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by

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RADIO NAVIGATION AND AIRPLANE NAVIGATION

Yu-Cai Wang

Modernized airplanes, whether they are passenger jets that fly for the airlines or supersonic fighter planes, cannot escape the influence of radio navigation technology. This article explains thoroughly but in simple terms the principles and uses of the various types of radio navigation devices extant today.

Armies on land use the magnetic compass in order not to lose their direction. When airplanes flying in clouds or at night rely upon navigation by compass, can they reach their destinations accurately? Certainly not. Equipment errors and subtle technical errors that occur when people use compasses can cause the airplane to go off course, but the principal source of problems is the effect of wind on the airplane while in flight. This causes the airplane to be blown leeward, even if the pilot maintains the bearing of the compass very accurately (cf. Fig. 1).

People look to radio navigation in order to fly accurately. They try to use the special properties of radio wave propagation, the ability of radio waves to be modulated and bunched, to provide information on the airplane's direction, distance, position, etc. Because of this, various types of radio navigation devices are being developed, and they have greatly improved the flight capabilities of airplanes.

The Radio Compass

The radio compass was an early radio navigation system in guidance stations. The guidance station on the ground would continuously emit radio waves, and the radio compass on the airplane used a circular antenna to receive the radio waves. The circular antenna was a directional antenna. The rotating circular antenna could detect and receive the weakest angles of radio waves and the incident angles of electric waves. With a vertically discriminating antenna the airplane's approximate position with respect to the guidance station could be measured. This method takes the nose of the airplane as the standard azimuth and the broadcasting station as the opposite azimuth, and registers the results on the indicator of the radio compass. So far as the guidance station is concerned, the radio compass system is reliable: one simply has to follow the indicator to aim for the guidance station, and then one can certainly reach the source of the radio waves, which is the air above the guidance station. This device is still in use on airplanes up to the present day. In the new models of radio compasses, the circular antenna can check the coming direction of the radio waves all along, with the result that it can automatically and continually indicate the broadcasting station's opposite azimuth. Some radio compasses can be adjusted in advance to monitor a guidance station's frequency, and thus allow the pilot to select quickly and use the necessary station while in flight. The medium-wave broadcasting stations of all countries can serve as high power guidance stations furnishing radio compass measurements. But because the guidance station works in medium- and long- wave wavebands, it receives a considerable amount of disturbance from thunder and lightning, and when airplanes approach an area that has thunder storms and clouds, the radio compass sometimes loses it efficiency. At night, because of the increased strength of waves reflected by the ionosphere, there result errors in the measurement of direction (night effect). In mountainous regions when the flight receives and sounds a guidance station, there will also be errors due to electric waves going off course (mountain effect). Aside from this, what the radio compass provides is just the azimuth of the opposite guidance station. The pilot must integrate his course and calculate in order to chart out the airplane's position on a map (cf. Fig. 2).

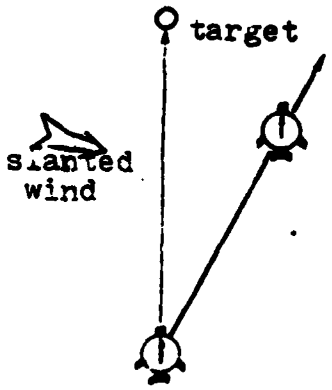

Fig. 1. Airplane being blown off course by slanted wind.

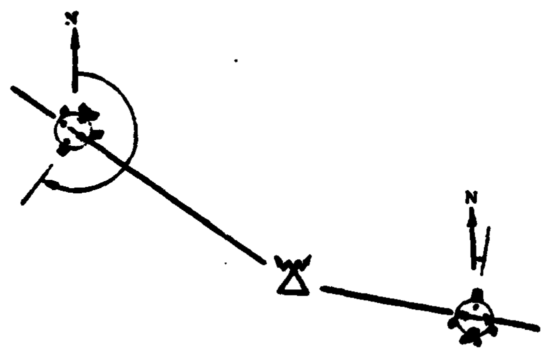

Fig. 2. Integrating the calculations of the airplane's course and plotting out the positional line of the airplane.

Automatic Direction

Taking the conection between reception and emission in turn, the airplane emits electric waves, and the ground sation uses receiving equipment to measure the coming direction of the electric waves. The automatic direction station performs the task of measuring direction. With this type of method, it is not necessary to increase the equipment on the airplane; it is only necessary to use the electric waves that an ultrashort wave communication system emits for several seconds. When waves are emitted, the fluorescent screen of the direction station on the ground has scanning lines to indicate the coming direction of the waves, using the magnetic north as the reference point. The operator can ascertain the directional reading that the scanning line indicates, and uses the communication station to report it to the pilot. This allows the pilot to examine and correct the airplane's course. The new direction station use numbers to control and demonstrate directly the directional reading, which means that errors arising from the operator's misjudgment are avoided. This makes the measurement of direction even faster and more accurate. It has an advantage over the guidance station, in that it gives the pilot the magnetic north as a positional datum (airplane azimuth), and it allows the pilot to know the position of the airplane with respect to the direction station (cf. Fig. 3). It is not like the guidance station, which only tells the pilot the opposite azimuth.

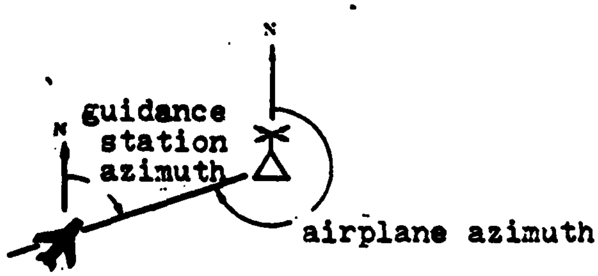

Fig. 3. Automatic direction.

The All-Direction Beacon

One relatively new radio navigation system is called the all-direction beacon, which works by matching a beacon emission system on the ground with receiving equipment on the airplane. It is like the radio compass in that it allows the pilot to perceive the ground directly, and to monitor continually the beacon's position with respect to the airplane. Additionally, this position uses the magnetic north as the basic electric station azimuth, which is not related to the airplane's course. It is thus very easy to sketch out the airplane's positional line on a map. The principle of its operation is: the beacon station on the ground emits modulated electric waves, and after the equipment on the airplane receives them, it releases two signals. One expresses the reference position, and the other changes according to the airplane's change in position. Then they undergo a rather different special circuit connection, are turned into electric signals, and convey the broadcasting station's azimuth and the airplane's azimuth to the indicator. Because this type of beacon station measures direction in all directions, it is called an all-direction beacon. The capacity of the all-direction beacon station, like that of the guidance station, has no restrictions. Airplanes in the air can use it; it works in ultrashort wave bands; it receives relatively little atmospheric interference, and is not subject to the night effect. Its precision in measuring direction is better than that of the guidance station and the radio compass, but when blind areas in the air are encountered, the low altitude effect renders it closer to the above-mentioned devices.

Range Finding

The various types of radio navigation systems described so far only give the pilot information corresponding to the position of stations on the ground; they do not tell what kind of relative position exists between the airplane and the ground station. They only indicate the existence of a distant object, without indicating how far away it is. If he wants to clarify the airplane's position, the pilot must do additional work; i.e., ascertain two or more position lines (azimuth lines), and sketch the intersection of the two lines on a map, with this intersection being the airplane's current position. These several positional lines can be measured at the same time separately from several guidance stations on the ground (directional station, all-direction beacon station), and can also be measured from a single ground station using different times before and after.

Range finding radio navigation systems are also extensively used to ensure that airplanes keep accurately on course. The special unchanging characteristic of using radio waves to propagate a speed is that the time spent by the electric waves in measuring the distance between the airplane and the range finding station is converted according to a minute (one second in a million minutes) 300 meter constant. Thus it is possible to try to obtain the distance (strictly speaking, the oblique distance) between two points. The procedure of this operation is: the range finding equipment on the airplane continually emits inquiring pulses. These pulses, after being received by the range finding station on the ground, cause the station's emission device to use another frequency pulse to respond. When the equipment on the airplane calculates the difference in time between emitting the inquiring pulse and receiving the response pulse, it converts it into a numerical signal, and the indicator then continually registers the distance to the range finding station. When the pilot knows the airplane's distance from a given known point, he then sketches a circular positional line on his map. If he obtains a second circular positional line for another range finding station, the intersection of the two circular arcs is the airplane's position (cf. Fig. 4a). A certain type of double range finding system that armies use utilizes this principle. Its accuracy in position measurement is very good, and it accurately leads airplanes to carry out their desired implementation of dropping bombs, air drops, parachute operations, aerial surveys, etc. Of course, one can also use a circular positional line and an azimuth line (straight positional line) to ascertain the airplane's position (cf. Fig. 4b). The International Civil Aviation Association uses an all-direction beacon in conjunction with a range finding device as one of its standard navigation devices. By using this set of equipment the airplane can simultaneously measure the azimuth and the distance data from a point on

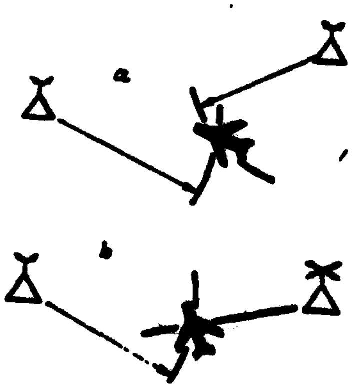

Fig. 4. Ascertaining position by range finding using two range finding stations.

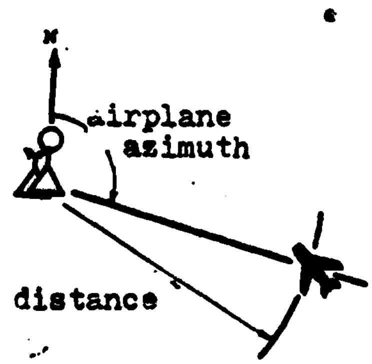

Fig. 5. Ascertaining position by simultaneously using azimuth and distance.

the ground, and realize the extreme coordinate position (cf. Fig. 5).

Direction Measurement and Range Finding

Because of military requirements, people have developed microwave direction measurement and range finding systems that ingeniously use a ground station to perform the functions of direction measurement and range finding. The direction measuring principle is similar to the all-direction beacon: the ground station continually emits radio pulses. The range of the pulses is modulated by a rotating antenna. After the equipment on the airplane receives these pulses, it can express the signal of the reference position and the signal that changes according to the airplane's change in position. As the position angle between them diverges, this expresses the azimuth of the ground station with respect to the airplane's broadcasting station, and it is registered on the indicator. The range finding response pulses are included in the pulses received while measuring direction, so that the two tasks are performed simultaneously. The reliability and precision of direction finding and range finding navigation systems are greater than in the all-direction beacon. The range finding device has improvements, and it has simplified the equipment on the airplane, so that it is as convenient for the pilot as using a radio. Since the idea of position is clear, it can be produced quickly. Small ground stations have a high degree of mobility, and are easy to set up, so they are often used in field warfare. But this type of equipment shows weaknesses when blind areas or low altitudes are encountered. When the above-mentioned station is used to measure direction, the airplane's capacity has no limitations, but when range finding it can be used by 100 airplanes at once. What is of interest here is that with so many airplanes simultaneously emitting inquiry pulses of similar frequencies to the ground station, and the ground station emitting response pulses of different frequencies, the response pulses crisscross together. How can the receiving equipment on each airplane find its own response pulse from among so many response pulses? If an airplane cannot distinguish the response pulse intended for it, then obviously it cannot perform its range finding task. The stochastic method is used to solve this problem. Although the working frequency of the emitting device on each airplane is the same, and the inquiry pulses are the same, the intervals between pulses are not arranged very strictly, and with this kind of stochastic inequality, each emitting device "does things in its own way." Because it can be considered that the airplane's distance from the ground station is unchanging at each instant, then as the equipment on the airplane receives the response pulses, it finds the series of pulses corresponding to the interval change pattern of the pulses emitted by that airplane. In this way it can ascertain that they are response pulses intended for the same airplane, and the receiving equipment automatically makes range finding calculations in accordance with these response pulses. Then the indicator registers the airplane's distance from the station. The pilot thus can use this type of navigation equipment without worrying about making mistakes. Of course, all experienced pilots know that flight navigation requires many types of navigation devices used in conjunction in order to prevent the possibility of passive situations arising.

Long Range Navigation

For the radio navigation equipment discussed above, the effective radius is usually within 200-300 kilometers, and very seldom exceeds 400 kilometers; all these devices can be considered only as short range navigation equipment. For intercontinental and transoceanic flights, as well as flights into an enemy's rear area, short range navigation equipment is of little help, and cannot satisfy the requirements. It then becomes necessary to use long range navigation equipment to ensure the flight's course. At present, long range navigation works primarily with long wave and ultralong wave band hyperbolic navigation systems (e.g., Roland C, Omega, etc.). Systems of this type are usually composed of several ground stations, and their working area can extend over the entire surface of the earth. They work according to the hyperbola theorem of geometry: if the distance from a moving point to two fixed poinsts is set at a fixed length, then the trace of this moving point is a hyperbola. Hyperbolas can be constructed for all different distance values, and thus between two fixed points one can draw a class of hyperbolas for different distance values (cf. this magazine in February of the same year, page 19, Fig. 2). When an airplane is in flight, it is a moving point, and the special equipment on the airplane receives simultaneously the radio waves synchronically emitted by a pair of ground stations. It then accurately calculates the the difference in time required for the two signals to reach the airplane, as well as the difference in the two signals' relative positions, and determines the difference in the airplane's distance from the two ground stations, in order to obtain the airplane's positional curve. After measuring a second positional curve from another pair of ground stations, it is possible to mark the airplane's position on a special flight chart book that has hyperbolic nets, or to calculate directly the airplane's position by entering the data into a computer. Because the hyperbola is derived according to the difference in distances, the hyperbolic navigation system is also called the differential distance navigation system. This kind of system has considerable navigational accuracy, and it is not necessary to equip the airplane with emitting equipment and high precision time reckoning equipment; it works well at both high and low altitudes, and it can be used by arbitrarily many airplanes. Thus it has come into widespread use.

After the appearance of manmade satellites orbiting the earth, people naturally thought of using them for navigation purposes. The orbit parameters of navigation satellites and their exact positions in space are known, so when an airplane receives simultaneously the signals emitted by several navigation satellites, it feeds them into an electronic computer for calculation, and then directly determines the airplane's position in space. Satellite navigation is a kind of global and all-weather navigation system; its accuracy in determining position is very high, and it can even fulfill the requirements of weapons projection. It is a kind of radio navigation equipment that is currently being developed.

Doppler Navigation

All the navigation systems discussed so far have ground stations or navigation satellites working in conjunction with equipment on the airplane, and furnish various kinds of navigational data. Are there any methods for supplying navigational data that do not rely on external mechanisms, but instead solely use radio equipment on the airplane itself? There indeed does exist such an "independent" navigation system, and this is the Doppler radio navigation system. It uses radar equipment to emit pulses toward earth continually, and then measures the Doppler effect of waves reflected by the earth (degree of drift) in order to determine the airplane's velocity relative to ground and angle of drift. It then feeds the velocity relative to ground and angle of drift into a navigational computer, in order to calculate the airplane's position (longitude and latitude) and other necessary data (such as direction, distance, etc.). This then is the so-called self-sufficient radio navigation system. The data that is sought not only provides navigational information, but also can be used by bombers, parachute planes, and paradrop planes to furnish important information on high altitude wind direction and wind velocity. At present Doppler radar is already in widespread use on all kinds of large airplanes.

Because of the development of radio navigation techniques, and because of the many types of navigation device combinations used, it can be said that modern aviation can achieve freedom of flight under any weather conditions.

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