The Instrument Meteorological Conditions (IMC) Rating

Pilot's Notes

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Warning

This set of pilot's notes do not form part of an officially approved IMC course of training. Authorised training manuals and learning material must always be used for training.

Version Control

Version	Issue Date	Author	Comments
3.0	30/04/03	Peter Dodds	Section added on selection of entry type to the NDB Hold
2.0	20/06/02	Peter Dodds	Captions and TOF added
1.0	08/05/02	Peter Dodds	First issue

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Section 1: The Private Pilot’s Licence Privileges and Restrictions

The privileges of the Private Pilot’s Licence (PPL), and the additional privileges granted by the gaining an IMC rating are shown in the table below.

<table>
<tr><th colspan="8">PPL/IMC Licence
Privileges Table</th></tr>
<tr><th>Airspace</th><th>Class A</th><th>Class B</th><th>Class C</th><th>Class D</th><th>Class E</th><th>Class F</th><th>Class G</th></tr>
<tr><td rowspan="2">PPL</td><td>SVFR
>10 km visibility
Channel Islands only</td><td colspan="4">VMC
SVFR
>10 km visibility</td><td colspan="2">>3Km visibility</td></tr>
<tr><td colspan="7">Always in sight of surface</td></tr>
<tr><td rowspan="2">PPL/IMC</td><td colspan="5">SVFR
>3 km visibility</td><td colspan="2">VFR
Below 3000 feet and at <140 knots
>1.5 km visibility, in sight of surface and clear of cloud</td></tr>
<tr><td colspan="3"></td><td colspan="4">Take off and landing:
>1800m forward visibility
Cloud above 600 feet aal.</td></tr>
</table>

Instrument Flight Rules (IFR)

1) Must maintain an altitude 1000 feet above the highest fixed obstacle within 5 nautical miles each side of track, except for
   a) Take off and landing
   b) Routes notified in the Air Navigation Order (ANO)
   c) Permission of the Civil Aviation Authority (CAA)
   d) Below 3000 feet in sight of the surface
2) Must obey the Quadrantal Rule outside controlled airspace.
3) Must file a flight plan. This may be done whilst airborne in the standard format: -

Airborne Flight Plan
Call Sign
Aircraft Type
Route
Position

Airborne Flight Plan
Altitude (and QNH)
Heading
ETA next waypoint
Persons on Board
Endurance

Instrument Meteorological Conditions

Instrument Meteorological Conditions are in reality simply conditions below the Visual Flight Rules (VFR) minima.

Rule 1d) flight is effectively VFR except that the minimum forward visibility for VFR flight is not required. Note that VFR flight for an IMC rated pilot requires a minimum forward visibility of 1500 metres. Flight in less than 1500 metres forward visibility will have to be conducted under IFR, and a flight plan filed. Having filed a flight plan, it is essential to obtain a radar service. A radar service will normally be given automatically by the service with which the pilot has filed an airborne flight plan.

Section 2: The Flight Instruments

The Control Instruments

The Attitude Indicator

The Attitude Indicator (AI) is the master instrument. It is the Pilot's "porthole on the world". It is an instantaneous feedback to the pilot of the aircraft's behaviour.

The central dot on the horizon bar is 5^o wide, and each graticule of the vertical scale represents 5^o.

The pilot has to learn to watch this instrument whilst doing other things, such as changing radio frequencies, turning onto headings etc.

In **pitch**, the effect is instantaneous, but the attitude is miniaturised – very small changes in the AI horizon position are the result of large changes in the aircraft's pitch.

In **bank**, the effect is instantaneous, and the angle of bank is displayed accurately to scale, degree to degree. Turns are always made at "rate one" in IMC. Rate 1 is 180^o in one minute, or 3^o per second. To achieve this, the bank angle may be calculated, using the empirical formula:

$$\textit{Bank angle in degrees} = \frac{\textit{True Airspeed in knots}}{10} + 7$$

At 100 knots, the bank angle to achieve a rate one turn is therefore $17^{o.}$

In the turn, the objective is to keep the horizon line centred in the middle of the dot. Back pressure needs to be applied to the yoke to achieve this.

The Turn Co-ordinator

It is a gyroscopic instrument with its axis of spin in the horizontal plane at right angles to the direction of travel of the aircraft. Thus, by Coriolis effect, turning induces a tilt on the axis which is amplified and displayed on the instrument face. The instrument indicates turning. **It does not indicate bank**. The instrument face has calibrated markers to indicate a rate one turn. Often the instrument face also carries the legend

2 mins = 360^o.

The Tachometer

This instrument is coupled directly to the engine to indicate engine r.p.m., and thus, indirectly, the engine power being applied.

The Performance Instruments

The Performance Instruments are all of the instruments which are not Control Instruments, as defined above. They provide an indirect indication of the aircraft's performance.

Instrument	**Power Source**	**Direct Indication**	**Indirect Indication**
ASI	Pitot head plus pitot static source	Relative air pressure between the Pitot head plus and the pitot static source gives calibrated air speed	Pitching or pitched
Altimeter	Pitot Static source	Pressure altitude	Pitching or pitched
VSI		Rate of climb Rate of Descent	Pitching or pitched
Compass	Earths Magnetic Field	Direction relative to Magnetic North	Banking or yawing
Direction Indicator	Pitot driven gyroscope	Direction relative to Magnetic North	Banking or yawing
Turn Co-ordinator	Electrically driven gyroscope	Directional change relative to time	Banking or yawing
Slip ball	Gravity & Centrifugal force	Yaw (Balance)	Yaw

Section 3: Basic Instrument Flight

Instrument flight is flight conducted by sole reference to the aircraft instruments. The principal technique involved is the **Selective Radial Scan**.

Straight and Level Flight

The requirement is establish the power setting and attitude to achieve a steady airspeed, whilst neither climbing, descending nor turning. Learn the characteristic "setting" for your aircraft, e.g. in the Piper Warrior, 2300 rpm plus 2½° nose down attitude (horizon just on the top of the dot in the centre of the AI) will achieve 100 knots.

The Selective Radial Scan for this condition is: -

The Selective Radial Scan							
Major scan	AI	ASI	AI	Altimeter	AI	DI	AI
	Attitude	Speed	Attitude	Height	Attitude	Heading	Attitude
Minor scan	AI	TC	AI	RPM	A		
	Attitude	Turning	Attitude	Power	Attitude		

The main objective is to use the AI as the **Master Instrument**.

Climbing

The Altimeter can be ignores in the Selective Radial Scan until near the desired altitude. Anticipate the levelling out by 10% of the rate of climb, and add in the altimeter to the scan at that time. Remember Attitude – Power – Trim when levelling out from the climb

Safety Checks	**Control Instrument Settings**	**Performance**
FREDA check	Power to full	Climb at about 80 knots
Ice	Set attitude about 8° nose up – will give about 80 knots.	
Carburettor heat set cold	Trim	
Mixture Full rich.	Check balance	
Check Ts and Ps every 500 feet		

Cruise Descent

The Altimeter can be ignored in the Selective Radial Scan until near the desired altitude. Anticipate levelling out by 100 feet, and add in the altimeter to the scan at that time. Remember Power – Attitude - Trim when levelling out from the descent.

Safety Checks	**Control Instrument Settings**	**Performance**
FREDA check	Reduce Power to 2000 rpm	Descend at about 100 knots
Ice	Set attitude about 5° nose down – will give about 80 knots.	
Carburettor heat set hot	Trim	
Mixture Full rich.	Check balance	
Check Ts and Ps every 500 feet		

To stop the descent, increase power to 2300 rpm, raise nose to 2° nose down (ensure 2° nose down, do not pitch up), and trim.

Turns

Always a maximum of rate one (angle of bank about 15°). Hold the dot of the AI in the same place as for straight and level. This will require back pressure on the yoke. Check altitude and adjust attitude to correct any errors.

The Selective Radial Scan							
Major scan	AI	Altimeter	AI	DI	AI	TC	AI
	Attitud e	Height	Attitude	Heading	Attitude	Rate 1	Attitud e
Minor scan	RPM						
	Power						

Holding a turn, the Selective Radial Scan becomes: -

Major scan	AI	Altimeter	AI	ASI	AI
	Attitude	Height	Attitude	Speed	Attitude

Anticipate the required heading by 5° (not 10° as in VFR flight), then rolling wings level with reference to the AI and check the heading achieved. Correct if required.

Section 4 Radio Navigation

Instrument Flight Procedures

By flying precise headings and times relative to a radio beacon, aircraft may be accurately manoeuvred in IMC. Certain standard procedures have been internationally agreed and adopted. These procedures are normally used in the approach phase of flight, when positioning for a landing. They are set out on specially designed charts known as Approach Plates.

En Route Instrument Navigation

Aircraft flying in IMC but not flying in airways must comply absolutely with the same restrictions in respect of controlled airspace, terrain clearance (including over congested areas), Military Aerodrome Traffic Zones, Restricted and Danger Areas, Gliding sites and Parachute drop zones etc., as in visual flight. Whereas ideally, a pilot would fly direct from beacon to beacon, he may need to modify his course to avoid these areas.

Note: Because of his relative lack of training compared to a full Instrument rating, an IMC rated pilot should avoid flying in cloud for prolonged periods.

Flying above cloud, but technically in IMC (out of sight of the surface) where there is a visible horizon formed by the cloud tops is much safer (sometimes known as "VFR on top") and should be adopted where possible. However, in many parts of the UK, care has to be taken to stay clear of controlled airspace whose lower altitude limit is lower than the altitude of the cloud tops.

Instrument Approach Procedures

The principal horizontal manoeuvring actions in an approach are made either by following ATC instructions ("vectors") to position for an instrument landing, or by means of fixed headings and "procedural turns". These Instrument Approach Procedures (IAPs) are shown on special diagrams known as Approach Plates.

All Instrument Approach Procedures are published in three standard formats, the British Airways/Aerad style, the Jeppesen style, and least common, the UK CAA style. All contain the same information, but set out somewhat differently. It is a matter of personal choice which a pilot uses.

Horizontal Manoeuvring – Headings

Approach plates indicate the required headings to fly, once the aircraft has reached a defined point in the approach (the initial approach fix). This may be an NDB or VOR positioned on or off the airfield. Once this position is reached, unless the aircraft is being vectored by ATC under radar control, a procedural approach is made which follows the headings and turns shown on the approach plate.

Horizontal Manoeuvring – The Procedural Turn

The procedural turn is used to make a turn onto a reciprocal track or a reciprocal heading. An aircraft may approach an NDB or a VOR which is in a known position relative to the runway, then turn outbound on the reciprocal of the runway bearing (still often referred to by its "Q code" morse identification QDE), and then turn 180° to approach the runway on the runway bearing (similarly frequently referred to as QDM). A timed distance is often flown before the turn is initiated, for instance where the NDB is on the airfield, to give the aircraft time and distance to make the approach.

The most commonly used procedural turn is the 45° Turn.

In light aircraft, with an airspeed of 100 knots or less, the timed leg after the initial turn is reduced to 45 seconds.

Two other types of procedural turn exist.

a) The long teardrop (as illustrated on page 13 in the figure of eight exercise diagram), and
b) The 70/280 degree turn, where the initial turn is 70°, followed immediately by a 280° turn back on to track. However, this type of procedural turn is rarely used.

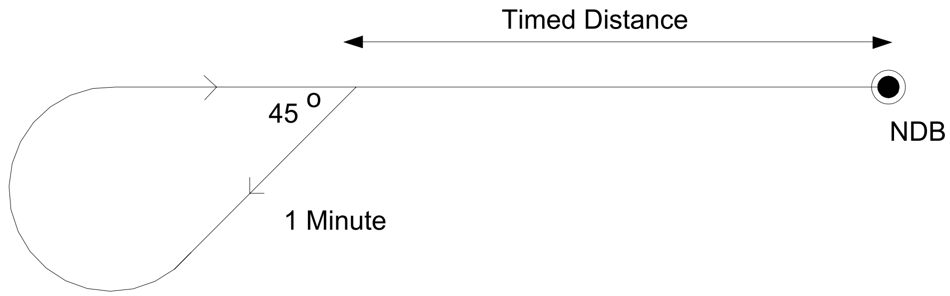


Figure 1 The 45° Procedural Turn

Vertical Manoeuvring - Rate of Climb and Descent

The minimum rate of climb or descent in instrument flight is 500 feet per minute.

Estimating Winds Aloft

As a rule of thumb, if the surface wind is known, but winds aloft are unknown, then add 30° to the direction and double the wind speed to get an estimate for the wind at 2000 feet.

The NDB

The Non-directional Beacon (NDB) radiates a radio signal which, when received by the receiver in the aircraft is converted into a dial scale deflection on the Automatic Direction Finding (ADF) cockpit instrument. In principle, the ADF needle always points to the NDB, regardless of the aircraft's position and heading.

To tune in an NDB station, the procedure is as follows: -

1. Switch on the ADF radio
2. Select the frequency. Fractional frequencies are tuned in by selecting the next lowest whole number. For example, for 349.5, select 349.

3. Identify the NDB station from its Morse code ident. This is transmitted with the NDB signal, and is received as an audible signal by selecting the ADF button on the communications selector panel, and adjusting the ADF radio volume as required. The Morse ident is three alpha characters, e.g. HAW (Hawarden).
4. Confirm the station. Listen to the ident at least twice, and observe that the ADF needle is giving a sensible indication.
5. On some ADF radios, selecting 'ANT' will cause the ADF instrument needle to point to 090°. Selecting 'ADF' will cause the ADF instrument needle to point to the station.
6. Listen to the ident at all times, as it is the only way you know that it is working. If the signal is not received, the ADF needle will point to a random position, often, the position of the last received signal.

NDB Tracking

When tracking to or from a station, add 1 second to the planned outbound time for each knot of headwind component, and subtract 1 second for each knot of tailwind component. This approximation works for distances of about 2 to 4 miles and 100 knots. (At 100 knots over a distance of 2.5 miles and 200 knots over a distance of 10 miles it is exact).

Airspeed	**Track Distance**	**Headwind**	**Time**	
			m	s
100	3	0	1	48
100	3	5	1	54
100	3	10	2	00
100	3	20	2	15
100	3	30	2	34
100	3	40	3	00

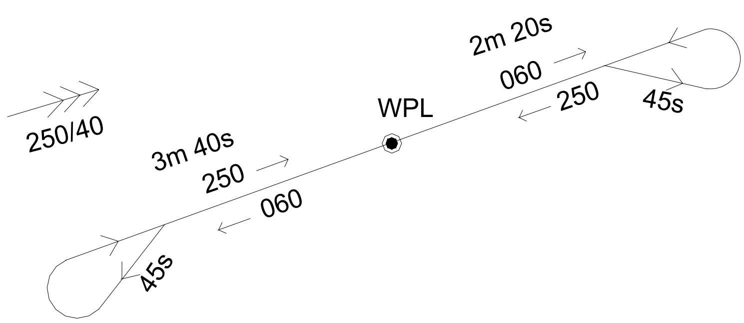


Figure 2 NDB Tracking – Time Correction for Wind

Headwind and tailwind components can be estimated by interpolation from the following table and diagram:

Relative Bearing	Headwind or Tailwind Component
0°	100%
30°	90%
45°	70%
60°	50%
90°	0%

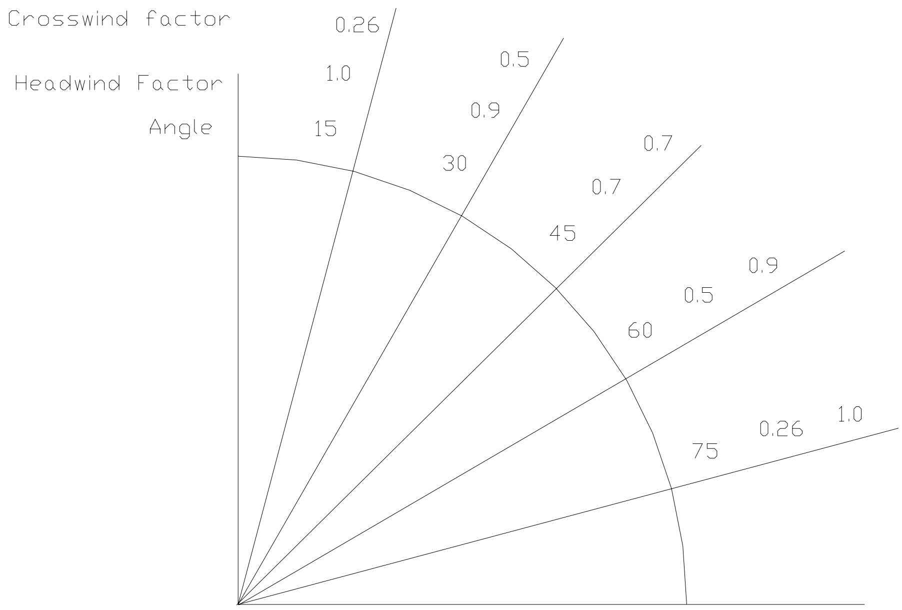


Figure 3 Crosswind and Headwind Correction Factors

The four golden rules of NDB tracking are:

The needle always points to the station
The head of the needle always falls
The needle **mirrors** the turn. – e.g., if the aircraft turns right, the ADF needle turns left.
The ADF needle is a Command Instrument – it tells you where to go.

Correcting Track Errors

It is important for the Pilot to maintain spatial awareness of the aircraft's [position at all times during instrument flight. If the pilot loses this mental picture of his position relative to the NDB, then he should simply turn parallel the track required and observe the ADF needle position. It will indicate which way to turn to re-establish track.

The basic technique is to turn onto the intended heading. Do not turn onto the ADF bearing (ADF instrument pointing 360°). Observe the ADF needle offset (from 360°). Turn twice the ADF offset to get back onto track. When the ADF needle falls to an equal and opposite value as the heading change, turn back to the estimated new heading. This can be repeated as required.

In the situation illustrated below, assuming no wind, the ADF needle should point to 180° when the aircraft is on track. Let us assume that the aircraft is left of track such that the ADF is showing 170°. A right turn of 20° is initiated (+20°), and the ADF needle will now show 150° (-20°). The new heading is held until the ADF needle indicates 160°, when a turn left of 20° (-20°), will bring the aircraft back onto the correct heading, and also the correct track, and the ADF needle will point to 180o (160° +20°). The figures in brackets are an illustration of the principle that every heading change will result in an equal and opposite ADF indication.

The correcting turn should be twice the error angle, because in a holding pattern, there isn't a lot of time or distance available to establish on the correct track, so coarse heading adjustments are necessary.

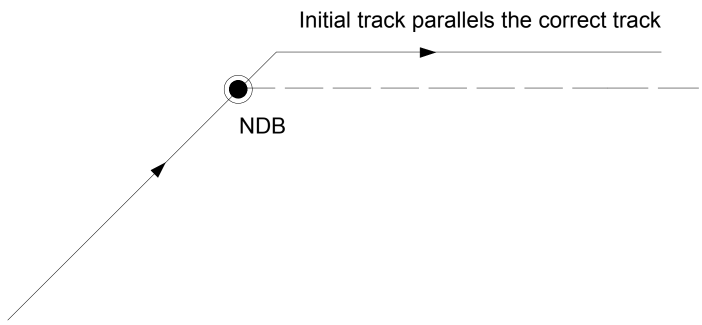


Figure 4 Paralleling the Required Track to Regain Orientation

Turn Errors

Rarely will the aircraft come round a turn exactly on track. To improve accuracy, roll out 30° before the intersection and wait for the needle to come round to 30° off (330° or 030°) then continue the turn.

The ADF needle is only accurate with the wings level. It has a bias towards the lower wing in the turn, due to the magnetic field of the aircraft.

Drift Correction

To track accurately to or from an NDB, proper allowance must be made for drift, and the appropriate technique used to correct any track errors which occur.

In the diagram below, a large heading change of 40° into wind has been applied to overcome the track error caused by a strong crosswind. When the correct track is regained, the ADF needle will indicate 320°. To prevent the wind creating a further track error, an into-wind heading of 10° is maintained. The left turn onto track is therefore not 40° but 30°, and the ADF needle will indicate 350°. If the correction for drift is correct, the ADF needle will hold this value right up to the NDB, indicating to the pilot that he is maintaining correct track.

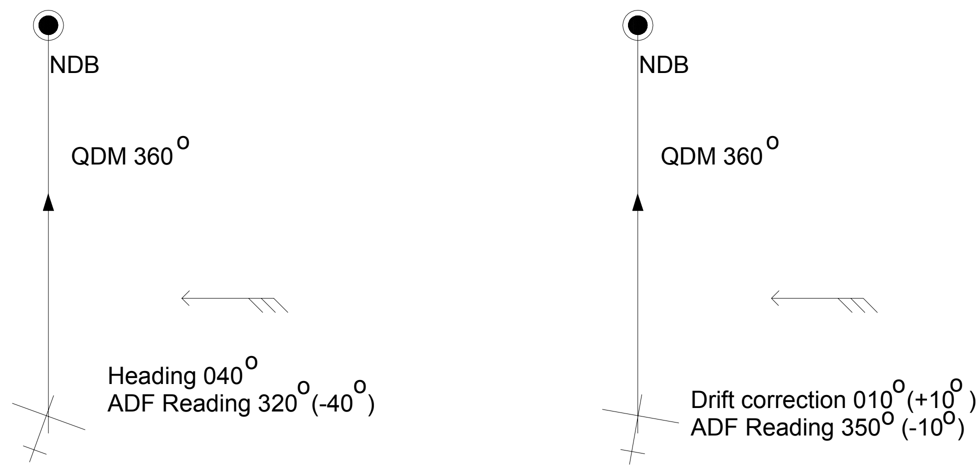


Figure 5 Coarse Heading Corrections to Regain Track, and Track Maintained by adding Drift Correction.

A very useful formula for calculating drift is shown below. It avoids the need to use the "Whiz Wheel" flight computer during flight - a fairly impractical operation, particularly in IMC. The maximum drift angle, with the wind directly abeam, is given by: -

$$Drift = Windspeed \times \frac{60}{TAS}$$

A simple NDB tracking exercise illustrates drift correction. Starting on a heading of 280° towards the NDB ("beacon inbound"), the aircraft is flying directly downwind and no drift correction is required. It passes the NDB and maintains the same heading ("beacon outbound"). Turning onto a heading of 130°, the aircraft is now on an out of wind heading, the wind at 30° off the nose. The headwind component (0.9 x 40 knots = 36 knots) is used to calculate the outbound leg time, and the crosswind component used to calculate the drift correction. The maximum drift is 40 x 60/100 = 24°, and with the wind at 30° off the nose, the drift correction is 0.5 x 24 = 12°. The heading to steer is therefore 130-12 = 118°, and the ADF needle will point to 012° on the inbound leg. As the aircraft passes the beacon, the needle drops, and will point to 192° on the outbound leg, a change of 180°.

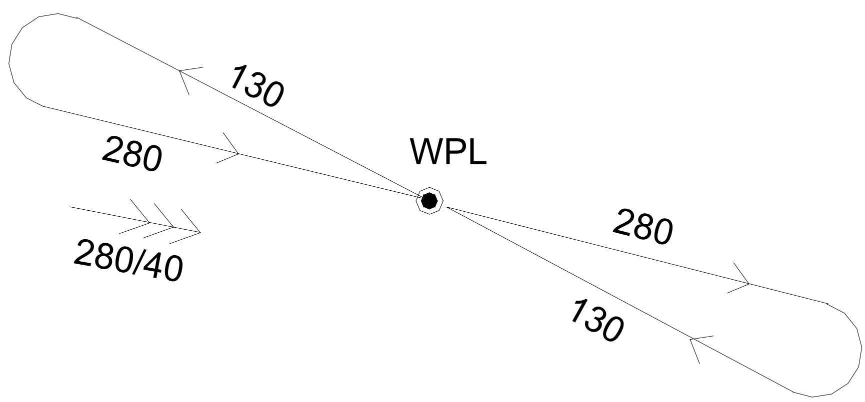


Figure 6 Figure of Eight NDB Tracking exercise

For example, in the diagram above, the out of wind leg is 30° into wind. The wind is 280° at 40 knots; hence the maximum drift angle would be 24° (from the formula above). In the diagram above, flying the out of wind leg (30 degrees into wind), the crosswind component at would be half that; say 12°. The out of wind leg would therefore be flown on a heading of (130-12) = 118°.

The NDB Holding Pattern

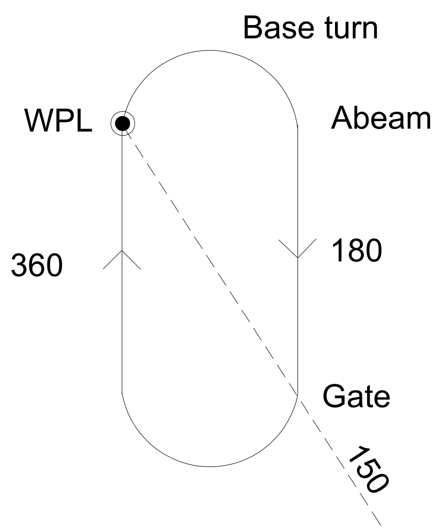


Figure 7 NDB holding pattern for Welshpool runway 22

On the outbound leg, the heading flown must be corrected for drift. Because correcting for drift in the base (outbound) turn is almost impossible, the outbound leg drift correction includes the drift correction for both the outbound and inbound turns. However, the inbound turn can be adjusted by observing the lead on the ADF instrument.

The outbound leg drift correction is 3 x drift if the wind is blowing the aircraft away from the holding side, and 2 x drift if the wind is blowing the aircraft towards the holding side. However, the maximum into wind correction should be 30°. The correction for final track is then made on the inbound turn, by reducing the rate of turn. During this correcting turn, it is a useful tip to fly wings level for a few seconds to get a fix on the beacon, without having to subtract the ADF turning error.

A secondary position fix is obtained at “the gate”. This point is the start of the inbound turn and is always 30° off the inbound track. Thus the ADF needle should point 180° ± 30° (depending on the direction of the pattern), ± the drift correction.

If the pilot arrives at the end of the outbound leg, ready to commence the inbound turn, and the angle is less than calculated, then he is inside the pattern. He should then turn onto the gate angle (a turn of approximately 30° away from the pattern) for a few seconds, before commencing the inbound turn. This gives the aircraft time and space to make the turn without overshooting the inbound track.

If the pilot arrives at the end of the outbound leg, and the angle is greater than calculated, then he is outside the pattern. He should then continue to make the inbound turn and use the ADF needle lead to adjust his turn rate to bring the aircraft accurately onto the inbound track.

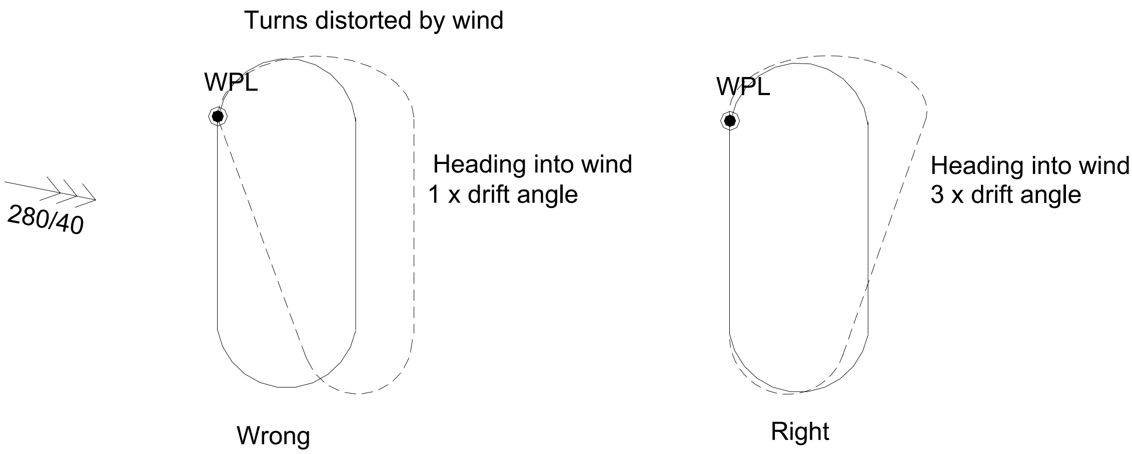


Figure 8 Effect of the wind on holding pattern.

Entry to the NDB Hold

There are three types of entry to an NDB hold, depending on the direction from which the NDB is approached. These are called the Direct Entry, the Parallel Entry and the Teardrop Entry.

The type of entry to be used depends on the angle of approach to the holding pattern. The objective is to minimise the initial turn angle into the holding pattern, which in turn minimises the effect of the initial turn radius on the accuracy of the initial outbound leg. If the initial outbound leg is flown accurately, then the initial inbound leg will also be accurate, and overall, the pilot's workload will be reduced.

The diagram below illustrates the approach sectors for each of the three types of entry.

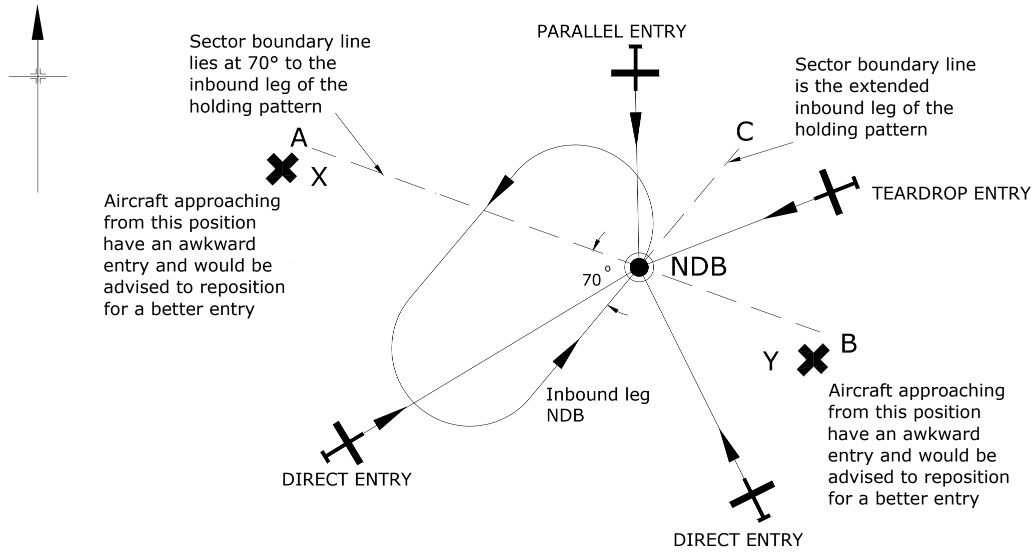


Figure 9 NDB Holding Pattern – Selection of Entry Type

The three NDB hold entry sectors are shown above. The principal sector boundary line is drawn at 70° to the inbound track of the NDB hold, with a further sector boundary line formed by extending the inbound NDB hold track, as shown above.

Aircraft approaching from the sector defined by the area within the lines A – NDB - C will make a parallel entry. Aircraft approaching from the sector defined by the area within the lines C – NDB - B will make a teardrop entry. Aircraft approaching from outside either of these two sectors will make a direct entry. As the direct entry sector is half of the whole area available, the direct entry is the easiest and most commonly used entry method. (Note that in an IMC examination, it is more than likely that this method will NOT be given the student!).

Approaches near the sector boundaries are more difficult, and it may be advisable to reposition the aircraft well before the approach to the beacon so that an easier entry can be executed. An aircraft in the positions shown by the thick crosses above would have a considerable turn angle to make, whichever entry type was chosen. An aircraft in position X would be best to reposition further south for a direct entry, whereas an aircraft in position Y might choose either to position further south for a direct entry, or further north for a teardrop entry.

The Direct Entry

For a direct entry, fly direct to the entry point (the NDB) to begin the procedure. Alternatively, (and better practice), join the procedure on the inbound leg. If the approach crosses the holding pattern, the base turn will necessarily be wider than standard, as illustrated. The start of the outbound leg will still be timed from abeam the beacon, i.e. when the ADF needle shows 90° or 270 °, depending on whether the hold is a right or left hand pattern.

An example of both left and right hand holding patterns are illustrated below.

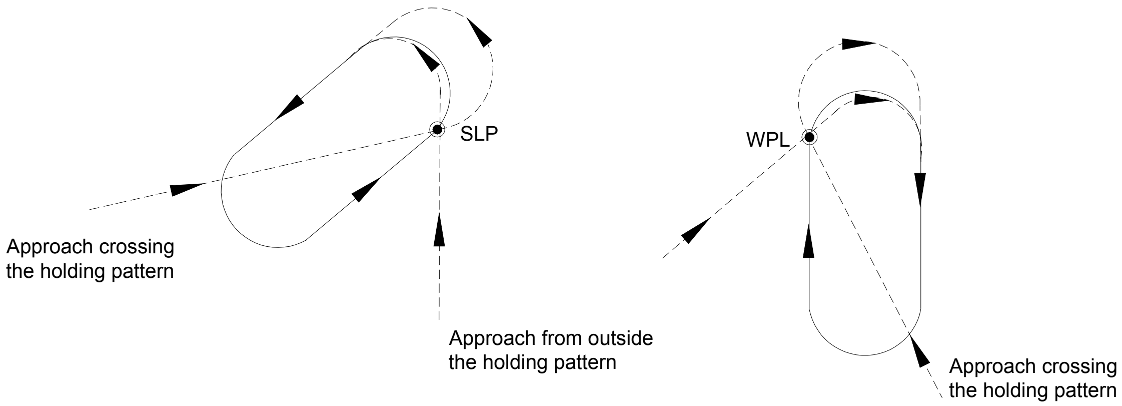


Figure 10 The Direct Entry to the NDB Hold

The Parallel Entry

For a parallel entry, fly to the entry point (the NDB) then turn to fly outbound along the inbound track for 1 minute, then make a rate one turn through approximately 210 ° and fly direct to the beacon. On passing the beacon, the outbound turn is commenced to start the holding procedure.

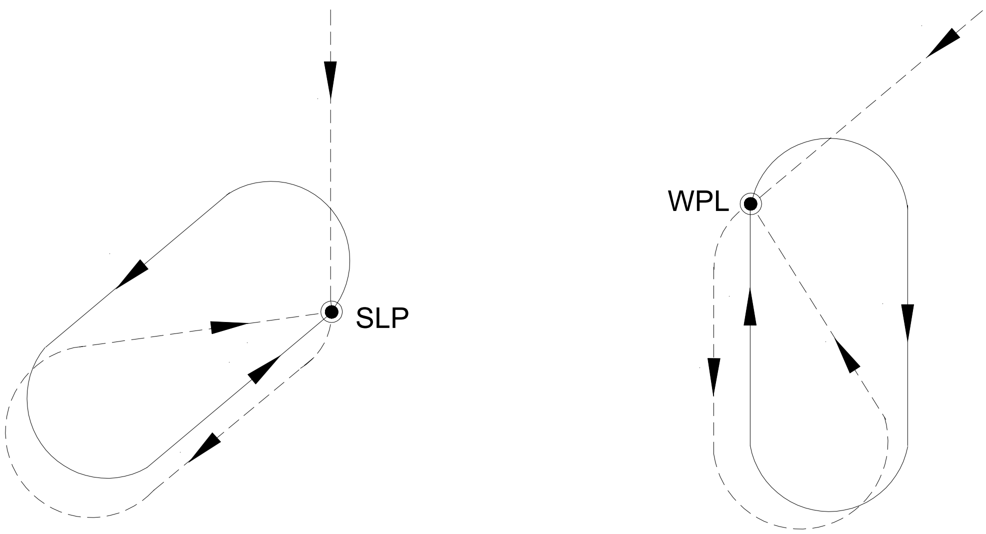


Figure 11 The Parallel Entry to the NDB Hold

The Teardrop Entry

The teardrop entry is probably the least used as the approach sector is the narrowest of the three available. To make a teardrop entry, fly to the entry point (the NDB) then continue outbound from the beacon on a heading 30 ° to the inbound leg (as illustrated below) for 1 minute. Then make a rate one turn through approximately 210 ° to join the inbound track.

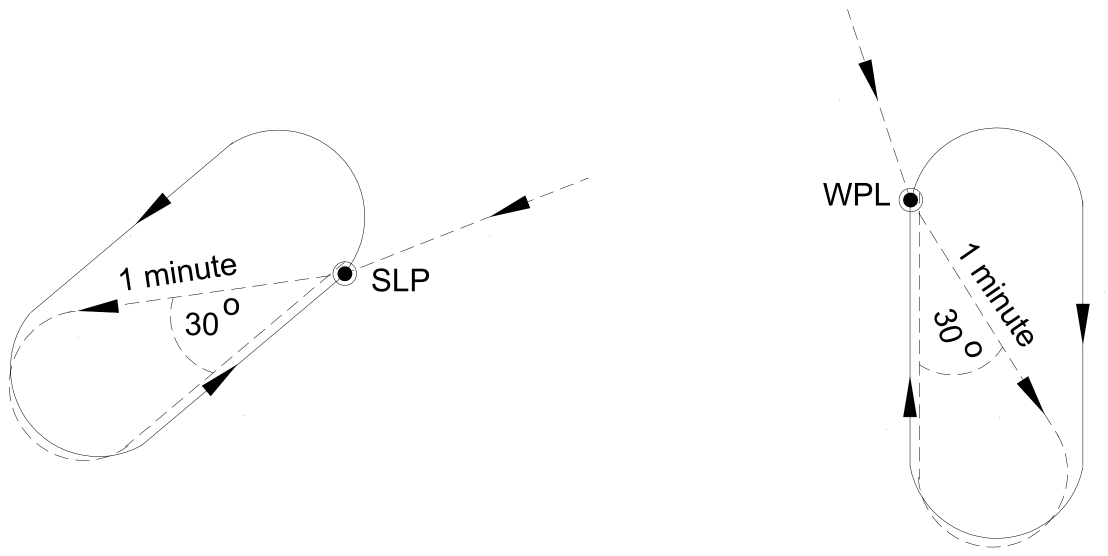


Figure 12 The Teardrop Entry into the NDB Holding Pattern

Flying an NDB Holding Pattern

Right Hand Hold - Welshpool

This example uses the Welshpool Runway 22 holding pattern as illustrated above.

The wind is 240° at 10 knots. Airspeed is 100 knots.

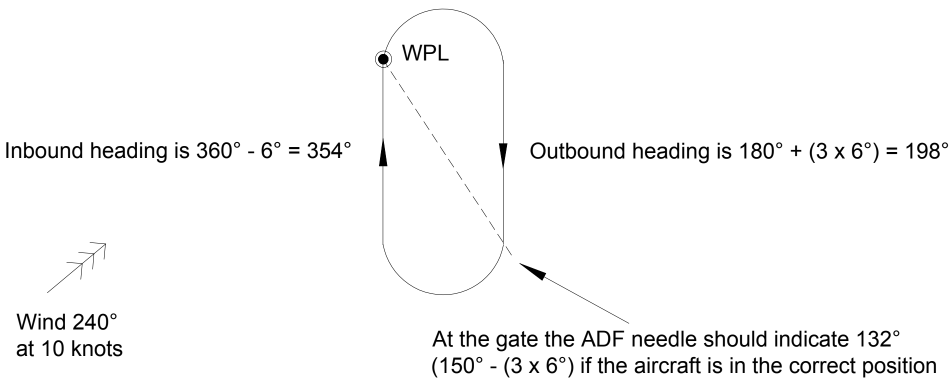


Figure 13 Flying the Welshpool holding pattern

First make the drift calculation. Max Drift angle = 10*60/100 = 6°. The wind is at 60° to the inbound and outbound tracks, therefore the effective crosswind component is 0.9 x maximum, and the headwind component is 0.5 x 10 knots = 5 knots.

The adjusted drift angle is 6° x 0.9 = 5.4°.As a slightly wide pattern is preferable to a too-tight one, use 5° rather than 6°. If anything, this will take the aircraft slightly east of the true outbound track, allowing a wider inbound turn. Had the wind been from the east, blowing the aircraft towards the non-holding side, it would have been preferable to tighten the inbound turn, and therefore use 6o. However, such finesse (flying blind to ± 0.5°) is probably beyond the skill of the average IMC rated pilot anyway.

Because the wind is blowing the aircraft away from the pattern, the drift correction is 3 x the calculated drift angle.

Next, fly towards the beacon from the southeast for a direct entry.

On passing the beacon, the ADF needle falls rapidly through 180°, and the base turn is commenced.

Roll out wings level onto a heading of 198°, (180°+(3 x 6°) drift correction).

When the ADF needle points to 072° (90°-18° drift correction), start the stopwatch and fly the outbound leg for 1 minute, minus 5 seconds (for 5 knots tailwind component).

At the end of this time, check the ADF needle. It should show 132° (150°-18°) if you have arrived at the gate accurately.

If the ADF needle angle is less than this, you are wide of the true gate position. Continue to make the inbound turn, but at less than rate one. If the ADF angle is less than this, turn left onto a heading of 150° for (say) 10 seconds, then commence the inbound turn.

You can check your position in the turn, by briefly rolling wings level, and observing the ADF needle as follows. In the turn, the drift correction is ignored.

Roll out wings level onto track (180°), and check that the ADF needle shows 360°. Correct any error by turning twice the error angle towards the ADF needle. The ADF needle will now show an equal and opposite angle to the error angle. Fly the heading until the ADF needle falls to the angle equal to your correcting turn, when a turn back, the same number of degrees, should bring the ADF needle back to 360°, i.e. you are on track. To maintain track, reapply the drift correction of 6°, maintaining a heading of 354° back to the beacon.

On reaching the beacon, the procedure may be repeated if required.

Clockwise turn			
Angle of turn completed	**DI Indication**	**ADF Indication**	**ADF lead**
0°	Inbound track - 180°	150°	0°
90°	Inbound track - 90°	80°	10°
120°	Inbound track – 60°	55°	5°
150°	Inbound track - 30°	27°	3°
180°	Inbound track	360°	0°
Anticlockwise turn			
Angle of turn completed	**DI Indication**	**ADF Indication**	**ADF lead**
0°	Inbound track + 180°	210°	0°
90°	Inbound track + 90°	280°	10°
120°	Inbound track + 60°	305°	5°

150°	Inbound track + 30°	333°	3°
180°	Inbound track	360°	0°

Left Hand Hold - Sleap

This example uses the Sleap Runway 23 holding pattern as illustrated below.

The wind is 280° at 30 knots. Airspeed is 100 knots.

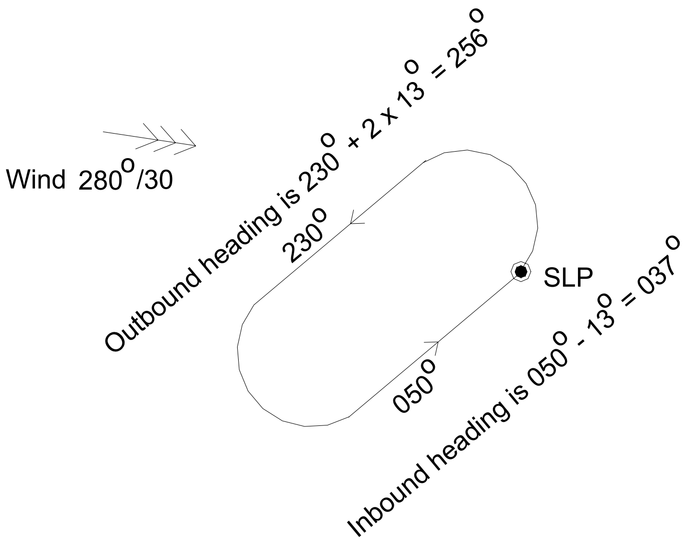


Figure 14 Flying the Sleap holding pattern

The maximum drift is $30 \times \frac{60}{100} = 18^{\circ}$

The wind is 50° to the right of track on the outbound leg, so the crosswind component is 0.7 x maximum drift - 0.7 x 18 = 12.6 = 13°. The wind is blowing the aircraft into the pattern, therefore apply a correction equal to twice the drift - 26°. The heading to fly outbound is therefore

230° + 26° = 256°.

The wind is 50 ° to the right of the aircraft on the outbound leg, and is a headwind. The headwind component is therefore 0.7 x 30 = 21 knots. The outbound leg time must be extended by 21 seconds.

Inbound, the crosswind component is still 13°, but from the left. The pilot therefore heads into wind, this time not 2 x the drift, but only 1 x the drift as he is heading directly towards the beacon and can maintain the inbound track much more accurately than the outbound. The heading to steer is therefore

050° - 13° = 037°.

Planning an NDB Approach

A significant amount of planning is required to fly an instrument approach, and wherever possible, this should be done on the ground before flight. For the IMC rated pilot, the planning procedure is as follows: -

1. Category of Aircraft is ‘A’. This category is for aircraft with an approach speed of less than 100 knots, and because of these lower speeds, the approach parameters differ in some respects from the approach parameters for faster aircraft. Commercial passenger jet aircraft are category ‘C’.
2. Check minimums. ATC will sometimes advise the pilot to “check your minimums” on an approach. Using the Sleap runway 23 approach plate, we can calculate our minimums as follows: -
   a) Obstacle clearance height (OCH) from the approach plate is 500 feet above aerodrome level (QFE). Add the aerodrome elevation (from the approach plate) – 275 feet to obtain the OCH above sea level of 775 feet (QNH).
   b) The minimum descent height for an NDB approach is 350 feet aal. Check which of a) or b) is the greater. In this case it is a).
   c) Is an altimeter correction necessary? For a non-precision approach, such as an NDB approach, no altimeter correction is required.
   d) IMC rated pilots must add 200 feet to the minimum descent height thus far calculated. The minimum is therefore increased to 700 feet aal.
   e) The absolute minimum descent height for an IMC rated pilot is 600 feet. Item d) is still the greater, so the Minimum Descent Height (MDH) is 700 feet, and the Minimum Descent Altitude (MDA) is 975 feet.

Do not get confused between Minimum Descent **Height** (the minimum height above aerodrome level) and the Minimum Descent **Altitude** (the minimum height above sea level). ATC will often ask you whether you are descending on QNH (MDA) or QFE, (MDH). It is usually best to work throughout in QNH and use the MDA.

Radio Calls

1. The initial call is "*G-GYAV inbound to Sleap, IFR, ETA [minutes], Request NDB Approach*". Repeat back the clearance given.
2. First time over the NDB, the call is "*G-GYAV maintaining 3000 feet, entering the hold*".
3. When you pass over the NDB and start the procedure proper, the call is "*G-GYAV, Beacon outbound, ready for procedure.*"
4. ATC will respond "*Report base turn complete*"
5. "*G-AV Sleap - base turn complete*"
6. "*Sleap - G-GYAV - Continue your approach, report field in sight*"

If you have a radio failure on an IFR flight within controlled airspace, and for which a flight plan has been filed, then you may complete the procedural approach to land. If you a radio failure within controlled airspace and are flying VFR, then you must immediately leave controlled airspace.

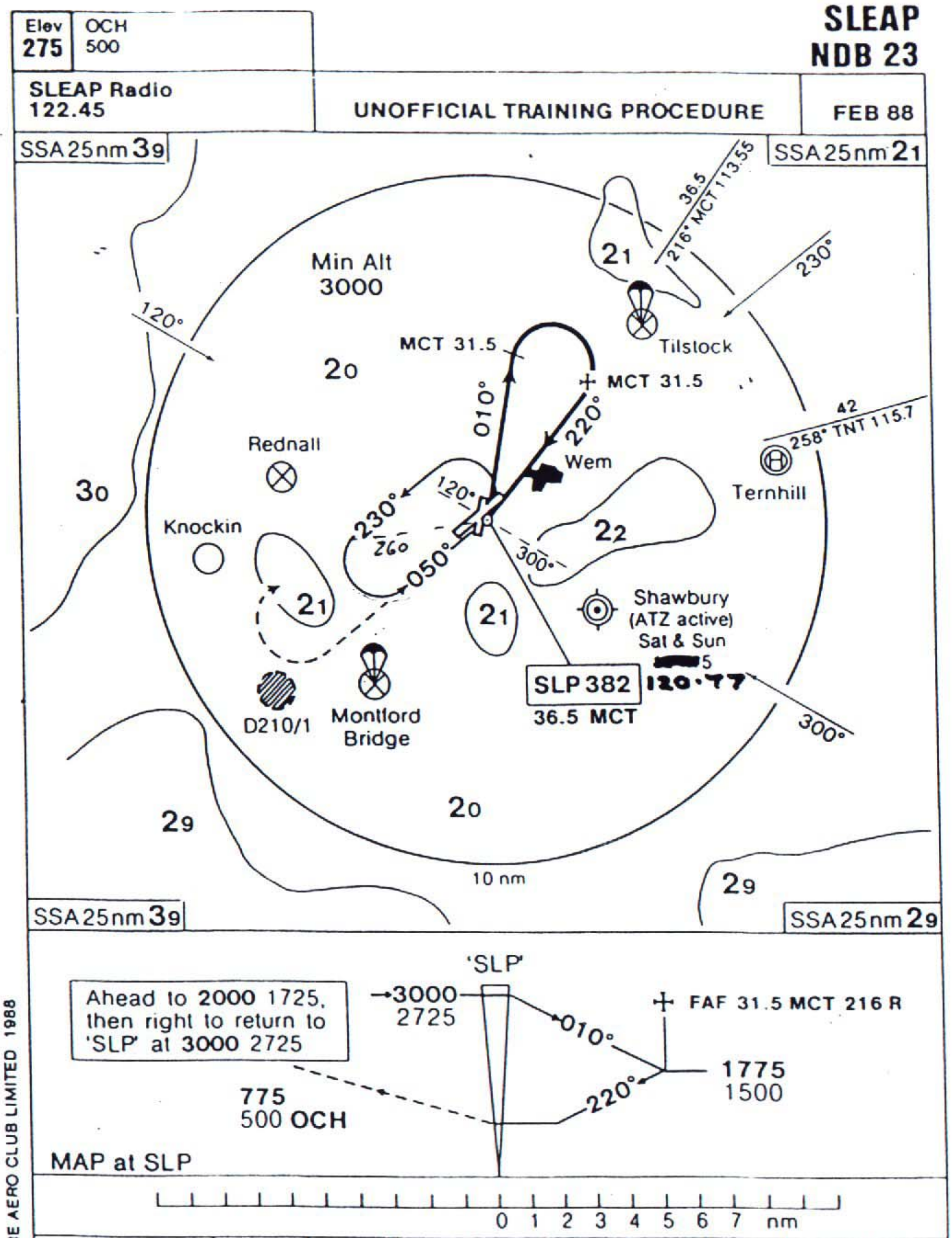
Flying an NDB Approach

We will use the Sleap NDB approach procedure shown overleaf.

To start the approach procedure, the aircraft turns onto a track of 010° immediately passing the beacon. The wind is now 90° to the left, so the drift correction is the full 18°. To maintain this track, the pilot flies a heading of 010° - 18° = 352°. As he crosses the beacon, and the ADF needle falls, he makes his "*Beacon outbound*" call. He maintains this heading, and descends to the base turn altitude of 1775 feet, until the Distance Measuring Equipment (DME) instrument, tuned to the Manchester VOR/DME MCT (113.55) reads 31.5 miles, at which point he starts his base turn.

The heading required to follow the inbound track of 220° is 220° + 18° = 238°. Following this track, the ADF needle will need to point to -18° (342°). The base turn is 352° - 238°, or 238° + 8° = 246°. At rate 1, (3° per second) this will take 1 minute and 22 seconds. By rolling wings level in the turn at 90° to the inbound heading the pilot can check whether he is too tight or too far out in the turn.

As an approximation, at 90° to the inbound heading, the bearing from the aircraft to the NDB will be a little more than 040° (the outbound heading plus half the included angle between the outbound and inbound headings), so the ADF needle should indicate between 075° and 080°. If the ADF reading is less, then the turn is going to be too tight, and the pilot should fly level for a few moments, and if more, then he is likely to fly through the final approach track, and will have to make a correction. The way that a correction is made is to fly the inbound track for a moment, and observe the ADF needle. Follow the NDB tracking procedure, as explained on page 10 to establish the correct track.



GROUND SPEED - KNOTS	60	70	80	90	100	110	120	150
Time from NDB to turn & FAF to RWY	5:00	4:15	3:45	3:20	3:00	2:40	2:30	2:00
Rate of descent from FAF to RWY	300	350	400	450	500	550	600	650

PROCEDURE IS TO BE USED ONLY WITH PRIOR 'AIR TRAFFIC' NOTIFICATION AND IN VMC

Figure 15 Sleap NDB Training Procedure for Runway 23

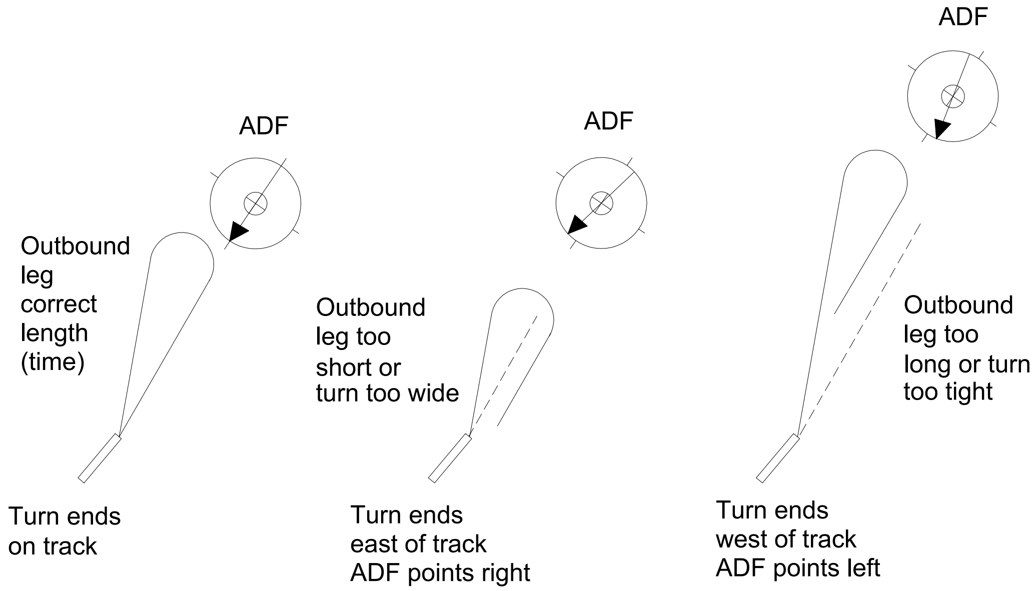


Figure 16 The effect of incorrect outbound leg length or incorrect base turn radius

At the Final Approach Fix, MCT 31.5 DME again, and 5 miles from the runway threshold, the aircraft should be at the required altitude, 1775 feet, and on the inbound track. This can sometimes be difficult to achieve in the short time available, but if not achieved, a missed approach must be initiated. If the Final Approach Fix is established, then the descent may continue to Minimum Descent Altitude (assuming that QNH is being used throughout the procedure). For the Sleap procedure, this is 975 feet, calculated by the method explained on page 20.

The Surveillance Radar Approach

The Surveillance Radar Approach (SRA) is a non-precision approach in which the ATCO "talks down" the aircraft. The Minimum Descent Altitude (Height) is the same as for an NDB approach, with an absolute minimum of 600 feet above aerodrome level, and 200 feet added for IMC rated pilots.

The R/T procedure is as follows: -

Pilot: Liverpool G-GYAV request SRA, on QNH

ATC: G-GYAV Liverpool. This will be an SRA terminating at 2 miles from touchdown. Obstacle Clearance Height is 420 feet. Check your Minimums and Missed Approach Procedure.

Pilot: Repeats back ATC instructions.

ATC: G-GYAV, identified (on radar) your position is 3 miles south east of the field. Turn right, heading 090° for base leg.

Pilot: Repeats back ATC instructions.

ATC: G-GYAV, QNH 1022, Descend 1800 feet

Pilot: Repeats back ATC instructions.

ATC: G-GYAV, turn left heading 273° (ATC will include any drift correction required)

Pilot: Repeats back ATC instructions.

ATC: G-GYAV, Descend 1650 feet.

Pilot: Repeats back ATC instructions.

ATC: Slightly left of track, turn right, heading 280°

Pilot: Repeats back ATC instructions.

ATC: G-GYAV, 5 miles from touchdown, commence descent for 3° glidepath

Pilot: Repeats back ATC instructions.

ATC: G-GYAV, 4.5 miles from touchdown, your altitude should be 1475 feet. Do not reply to further instructions.

ATC: G-GYAV, Turn left heading 273°.

ATC: *G-GYAV,* 4 miles from touchdown, on track. Turn right heading 275°. Your altitude should be 1325 feet

ATC: G-GYAV, 3.5 miles from touchdown, on track. Your altitude should be 1075 feet.

Instructions continue until the ATCO releases the aircraft as follows, or until the aircraft breaks cloud and the Pilot reports "field in sight, request continue with visual approach".

ATC: *G-GYAV,* 2 miles from touchdown, on track. Check your minimums. Radar service terminated. Maintain not below your Minimum Descent Height and fly to the Missed Approach Point. If not visual, go around.

If the pilot is not visual at the end of the procedure, he must maintain his Minimum Descent Altitude to the Missed Approach Point, then execute a Missed Approach.

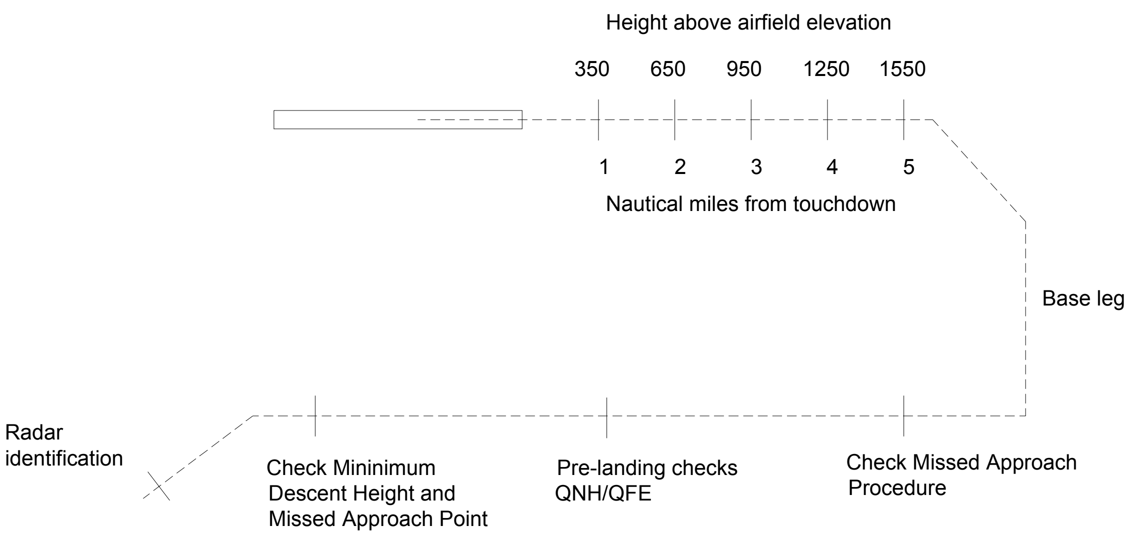


Figure 17 Surveillance Radar Approach

For a 3° glideslope the required height at any point on the approach is the distance from touchdown x 300 + 50 feet.

The rate of descent to set up to maintain a 3^o glideslope is

(Groundspeed x 5) feet per minute.

This is achieved with a throttle setting approximately 1600 rpm in the Cessna 172.

The VOR

VOR stands for **V**HF **O**mni-**R**ange. It works by transmitting two radio signals.

7. The reference phase, and
8. The Variable Phase.

When due magnetic north of the station, the two are in phase
When due magnetic east of the station, the two are out of phase by +90 °
When due magnetic south of the station, the two are out of phase by 180 °
When due magnetic west of the station, the two are out of phase by -90 °
Every 10 seconds the station transmits a 3 character Morse ident.

The range of a VOR depends on line of sight, and is a function of the height of the aircraft above the station.

$$\sqrt{1.5xheight\_in\_feet}$$

The cockpit display is the **O**mni-**B**earing **I**ndicator (OBI). Although all the indicators are shown in the drawing below, the "TO" and "FROM" flags do not display at the same time, and when a valid signal is being received, the "OFF" flag does not dispaly.

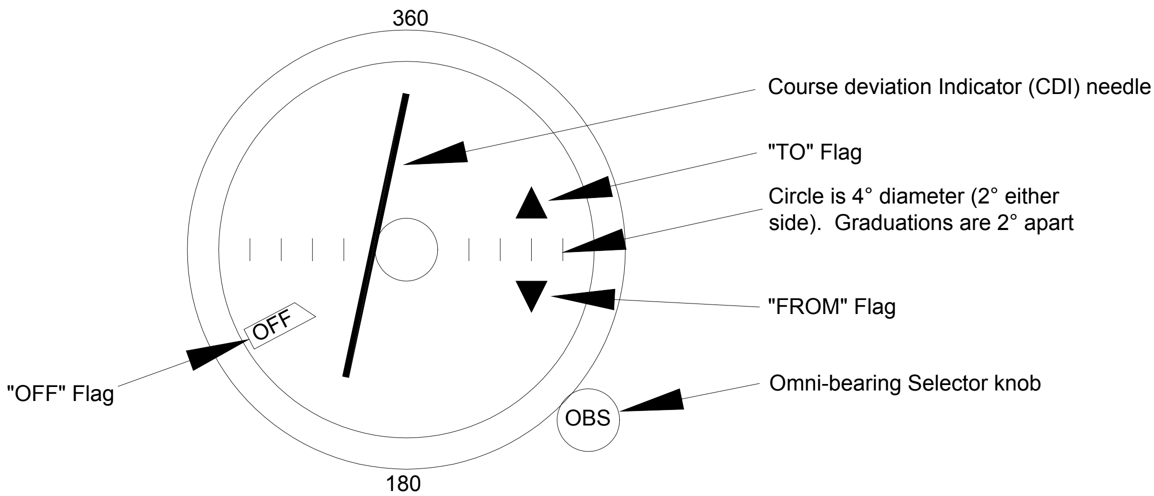


Figure 18 The Omni-bearing Indicator (OBI)

When tracking a VOR, your heading must be within 180° of the track required. Although possible, it is difficult to fly "TO" a VOR on a "FROM" heading as the CDI needle indication is reversed, which can quickly lead to disorientation. The "OFF" flag is displayed when the instrument is unable to receive signals on the selected frequency. This may be because the aircraft is out of range of the VOR transmitter, or, as quite commonly occurs, it is out of service due to a fault, or for maintenance.

Preparing the VOR for Use

Before take off: -

a) Switch on
b) Select desired frequency
c) Identify - listen to the Morse ident at least twice
d) Check that the "OFF" flag is not showing.

This check may be called the "SID" rule (Select, Identify, Display).

VOR Tracking

VOR tracking is used to determine: -

a) Where am I? (Bearing and distance FROM the VOR)
b) Where do I want to go? (Following a radial by keeping the CDI needle centred).

By turning the Omni-bearing selector (OBS) until the CDI needle is centred and the "FROM" flag is displayed, and observing the DME instrument, the pilot is able to obtain a "position fix", which will be, for example 120° FROM the VOR (i.e. to the south east of it) and 21.5 miles from it along the 120° radial.

By selecting a second VOR within range and carrying out the same exercise, the position fix may be confirmed, or the accuracy of the pilot' s rough plot on the chart improved (remember he/she is flying the aircraft at the same time! Ideally the radials from the two VORs should intersect as nearly at right angles as possible.

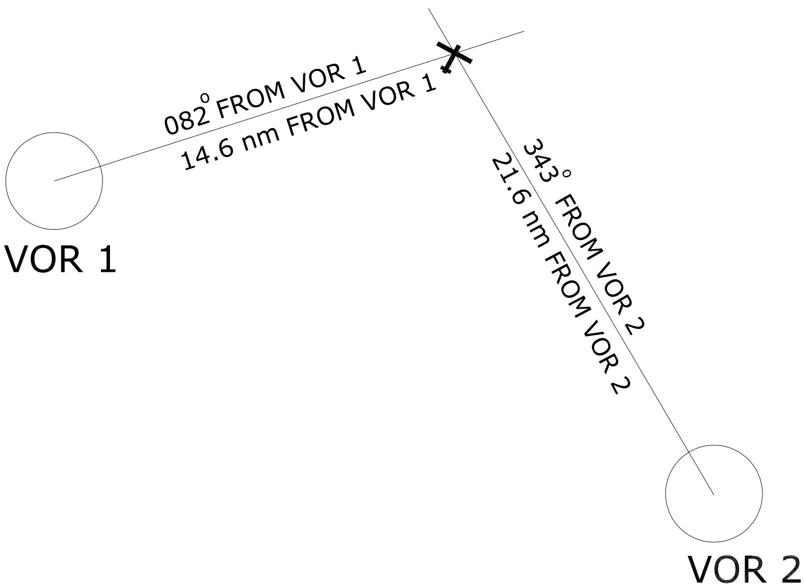


Figure 19 Position fix from two VORs

Section 5: Unusual Instrument Flight Conditions

Flying on Limited Panel in IMC

Instrument flying is subtle, but on limited panel, it is much more subtle. ***Wait*** for the instruments to respond after each small attitude, heading or power change.

The commonest problem is suction pump failure, which results in loss of the Artificial Horizon and the Direction Indicator, the two most important instruments.

Remember: -

Power plus attitude = performance

Which becomes: -

2300 rpm + x = 100 knots (with no climb or descent)

In practice, set 2300 rpm, and adjust attitude by feel until you have achieved 100 knots with no climb or descent. This is then maintained until the approach to land, which should be made as soon as possible at the nearest airfield.

Power and Balance are the critical control inputs. Do not chase the needles, and TRIM accurately.

Recovery from Unusual Attitudes in IMC

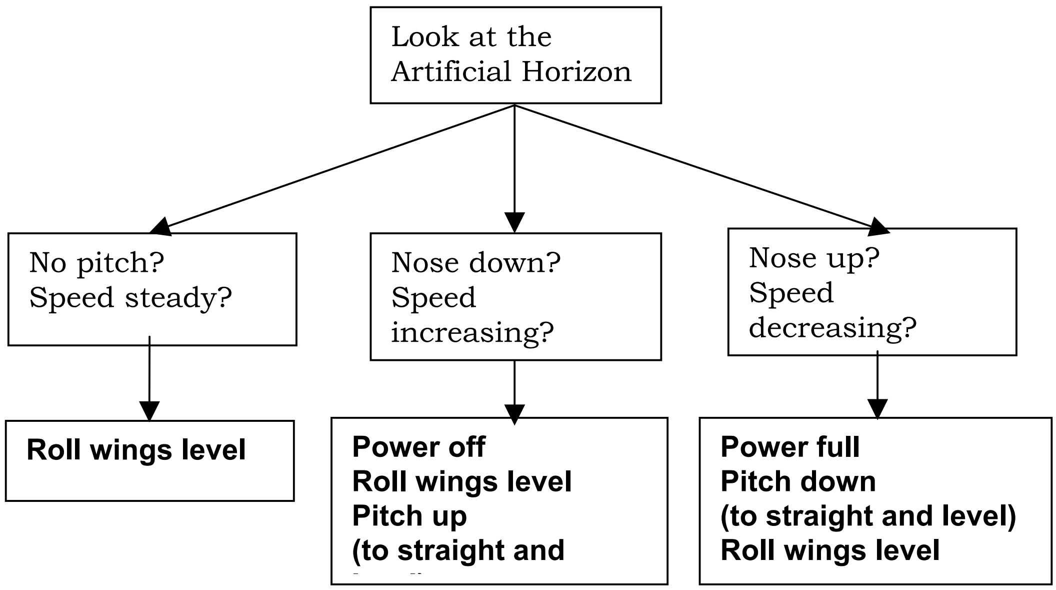


Figure 20 Recovery from Unusual Attitudes

On limited panel, you will be looking for the secondary effects of a pitch change.

Aircraft Motion	**Active Instruments & Controls**
Turning?	DI + Turn Co-ordinator
Climbing?	Altimeter + VSI
Descending?	Altimeter + VSI
Wind noise?	RPM + VSI
Stall warner	RPM + VSI

Ignore the inner ear signals, which may make you feel strongly that the aircraft attitude and behaviour is contrary to the instrument indications.

Rely completely on your eyes scanning the instruments.

Recovery is working when the instruments reverse their trends. Do everything **gently** - don't chase the needles.

Section 6: The Instrument Landing System

Components of the ILS

Ground Equipment

The Instrument Landing System ground equipment comprises several components. The principal components are a radio beam indicating the runway centreline, the Localiser, and another radio beam, the Glideslope, radiating upwards from ground level at the runway threshold. The angle of this beam is normally 3^{o}, but may be occasionally more. London City Airport has the steepest ILS glideslope in the UK, which is 4.5^{o}. In addition to the localiser and glideslope, there may be additional radio marker signals. These marker signals radiate vertically upward in a narrow beam, and generate an audible and visible indication in the cockpit.

Signal	Abbreviation	Frequency	Morse Ident
Outer Marker	OM	400 Hz	— — — —
Middle Marker	MM	1200 Hz	— . — . — .
Inner Marker	IM	3000 Hz	. . . .

Many installations have an Outer Marker, but the Middle Marker and Inner Marker are less commonly installed. Frequently, the Outer Marker is co-located with an NDB, known as the "Locator". The outer marker is then called a Locator-Outer Marker (LOM)

Aircraft Equipment

The ILS instrument in the aircraft is an Omni-bearing Indicator coupled to one of the NAV radios, with an additional needle to indicate glideslope. The OBI may be used with a VOR, in which case the glideslope needle is inactive, and the GS warning flag is displayed, or it may be used with the ILS. When used with an ILS the bearing selector has no effect, as it is responding to a single radial aligned with the runway.

The OBI has two warning flags, GS for glideslope and LOC for the localiser. When tuned to an ILS frequency, if either of these flags is showing, the approach procedure cannot be used.

In addition to the OBI, the aircraft is fitted with an annunciator panel comprising a blue light, a red light and a white light. When the aircraft passes over the Outer Marker, the blue lamp lights and the audible ident is heard simultaneously. Similarly, the red lamp lights for the Middle Marker, and the white lamp lights for the Inner Marker.

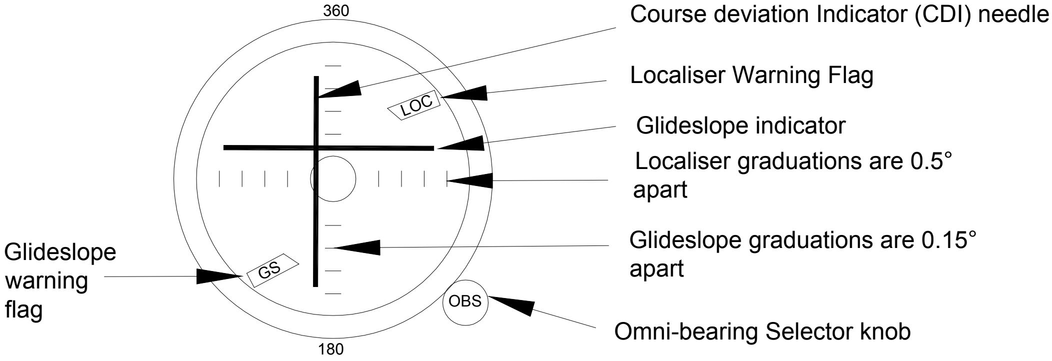


Figure 21 The ILS Omni-Bearing Indicator

Calculation of Decision Height

For a precision approach, the minimum height to which a pilot must descend before executing a missed approach is referred to as the Decision Height. (For a non-precision approach, it is referred to as Minimum Descent Height - see page 20). Using Hawarden Runway 23 ILS Approach Plate for example: -

a) Obstacle clearance height (OCH) for a category A aircraft with a 3% climb grade performance capability is 300 feet above aerodrome level (QFE).
b) Add the aerodrome threshold elevation (from the approach plate) – 17 feet to obtain the OCH above sea level of 317 feet (QNH).
c) The minimum descent height for an ILS approach is 200 feet aal. Check which of a) or b) is the greater. In this case it is a).
d) Is an altimeter correction necessary? For a precision approach, an altimeter correction of +50 feet is required.
e) IMC rated pilots must add 200 feet to the minimum descent height thus far calculated. The minimum is therefore increased to 550 feet aal.
f) The absolute minimum descent height for an IMC rated pilot on an ILS approach is 500 feet aal. Check if d) is greater than 500.
g) In this case it is, so the Decision Height (DH) is 550 feet, and the Decision Altitude (DA) is 567 feet.

The ILS Procedure

The Instrument landing System (ILS) is a Precision Approach. The pilot first positions the aircraft to intercept the ILS Localiser. This may be by means of an approach ***procedure***, such as over-flying a Locator NDB at a designated altitude, (the initial approach fix (IAF)), then making a procedure turn onto the Localiser. More commonly, the Air Traffic Control Officer (ATCO) will provide ***vectors*** either routinely or at the Pilot's request, to bring the aircraft onto an approach to the localiser at 30°.

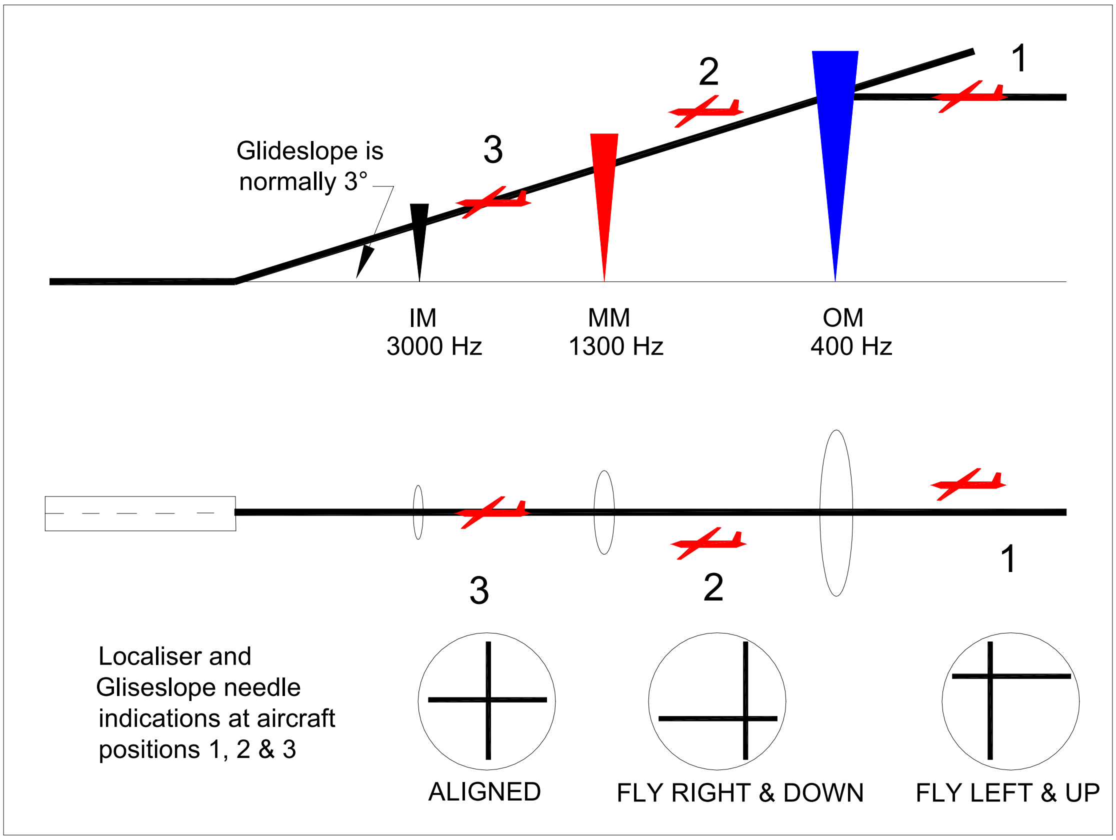


Figure 22 Making an ILS Approach

The ILS approach normally commences at a distance of 9 or 10 miles and at a height above aerodrome level of 3000 feet. This ensures that the aircraft, having captured the localiser, approaches the glideslope from below to avoid the possibility of capturing false glideslopes at higher altitudes which are sometimes present due to radio reflection etc. The ATCO may vector an aircraft into an intersect at a closer distance and lower altitude. This is commonly done when mixing slower light aircraft with larger commercial aircraft.

Once the aircraft is on an intercept heading to the localiser, the pilot watches the localiser needle, which will begin to come alive as the intercept is approached. As soon as the needle begins to move, the pilot turns onto the runway bearing, and mentally estimates a heading to steer to take account of wind. Once the localiser needle is "off the stops" the pilot reports "localiser captured" and maintains altitude until the glideslope needle begins to fall on the OBI. He commences his descent just as the glideslope needle reaches centre.

The power should be set to achieve the required rate of descent to remain on the glideslope. The rate of descent required is given by: -

Descent rate in feet per minute = Groundspeed in knots x 5.

The groundspeed may be observed on the DME instrument, or calculated from knowing the wind speed and direction.

The localiser and glideslope should be aligned within half full-scale deflection by the time the aircraft reaches the Final Approach Fix (FAF), otherwise a missed approach should be initiated. The pilot should not chase the needles, but make small corrections only - less than 10^{o} heading changes, and pitch changes of 1^{o} or 2^{o} at most.

In normal VFR flight in light aircraft, power is used to control climb and descent and pitch to control airspeed. For an ILS approach, glideslope is generally maintained by adjusting pitch, not power. Airspeed can be allowed to change as a result of pitch changes, because the correct approach airspeed can be re-established once the runway is in sight and the instrument approach is terminated. Similarly, for light aircraft, flaps are normally deployed only when the runway is visible. However, for all aircraft with retractable undercarriage, the undercarriage is extended as soon as the Localiser is captured.

Continuing the approach, a missed approach is also initiated if the aircraft reaches the Descent Height and the runway is still not visible.

The Missed Approach Procedure

The missed approach is a procedure which provides formal rules for the aircraft's path following a failure to see the runway ahead at

a) Minimum Descent Height for an Non-precision approach, or
b) Decision Height for a precision approach
c) If either of the OBI needles exceed half full scale deflection in an ILS approach.

A missed approach must also be initiated if the aircraft is not in the correct position and at the correct height for a successful landing.

The ATCO may provide vectors to shorten the procedure if appropriate. The missed approach procedure is set out on the instrument approach plate.

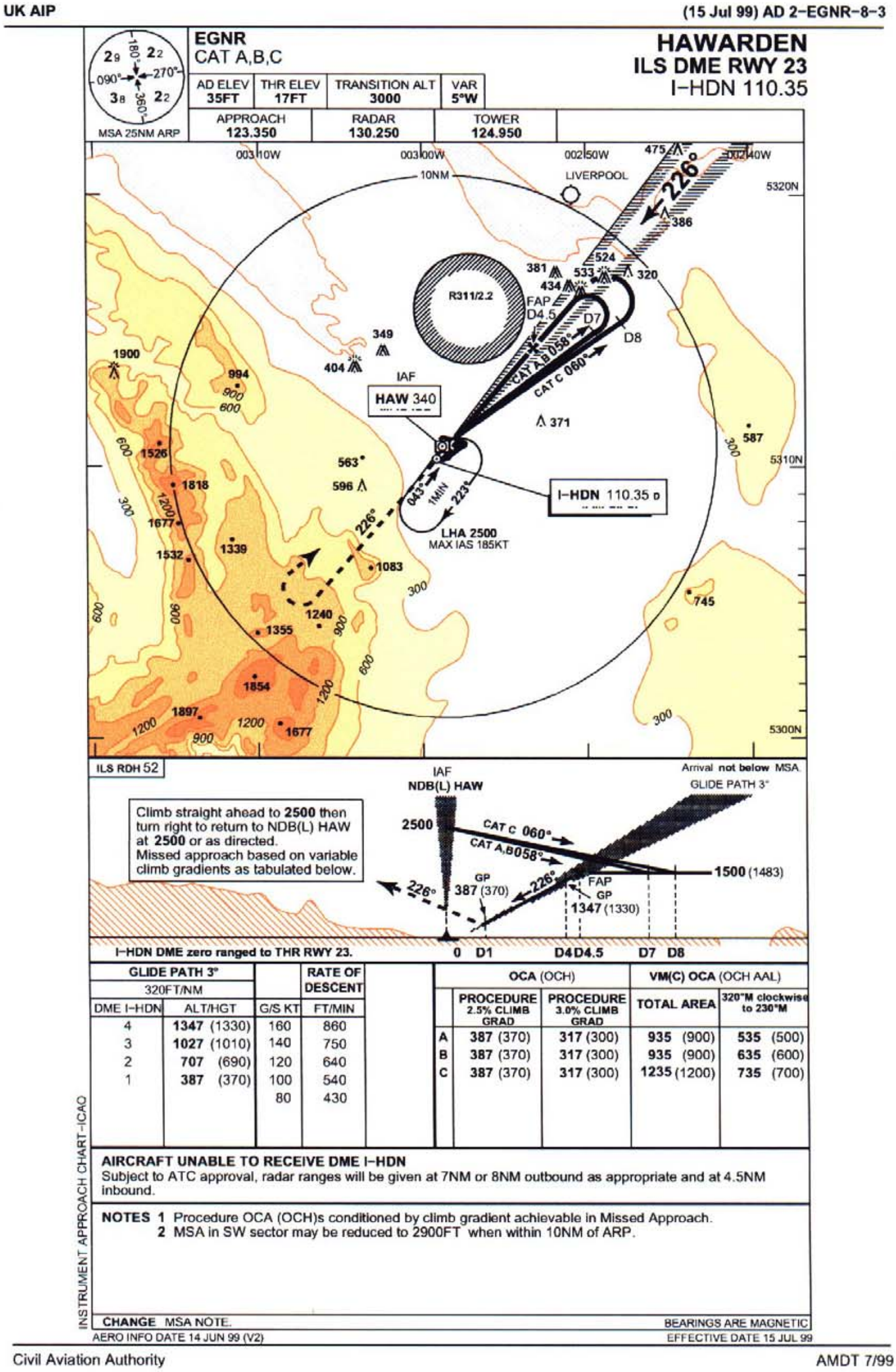


Figure 23 Hawarden Runway 23 ILS Approach Plate