and, during the previous three years, industry representatives were embarrassed by criticism targeted at both the Laboratory and visual beacon system by Airways Division personnel.[26]

Assistant Secretary Young acted decisively. He prepared a statement to be read into the minutes of the Executive Board of the Aeronautics Branch during a meeting held in his office. He determined that the two divisions would work together and conduct tests of the visual system on the Mid-continent Airway between Kansas City and Los Angeles. He asked that each division designate a representative and they were to collaborate in carrying out the work. "The project will be considered as beginning afresh under this arrangement," the memo stated and with that visual beacons were to be installed on the Mid-continent route.[27]

One possible reason for the tiff between the two bureaucratic units was the cost of modifying established aural radio range beacons for the visual system. By the end of fiscal year 1931 there were 53 radio beacons in operation and another 13 were close to completion. Almost all these beacons would have to be modified to employ the visual system. Yet another modification would combine the radiotelephony transmitters and towers with the beacon sites. Radio engineer Walls of the Airways Division was not happy about the prospect of significant system changes and argued in a memo to Hingsburg that there were a number of problems which should be considered.

The disadvantages of system modifications included the requirement to rebuild 51 radio range transmitters and 41 radiotelephony transmitters. Walls believed that there were engineering factors that had not been considered and more testing on a smaller scale was in order before large scale modifications were begun. His preliminary estimate for changes only to the radiotelephony stations was $1,250,000 and converting aural beacons would cost the Airways Division an additional $210,000. Additional personnel required at the combined sites would amount to another

$400,000 annually, he estimated. He also pointed out that a 12 to 18 month lead-time was required before the transmitting sites would be operational. "At least $2,000,000.00 will be required to replace the present system," and "it should be determined whether or not this expenditure is justified," he wrote Hingsburg.[28]

Hingsburg was tasked with providing and maintaining other types of navigation aids in addition to radio aids. When the Branch was organized in 1926, the primary emphasis was placed on providing lighted airways. This strategy was based on the premise that if commercial aviation were to successfully compete with surface transportation, it must be capable of flying on a 24-hour schedule. There were no workable electronic beacons in 1926 and it was a logical decision to continue lighting airways. Instrument flying was almost unknown and, in fact, scheduled air transport pilots were not required to be certificated for instrument flight until 1933. Time and resources were required for air carriers to train pilots and equip aircraft to use radio beacons. The government needed time to prove electronic navigation aids, develop engineering standards and negotiate contracts for construction. Radio beacons were expensive to construct and operate. The price tag for construction amounted to $24,000 per beacon, and an additional $12,000 was required for annual up-keep. It was fiscal year 1931 before construction of radio beacons began in earnest. The airways required other types of navigation aids that consumed resources. For instance of the $3,091,500 appropriated in 1928, the Division established only one radio beacon—Hadley, using the remainder of the funds to extend the lighted airways and build intermediate fields, airway radio stations, and weather reporting stations.[29]

Once airways, defined by radio beacons, began to be built progress was rapid. Construction went as fast as time and funds would permit. Ninety radio beacons defining 18,000 miles of airways and seventy marker beacons were in operation by 1933. The Division deployed additional lower-powered radio beacons, aligned with the centerlines of intermediate fields, as localizers. These beacons served two functions: they filled short gaps in the airway and provided an instrument approach to the field. The budget required to operate the radio and lighted beacon system, including ground support, amounted to $4,500,000—approximately half of the Aeronautic Branch's total budget in 1933. The benefits derived from modifying the aural beacon system might not have been, as far as Hingsburgh was concerned, worth expending additional resources. There were more pressing concerns. By fiscal year 1933 the Branch's budget had been slashed from $10.4 million in 1932 to $8.6 million. Young had no choice but to cut back on airway service, lighting some of them on a part-time schedule, and decommissioning others. The reductions were a product of the depression and more reductions would follow. Fiscal year 1934 saw a further cut to $7.7 million. A few weeks later, President Franklin Delano Roosevelt impounded 32 percent of those appropriations leaving the Branch with only $5.17 million for the year. Construction of visual beacons, or, for that matter, any beacons, would cease.[30]

Night Effect Revisited

The NBS had other problems to resolve. The night effect problem they thought was solved with the vertical antenna in 1928 had returned. We occasionally heard reports from pilots reporting errors in the radio range at night and over mountains, Dellinger commented. Most of the errors were experienced in mountainous regions. Tests of the visual system on the Mid-continent airway confirmed the errors. NBS physicists and researchers immediately set about to find a solution to the problem. A former NBS researcher Frank Kear, who had become a doctoral student at the Massachusetts Institute of Technology, proposed he study the problem of night effects for his dissertation. L. J. Briggs, chief of the Aeronautics Research Division was all too happy to oblige and offered him the use of equipment for the study. The solution to the problem, according to Diamond and Kear, appeared to be completely eliminating the horizontal component of the transmission by using the Adcock antenna system.[31]

In 1919 F. Adcock had patented an antenna system that diminished the effects of the horizontal component of a radio wave. His system consisted of two sets of vertical antennas at right angles (see Figure 5). NBS experiments in 1932 were based on variations of the Adcock antennas, which produced considerable reduction in night effect. In reporting the results of tests at Bellefonte, Briggs stated “our research has verified the hypothesis that the errors are due to components of the transmitted waves produced by the horizontal elements of the transmitting loop antenna.”[32] The researchers were able to confine the radiation to the four vertical antennas by shielding the cables of the transmission lines (see Figure 6). The system became known as the *Transmission-Line*, or T-L antenna. The name Adcock was not officially used, the Research Division believing the transmission line approach was significantly different to warrant a name change. Night effect was a critical error with potential fatal consequences and the Aeronautics Research Division had found a solution. A grateful Young expressed his gratitude “to the personnel of our Research Division” for their “accomplishment in the solution of the night error problem.”[33]

The T-L system eliminated night effects but did nothing to reduce another inherent problem, multiple courses produced by the low frequency ranges in mountainous terrain. Young notified air transport operators in a letter that “we have succeeded in developing equipment which overcomes some of the effects, while others are still under investigation."[34] He warned the operators that bent and multiple courses did exist and the Aeronautics Branch was doing all it could to solve the problem.[35]

The *Air Commerce Bulletin* announced the development of the T-L antenna system in July giving a complete technical summary of the theory and its operating principles. Diamond published his results in a report appearing in the *Bureau of Standards Journal of Research* and Kear wrote a *General Report on Research on Night Effect on Radio Range-Beacons*, in November 1932 submitting it as his doctoral thesis. Night effect, as far as the Aeronautics Branch was concerned, was solved. The antenna system, more commonly known as the Adcock radio range, began to replace the open loop ranges. The problems associated with bent and multiple courses, however, were not solved and, they would continue to cause aviators serious problems. The solution lay in higher frequencies but it would be 1937 before experiments in the 64 mHz range would demonstrate the superiority of navigation aids broadcasting in the Very High Frequency (VHF) range. Airway construction based on VHF aids, would not begin until 1944.[36]

The Adcock radio range would be the standard for years to come. Even through they could not be completely trusted, especially around mountainous areas, they would form the airways and their equi-signal courses would form the pathway for instrument approaches. Colin McIntosh, the Assistant Superintendent of Flying School Operations at American Airlines, wrote an instrument-training book for pilots. In it he praised the radio range system as "unquestionably the finest system of air navigational aids yet placed in service,"[37] and then warned pilots to be extremely careful because they produced multiple and bent courses. Multiple courses could be so very erratic, that there was no procedure that would positively identify which course was the correct one.[38]

Marker Beacons

Marker beacons, as the Radio Laboratory envisioned them, were to be *mile posts* placed every 25 miles along the airway system. The beacons were to be low-power, non-directional transmitters that broadcast a distinctive signal heard only as the aircraft passed overhead. Ford had built such a device for use by its pilots who reported it was an invaluable aid in locating the Dearborn, Michigan, airport in bad weather. During fiscal year 1927 radiotelephony and the directional beacon eclipsed work on marker beacons but the marker beacon was a relatively simple system and the Bureau was ready to employ prototypes of it in upcoming tests.[39]

Dunmore added a third vibrating reed to the visual indicator. The reed, tuned to 60 Hz, signaled the passing of a marker beacon. The amplitude of the vibrating reed would increase as the aircraft approached the beacon and then decrease as the airplane flew away from it. Work on marker beacons had now advanced to the point that 10 beacons were to be built and placed in operation during fiscal year 1929 and over 80 by 1932.[40]

POINT-TO-POINT COMMUNICATION

When the Aeronautics Branch was established it inherited from the Post Office 17 Airmail Radio Stations that were later renamed Aeronautical Communication Stations (ACS) under the administration of the Department of Commerce (see Figure 7). Though the system had worked well under the Post Office, it could not be considered altogether satisfactory. Weather reports and forecasts given to pilots prior to takeoff were stale after a few hours of flight. The system had no way of communicating with the aircraft after it departed.[41]

The Post Office had been using arc transmitters for point-to-point communication and these transmitters were turned over to the Aeronautics Branch. The Branch now had a decision to make. Should the current system, using arc transmitters, be extended along new routing or should the established arc transmitters be replaced with newer, continuous wave radiotelephone equipment? The decision-makers opted for newer technology. The old arc transmitters would continue to function as a point-to-point weather and flight information system, as they had under the Post Office, until they could be replaced. In the meantime newer feeder routes would have to wait for radio and, for now, use long distance telephone to collect and disseminate weather reports.[42]

The Aeronautics Branch awarded contracts for 12 radiotelephone transmitters in March 1928 with 7 to be installed by October. Each station was to operate on frequencies between 100 and 500 kHz. Output of the transmitter was 2 kW and was capable of transmitting radiotelephony or telegraphy. Hadley Field and Bellefonte were the first to receive the new transmitters and by the end of 1928 12 more stations were equipped with the new transmitters. The stations included Cleveland, Bryan, Chicago, Omaha, North Platte, Cheyenne, Rock Springs, Salt Lake City, Elko, Reno and Oakland.[43]

Reporting the weather along the routes fell to the Weather Bureau and by 1928 there were 42 upper air meteorological stations established along the airways with 48 Weather Bureau forecasters located at 18 airports. Chicago became one of the first aviation weather stations in the nation to operate on a 24-hour basis beginning April 1, 1927. Weather information was gathered from airway maintenance personnel stationed along the route and 64 reporting stations established by the Weather Bureau. Long distance telephone was the primary reporting method for the outlying areas. E. B. Craft, Executive Vice-President of Bell Telephone Laboratories, explained that an experimental weather gathering procedure was being tried in California, as reported in the October 6, 1928, issue of *Aviation*. The Weather Bureau, funded by the Guggenheim Fund and Pacific Telephone, arranged a system whereby telephone operators could establish connections with the numerous weather observers in the area. The observers were asked to hold the line until all were contacted. The operators telephoned the Weather Bureau meteorologist, and each observer, in turn, reported the local conditions. The Los Angeles and Oakland airports recorded f40 observations 5 times daily with each observer taking only thirty seconds to complete a report. Once the reports were collected, forecasts were made and transmitted to other stations along the airway.[44]

Similar methods were used in the east. A United Press story reported that in Peekskill, New York, The Sisters at St. Mary's School for Girls participated in gathering weather data. Their reports were sent to the Weather Bureau at Newark, New Jersey. The Weather Bureau supplied the Order with instruments and the Sisters took observations four times daily. Accuracy in reporting the weather was important to the Sisters. Pilots depending on their reports, the article said, "state emphatically that the Sisters' reports are exceptionally dependable…[and]…they err only on the side of safety."[45]

Weather, flight data and administrative messages could be distributed via a variety of modes: radiotelegraphy, telephone or commercial telegraph. None of these methods were particularly efficient. Radiotelegraph proved a slow and unreliable means of communication, requiring constant monitoring by station personnel in order to insure messages would not be missed. Another disadvantage was that providing channels for telegraphy reduced the number of channels available for air-ground telephony. As for the telephone, it was not an economical mode of communication. For instance, if an aircraft departed an airfield the departure message would have to be called in to not only the destination airport, but also those along the route, which proved to be an expensive proposition.[46]

The best solution lay in Teletype or telephone-typewriter circuits as they were called in 1928. The Teletype could transmit to all stations simultaneously, provide a printed copy of the weather or message and did not require constant monitoring. Automatic Teletype systems were installed for use on the New York to Chicago section (the eastern division) of the transcontinental airway. The Weather Bureau, National Air Transport and the Airways Division managed the service from a Cleveland office. Airports, intermediate fields, Airway Radio Stations and National Air

Transport's offices all had access to messages sent over the system. *Aero Digest* reported that the system made possible quicker connections to other stations and provided access to national weather reports from Washington. The equipment and lines were leased from AT&T at a cost of $70 per mile per year.[47]

"The teletype has been found particularly useful not only in connection with transmitting weather information, but also other information pertaining to air operations,"[48] Assistant Secretary MacCracken told a gathering at the Wilbur Wright Memorial Lecture in South Kensington, England. Point-to-point teletype communications conserved precious frequency spectrum needed for air-ground radio communication and were an important ground communication mode for transmitting information to other airfields and points along the airway. The Airways Division continued leasing and expanding Teletype service so that by June 1930 the system comprised 9,500 miles supporting 178 weather-reporting stations. Zones were established that same year to manage the volume of weather information being collected. The principal weather stations overseeing the collection and dissemination of weather reports in their zone included Cleveland, Omaha, Salt Lake City, Oakland, Portland, Atlanta and Dallas.[49]

Other improvements to the system came in 1932. The Aeronautics Branch began purchasing equipment instead of leasing. More page printers were employed and standard weather symbols were adopted for use (see Figure 8). The Weather Bureau had also established 12 reporting stations at airports to collect observations in their area and prepare route forecasts every three hours. The forecasts were distributed over the circuits to all other stations in the system. Each reporting sequence began at 42 minutes past the hour with the stations transmitting observations sequentially. When the last station in the sequence completed typing the report all the observers on the circuit had a complete hourly weather observation for the route served by the circuit.

Tape printers were found at most stations. They were less expensive and did not require the transmission of line feeds or carriage returns as did page printers. The tape reproduced each report on a narrow strip that could be cut and pasted in an order that best suited the station receiving the observations. As more and more Americans began to fly, this method became unwieldy, as each request for a weather briefing would require more cutting and pasting. Using page printers, on the other hand, only required advancing the page containing all the requested information, tearing it off and handing to the pilot. Page printers were found at larger facilities, and in 1932, the Weather Bureau used them in experimental map transmissions.

Using a separate circuit Kansas City, Cleveland, Chicago, Newark and Washington were able to distribute weather maps using Teletype. The service initially distributed maps six times daily but then cut back to four. Two maps would be sent; one depicting weather west of the Mississippi and the other the east (see Figure 9). The maps could then be reassembled at each receiving station and copied. Initially, the dissemination of the maps was limited, but one of the economic benefits of purchasing the equipment allowed for wider distribution of weather maps.[50]

Even during the worst of the depression, Hoover continued to support growth in the aviation industry. By 1934, 13,000 miles of Teletype service was in use for distributing weather and administrative messages. There were 205 interconnected Teletype stations at airports and an additional 317 Weather Bureau stations that used either telephone or telegraph. Thirty separate Teletype circuits were leased to the Aeronautics Branch by the Bell System and included repeater stations every 50 miles. The longest circuits were 2,000 miles servicing between 15 to 20 intermediate stations, and the shortest only 200 miles. Each station had both backup equipment and a spare line to insure continuous operation. There were 67 radio telephone stations on the airway system capable of transmitting weather information to aircraft. Each station serviced an area of approximately 200 miles.

Initially groups of three stations would broadcast weather reports once each hour at scheduled times. This was done to eliminate interference with other stations. Pilots were required to know the specific time a station was scheduled to broadcast the weather along their route of flight. The broadcasts were easy to miss. To alleviate this problem, the routes were divided into chains, each designated a color: brown, blue, orange and red. Blue chain stations broadcast on the hour and at five minutes past. At ten and fifteen minutes past the hour the stations on the brown chain provided weather reports and at fifty and fifty-five minutes, stations on the red chain broadcast. If pilots missed one report, then a station on another chain provided weather.[51]

In 1928 Bell's E. B. Craft predicted that an improved weather information system would help create a safer operational environment for aviation. Out of this would grow an increased number of flights that would greatly stimulate the demand for electronic navigation aids. Knowing the destination forecast and enroute weather and obtaining frequent updates during the flight added an essential element of safety to blind flying.[52]

CONCLUSION

At first, it was described it as fog signaling and blind flying by the scientists, pilots and builders of a system that would one day sustain an vital form of transportation. At first there would be no model from which they could build, but ultimately they would define its very form and function. While the technologies have changed, the basic model has not. Low frequency radio ranges no longer define airways, and teletype has given way to modern telecommunications technologies. Increasingly, the technologies that enable flight are themselves flown—in space. Satellites provide accurate, three-dimensional navigation in areas where it is impossible to build and uneconomical to maintain terrestrial navigation aids and communication facilities. Geosynchronous Earth Orbiting (GEO) satellites make possible ground-to-air and point-to-point communication while providing aircraft surveillance in areas where RADAR cannot. These new technologies are embedded in the concepts of researchers and politicians such as Otto Preager, Fredrick Kolster, Percival Lowell, Francis Dunmore and Francis Engel—men who visualized and fashioned aerial highways, engineering electronic navigation and communication technologies.

It would fall to the Federal Government to supply the navigation and communication infrastructure, a concept articulated by Herbert Hoover and embodied in the legislation that became the Air Commerce Act. Within the administrative bureaucracy, the interrelationship between the creators of technology and funders would ultimately define its form and utility. Such was the case of the visual indicator. J. Howard Dellinger (see Figure 10) correctly understood the advantages of a visual navigation system. In tests, pilots much preferred Dellinger's technique because it reduced fatigue and made course corrections easier. But it would be a politician who ultimately determined that the aural method would be selected as the primary form of navigation—the decision affecting radio navigation for the next forty years[53].

These builders of airways found a powerful ally in Herbert Hoover. Soon after the passage of the Air Commerce Act of 1926, Hoover began organizing the Department of Commerce to better support the research and development effort of the NBS. The physicists, scientists and researchers were given the political assistance and funding to support the development effort. Hoover's goal was to lead the world in aeronautical progress within three years of a legislative mandate, and he was well on his way. He was keenly aware of the importance of government support in the form of infrastructure for this fledgling industry and his political backing never wavered throughout his secretariat and presidency. William P.

MacCracken, within days of assuming the role of Assistant Secretary of Commerce for Aviation, stated:

> Little commercial aviation could be organized until the fundamental services [airways] were assured, as no commercial concern could undertake to provide these aids to navigation at his individual expense, not only because of the large preliminary out lay but because such facilities would be equally available to competitors.[54]

MacCracken, as did Hoover, understood the significance that an advanced and well-funded aeronautical telecommunications system would have on the future of commercial aviation. He also believed that support for such a system was the responsibility of the Federal government.[55]

Hoover's managerial ability and foresight insured its success, and when he left the presidency in 1935, he left behind an industry supported by a telecommunications infrastructure that had surpassed the whole of Europe and had become the foundation for commercial aviation in the United States.[56]

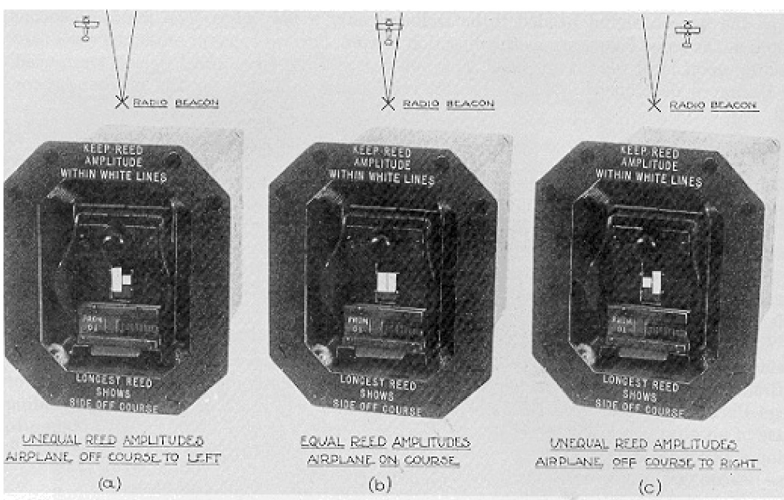

Figure 1—Reed Indicator[57]

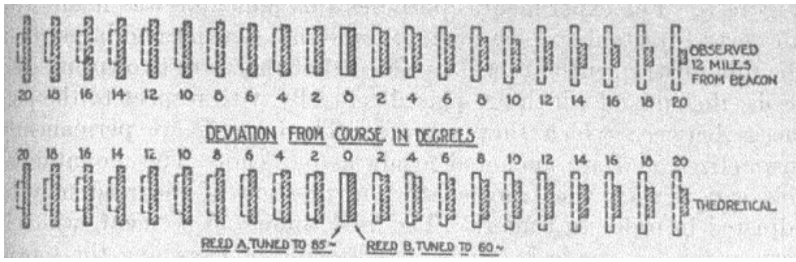

Figure 2—Reed Amplitude Vibration Correlated With Number of Degrees Off Course[58]

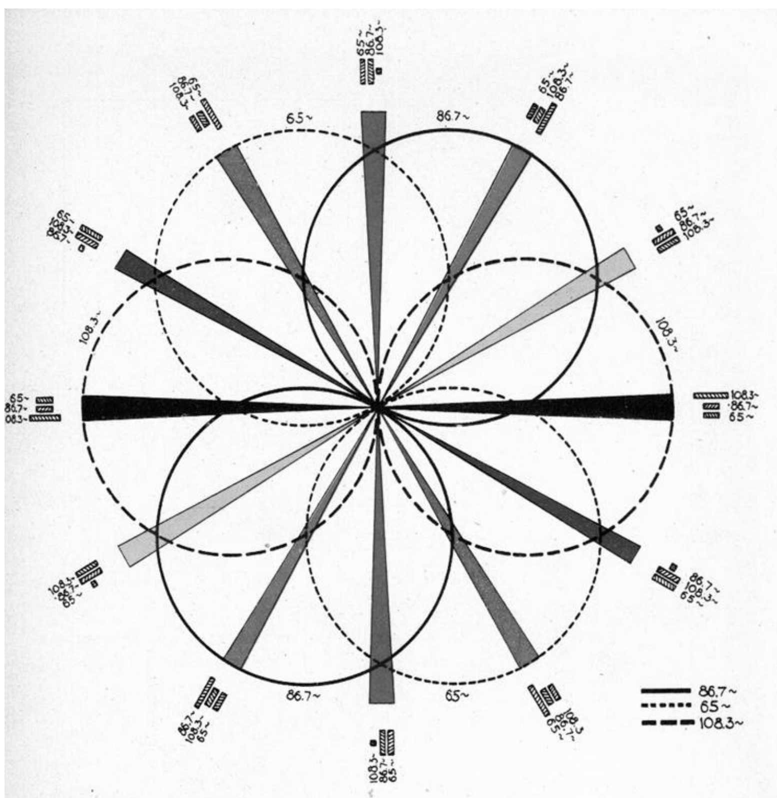

Figure 3—Twelve-Course Beacon[59]

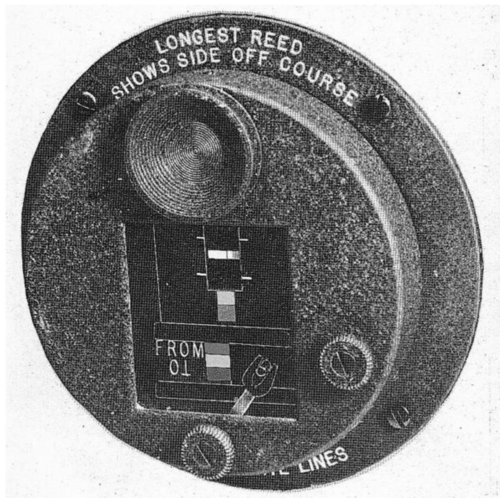

Figure 4—Twelve-Course Indicator[60]

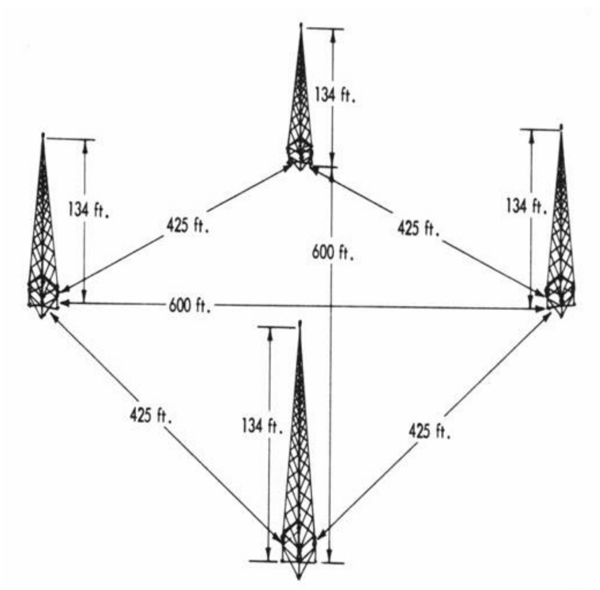

Figure 5—Adcock Radio Range System[61]

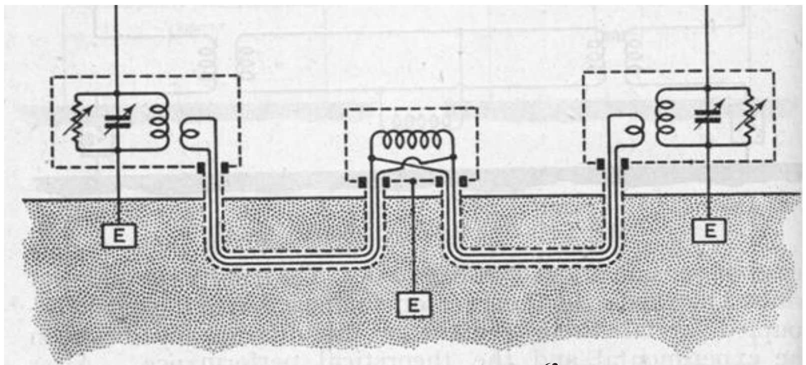

Figure 6—T L Antenna System[62]

Figure 7—Typical Aeronautical Communication Station[63]

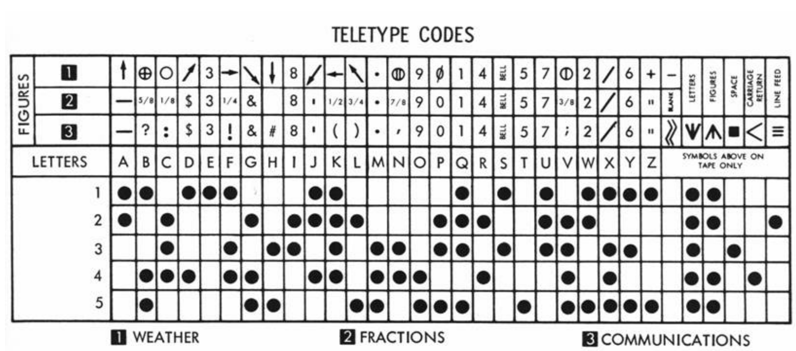

Figure 8—Teletype Codes[64]

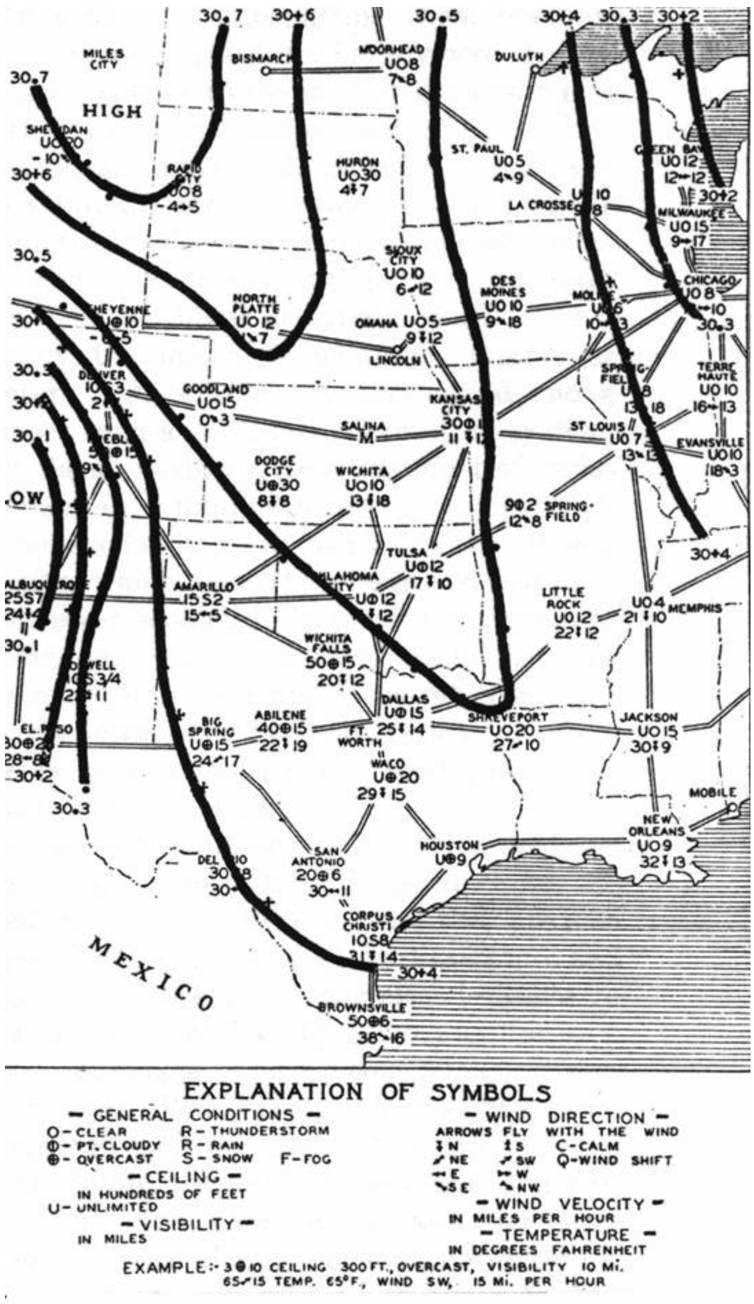

Figure 9—Weather Map[65]

Figure 10—Dellinger explaining the vibrating-reed to MacCracken (the pilot)[66]

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