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RADIO NAVIGATION

CHAPTER 4 – ADF AUTOMATIC DIRECTION FINDING (EQUIPMENT)

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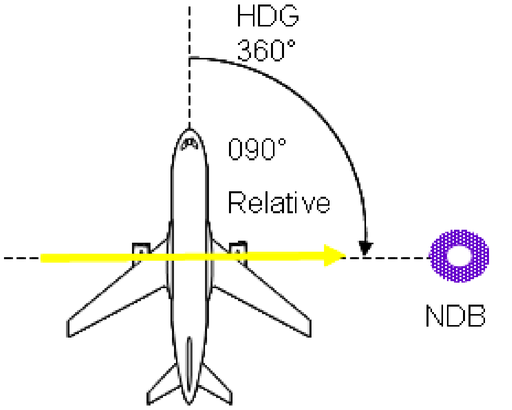
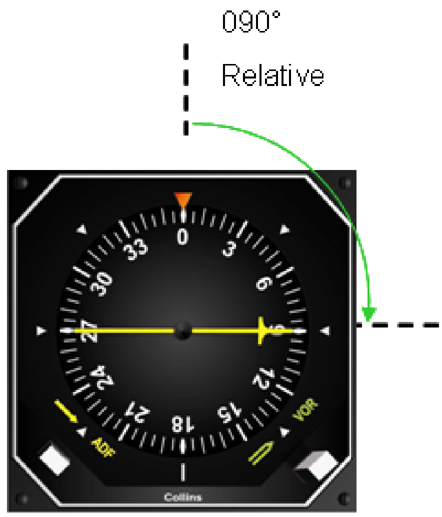
AUTOMATIC DIRECTION FINDING (ADF)

ADF equipment senses incoming radio waves as they arrive at the aircraft and measures their direction relative to the nose of the aircraft. For example, a radio wave arriving in line with the right wing has a direction 090^{O} relative. The direction of the radio wave may be shown on a Relative Bearing Indicator (RBI) or displayed on an indicator orientated with magnetic heading, known as a Radio Magnetic Indicator (RMI). On the RMI, the ADF indication is the magnetic bearing TO the source of the radio waves. This bearing is referred to as the QDM.





RBI

NON DIRECTIONAL BEACONS

The source of the radio waves used by ADF is normally a Non-Direction Beacon (NDB) transmitting in all directions, as its name implies.

The following is a list of characteristics of NDBs:

Frequency Bands- LF and MF

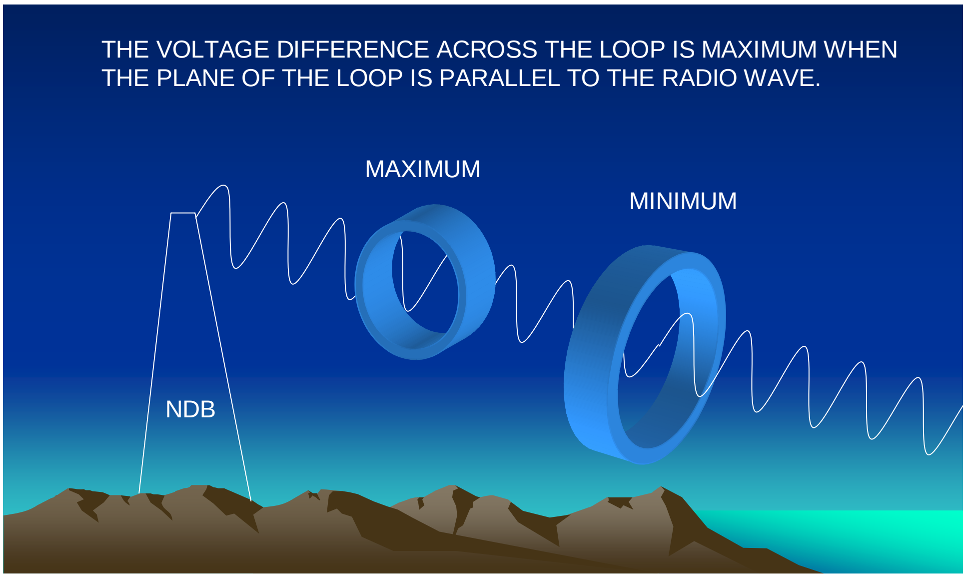
- Frequencies - 190 kHz to 1750 kHz (most commonly 200-500 kHz)
- Propagation- By SURFACE wave (Note: SKY waves may cause interference)
- Use- en route navigation, also homing and let-down in terminal areas using locators (low power NDBs).
- Power- 25 watts to 10 kilowatts (Note: Range is proportional to the square root of the power)
- Range- 10 nm (locator) to 500 nm (maximum for an enroute NDB)
- Ident.- 2 or 3 aural morse letters (Note: ATIS or other voice transmissions may be carried)
- Type of Emission- amplitude modulated and/or unmodulated.

The airborne ADF equipment can also measure bearings using radio waves from broadcast stations but care must be taken as:-

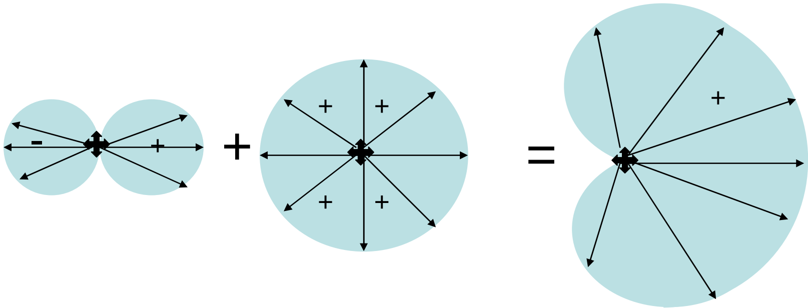
- The exact location of the transmitter may not be known.
- NOTAMS are not issued to warn when the transmitter is to be switched off.
- The radio signal may be received from a relay transmitter, the location of which may not correspond to the station identification.
- No positive station identification (i.e. no morse code)

THE PRINCIPLE OF ADF

ADF equipment finds the direction of the incoming radio wave by using a LOOP and a SENSE aerial. As the transmission from the NDB is vertically polarised, it is the vertical sections of the loop which are designed to pick up the radio wave. When the plane of the loop is parallel to the incoming radio wave, one vertical section of the loop will be closer to the NDB than the other. The radio wave therefore passes the vertical sections at different points in its cycle. This creates a phase difference between the voltages generated in the vertical sections and the voltage difference creates a current flow in the loop.



When the plane of the loop is perpendicular to the incoming radio wave, the phase difference and the resulting current flow are nil. The current flow (signal strength) varies according to the direction of the radio wave relative to the loop, with two directions in which flow is maximum and two directions in which it is zero. The polar diagram of the loop aerial is a figure-of-eight. The ambiguity of the loop aerial is overcome by adding a sense aerial which is omni-directional and therefore has a circular polar diagram. The signal strength from the sense aerial is equal to the maximum value from the loop aerial and so when the signals from loop and sense aerials are combined, a CARDIOID polar diagram is produced. The advantage of the cardioid is that it has only one direction for zero signal strength, referred to as a null position.

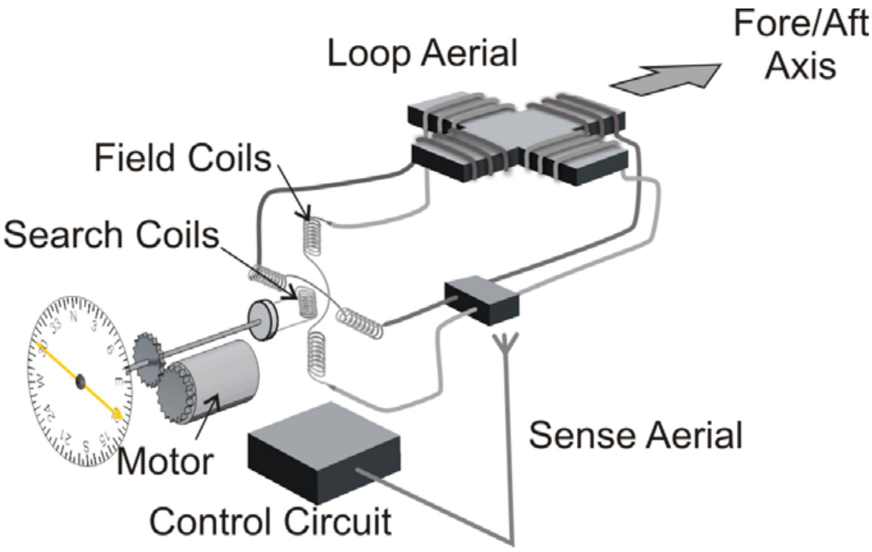


LOOP	plus	SENSE	equals	CARDIOID

The loop and the needle on the ADF indicator are made to rotate by means of the same motor and the null of the cardioid is used to determine the correct direction of the incoming radio wave.

FIXED LOOP THEORY

Modern ADF equipment replaces the rotating loop with a pair of fixed loops 90^{O} apart, one in the fore and aft plane and the other in the athwartships plane. The current flow, created by the radio wave as it passes the loops, sets up a magnetic field as it passes through the field coils.



The search coil, which is driven by the motor, is null (zero) seeking and will have no voltage induced in it when it lies at 90 ° to the magnetic field. There are two null positions but this ambiguity is overcome by using the sense aerial. The motor which drives the rotor also drives the ADF needle.

TYPICAL ADF CONTROL UNIT

There are many types of ADF equipment in use and the following is just one example of a variety of control units.

The purposes of positions on the function switch are as follows:

OFF	ADF is not in use, equipment switched off
ADF	Both sense and loop aerials are in operation. The ADF should give a continuous indication of the bearing to the station that has been tuned.
ANT	The sense aerial only is in use. This position is used for tuning and station identification. Audio quality should be better than in the ADF position. This switch position may be named REC (receive), OMNI or SENSE.
BFO	The Beat Frequency Oscillator position is used to hear unmodulated transmissions.

NDB emissions that are designated A2A or A3E are amplitude modulated with an audio signal. The audio signal is detected at the receiver and can be heard over the head-phones or loudspeaker. However some NDBs transmit unmodulated radio waves and as the emissions contain no audio signal, there is nothing to be detected and nothing to be heard. For these NDBs, an audio signal must be created at the receiver and this is achieved by mixing with the received radio wave a signal produced within the ADF receiver that differs in frequency from that of the NDB by an amount that lies within the audio range. For example, by mixing an internally produced frequency of 299 kHz with an NDB frequency of 300 kHz, a beat frequency of 1 kHz is created. The internally produced signal comes from the BEAT FREQUENCY OSCILLATOR (BFO) which must be switched on to hear unmodulated transmissions. The BFO switch may be marked VOICE/CW with CW corresponding to BFO-ON.

USE OF THE BFO SWITCH

TYPE OF EMISSION	TO HEAR TONE FOR TUNING	TO HEAR IDENTIFICATION
NON A1A	BFO ON (CW)	BFO ON (CW)
NONA2A	BFO ON (CW)	BFO OFF (VOICE)
A2A A3E	BFO OFF (VOICE)	BFO OFF VOICE)

It should be noted that NON A1A transmissions are broken during identification by the on-off keying of the carrier wave. This can cause the ADF needle to wander.

TO OBTAIN A BEARING BY ADF

a. Check that the aircraft is within the rated coverage of the NDB.

b. Turn up the gain (volume).

c. Select the frequency .

d. Select "ANT" (sense aerial)

e. Select BFO as required.

   Note: It is recommended that the BFO is firstly switched on to check for interference even when it will need to be switched off subsequently for identification of a modulated NDB.

f. Check identification.

g. Select ADF.

h. Note bearing, time and heading (if relative bearing has been obtained)

i. Relative bearing + magnetic heading = magnetic bearing to the NDB

   Note: If a true bearing is required, correction for variation at the aircraft must be applied.

ADF ORIENTATION

RBI RMI

As previously mentioned ADF information can be presented on two types of display: The Relative Bearing Indicator (RBI) or the Radio Magnetic Indicator (RMI).

The RBI indicates the direction of the radio wave measured in a clockwise direction with respect to the nose of the aircraft.

The RMI displays ADF bearing information with a compass card that is aligned with the aircraft's magnetic heading. Therefore magnetic bearings TO (QDM) and FROM (QDR) the station can be read from the instrument .

For aircraft equipped with a RBI, QDM and QDR can be determined using the following formula:

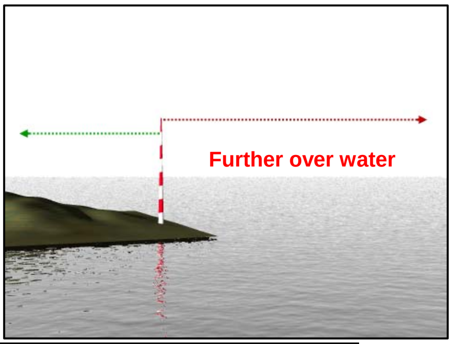
HDG + ADF = Track to Station

HDG: Aircraft's Magnetic Heading
ADF: Relative Bearing as displayed on RBI
Track to Station: QDM, QDR is simply the reciprocal.

(ADF orientation questions can be found at the end of the chapter)

THE FACTORS AFFECTING THE USEFUL RANGE OF AN NDB

a. TRANSMISSION POWER Increased power results in increased range so powerful NDBs operating at 10 kilowatts can achieve ranges as much as 500 nm. Range is considered to be proportional to the square root of the power and thus to double the range of an NDB wave requires four times the power.

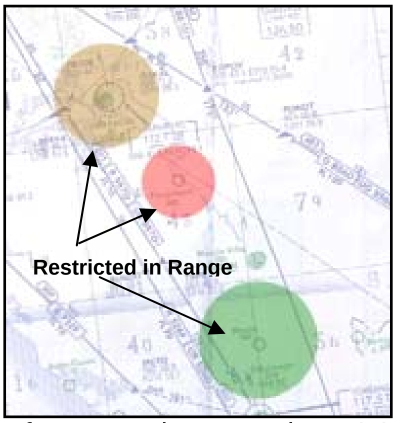


b. FREQUENCY Surface wave range increases as frequency decreases because attenuation is reduced.

c. TYPE OF TERRAIN Useful range is affected by the different rates of attenuation that occur over different surfaces. Maximum range will be achieved when the radio wave passes over water and range will be greatly reduced when the surface is dry soil or sand.

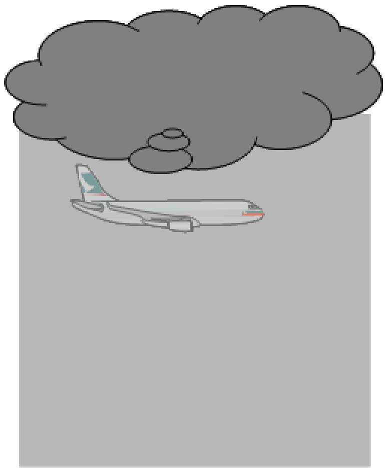
d. TYPE OF EMISSION For a given transmission power, the range of an unmodulated NDB will be greater than the range of a modulated NDB.

e. MUTUAL INTERFERENCE More than one NDB may be transmitting on a given frequency (or close to that frequency) and this can lead to mutual interference. To avoid the resulting problems, which include bearing errors, NDBs must not be used beyond their published maximum range, referred to as the "Designated Operational Coverage" (DOC). The DOC takes into account the signal strength of interference as well as the signal strength from the wanted NDB. Unlike VOR and DME, the DOC for an NDB is valid at all altitudes as range is not limited to line-of-sight. The DOC is valid for day only as at night skywaves extend the range of unwanted NDBs. The DOC of an NDB is to be found in the AIP. The maximum error within the DOC for an NDB is usually accepted to be ±5° during daylight hours.



THE LIMITATIONS OF ADF

The following factors are liable to affect NDB/ADF system performance and integrity:



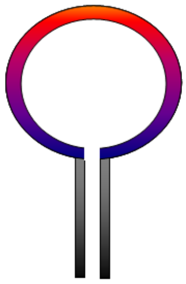
a. STATIC INTERFERENCE All kinds of precipitation and thunderstorms can cause static interference which may reduce the effective range and cause inaccurate bearings to be displayed.

b. STATION INTERFERENCE (See Mutual Interference above) The best protection against interference is to ensure that the aircraft is within the Designated Operational Coverage of the NDB. Even within this range, when operating at night or during twilight hours, interference can occur. It is essential that the call-sign of the tuned NDB is positively checked and that the volume is turned up regularly to check whether interference is occurring.

c. NIGHT EFFECT By definition, night effect refers to problems that occur when skywaves are received from the tuned NDB. ADF is designed to use only the vertically polarised ground wave and contamination by the skywave will cause bearing errors and wandering of the ADF needle. This occurs because:-

(i) The skywave is on the same frequency as the groundwave but arrives out of phase. This causes fading of the signal.

(ii) The skywave, having been refracted by the ionised layer, is no longer vertically polarised and so may induce voltages in the horizontal parts of the loop aerial. The resulting distortion of the cardioid polar diagram results in bearing errors.

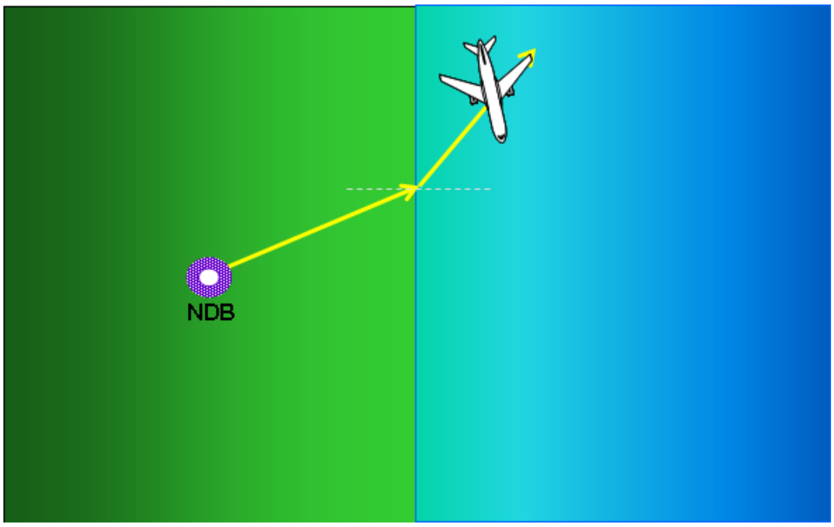


Note that Night Effect:

- cannot be reduced by using a narrower bandwidth
- may occur within the DOC
- may be reduced by using an NDB closer to the aircraft

d. MOUNTAIN (MULTIPATH) EFFECT ADF systems may be subject to errors caused by reflection and refraction of the signal in mountainous areas.

e. COASTAL REFRACTION When a radio wave from an NDB crosses the coast it tends to refract away from the normal to the coast.

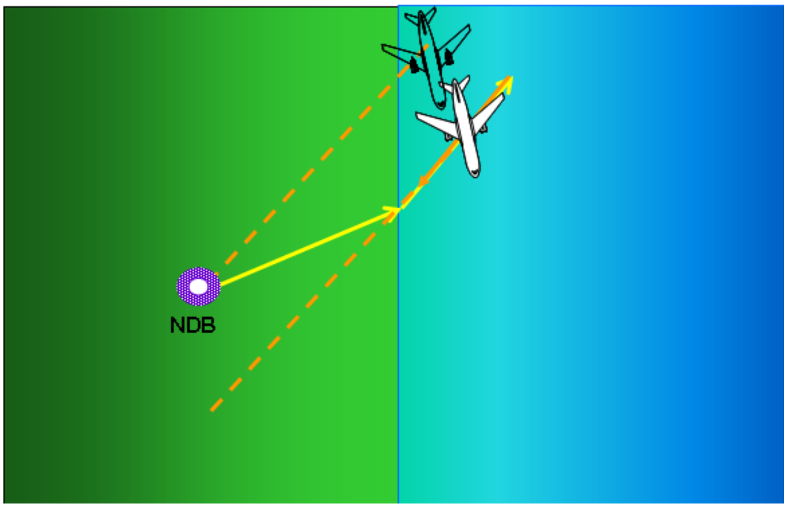


This occurs because radio waves travel faster over the sea than over the land. The amount of refraction will depend on:-

(i) the angle at which the radio wave crosses the coast. The error increases as the angle becomes more acute.

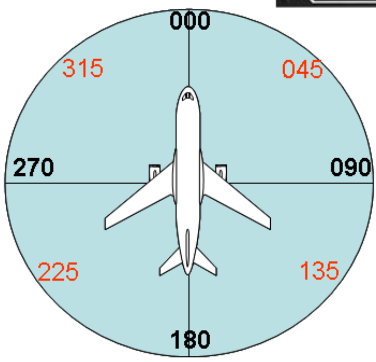
(ii) The nature of the land surface. Attenuation is greater over dry, sandy surfaces so that coastal refraction at a desert coast would be greater.

For the same amount of refraction, the error in terms of the distance between the a/c position and the false position line will be greater when the NDB is far inland compared with an NDB closer to the coast



f. LACK OF A FAILURE WARNING DEVICE Unlike more modern navigation aids, basic ADF equipment has no OFF flag or other failure warning device. There is risk that pilots may continue to follow the ADF needle after an NDB has failed. Some protection against this is achieved by continuously monitoring the audio identification signal.

g. QUADRANTAL ERROR This error is caused by reflections of the incoming radio wave from the wings and fuselage of the aircraft. The name of the error is taken from its characteristic of having maximum values on the quadrantal relative bearings 045°, 135°, 225° and 315°. Modern ADF circuits include quadrantal error corrections so that now it is rarely of significance.



h. DIP ERROR The ADF aerials are designed to detect the vertically polarized signal from the NDB by means of their vertical sections. However when the aircraft banks these sections of the aerials are displaced resulting in distortion of the cardioid polar diagram. The resulting minor error in bearing disappears when the wings are again level.

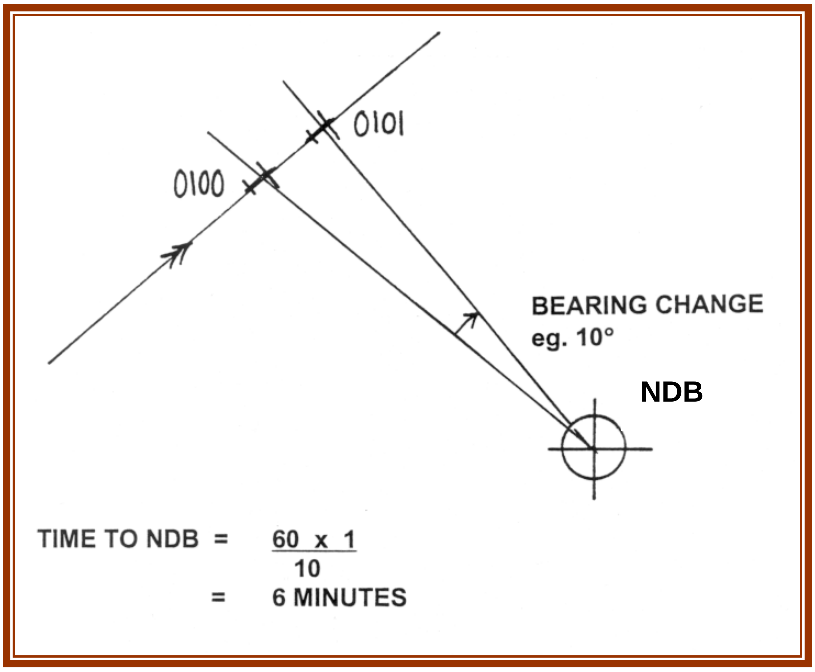
Note: ADF bearing accuracy is approximately ± 5°.

TIME AND DISTANCE TO THE NDB

The following formulae are based on the 1 in 60 rule and so provide only approximate answers:

$$\text{Time to NDB} = \frac{60 \text{ x minutes flown between bearings}}{\text{degrees of bearing change}}$$

$$\text{Distance to NDB} = \frac{\text{G/S x minutes flown between bearings}}{\text{degrees of bearing change}}$$



WORKSHEET - ADF

1. Quadrantal error is error in the relative bearing caused by the distortion of the _____ radio signals by _________.

   (a) transmitted / irregular terrain
   (b) received / the structure of the aircraft
   (c) transmitted / reflections from obstacles close to the transmitter
   (d) received / the aircraft's magnetic field.

2. The operating range of an ADF system depends on many factors including:

   (a) transmitter power, aircraft altitude and system noise.
   (b) receiver sensitivity, atmospheric noise and the proximity of other NDBs on the same frequency.
   (c) high ground between the NDB and the aircraft, NDB frequency and the type of surface.
   (d) sky wave interference, aircraft altitude and type of modulation.

3. Quandrantal error may be significant when the magnetic bearing to the NDB is _________ and the aircraft's magnetic heading is __________.

	BEARING	HEADING
(a)	065	335
(b)	205	025
(c)	315	225
(d)	165	210

4. The purpose of the beat frequency oscillator in an ADF receiver is to:

   (a) modulate NONA1A signals from NDBs
   (b) change FM radio waves into the AM signals used by ADF equipment.
   (c) prevent skywave interference by eliminating signals that are not vertically polarised
   (d) manufacture a signal which differs in frequency from the incoming signal by 1 or 2 kHz.

5. NDBs operate:

   (a) only in the LF band using surface waves only
   (b) in the MF band using sky wave only
   (c) in both LF and MF bands using surface and sky waves
   (d) in both the MF and LF bands using surface waves only

6. A signal received from an NDB at a range of 1000 nm:

   (a) should not be used as it is a skywave.
   (b) must have travelled over water.
   (c) can only be from an NDB transmitting in the LF band.
   (d) should be identified carefully to avoid interference from closer NDBs which may be transmitting on the same frequency.

7. Precipitation static will reduce the effective range and accuracy of the ADF because:

   (a) the ADF needle will tend to point towards heavy rain
   (b) the NDB signal will refract as it passes through a rain laden atmosphere
   (c) the NDB signal will be scattered by rain droplets
   (d) the signal to noise ratio will be reduced, due to the electromagnetic field which is produced when snow strikes the aircraft.

8. The problems of night effect of ADF bearings can be reduced by:

   (a) selecting a narrower passband on the receiver
   (b) not using unmodulated (NONA1A) NDBs
   (c) listening carefully to check whether another call-sign is breaking through
   (d) using NDBs which are close to the aircraft

9. Precipitation static may be caused by:

   (i) All kinds of precipitation, including snow, that fall on to the aircraft.
   (ii) Solid particles, including dust and sand, that fall on to the aircraft
   (iii) Precipitation falling between the aircraft and the NDB

   Which of the above statements are true?

   (a) All are true
   (b) (i) and (ii) are true
   (c) (i) and (iii) are true
   (d) (ii) and (iii) are true

10. The useful range of some NDBs is reduced at night because:

   (a) Surface wave range is less by night than by day
   (b) Skywaves extend the range at which radio waves from NDBs can be received
   (c) Surface attenuation, especially over dry sandy surfaces, is greater by night than by day
   (d) the signal-to-noise ratio increases at night.

11. Within the protective range of an NDB, the error should not exceed ______ and this accuracy is guaranteed by _________.

(a) 5^0 day and night
(b) $7^1/_2{}^0$ day and night
(c) 5^0 day only
(d) $7^1/_2{}^0$ day only

12. Compared with A2A emissions, NDBs which are unmodulated:

(i) are less prone to static interference
(ii) have greater range for the same transmitter power
(iii) require the use of the BFO for both tuning and identification

Which of the above statements are true?

(a) All are true
(b) (i) and (ii) are true
(c) (ii) and (iii) are true
(d) (i) and (iii) are true

13. The range of certain low power NDB is 25 nm. To increase the range to 50 nm, it would be necessary to increase the transmitter power:

(a) by 50% of the original power
(b) by 100% of the original power
(c) to twice the original power.
(d) to four times the original power.

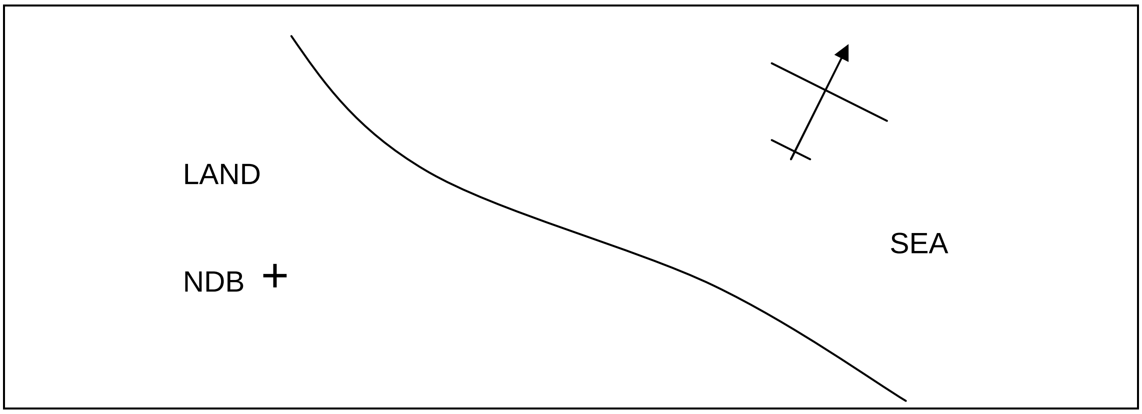
14. The average locator has a rated coverage of:

(a) 10-25 nm
(b) 25-50 nm
(c) 50-100 nm
(d) 50-200 nm

15. The transmission from a NONA2A NDB is ________ and _________.

(a) modulated / not continuous
(b) unmodulated / not continuous
(c) modulated / continuous
(d) unmodulated / continuous

16. In the diagram below, the aircraft which is over the sea is heading 010^0M. An ADF relative bearing of 225^0 is obtained using an NDB on the land.



The correct bearing of the aircraft from the NDB is likely to be ________ and the false position will indicate that the aircraft is _________the coast.

(a) 060^0M / closer to
(b) 050^0M / closer to
(c) 060^0M / further from
(d) 050^0M / further from

17 Abeam an NDB when flying off shore and parallel to the shore line:

(i) Coastal refraction is zero.
(ii) Quadrantal error is near to or at its minimum.
(iii) The error due to coastal refraction will increase if the NDB is located inland rather than on the coast.

a) All statements are true.
b) Only statements (i) and (ii) are true.
c) Only statements (i) and (iii) are true.
d) Only statements (ii) and (ii) are true.

ADF ORIENTATION PROBLEMS

Work out the following:

- the Bearing to the NDB (°M)
- the Drift (°L or °R)
- the Track Made Good (TMG) (°M)

Use the HATS formula and if necessary draw a sketch of the aircraft and track or DG and RBI to help with orientation.

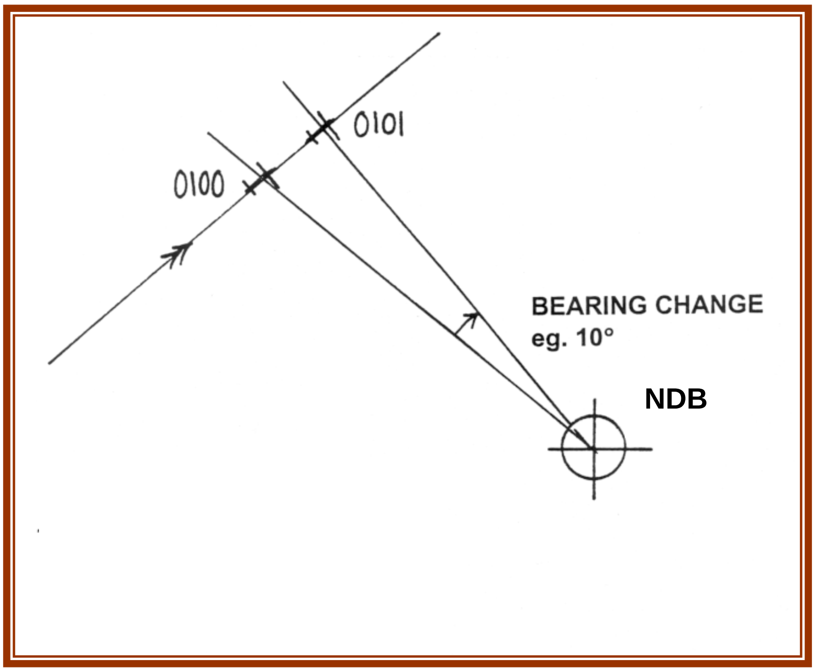
Question No	HDG (°M)	ADF (°R)	Bearing (°M)	Drift°	TMG
1	340	010			
2	190	200			
3	350	020			
4	200	210			
5	340	160			
6	030	210			
7	015	165			
8	340	340			
9	280	210			
10	110	160			

TIME AND DISTANCE TO THE NDB CALCULATIONS

Complete the table below by using the following formula:

$$\text{Time to NDB} = \frac{60 \text{ x minutes flown between bearings}}{\text{degrees of bearing change}}$$

$$\text{Distance to NDB} = \frac{\text{G/S x minutes flown between bearings}}{\text{degrees of bearing change}}$$



Exercise	Time (seconds)	Bearing Change	Mins to NDB	Ground Speed	Dist to NDB
1	60	10°	6	190	19
2	80	20°		180	
3	90	15°		220	
4	75	10°		200	
5	175	25°		120	