Low @-@ frequency radio range

The low @-@ frequency radio range (LFR) , also known as the four @-@ course radio range , LF / MF four @-@ course radio range , A @-@ N radio range , Adcock radio range , or commonly " the range " , was the main navigation system used by aircraft for instrument flying in the 1930s and 1940s , until the advent of the VHF omnidirectional range (VOR) , beginning in the late 1940s . It was used for en route navigation as well as instrument approaches and holds .

Based on a network of radio towers which transmitted directional radio signals , the LFR defined specific airways in the sky . Pilots navigated the LFR by listening to a stream of automated " A " and " N " Morse codes . For example , they would turn the aircraft to the right when hearing an " N " stream (" dah @-@ dit , dah @-@ dit , ... ") , to the left when hearing an " A " stream (" di @-@ dah , di @-@ dah , ... ") , and fly straight ahead while hearing a steady tone .

As the VOR system was phased in around the world , the LFR was gradually phased out , mostly disappearing by the 1970s . There are no remaining operational LFR facilities today . At its maximum deployment , there were nearly 400 LFR stations in the U.S. alone .

History

After World War I , aviation began to expand its role into the civilian arena , starting with airmail flights . It soon became apparent that for reliable mail delivery , as well as the passenger flights which were soon to follow , a solution was required for navigation at night and in poor visibility . In the U.S. , a network of lighted beacons , similar to maritime lighthouses , was constructed for the airmail pilots . But the beacons were useful mostly at night and in good weather , while in poor visibility conditions they could not be seen . Scientists and engineers realized that a radio based navigation solution would allow pilots to " see " under all flight conditions , and decided a network of directional radio beams was needed .

On September 24 , 1929 , then @-@ Lieutenant (later General) James H. " Jimmy " Doolittle , U.S. Army , demonstrated the first " blind " flight , performed exclusively by reference to instruments and without outside visibility , and proved that instrument flying was feasible . Doolittle used newly developed gyroscopic instruments ? attitude indicator and gyrocompass ? to help him maintain his aircraft 's attitude and heading , and a specially designed directional radio system to navigate to and from the airport . Doolittle 's experimental equipment was purpose @-@ built for his demonstration flights ; for instrument flying to become practical , the technology had to be reliable , mass @-@ produced and widely deployed , both on the ground and in the aircraft fleet .

There were two technological approaches for both the ground and air radio navigation components , which were being evaluated during the late 1920s and early 1930s .

On the ground , to obtain directional radio beams with a well @-@ defined navigable course , crossed loop antennas were used initially . The first loop @-@ based LFR system was commissioned by the U.S. Commerce Department on June 30 , 1928 . But the loop antenna design suffered from poor performance , especially at night , and by 1932 the Adcock antenna array , which had superior accuracy , became the preferred solution and replaced the loop antennas . The U.S. Commerce Department 's Aeronautics Branch referred to the Adcock solution as the " T @-@ L Antenna " (for " Transmission Line ") and did not initially mention Adcock 's name .

In the air , there were also two competing designs , originating from groups of different backgrounds and needs . The Army Signal Corps , representing military aviators , preferred a solution based on a stream of audio navigation signals , constantly fed into the pilots ' ears via a headset . Civilian pilots on the other hand , who were mostly airmail pilots flying cross @-@ country to deliver the mail , felt the audio signals would be annoying and difficult to use over long flights , and preferred a visual solution , with an indicator in the instrument panel .

A visual indicator was developed based on vibrating reeds , which provided a simple panel @-@ mounted " turn left @-@ right " indicator . It was reliable , easy to use and more immune to erroneous signals than the competing audio based system . Pilots who had flown with both aural and visual systems strongly preferred the visual type , according to a published report . The reed

@-@ based solution was passed over by the U.S. government , however , and the audio signals became standard for decades to come .

By the 1930s the LFR network of ground @-@ based radio transmitters , coupled with on @-@ board AM radio receivers , became a vital part of instrument flying . LFR provided navigational guidance to aircraft for en route operations and approaches , under virtually all weather conditions , helping to make consistent and reliable flight schedules a reality .

LFR remained as the main radio navigation system in the U.S. and other countries until it was gradually replaced by the much @-@ improved VHF @-@ based VOR technology , starting in the late 1940s . The VOR , still used today , includes a visual left @-@ right indicator .

= = Technology = =

= = = Ground = = =

The LFR ground component consisted of a network of radio transmission stations which were strategically located around the country , often near larger airports , approximately 200 miles apart . Early LFR stations used crossed loop antennas , but later designs were all based on the Adcock vertical antenna array for improved performance , especially at night .

Each Adcock range station had four 134 @-@ foot @-@ tall (41 m) antenna towers erected on the corners of a 425 × 425 ft square , with an optional extra tower in the center for voice transmission and homing . The stations emitted directional electromagnetic radiation at 190 to 535 kHz and 1 @,@ 500 watts , into four quadrants . The radiation of one opposing quadrant pair was modulated (at an audio frequency of 1 @,@ 020 Hz) with a Morse code for the letter A (· ?) , and the other pair with the letter N (? ·) . The intersections between the quadrants defined four course lines emanating from the transmitting station , along four compass directions , where the A and N signals were of equal intensity , with their combined Morse codes merging into a steady 1 @,@ 020 Hz audio tone . These course lines (also called " legs ") , where only a tone could be heard , defined the airways .

In addition to the repeating A or N modulation signal , each transmitting station would also transmit its two @-@ letter Morse code identifier once every thirty seconds for positive identification . The station identification would be sent twice : first on the N pair of transmitters , then on the A , to ensure coverage in all quadrants . Also , in some installations local weather conditions were periodically broadcast in voice over the range frequency , preempting the navigational signals , but eventually this was done on the central fifth tower .

The LFR was originally accompanied by airway beacons , which were used as a visual backup , especially for night flights . Additional " marker beacons " (low power VHF radio transmitters) were sometimes included as supplementary orientation points .

= = = Air = = =

The airborne radio receivers ? initially simple Amplitude Modulation (AM) sets ? were tuned to the frequency of the LFR ground transmitters , and the Morse code audio was detected and amplified into speakers , typically in headsets worn by the pilots . The pilots would constantly listen to the audio signal , and attempt to fly the aircraft along the course lines (" flying the beam ") , where a uniform tone would be heard . If the signal of a single letter (A or N) became audibly distinct , the aircraft would be turned as needed so that the modulation of the two letters would overlap again , and the Morse code audio would become a steady tone . The " on course " region , where the A and N audibly merged , was approximately 3 ° wide , which translated into a course width of ± 2 @.@ 6 miles when 100 miles away from the station .

Pilots had to verify that they were tuned to the correct range station frequency by comparing its Morse code identifier against the one published on their navigation charts . They would also verify they were flying towards or away from the station , by determining if the signal level (i.e. the audible tone volume) was getting stronger or weaker , respectively .

Approaches and holds

Final approach segments of LFR instrument approaches were normally flown near the range station , which ensured increased accuracy . When the aircraft was over the station , the audio signal disappeared , since there was no modulation signal directly above the transmitting towers . This quiet zone , called the " Cone of Silence " , signified to the pilots that the aircraft was directly overhead the station , serving as a positive ground reference point for the approach procedure .

In a typical LFR instrument approach procedure , final approach would begin over the range station , with a turn to a specific course . The pilot would descend to a specified minimum descent altitude (MDA) , and if the airport was not in sight within a specified time (based on ground speed) , a missed approach procedure would be initiated . In the depicted Joliet , IL LFR approach procedure , minimum descent altitude could be as low as 300 feet AGL , and required minimum visibility one mile , depending on aircraft type .

The LFR also allowed air traffic control to instruct pilots to enter a holding pattern " on the beam " , i.e. on one of the LFR legs , with the holding fix (key turning point) over the LFR station , in the Cone of Silence , or over one of the fan markers . The holds were used either during the en route portion of a flight or as part of the approach procedure near the terminal airport . LFR holds were more accurate than NDB holds , since NDB holding courses are predicated on the accuracy of the on @-@ board magnetic compass , whereas the LFR hold was as accurate as the LFR leg , with an approximate course width of 3 ° .

Non @-@ directional beacons

From its beginning in the early 1930s , the LFR was augmented with Low Frequency Non @-@ directional beacons (NDBs) . While the LFR required a complex ground installation and only a simple AM receiver on board the aircraft , NDB ground installations were simple single @-@ antenna transmitters requiring somewhat more complex equipment on board the aircraft . The NDB 's radio emission pattern was uniform in all directions in the horizontal plane . The NDB 's on @-@ board receiver was called a radio direction finder (RDF) . The NDB @-@ RDF combination allowed pilots to determine the direction of the NDB ground station relative to the direction the airplane was pointing . When used in conjunction with the on board magnetic compass , the pilot could navigate to or from the station along any chosen course radiating from the station .

Early RDF receivers were costly , bulky and difficult to operate , but the simpler and less expensive ground installation allowed the easy addition of NDB based waypoints and approaches , to supplement the LFR system . Modern RDF receivers , called " automatic direction finders " (or " ADF ") are small , low cost and easy to operate . The NDB @-@ ADF system remains today as a supplement and backup to the newer VOR and GPS navigation systems , although it is gradually being phased out .

Limitations

Although the LFR system was used for decades as the main aeronautical navigation method during low visibility and night flying , it had some well known limitations and drawbacks . The course lines , which were a result of a balance between the radiation patterns from different transmitters , would fluctuate depending on weather conditions , vegetation or snow cover near the station , and even the airborne receiver 's antenna angle . Under some conditions , the signals from the A quadrant would " skip " into the N quadrant (or vice versa) , causing a false " virtual course " away from any real course line . Also , thunderstorms and other atmospheric disturbances would create electromagnetic interference to disrupt the range signals and produce crackling " static " in the pilots ' headsets .

Replacement by VOR

The LFR navigation system required , at a minimum , only a simple AM radio receiver on board the aircraft to accurately navigate the airways under instrument meteorological conditions , and even execute an instrument approach to low minimums . On the downside , however , it had only four course directions per station , was sensitive to atmospheric and other types of interference and aberrations , and required pilots to listen for hours to an annoying monotonous beep , or a faint stream of Morse codes , often embedded in background " static " . Its eventual replacement , the VHF band VOR navigation system , had many advantages . The VOR was virtually immune to interference , had 360 available course directions , had a visual " on course " display (with no listening needed) , and was far easier to use . Consequently , when the VOR system became available in the early 1950s its acceptance was rapid , and within a decade the LFR was mostly phased out . VOR itself is gradually being phased out today in favor of the far superior Global Positioning System (GPS) .

Sounds

The following are simulated sounds for the Silver Lake LFR . The range station ? located about 10 miles north of Baker , California ? would preempt the navigational signals every 30 seconds to transmit its Morse code identifier (" RL ") . The station identification would be heard once or twice , possibly with different relative amplitudes , depending on the aircraft location . Pilots would listen to and navigate by these sounds for hours while flying . Actual sounds contained " static " , interference and other distortions , not reproduced by the simulation . Adjusting the volume would affect the effective course width . For example , in the simulated sound for " twilight " A below , where the aircraft is nearly on the beam but slightly inside the A quadrant , a low volume almost obscures the weak A sound , whereas a loud one makes it more distinct .

(See Wikipedia : Media help if you encounter problems playing these sound files .)