AIR NAVIGATION …and the Future

Capt. M.P. "Pappy" Papadakis

The aviation navigation systems in use today cover the gamut from antique to superlative star wars. The oldest system in use is the N.D.B. **N.D.B.** stands for non-directional (radio) beacon. It consists of a radio beacon located on the ground that continually broadcasts on a advertised frequency. The beacon also broadcasts an aural identifier consisting of a Morse code letter identifier.

In an airplane equipped with an **A.D.F.** receiver a pilot may receive the signal when tuning the appropriate frequency. When this occurs a arrow pointer mounted on a compass face will point to the station at all times. Thus if a pilot flies to a station that is directly North of him the "needle" will point to North. As the airplane flies over the station the needle will rotate, 180 degrees and now will point south. The opposite end of the needle will now be North with the arrowhead end pointing to the station. In the United States it is unusual for an N.D.B. station to be utilized for cross-country navigation. It is regularly used for shooting instrument approaches to airports.

V.O.R. The mainstay of the cross-country navigational system in the United States is the V.O.R. stations. These again are radio stations on the ground that radiates a specialized radio signal. The station broadcasts a signal that allows the receiving radio to determine on what radial line he is on. North is the 000 degree radial and there are naturally 360 radials to choose from. These radials emanate from the ground station. Each station has a discreet frequency and is also identified by broadcasting aural code letters.

The typical receiver in the airplane uses a needle similar to the A.D.F. needle again located on the compass face. This needle also always points to the station. Additionally the pilot is provided a Horizontal situation course deviation indicator instrument. On this instrument the pilot may dial in the appropriate course radial and it will display whether the pilot is left or right of that radial. The display will also show whether the airplane is going to or from the station on the selected radial.

The omni **V.O.R.** system is the most widely used for navigation within the U.S.A. It is the backbone of both the high and low altitude route structure. The high altitude stations are powerful enough to be received about 200 miles from the station ,the lower powered stations on the low altitude system are limited to less distance.
V.O.R. approaches to airports are a standard published approach at most instrument airports. These like the N.D.B. approaches are considered non precision approaches.

V.O.R./D.M.E. is a variant to the V.O.R. in which the pilot obtains bearings to and from the station only. D.M.E. stands for distance measuring equipment. In this case the station broadcasts a signal that allows the pilot to determine bearings and distance from the station in nautical miles. Today the D.M.E. feature is very common although not universal.

Automatic Tuning V.O.R. systems are sometimes employed by newer aircraft. Usually the pilot has to tune and identify individual V.O.R. stations as he approaches them. Some newer airplanes auto tune selected stations and display which stations are being utilized. This function is usually used in conjunction with another navigation system that is being used simultaneously.

TACAN is a military version of a navigational system that gives both bearing and distance to a station on selectable - frequencies. This system is displayed and flown in an identical fashion to a V.O.R. /D.M.E. It is prevalent on navy ships in particular.

Loran and Loran c, is a military low frequency navigation system utilized by the Navy primarily. Radio stations are geographically located worldwide and broadcasting continually on predetermined frequencies. If an aircraft picks up any three such stations it displays where it is through simple triangulation. Since it now knows where it is, through a computer and by pre selecting latitudes and longitudes it knows where it wants to go, the system is capable of navigation worldwide for so long as it receives adequate signals from the ground based signals.

OMEGA is similar to LORAN. It is a civilian navigation system used worldwide. It utilizes radio signals from several land based civilian low frequency radios. When these are not receivable the system utilizes Navy radio stations as back up radios. The system relies on triangulation from three known stations for position location through triangulation.

The system allows the pilot to initialize the system at the gate (a known latitude and longitude). The pilot may then type in and store the latitude and longitude of all subsequent places he desires to fly (called waypoints). Once this is accomplished an Omega system will display where the airplane is at any time, and where it must fly to. Range and bearing to any waypoint, groundspeed, wind components, time to waypoints and much, much, more. The system is accurate to about 1/10 nautical mile.
Some systems are considered accurate enough to begin approaches from, most are not.

RNAV is a variant of, and an advance in the concept of Omega except it utilizes auto tuned V.O.R. stations to triangulate or range and bearing to locate positions. It is initialized very similar to Omega and waypoints are stored. The display and information that can be displayed are similar to Omega. It is considered accurate enough to initiate an approach from a stored waypoint position.

Inertial Navigation systems are very simple devices. A system consists of two very rapidly spinning gyros. Since gyros are stable in space they will always remain aligned as they were when they were turned on. This stability in space is critical to the operation of the system. Once the system is initialized and the airplane moves the gyro remains aligned as it was at takeoff. The airplane and the case of the gyro accelerates and moves relative to the stationery gyro. Very delicate sensors detect such accelerations and motions and through a computer display the geographical new location of the aircraft. This system is entirely self-contained and relies on no outside radios.

It must be initialized and then any number of way points may be typed into the computer. Once this is accomplished, the displays and capabilities are similar to Omega or Rnav. Inertial units are susceptible to precession and gyro drag. These may cause errors in navigation that are insidious. It was not unusual for the older, cheaper units to be off at the rate of a 1/2 mile per hour. This can add up on an international flight. The newer laser gyros are superb and don't usually have large errors.

In fact the airline versions of the laser gyro inertial navigation systems have intentionally been randomly detuned so as to introduce some errors. This was done since they are the same type units used for the military as guidance on rockets. In case of a hijacking the government did not want our best units placed in enemy hands.

Triple mix Inertial Navigation Systems are a variant of a single system. For international flying, it was needed to have redundant inertial systems. To this end it was thought that three units would be ideal. The units can be separated and flown individually with each displaying it's version of where it believes it is. Remember that no unit will be the same because of the expected precession rates. If one unit either fails or goes out of tolerance it can be easily determined since two units give nearly identical readings while the third seemingly is drifting away.

The system may be integrated by selecting triple mix. In this case an internal computer senses the position that each unit is currently displaying. Since these are not exactly the same, the three positions make up a small imaginary triangle. The computer then places the position of the airplane in the center of that triangle and displays this average position as being the most likely accurate position. The triple mix configuration will sense if any single unit is drifting out of tolerance or has failed. It will automatically alert the pilot to deselect triple mix and to deselect the failing unit.

Automatic Triple Mix the newer systems are always in triple mix unless there is a failure or error within the system and then they alert the pilot of the problem set.

Auto tune V.O.R. and V.O.R. in conjunction with Inertial Navigation Systems. An Inertial Navigation System used to navigate in the airways system admits to itself that it is imperfect and it always tries to update itself with better information. To this end whenever it is in range of V.O.R. stations it will utilize this data and display that it is receiving such information. Only when the airplane goes out to sea or otherwise loses such signal does it function solely on the inertial units.

Since international flying requires the loading of many waypoints into the system, human errors can occur in typing the waypoints. Most airlines have strict procedures that are to be followed in typing in waypoints and otherwise loading the inertial programs.

Generally each unit is loaded separately, while the other pilot observes. Once a unit is loaded the role is reversed and the other pilot displays and reads off the waypoint while the other checks each reading with the flight plan. Each unit is loaded separately and the double check should be accomplished. Disaster can result from mistyping the location of a waypoint. This is precisely what happened to K.A.L. 007. The I.N.S. was misloaded and the airplane flew precisely where it was programmed.

Satellite Navigation is the wave of the future. The United States Government has launched satellites that give pinpoint navigation worldwide. The military is already using the system and other satellites are to be launched that will provide a similar system for civilian aviation as well. In fact the system is in place for most of the world. most civilian aircraft are not currently equipped with the equipments needed to utilize this system.

F.M.S., Flight Management Systems are not really navigational systems at all. They are a specialized computer, combined with an up to date software program that stores and displays information relative to the flight, navigation and the airplane's capabilities. Some systems will have every airport with over 5.000 feet of runway stored. It may have every navigational fix on the entire airways systems stored. It may have all normal international waypoints stored and it may have every V.O,R in the world stored. An F.M.S. can be utilized to load I.N.S. information and flight plans.

An F.M.S. programs flight plans to maximize fuel savings or best cruise speeds or turbulence speeds. It predicts the best descent speeds, descent points, and much, much more. An investigator must realize that this device is simply a computer with a large memory circuit board. The N.T.S.B. is not equipped to retrieve data that is available to an investigator. Likewise since a system stores navigational programs it is important to check that the stored information was correct and the most recent edition. They are changed regularly to keep abreast of the latest information.

The K.A.L. 007 flight accident is attributable to loading error in the I.N.S. There is South American accident where a airliner flew into a mountain while failing to switch off a non authorized mode for an approach to the authorized V.O.R. mode of navigation. For as many accidents that exist from using the wrong mode of navigational system, there are more accidents recorded where a pilot either ignores or fails to utilize a navigation system where it could have provided life saving information.

Making the systems of navigation even more sophisticated is current state of the art. The older first generation models simply displayed visual information to the pilot that he interpreted and made corrections for while he flew the airplane. The data displayed was raw data that simply gave him actual status of the positioning of the airplane relative to a known ground station. The airplane was displayed and the track desired was displayed. It was up to the pilot to hand fly the airplane to the desired track utilizing the pilots judgment as how to best accomplish the transition and movement.

The next generational step was to provide the pilot an autopilot. In this case the pilot still received raw navigational data through visual displays and he in turn commanded the autopilot to fly as the pilot directs to the appropriate navigational fixes. The pilot now still interprets the navigational data and commands the autopilot to fly the airplane as the pilot desires.

The next step was to directly allow the autopilot to take input from the navigational data in a series of modes where the navigational system directly orders the autopilot where to fly. The pilot still obtains raw data display of navigational instruments and he monitors both airplane and navigational progress.

The next generational step was to incorporate a FLIGHT DIRECTOR system that is essentially a computer that analyses raw data navigational inputs, determines, and displays the appropriate way the airplane should be flown to return to desired on course positions. The pilot will receive both Flight director and raw data displays simultaneously. Raw data tells the pilot where the airplane is with respect to the desired track. Flight Director Data displays the optimum track to fly to return to the desired track. Somewhat later speed control was incorporated into auto pilot systems, and the throttle power systems were now moved to coincide with the desired speeds selected.

The last steps in creating an Auto flight system from an autopilot was to design a system where the autopilot could capture and fly the descending glide slope, thereby flying I.L.S. landings entirely on autopilot.

The last step was to design an auto flight system that would recognize the close proximity of the ground and simultaneously change the aircraft attitude by flaring to landing attitude and retarding the throttles to Idle. Finally the designers decided that such a system should utilize two autopilots and two computers and integrate the information for further flight safety.

Such systems exist today that allow fog landings down to 700 feet visibility in the United States and 100 meters in Europe.
An airliner landing at 150 MPH is traveling 250 feet a second. One can see that a pilot would have about one and one half seconds reaction time based on visual references. What has occurred is that some airplanes are certified to auto land essentially blind! For this to occur there has to be a great amount of confidence in the system.

One can see that the pilot has been taken out of the control loop and has become a system monitor or a computer manager. This transition will continue as technology and reliability continues to escalate. However it is still the co coordinated actions of an alert flight crew that insures the safety of such operations.