AIRCRAFT TECHNICAL BOOK COMPANY

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AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

AIRCRAFT AERODYNAMICS

STRUCTURES AND SYSTEMS

13

COMPLIANT WITH EASA

EASA PART 66/147

EASA 2023-989 COMPLIANT

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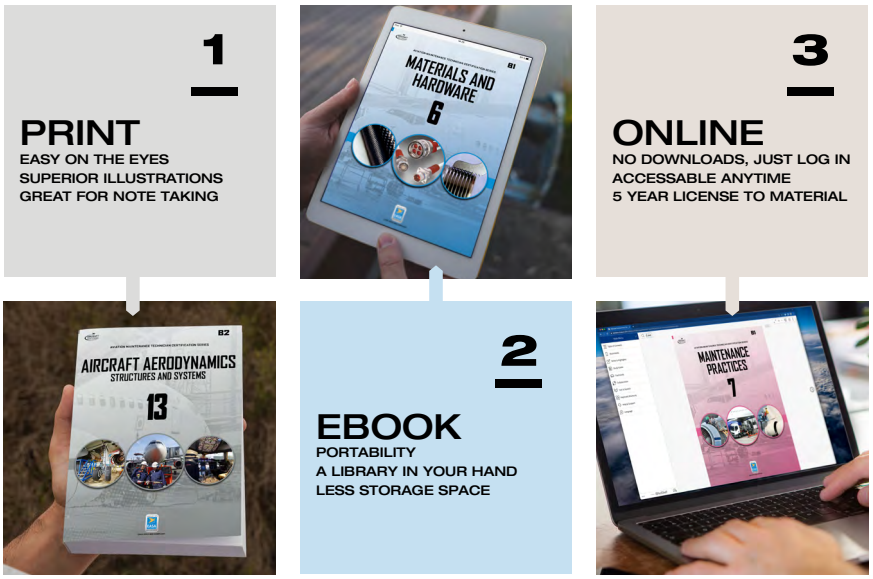

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VERSION	EFFECTIVE DATE
005.2	2026.09

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ISBN-13: 978-1964302102

REVISION LOG

Update notices for this book will be available online at www.actechbooks.com/revisions.html

VERSION	EFFECTIVE DATE	DESCRIPTION OF REVISION(S)
001	2016.01	Module creation and release.
002	2017.02	Format updates and minor type corrections.
003	2019.11	Submodule 3 revisions. Typo corrections in Submodules 3, 4 and 8.
004	2020.02	Enhanced or modified content within the following Submodules: 13.3: Added Autopilot Modes of Operation 13.4: Reorganized based on Part-66 2018 changes; added content: ADS-B and Datalink; Corrected Figures 4-78 and 4-79. 13.7: Added Fly-By-Wire Failsafe and Fly-By-Wire operation.
004.1	2021.04	Enhanced or modified content within the following Submodules: 13.4: Corrected 150 Mhz to 150 Hz. 13.8: Corrected Figure 8-12; Engine Pressure Ratio (EPR) 14.7 psi to 14.5 psi.
004.2	2022.10	Inclusion of Measurement Standards for clarification, page iv. Minor appearance and format updates.
004.3	2023.04	Minor appearance and format updates.
005	2024.12	Regulatory update for EASA 2023-989 compliance.
005.1	2026.06	Replaced practice questions and answers in Submodule 11.
005.2	2026.09	Minor typographical updates and topic clarification. Rewrite of Fuel Systems - Section E, Longitudinal Balance Fuel Systems.

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Acronym Definitions A.1

The CVR consists of a chassis and front panel, three printed wiring assemblies (the aircraft interface, audio compressor, and acquisition processor, and the Crash Survivable Memory Unit (CSMU). The CSMU contains the solid state flash memory used as the recording medium.

An Underwater Locator Device (ULD), also referred to as an underwater acoustic beacon, is mounted horizontally on the front of the CSMU and is also used as the recorder's carrying handle. The ULD is equipped with a battery that has an expected life of six years.

The ground support equipment connector is located on the front of the CVR. This connector provides the interface from the recorder to the ground equipment for checkout of the recorder or to transfer data to a readout device. The CVR is connected to aircraft wiring via a 57 pin, DPXB style connector. Both are tray mountable.

The following are salient functionality features of a modern CVR:
- 2 hours, 4 channel, high quality audio recording.
- Three voice channel inputs (150-3500 Hz).
- One cockpit area microphone input (150-6000 Hz).
- 32 Mbytes of dedicated data link recording memory.
- Dedicated ARINC 429, high speed, data link input.
- 28 VDC (10 W max) power input.

POST CRASH CVR/FDR UNIT RECOVERY

All modern aircraft are equipped with an Emergency Locator Transmitter. This radio beacon with an external fixed antenna interfaces with a dedicated search and rescue non-geostationary satellite system (COSPAS-SARSAT). When activated, such beacons send out (50 seconds after activation) a worldwide monitored distress signal on 406 MHz (formerly 121.5 MHz), that either can be located by triangulation or by a GPS (Global Positioning System) signal, whenever equipped. The ELT can be:
- Automatic Fixed: Rigidly mounted inside the fuselage of the aircraft and automatically triggered by the G force sensing switch, or manually from the cockpit (it cannot send a signal to the satellite system when underwater).
- Portable Survival (as a complement of the automatic fixed): Generally carried in the cabin or packed into the escape slides/rafts of the aircraft. It floats and can be manually activated, water activated or both, depending on the model. The cabin crew would normally activate these beacons on evacuating the aircraft or requires a survivor to manually do so when the model is not water activated.

When the ELT signal is properly received, it indicates the accident occurrence and the ground localization. As it doesn't work under water, the sunken wreckage can be located thanks to the underwater locator device. The ULD is attached to the memory unit of each recorder and emits, upon immersion, an acoustic signal of 37.5 kHz at an interval of one per second.

POST CRASH DATA RECOVERY

After the recorder recovery, the crash survivable memory unit is extracted from its crash protection housing for data recovery for further investigation. The FDR and CVR have brought a great

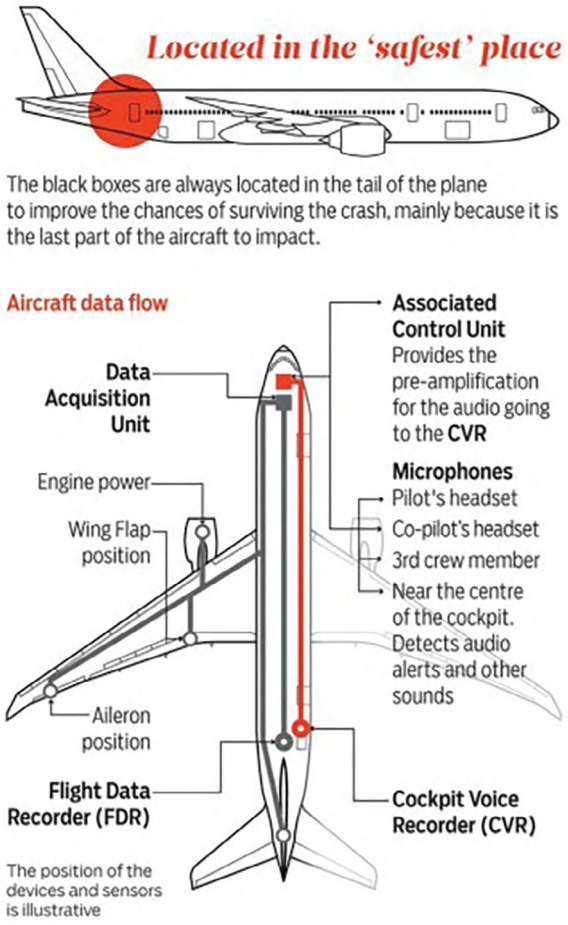

Figure 4-69. A typical placement of CVR/FDR in an aircraft.

contribution to safety by allowing experience feedback from accidents for improving designs of aircraft, air traffic management, improved operational procedures and trainings. However, there are still possibilities for improvement. Data and voice recordings sometimes do not completely allow the root cause analysis of an accident. Additional recordings are under study to enhance the investigation process.

VERY HIGH FREQUENCY OMNIDIRECTIONAL RANGE (VOR)

One of the oldest and most useful navigational aids is the VOR system. The system was constructed after WWII and is still in use today. It consists of thousands of land based transmitter stations, or VORs, that communicate with radio receiving equipment on board aircraft. Many of the VORs are located along airways. The Victor airway system is built around the VOR navigation system. Ground VOR transmitter units are also located at airports where they are known as TVOR (terminal VOR). The U.S. Military has a navigational system known as TACAN that operates similarly to the VOR. When VOR and TACAN transmitters share a location, they are known as VORTACs.

The position of all VORs, TVORs, and VORTACs are marked on aeronautical charts along with the name of the station, the frequency to which an airborne receiver must be tuned to use the station, and a Morse code designation for the station. Some VORs also broadcast a voice identifier on a separate frequency that is included on the chart. [**Figure 4-71**]

VOR uses VHF radio waves (108–117.95 MHz) with 50 kHz separation between each channel. This keeps atmospheric interference to a minimum but limits the VOR to line of sight usage. To receive VOR VHF radio waves, generally a V-shaped, horizontally polarized, bi-pole antenna is used. A typical location for the V dipole is in the vertical fin. Other type antennas are also certified. Follow the manufacturer's instructions for installation location. [**Figure 4-72**]

The signals produced by a VOR transmitter propagate 360° from the unit and are used by aircraft to navigate to and from the station with the help of an onboard VOR receiver and display instruments. A pilot is not required to fly a pattern to intersect the signal from a VOR station since it propagates out in every direction. The radio waves are received as long as the aircraft is in range of the ground unit and regardless of the aircraft's direction of travel. [**Figure 4-73**] A VOR transmitter produces two signals

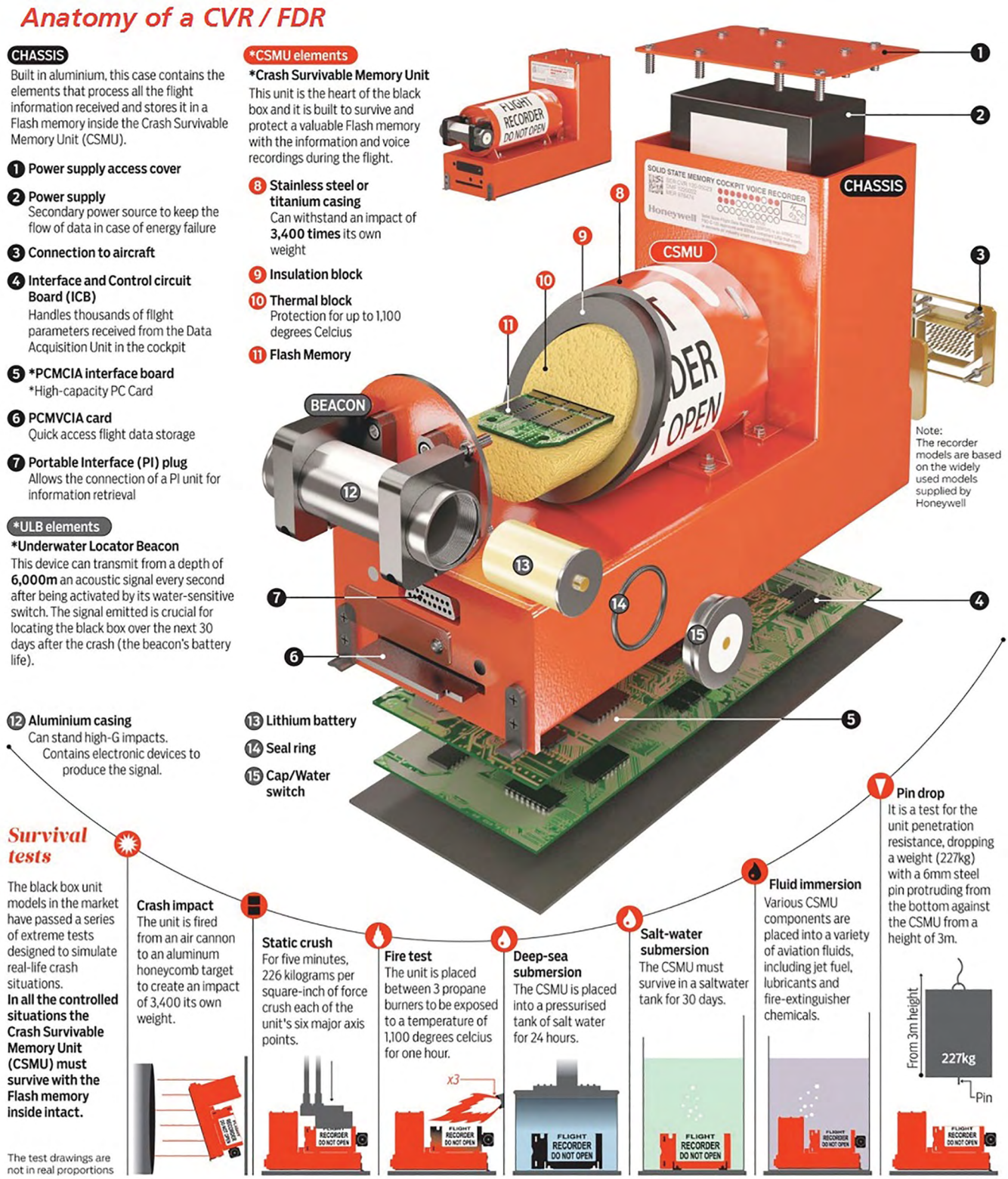

Figure 4-70. The anatomy of a Cockpit Voice Recorder (CVR)/Flight Data Recorder (FDR).

Figure 4-71. A VOR ground station.

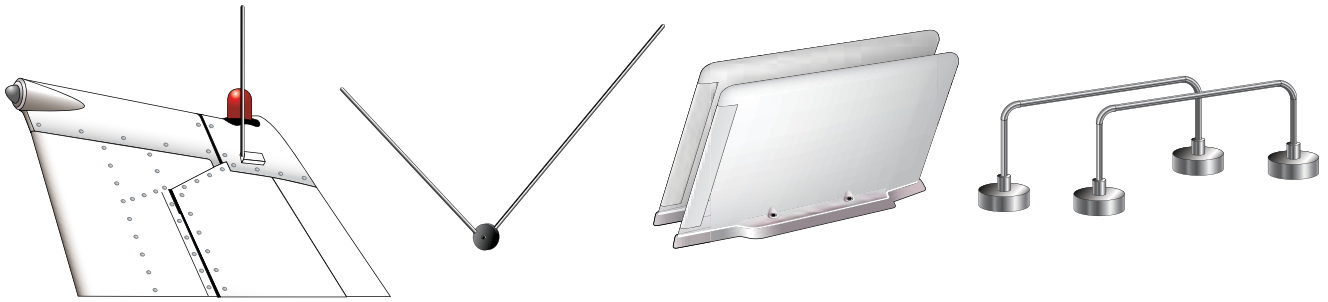

Figure 4-72. V-shaped, horizontally polarized, bi-pole antennas are commonly used for VOR and VOR/glideslope reception. All antenna shown are VOR/glideslope antenna.

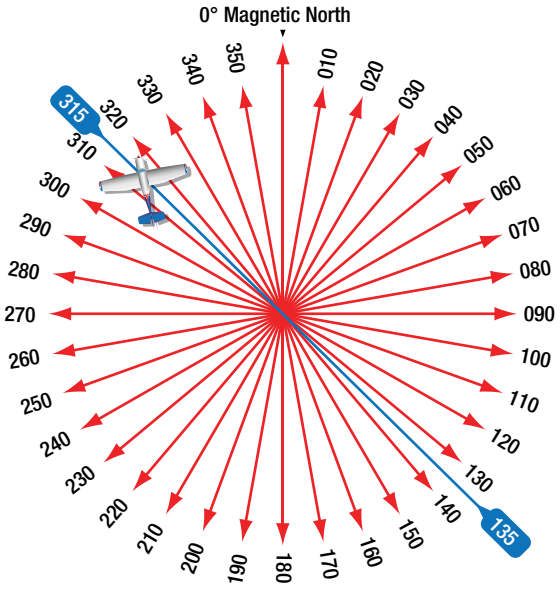

Figure 4-73. A VOR transmitter produces signals for 360° radials that an airborne receiver uses to indicate the aircraft's location in relation to the VOR station regardless of the aircraft's direction of flight. The aircraft shown is on the 315° radial even though it does not have a heading of 315°.

that a receiver on board an aircraft uses to locate itself in relation to the ground station. One signal is a reference signal. The second is produced by electronically rotating a variable signal. The variable signal is in phase with the reference signal when at magnetic north, but becomes increasingly out of phase as it is rotated to 180°. As it continues to rotate to 360° (0°), the signals become increasingly in phase until they are in phase again at magnetic north. The receiver in the aircraft deciphers the phase difference and determines the aircraft's position in degrees from the VOR ground based unit. [**Figure 4-74**]

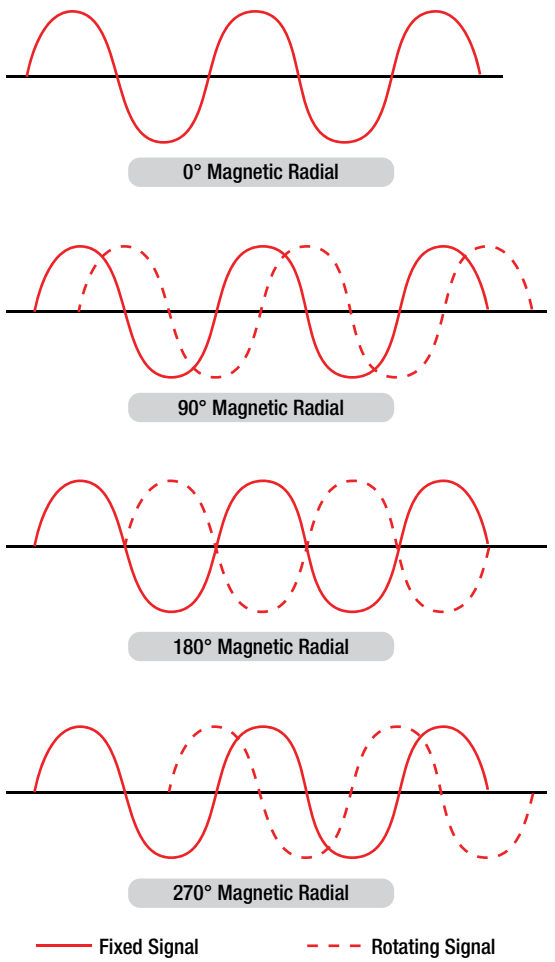

Figure 4-74. The phase relationship of the two broadcast VOR signals.

Most aircraft carry a dual VOR receiver. Sometimes, the VOR receivers are part of the same avionics unit as the VHF communication transceiver(s). These are known as NAV/COM radios. Internal components are shared since frequency bands for each are adjacent. [**Figure 4-75**]

Figure 4-75. A NAV/COM receiver typically found in light aircraft.

Large aircraft may have two dual receivers and even dual antennas. Normally, one receiver is selected for use and the second is tuned to the frequency of the next VOR station to be encountered en route. A means for switching between NAV1 and NAV2 is provided as is a switch for selecting the active or standby frequency. [**Figure 4-76**] VOR receivers are also found coupled with instrument landing system (ILS) receivers and glideslope receivers.

Figure 4-76. An airliner VOR control head with two independent NAV receivers each with an active and standby tuning circuit controlled by a toggle switch.

A VOR receiver interprets the bearing in degrees to (or from) the VOR station where the signals are generated. It also produces DC voltage to drive the display of the deviation from the desired course centerline to (or from) the selected station. Additionally, the receiver decides whether or not the aircraft is flying toward the VOR or away from it. These items can be displayed a number of different ways on various instruments. Older aircraft are often equipped with a VOR gauge dedicated to display only VOR information. This is also called an omnibearing selector (OBS) or a course deviation indicator (CDI). [**Figure 4-77**]

The CDI linear indicator remains essentially vertical but moves left and right across the graduations on the instrument face to show deviation from being on course. Each graduation represents 2°. The OBS knob rotates the azimuth ring. When in range of a VOR, the pilot rotates the OBS until the course deviation indicator centers. For each location of an aircraft, the OBS can be rotated to two positions where the CDI will center. One produces an arrow in the TO window of the gauge indicating that the aircraft is traveling toward the VOR station. The other selectable bearing is 180° from this. When chosen, the arrow is displayed in the FROM window indicating the aircraft is moving away from the VOR on the course selected. The pilot must steer the aircraft to the heading with the CDI centered to fly directly to or from the VOR. The displayed VOR information is derived from deciphering the phase relationship between the two simultaneously transmitted signals from the VOR ground station. When power is lost or the VOR signal is weak or interrupted, a NAV warning flag comes into view. [**Figure 4-77**]

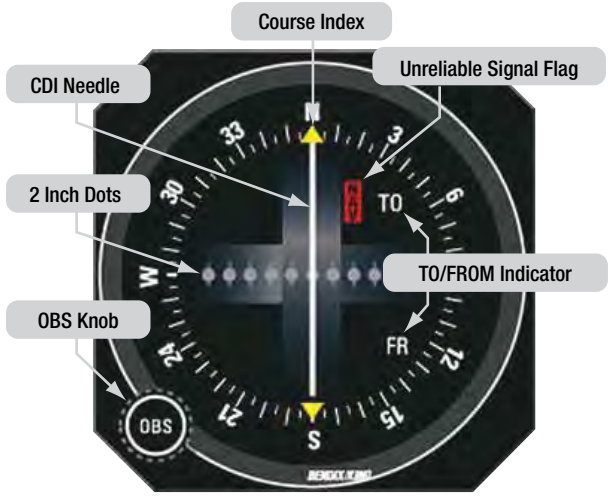

Figure 4-77. A traditional VOR gauge, also known as a course deviation indicator (CDI) or an omni-bearing selector (OBS).

A separate gauge for the VOR information is not always used. As flight instruments and displays have evolved, VOR navigation information has been integrated into other instruments displays, such as the radio magnetic indicator (RMI), the horizontal situation indicator (HSI), an EFIS display or an electronic attitude director indicator (EADI). Flight management systems and automatic flight control systems are also made to integrate VOR information to automatically control the aircraft on its planned flight segments. Flat panel MFDs integrate VOR information into moving map presentations and other selected displays. The basic information of the radial bearing in degrees, course deviation indication, and to/from information remains unchanged however. [**Figure 4-78**]

At large airports, an instrument landing system (ILS) guides the aircraft to the runway while on an instrument landing approach. The aircraft's VOR receiver is used to interpret the radio signals. It produces a more sensitive course deviation indication on the same instrument display as the VOR CDI display. This part of the ILS is known as the localizer and is discussed below. While tuned to the ILS localizer frequency, the VOR circuitry of the VOR/ILS receiver is inactive.

It is common at VOR stations to combine the VOR transmitter with distance measuring equipment (DME) or a non-directional beacon (NDB) such as an ADF transmitter and antenna. When

used with a DME, pilots can gain an exact fix on their location using the VOR and DME together. Since the VOR indicates the aircraft's bearing to the VOR transmitter and a co-located DME indicates how far away the station is, this relieves the pilot from having to fly over the station to know with certainty his or her location. These navigational aids are discussed separately in the following sections.

Functional accuracy of VOR equipment is critical to the safety of flight. VOR receivers are operationally tested using VOR test facilities (VOT). These are located at numerous airports. Specific points on the airport surface are given to perform the test. Most VOTs require tuning 108.0 MHz on the VOR receiver and centering the CDI. The OBS should indicate 0° showing FROM on the indicator or 180° when showing TO. If an RMI is used as the indicator, the test heading should always indicate 180°. Some repair stations can also generate signals to test VOR receivers although not on 108.0 MHz. Contact the repair station for the transmission frequency and for their assistance in checking the VOR system. A logbook entry is required. It may be noted that some airborne testing using VOTs is possible by the pilot.

An error of ±4° should not be exceeded when testing a VOR system with a VOT. An error in excess of this prevents the use of the aircraft for IFR fight until repairs are made. Aircraft having dual VOR systems where only the antenna is shared may be tested by comparing the output of each system to the other. Tune the VOR receivers to the local ground VOR station. A bearing indication difference of no more than ±4° is permissible.

AUTOMATIC DIRECTION FINDING (ADF)

An automatic direction finder (ADF) operates off of a ground signal transmitted from a NDB. Early radio direction finders (RDF) used the same principle. A vertically polarized antenna was used to transmit LF frequency radio waves in the 190 kHz to 535 kHz range. A receiver on the aircraft was tuned to the transmission frequency of the NDB. Using a loop antenna, the direction to (or from) the antenna could be determined by monitoring the strength of the signal received. This was possible because a radio wave striking a loop antenna broadside induces a null signal. When striking it in the plane of the loop, a much stronger signal is induced. The NDB signals were modulated with unique Morse code pulses that enabled the pilot to identify the beacon to which he or she was navigating.

With RDF systems, a large rigid loop antenna was installed inside the fuselage of the aircraft. The broadside of the antenna was perpendicular to the aircraft's longitudinal axis. The pilot listened for variations in signal strength of the LF broadcast and maneuvered the aircraft so a gradually increasing null signal was maintained. This took them to the transmitting antenna. When over flown, the null signal gradually faded as the aircraft became farther from the station. The increasing or decreasing strength of the null signal was the only way to determine if the aircraft was flying to or from the NDB. A deviation left or right from the course caused the signal strength to sharply increase due to the loop antenna's receiving properties.

The ADF improved on this concept. The broadcast frequency range was expanded to include MF up to about 1 800 kHz. The heading of the aircraft no longer needed to be changed to locate the broadcast transmission antenna. In early model ADFs, a rotatable antenna was used instead. The antenna rotated to seek the position in which the signal was null. The direction to the broadcast antenna was shown on an azimuth scale of an ADF indicator in the flight deck. This type of instrument is still found in use today. It has a fixed card with 0° always at the top of a non-rotating dial. A pointer indicates the relative bearing to the station. When the indication is 0°, the aircraft is on course to (or from) the station. [**Figure 4-79**]

As ADF technology progressed, indicators with rotatable azimuth cards became the norm. When an ADF signal is received, the pilot rotates the card so that the present heading is at the top of the

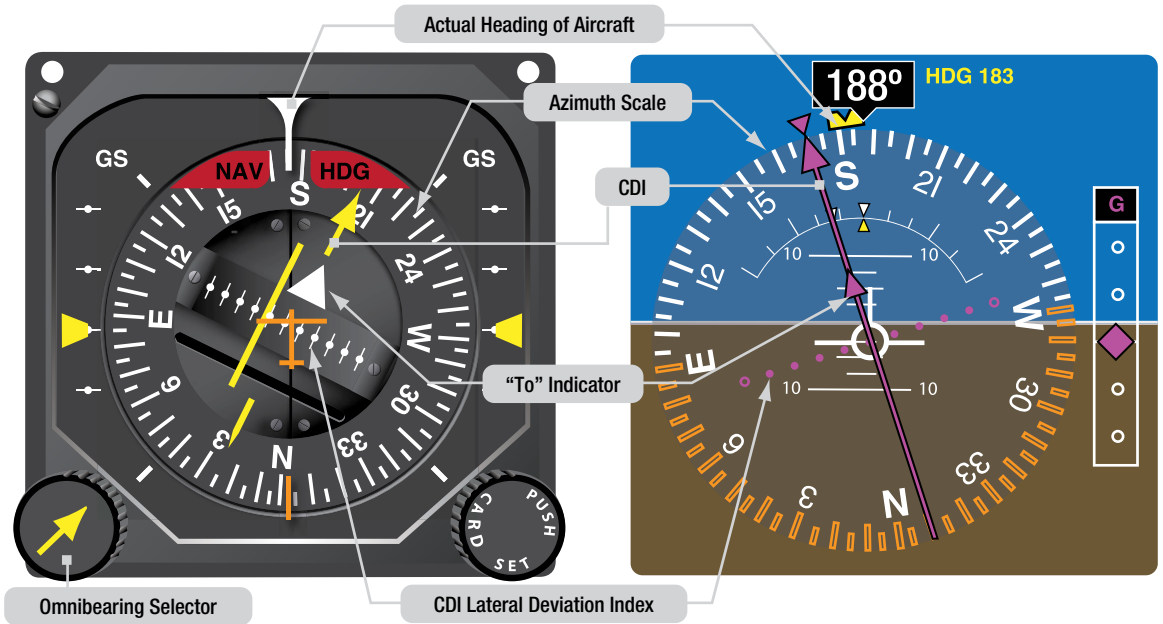

Figure 4-78. A mechanical HSI (left) and an electronic HSI (right) both display VOR information.

scale. This results in the pointer indicating the magnetic bearing to the ADF transmitter. This is more intuitive and consistent with other navigational practices. [**Figure 4-80**]

In modern ADF systems, an additional antenna is used to remove the ambiguity concerning whether the aircraft is heading to or from the transmitter. It is called a sense antenna. The reception field of the sense antenna is omni-directional. When combined with the fields of the loop antenna, it forms a field with a single significant null reception area on one side. This is used for tuning and produces an indication in the direction toward the ADF station at all times. The onboard ADF receiver needs only to be tuned to the correct frequency of the broadcast transmitter for the system to work. The loop and sense antenna are normally housed in a single, low profile antenna housing. [**Figure 4-81**]

Any ground antenna transmitting LF or MF radio waves in range of the aircraft receiver's tuning capabilities can be used for ADF. This includes those from AM radio stations. Audible identifier tones are loaded on the NDB carrier waves. Typically, a two character Morse code designator is used. With an AM radio station transmission, the AM broadcast is heard instead of a station identifier code. The frequency for an NDB transmitter is given on an aeronautical chart next to a symbol for the transmitter. The identifying designator is also given. [**Figure 4-82**]

ADF receivers can be mounted in the flight deck with the controls accessible to the user. This is found on many general aviation aircraft. Alternately, the ADF receiver is mounted in a remote avionics bay with only the control head in the flight deck. Dual ADF receivers are common. ADF information can be displayed on the ADF indicators mentioned or it can be digital. Modern, flat, multipurpose electronic displays usually display the ADF digitally. [**Figure 4-83**] When ANT is selected on an ADF receiver, the loop antenna is cut out and only the sense antenna is active. This provides better multi-directional reception of broadcasts in the ADF frequency range, such as weather or AWAS broadcasts.

When the best frequency oscillator is selected on an ADF receiver/controller, an internal beat frequency oscillator is connected to the IF amplifier inside the ADF receiver. This is used when an NDB does not transmit a modulated signal. Continued refinements to ADF technology has brought it to its current state. The rotating receiving antenna is replaced by a fixed loop with a ferrite core. This increases sensitivity and allows a smaller antenna to be used. The most modern ADF systems have two loop antennas mounted at 90° to each other. The received signal induces voltage that is sent to two stators in a resolver or goniometer. The goniometer stators induce voltage in a rotor that correlates to the signal of

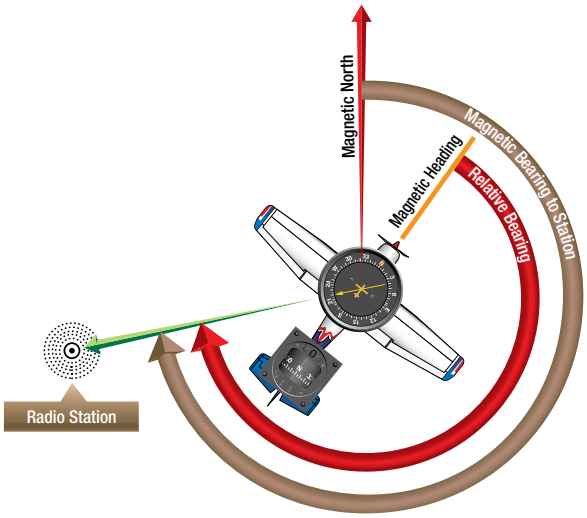

Figure 4-79. Older ADF indicators have nonrotating azimuth cards. 0° is fixed at the top of the instrument and the pointer always indicates the relative bearing to the ADF transmission antenna. To fly to the station, the pilot turns the aircraft until the ADF pointer indicates 0°.

Figure 4-80. A movable card ADF indicator can be rotated to put the aircraft's heading at the top of the scale. The pointer then points to the magnetic bearing the ADF broadcast antenna.

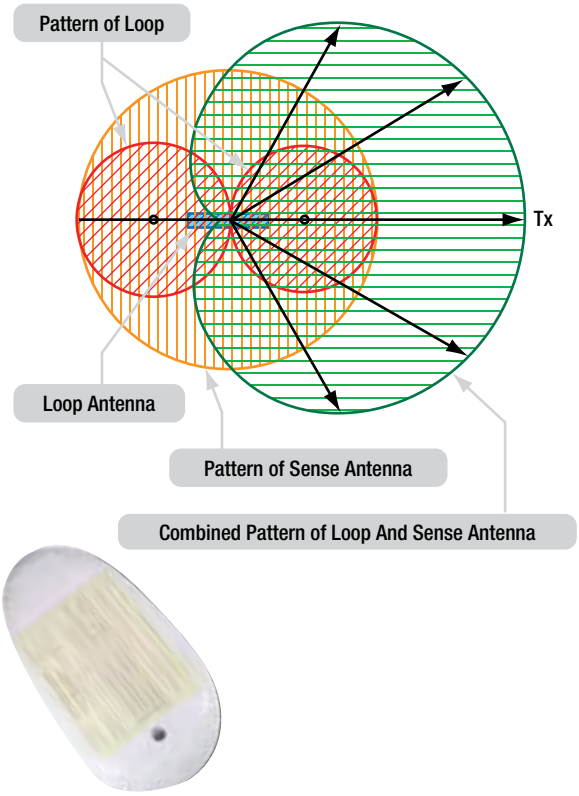

Figure 4-81. The reception fields of a loop and sense antenna combine to create a field with a sharp null on just one side. This removes directional ambiguity when navigating to an ADF station.