



NAVIGATION INSTRUMENTS - BASICS

1. Introduction

Several radio-navigation instruments equip the different airplanes available in our flight simulators software.

The type of instrument that can be found on a specific airplane depends on its level of sophistication: a light VFR plane is equipped with simple instruments while a jet needs quite much more complex devices to ensure proper navigation.

Despite the very large variety of equipment that can be found in many aircraft, the main radio-navigation instruments listed below are not numerous and provide all functions needed to perform IFR navigation:

- **NDB** receptor (Non Directional Beacon)
- **VOR** receptor (VHF Omnidirectional Range)
- **DME** receptor (Distance Measurement Equipment)
- **ILS** receptor (Instrument Landing System)
- **GPS** receptor (Global Positioning System)

Information from these receptors is displayed on the radio-navigation instruments which are listed below:

- **ADI** (Attitude Director Indicator) or **EADI** (Electronic ADI),
- **ADF** (Automatic Direction Finder)
- **HSI** (Horizontal Situation Indicator) or **EHSI** (Electronic HSI)
- **RMI** (Radio Magnetic Indicator)
- **CDI** (Course Direction Indicator)
- **EFIS** (Electronic Flight Instruments System) which includes :
- **PFD** (Primary Flight Display)
- **ND** (Navigation Display)

Some supplementary systems are not available on basic aircraft but some can be integrated through add-ons:

- **TACAN**
- **LORAN**
- **OMEGA**
- **MLS**
- **INS**
- **HUD**
- **FMS / FMC**

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2. The NDB equipment

A Non Directional Beacon (NDB) is a radio station placed in an identified location and it is used as an aviation or maritime navigation aid. In the aviation, the NDB use is regulated by the annex 10 of ICAO which specifies that NDB are exploited over a frequency range between 190 and 1750 kHz (in Europe this range is reduced within 255 and 525 kHz).

These beacons are mostly located near airports since they provide the simplest navigation information to reach an airport.

A NDB is characterized by its range:

- **Long range (100 NM)**: it is used as a reference point for en route navigation but also as a holding fixe or an initial approach fixe (IAF) near airports.
- **Small range (25 NM)**: it is essentially used as a holding or initial approach fixe near airports. In some countries, when NDB are used as IAF, they are often called locators.

The signals from a NDB are received by an instrument on the airplane called ADF (Automatic Direction Finder).

2.1. The ADF selector

In most airplanes, the NDB frequency is set into the ADF selector which can be found on the radio panel:



ADF selector on a Boeing radio panel



ADF selector on a Beechcraft radio panel

2.2. The ADF bearing display

The NDB signal is received by the ADF which automatically and continuously displays the relative bearing from the aircraft to the selected NDB.



ADF display on a Cessna

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The NDB bearing can also be displayed on a radio-compass or RMI (Radio Magnetic Indicator):



RMI equipment

In modern jets, the simple ADF display is integrated into the Electronic Horizontal Situation Indicator (EHSI). The blue arrow indicates the NDB bearing (the direction towards the NDB, heading 150° in the example below).



EHSI equipment

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3. The VOR equipment

A VHF Omnidirectional Range (VOR) beacon is a short-range radio-navigation system enabling aircraft with a receiving unit to determine their position and stay on a given course.

The VOR beacon simultaneously transmits two signals, a constant omnidirectional signal called the *reference phase* and a *directional signal which rotates* through 360°, during a 0.03 second system cycle, and consistently varies in phase through each rotation. The two signals are only exactly in phase once during each rotation – when the directional signal is aligned to magnetic north.

VOR are exploited over the Very High Frequency (VHF) band from 108 to 117.95 MHz with channels spaced of 50 or 100 kHz (50 kHz for dense zones, 100 kHz elsewhere). The first 4 MHz is shared with the ILS band, the VOR being allocated to 160 of the 200 available channels. To leave channels for the ILS, in the range 108.0 to 111.95 MHz, the 100 kHz digit is always even. Of these 160 channels, 120 are allocated to VOR stations intended for en route navigation while the other forty are for terminal VOR stations.

Two types of VOR beacons are used:

- **Terminal VOR (T-VOR):** it is used in the terminal area of airports and covers a relatively small geographic area protected from interference by other stations on the same frequency. T-VOR output power is 50 W which allows covering a region from 1000 ft AGL up to and including 12000 ft AGL at radial distances out to 25 NM. The allocated band ranges from 108 to 111.850 MHz with the 100 kHz digit being always even.
- **En route VOR:** they are used as route fixes within high or low airspace. Their output power is 200 W which provides a range up to 200 NM. The allocated band ranges from 112 to 117.950 MHz

A VOR receiver enables the aircraft to determine its bearing with respect to the beacon (the position of which is known). From the phase shift measurement, the VOR receiver enables to determine the direction in degrees, called the **radial**, from the station to the aircraft.

From the radial detection, the aircraft can follow any course passing through the VOR station, either inbound or outbound. Crossing two VOR radials allows the determination of the exact position of an aircraft.

The VOR station is often coupled to a DME system to provide a distance measurement between the aircraft and the beacon.

3.1. The VOR selector

In all planes, the frequency of a VOR is set into the NAV1 and NAV2 selector which can be found on the radio panel:



Boeing radio panel to select NAV1 and NAV2

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Many panels have two frequencies:

- one active located at the left of the frequency selector
- one stand by located at the right of the frequency selector

The stand by frequency is used to prepare the right frequency before transferring it to active. (next frequency preparation).



Beechcraft radio panel to select NAV1 and NAV2



Other radio panel to select NAV1 and NAV2

The NAV1 selector is common to the VOR and ILS. Only the frequency set is able to differentiate the two systems.

3.2. The VOR course display

The VOR signal is analyzed by a receiver and displayed by a Course Deviation Indicator (CDI).



CDI 1 and 2 equipment of a Cessna

The white vertical bar indicates the position of the selected radial with respect to the airplane course. In this example, the radial, selected with the OBS (Omni Bearing Selector), is on the left of the aircraft. The white triangle is the TO/FROM indicator (in this example the selected radial is inbound). The CDI1 also displays the ILS glide slope (horizontal bar).

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Horizontal Situation Indicator (HSI) of a Beechcraft

The yellow vertical bar indicates the position of the selected radial with respect to the airplane course. The white triangle is the TO/FROM indicator (in this example the selected radial is inbound).

The VOR course can also be displayed on a radio-compass or RMI (Radio Magnetic Indicator):



RMI equipment



EHSI equipment

The pink vertical bar indicates the position of the selected radial with respect to the plane (VOR AN 110.50). The green indicator works in RMI mode and indicates the direction of the VOR beacon (VOR AVN 112.30).

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4. The DME equipment

A Distance Measuring Equipment (DME) is a radio-transponder which allows knowing the distance from the airplane to a ground station. It measures the time spent by a UHF (Ultra High Frequency) radio signal to make the round trip between beacon and the airplane. More precisely, it measures the slant range, i.e. the hypotenuse of the triangle represented by the altitude of the aircraft and the distance between the radar antenna and the aircraft's ground track.

Whenever a DME is coupled to a VOR or an ILS, it is automatically displayed by the selection of the VOR or ILS frequency. Otherwise, like in TACAN, the DME frequency must be specifically set.

4.1. The DME display

In some airplanes, the DME measurement can be found on the radio panel, associated with the ground speed of the airplane.



DME display in a Cessna

In this example the DME distance is 27.5 NM and the ground speed is 98 kt.



EHSI equipment

In this example the DME distance is 0.5 NM from the VOR AN (110.50).

The AVN VOR is not equipped with a DME and the lack of distance information is indicated with '- - - -'

The DME measurement can also be integrated into a RMI display:



RMI equipment with DME

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5. The ILS equipment

The Instrument Landing System (ILS) is the most precise navigation equipment used in IFR flight. It is today the most used precision approach system in our current flight simulators.

It is composed of at least two of the following elements:

- A **Localizer** (LOC) which provides the horizontal deviation with respect to the runway axis. The LOC frequencies range between 108.10 MHz and 111.95 MHz (with the 100 kHz first decimal digit always odd) and are not used for any other purpose.
- A **Glide Slope** (GS, or Glide Path GP) which provides the vertical deviation with respect to the nominal approach slope (most commonly 3°). The GP signal is in the 330 MHz (UHF) range.

Together with the previous, two other pieces of equipment can be also available:

- A **DME** which provides the distance between the LOC and the airplane
- A (set of) **MARKER** beacon(s) which provides a light and a sound indication at a published distance from the runway threshold.

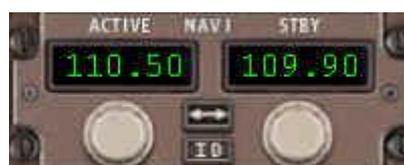
The certified range is 15-20 NM (25 NM in flight simulator) for the LOC and slightly less for the GS. The glide information is not reliable anymore when going below 50ft AGL.

In practice, the pilot sets **only the LOC frequency** since the GS (and eventually the DME) frequencies are paired to the LOC frequency.

The Localizer (LOC) provides only one of the two fundamental functions of an ILS. However, some small airports do not dispose of a full ILS but only the localizer part.

5.1. The ILS selector

In most airplanes, the frequency of the ILS (or the LOC) is set into the NAV1 selector on the radio panel.



Boeing radio panel to select NAV1



Beechcraft radio panel to select NAV1

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5.2. The ILS display

The two ILS signals (LOC and GS) are displayed on the following instruments.



CDI 1 equipment of a Cessna

The white vertical bar indicates the localizer course (in this example the runway axis is on the left). The white horizontal bar indicates the glide (in this example the glide slope indicates that the plane is over the approach slope; when the glide is inactive, the rectangle GS is filled with red and white stripes).



HSI equipment of a Beechcraft

The yellow vertical bar indicates the localizer course (in this example the runway axis is on the right). The glide marker is indicated by the two yellow arrows on the left and right borders of the HIS (named GS).

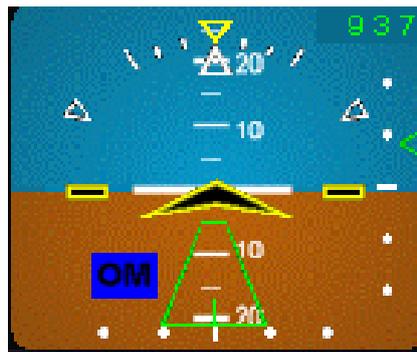


EHSI equipment

The pink vertical bar indicates the localizer course (in this example the runway axis is on the left).

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In some airplanes, the ILS is displayed on the Electronic Attitude Direction Indicator (EADI).



PFD/EADI equipment

The green rectangle indicates the localizer course and the glide marker is indicated by the green arrow on the right border of the EADI.

5.3. The MARKER beacons

MARKER beacons provide a light and a sound indication at a published distance from the runway threshold. They operate at a carrier frequency of 75 MHz and are going to be replaced by a systematic use of a DME coupled to the LOC.

Three beacons can be available:

- **Outer Marker (OM)**: it normally identifies the Final Approach Fix (FAF) and is situated on the same course/track as the LOC and the runway center-line, 4 to 7 NM before the runway threshold. It is typically located about 1 NM inside the point where the GS intercepts the intermediate altitude. The outer marker is often coupled to a NDB (Locator Outer Marker)
- **Middle Marker (MM)**: it is normally positioned 0.5 to 0.8 NM before the runway threshold and is used to alert the pilot that the CAT I missed approach point (typically 200 ft AGL) has been passed.
- **Inner Marker (IM)**: it is located at the threshold of the runway on some ILS approach systems (usually Category II and III) having decision heights of less than 200 ft AGL.

Marker beacons can be indicated on the EADI (see figure above) but also close to the radio panel:



6. The GPS equipment

The Global Positioning System (GPS) permits earth-centered coordinates to be determined and provides the aircraft position referenced to the World Geodetic System. Satellite navigation systems are unaffected by weather and provide global navigation coverage that fully meet the civil requirements for use as the primary means of navigation in oceanic airspace and certain remote areas.

Navigational values, such as distance and bearing to a waypoint and groundspeed, are computed from the aircraft's current position (latitude and longitude) and the location of the next waypoint. Course guidance is provided as a linear deviation from the desired track of a Great Circle route between defined waypoints.

GPS operation is based on the concept of **ranging and triangulation from a constellation of satellites** in space which act as precise reference points. The receiver uses data from a **minimum of four satellites** above the mask angle (the lowest angle above the horizon at which it can use a satellite).

In most of the airplanes, the GPS signal is received by one of the following instruments:



GPS text receiver



Garmin GPS receiver in flight simulator:

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7. The TACAN equipment

The **TACAN** (**TACTical Air Navigation**) is a navigation system used by military aircraft. It provides the pilot with bearing and distance (slant-range) to a ground or ship-borne station. It is a more accurate version of the VOR/DME system used for civil aviation.

The TACAN operates in the UHF band and its frequency ranges from 960 to 1215 MHz. Its characteristics allow simpler and smaller emitters compared to VOR. This makes possible its installation on a building, a large truck, an airplane, or a ship, and be operational in a short period of time.

The DME portion of the TACAN system is available for civil use.

At **VORTAC** facilities where a VOR is combined with a TACAN, civil aircraft can receive VOR readings. Aircraft equipped with TACAN avionics can use this system for en-route navigation as well as non-precision approaches to landing fields.

The TACAN is not a default equipment in our flight simulators software.

8. The LORAN equipment

The **LORAN (Long Range Navigation)** is a hyperbolic radio navigation system developed in the US during World War II. It is based on the calculation of the time difference between two radio pulses, emitted by two ground stations, one master and one slave, typically separated by about 1000 km. Each pair broadcast at one of four frequencies (1.75, 1.85, 1.9 or 1.95 MHz).

LORAN systems have been decommissioned.

The LORAN is not a default equipment in our flight simulators software.

9. The OMEGA equipment

OMEGA is an old navigation system which enabled ships and aircraft to determine their position over a very large range (8000 Km) by receiving Very Low Frequency (VLF) radio signals in the range 10 to 14 kHz, transmitted by a network of fixed terrestrial radio beacons, using a receiver unit.

It became operational around 1971 and was shut down in 1997 in favour of the GPS system.

The OMEGA is not a base equipment in our flight simulators software.

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10. The MLS equipment

The **Microwave Landing System (MLS)** is an all-weather precision landing system originally intended to replace or supplement the ILS.

MLS has a number of operational advantages, including a wide selection of channels to avoid interference with other nearby airports, excellent performance in all weather, small footprint at the airports, and wide vertical and horizontal capture angles that allows approaches from wider areas around the airport. It operates on frequencies around 5 GHz and has a range of around 20 Km.

In real life, it is presently used only at the London Heathrow (EGLL) airport.

The MLS is not a default equipment in our flight simulators software.

11. The INS equipment

The **Inertial Navigation System (INS)** is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of an aircraft without the need for external references.

The INS is not a default equipment in our flight simulators software. But it can be present in some addons.

12. The HUD equipment

The **Head-Up Display (HUD)** is a transparent display that presents navigational data without requiring the pilot to look away from his usual viewpoints.

In most cases it displays airspeed, altitude, a horizon line, heading, turn/bank and slip/skid indicators. In some aircraft (the Boeing 787, for example) the HUD displays data from guidance computation for low visibility take-off and low visibility approach, coming from the same flight guidance computer that drives the autopilot.

The HUD is not a default equipment in our flight simulators software. But it can be present in some addons.

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13. The FMS equipment

The **Flight Management System (FMS)** is a specialized computer system that automates a wide variety of in-flight tasks.

Its main function is the in-flight management of the flight plan: using various sensors (such as GPS and INS often backed up by radio-navigation aids) to determine the aircraft's position, the FMS can guide the aircraft along the flight plan. From the cockpit, the FMS is normally controlled through a Control Display Unit (CDU) which incorporates a small screen and keyboard or touchscreen. The FMS sends the flight plan for display to the Electronic Flight Instrument System (EFIS), Navigation Display (ND), or Multifunction Display (MFD).

The HUD is not a default equipment in our flight simulators software. But it can be present in some addons.

13.1. The navigation database

All FMS contain a **Navigation DataBase (NDB)**. The navigation database contains the elements from which the flight plan is constructed.

These are defined via the **ARINC 424** standard. The navigation database is normally updated on ground every 28 days, in order to ensure that its contents are current. Each FMS contains only a subset of the ARINC data, relevant to the capabilities of the FMS.

The NDB contains all of the information required for building a flight plan, consisting of:

- Waypoints/Intersections
- Airways
- Radio navigation aids
- Airports
- Runways
- Standard procedures (SID, STAR, IAP, holds)

Waypoints can also be defined by the pilot along the route or by reference to other waypoints with entry of a place in the form of a waypoint (e.g. a VOR, NDB, ILS, airport or waypoint/intersection)

The FMS is not a default equipment in our flight simulators software.

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