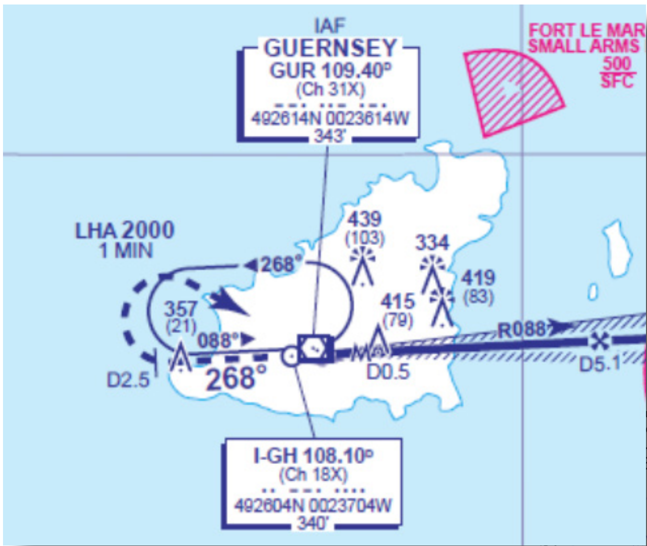
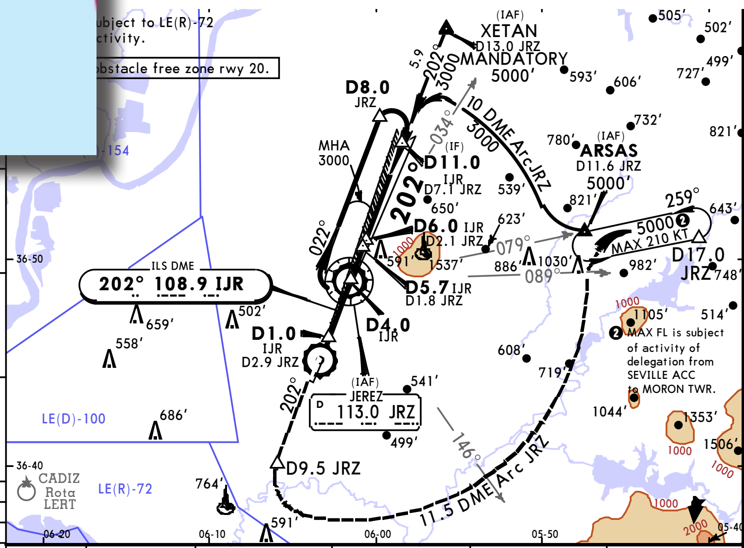
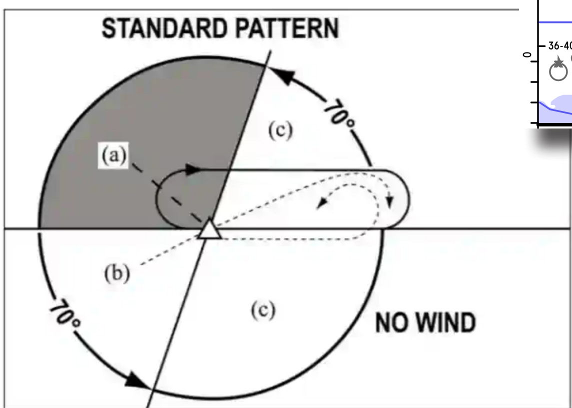
Student Study Guide

The RBI & Single Needle Tracking

Stephen R.S. Evans







EvansAbove !

The Radio Bearing Indicator

"Simplicity is a virtual, that's why so many Land Rover Defenders still live"

The Relative Bearing Indicator

This is Part 3 in what is (currently) a 6-part series of student notes on practical ways to fly under Instrument Flight Rules.

In the previous sections, we looked at preparation for the course. Then in the second part, we looked at best practices for maintaining control of the aircraft in IMC conditions and started to look at Radio Navigation.

This section builds on that by introducing Single-Needle tracking and Interception. The hardest Instrument to use for this purpose and technically the simplest, is the Radio Bearing Indicator or "RBI".

The design of the RBI goes back almost 100 years when the United States Postal Service needed to provide a means of navigation for their postal aircraft.

These would be recognisable today as Non-Directional Beacons, NDB's. By today's standard the receiver in the aircraft was quite crude with the Pilot or Navigator having to manually rotate an on-board aerial to detect where the signal was coming from.

With advances in technology, the manual aerial was replaced with an electronic one and the Automatic Direction Finder or ADF was introduced.

Further advances, such as digital tuning, shown here, further increased the accuracy of the units and their adoption.

In the aircraft the equipment is split into two parts. There is the detection unit (shown above at the bottom) with the LED display, and the Indicator device, shown at the top with the Compass Rose.

The detection unit is the ADF, and it is capable of driving a variety of different types of Indicator device depending on the equipment fit of the aircraft. For example it can drive an RBI (shown above), an RMI or even a G1000 flat-panel Primary Flight Display

The most common display device is the RBI for its cost and reliability, the next more sophisticated display device is the RMI. They both share the common function of providing a Relative Bearing ("RB") from the nose of the aircraft.

Where they differ, is that the Compass Rose of an RMI is automatically synchronised to the magnetic heading of the aircraft, but the RBI Compass Rose has to be rotated manually by the pilot. However, once aligned, an RBI can be used like an RMI. On a long straight cross-country segment of flight, this is perfectly acceptable, however in a busy training environment, having to constantly realign the Compass Rose of an RBI is an unwelcome distraction.

For this reason, we teach the "North-Up" method at FIS, where the RBI Compass Rose is setup with the "N" or 360˚ marker on the Rose being under the lubber line at the top. It is then left alone.
All instrument interpretation for QDM and QDR is by done by comparing the RB with the heading information. In the above image the RB is 220˚.

Radio Navigation
Single Needle Navigation

Despite the introduction of GNSS navigation and computer-controlled auto-pilot navigation in a Commercial environment, it is a requirement that Pilots wishing to achieve an Instrument Rating should be able to navigate with sole reference to navigational beacons using direction-finding techniques.

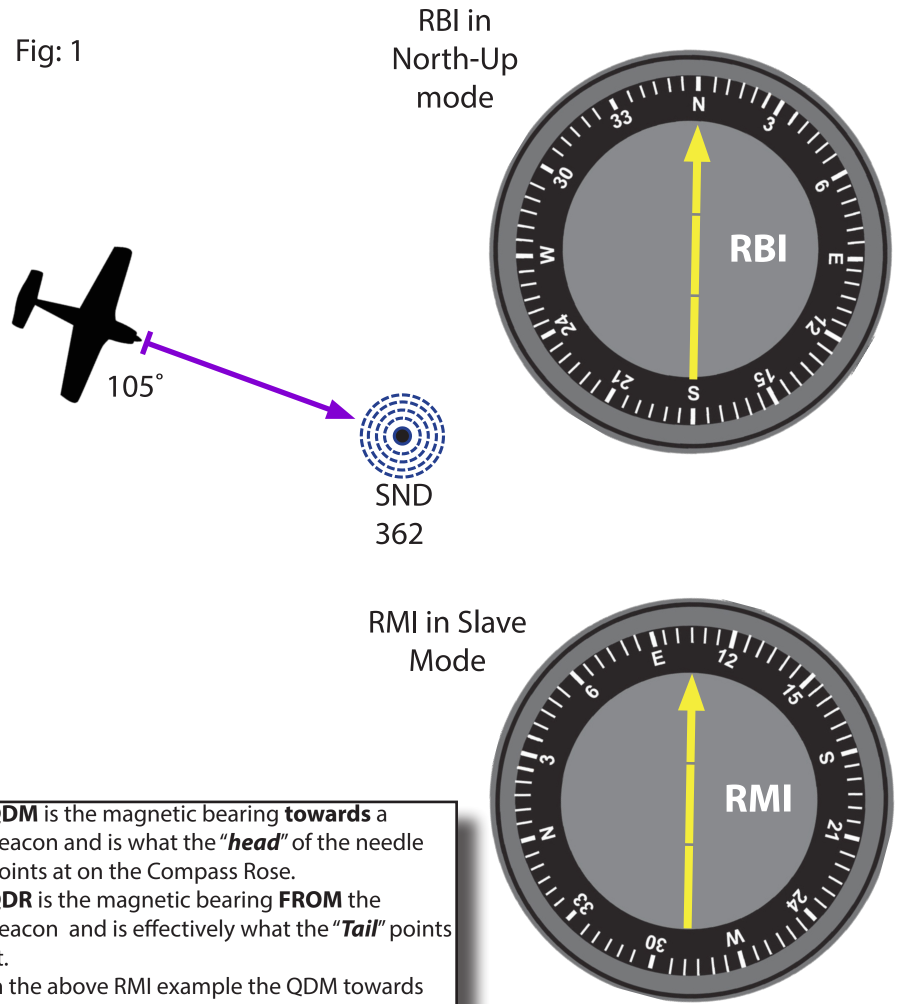
This consists at it's most basic of a single needle instrument that simply "points" at a Beacon. In reality this means either a NDB or a VOR ground station.

There are two types of bearing indicator, the Radio Bearing Indicator, or "RBI" and the Radio Magnetic Indicator, the "RMI". The difference between them is that the Compass Rose on an RBI has to be rotated by hand, for which there is a rotating knob similar to that found on a Direction Indicator

However the Compass Rose on an RMI is rotated electronically using a signal from a wing-tip magnetometer that detects the Earth's magnetic field and automatically and continuously (at 3˚ per second) synchronises the Compass Rose to magnetic North. This is one reason why all turns under IFR are Rate-One turns, so that no de-synchronisation of an RMI (or HSI if fitted) can take place.

In both cases, the Needle of the RMI/RBI points towards the beacon **relative** to the nose of the aircraft, however the RMI gives a direct read-out of the QDM on the Compass Rose from the "head" of the pointer arrow, whereas the RBI gives the bearing relative to the nose.

Fig: 1



Imagine an aircraft with both an RBI and an RMI installed, driven by the same ADF.

In Fig: 1. on the left, we have an aircraft flying towards an NDB, in this case the SND on frequency 362KHz.

The aircraft is on a heading of 105˚.

In the top instrument, the Pilot has rotated the Compass Rose of the RBI to what is called "North-Up", that is 360˚/0˚is at the top.

In both cases the RBI and RMI have the needle pointing straight ahead, which is correct as the beacon is straight ahead of the aircraft.

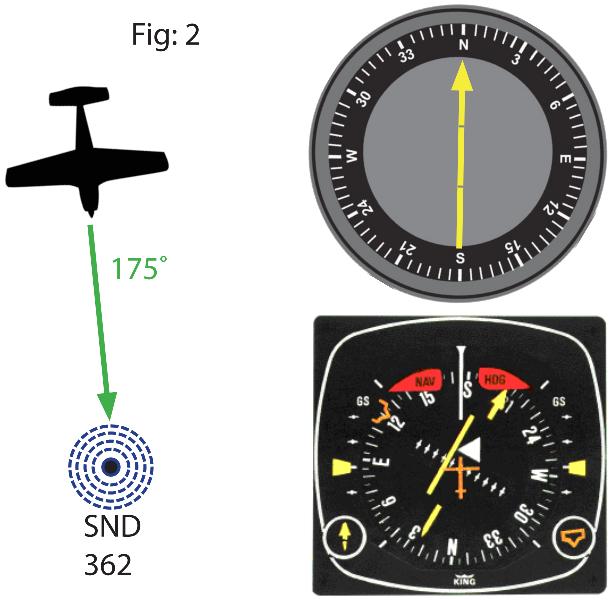
However the RBI only gives the Relative Bearing as being "0°", whereas the RMI is reading out the QDM of 105˚

QDM is the magnetic bearing **towards** a beacon and is what the "***head***" of the needle points at on the Compass Rose.
QDR is the magnetic bearing **FROM** the beacon and is effectively what the "***Tail***" points at.
In the above RMI example the QDM towards the beacon is reading 105˚ and the QDR of the aircraft from the Beacon is 285˚

Using the RBI

The RBI is harder to use and interpret than the RMI, simply because the Pilot has to mentally convert their Relative Bearing (“RB”) to either QDM or QDR using either the magnetic Compass, Direction Indicator or HSI.

Fig: 2



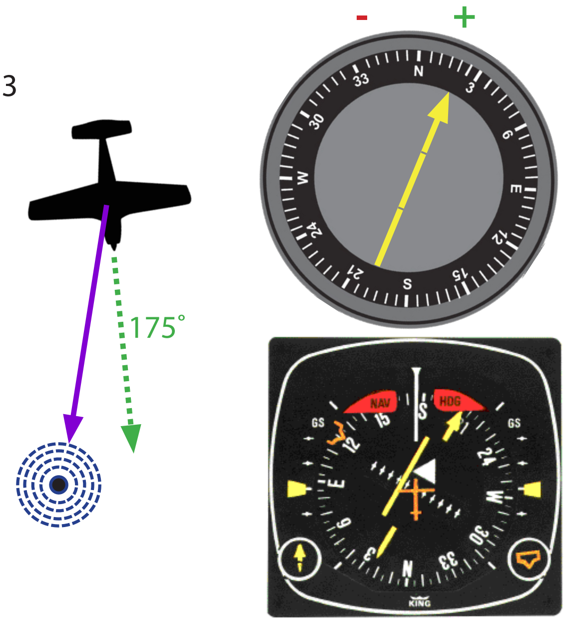
In the example on the left, Fig.2, the aircraft is on a QDM of 175° towards the SND beacon.

The RB is 0°.

The RMI (which has a slaving Compass Card) is indicating a heading of 185°.

Therefore the QDM is 175 - 0 = 175° and the QDR is 355°

Fig: 3



In the example Fig.3, the aircraft is on a heading of 175°

The RB is **+20**°

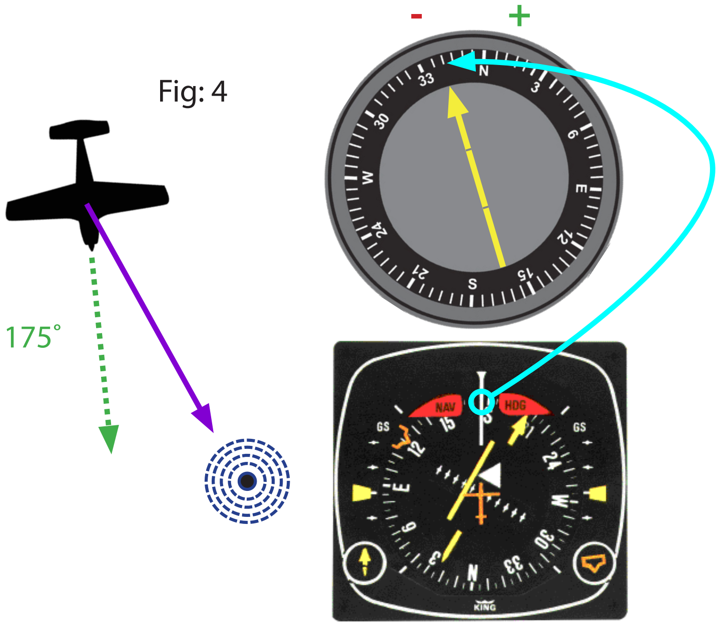
The RMI is confirming the heading of 175°.

Therefore the QDM towards the beacon is

175 + 20 = 195° and the QDR is 015°

Note: We use a convention of **+** (positive) when the needle is to the right of North and **-** (negative) when to the left of North on the RBI

Fig: 4



In the example Fig.4, the aircraft is (again) on a heading of 175°

The RB is 340°or **-20**°

The RMI is confirming the heading of 185°.

Therefore the QDM towards the beacon is

175 - 20 = 155° and the QDR is 335°

The key to using the RBI is to quickly transfer the heading from the HSI or Compass to the RBI Compass rose and from there the QDM

Sources of Heading Information

There are multiple sources of Heading information depending on which type of aircraft you fly and the Avionics fit installed. If you are lucky, you will have a HSI, and maybe an RMI.

You may have EFIS-type system like a Garmin G5, or at its simplest, a Compass and Direction Indicator

HSI with Mag Hdg

Contrary to popular belief, an HSI is in many respects the easiest to use.

The reason is that the Compass Rose is slaved to the magnetometer flux-gate in the wing-tip and therefore always points at your magnetic heading.

It rotates and synchronises at 3˚ per second, so if you exceed this turn rate, it will, until it has caught-up, be under-reading.

The beauty of the HSI is that it gives a simplified, intuitive display for the whole of the Compass Rose, therefore making the conversion of RB's to QDM/QDR's fast and easy.

G5 with GPS Hdg

A word of warning about Garmin G5's. They can come in two flavours, one with a Magnetometer and the other without. A G5 with magnetometer will give you Magnetic track at the top of the display.

If it does not, then a GPS track readout is displayed instead. Currently European Magnetic Deviation is very low being +/-3˚, so this difference can almost be ignored.

One disadvantage of this layout though is that there is no Compass Rose in this Configuration (granted a twin G5 set will do this), which can make some calculations more difficult. More on this later.

Compass & DI

At the simplest level, your aircraft may be fitted with a Direction Indicator and a magnetic compass.

If this is the case, then take care to synchronise the DI with the Compass, but once this is done, for short tracks of less than 10 minutes then Earth drift can be ignored.

Every 10-15 minutes, re-align the DI with the Compass to ensure accurate headings.

Once done, the Compass Rose of the DI can be used in the same way as an HSI, both for situational and positional awareness, but also as a circular calculator, more of which later.

Throughout the rest of this document, I shall not refer to any particular type of Heading Indicator, so as to be as aircraft-agnostic as possible.

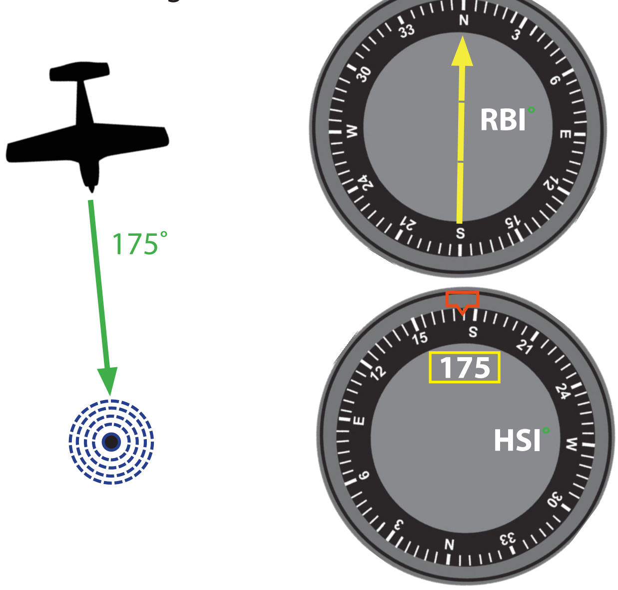
The Indicator on the left can be thought of as a generic Heading Indicator, with the current heading marked in white lettering at the top. In this case "175˚"

Correcting for Errors

One of the most basic skills of an Instrument pilot is tracking towards a beacon. Note the use of the word "tracking". Tracking is defined as maintaining a constant QDM towards or QDR away from a beacon or fix. During your IR skills test, the Tracking accuracy expected of the candidate is +/- 5˚.

Due to wind, accuracy of pilot handling or instrument drift, it is inevitable that some deviation away from a desired QDM/QDR may occur. It is vitally important that the pilot monitors and corrects for any deviations before they become an error.

Fig: 6



In Fig 6, the aircraft is once again on a heading of 175˚ with a RB of 0˚, so therefore the QDM is 175˚

However if the aircraft drifts to the East (as shown in Fig 7.), perhaps by a westerly wind, or inaccurate flying by the pilot, then the QDM will increase as the beacon (as seen from the pilots perspective) moves to the right.

This is indicated in the cockpit by the RBI needle rotating clockwise and now pointing to +20˚ and the QDM is now 175 + 20 =195˚

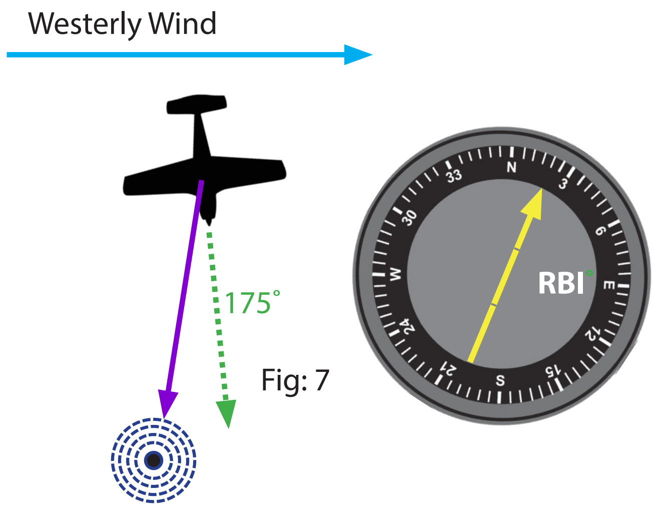


Fig: 7

This is shown on the RBI in Fig 7. The solution to regain the original QDM track of 175˚ is for the pilot to turn to the right, but by an amount that is approximately double the error.

Here the error is 20˚, so turn right by 40˚ onto a heading of 175 + 40 = 215˚.

In Fig 8, this is shown by the HSI heading now reading 215˚.

The RB is now reading 350˚ or -20˚ (we turned through 40˚so +20˚ became -20˚).

Our QDM is: 215˚ - 20˚ = 195˚ (the aircraft hasn't moved, just turned), but we want to get back to a QDM of 175˚

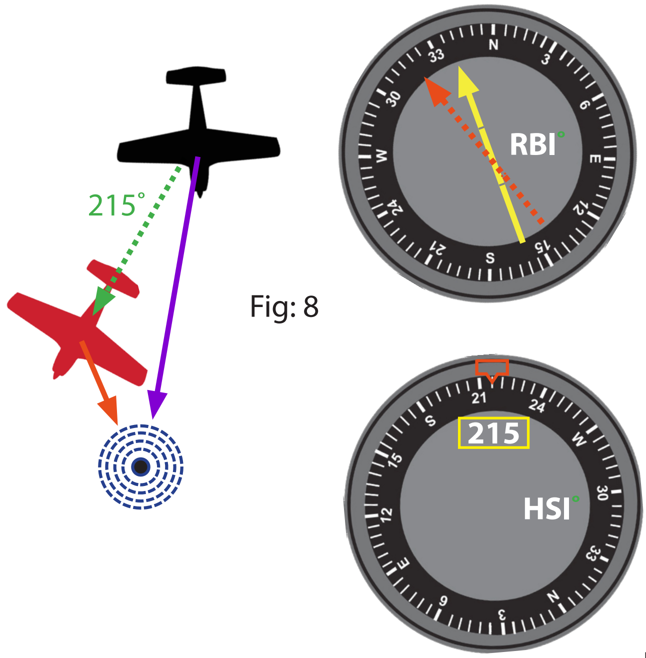


Fig: 8

If you look at the second position of the aircraft (shown in red), then after the aircraft has flown on the heading of 215˚ for a while, then the RB has increased from -20˚ to -40˚.

The effect is shown on the RBI in Fig 8 with the orange-dotted needle. Therefore the aircraft has now returned back to a QDM of 175˚

215˚ - 40˚ = 175˚

This correction now ensures that the aircraft TRACKS towards the beacon on 175˚.

Push the Head, Pull the Tail

To help you visualise this process in the cockpit, we use a simple memory aid. "Push the Head, Pull the tail".

If we take the previous example, the RBI needle is 20˚ to the left of the nose of the aircraft when the aircraft is in the position shown by the black image on the right.

This is represented by the yellow needle in the diagram. By flying 215˚, the pilot is going to "push" the head of the needle away from the North (or 360˚/0˚) position of the RBI.

By continuing to fly on heading of 215˚ (in this example) the head of the needle is "pushed" from the yellow needle position to the orange needle position.

This technique of "Push the Head, Pull the Tail" has multiple uses, but let us first look at "Pulling the Tail"

The needle head starts left of the North position (yellow), so by continuing to fly in this direction the Head is pushed further away **from** the North to the left, as shown by the purple arrow, ending at the orange arrow position

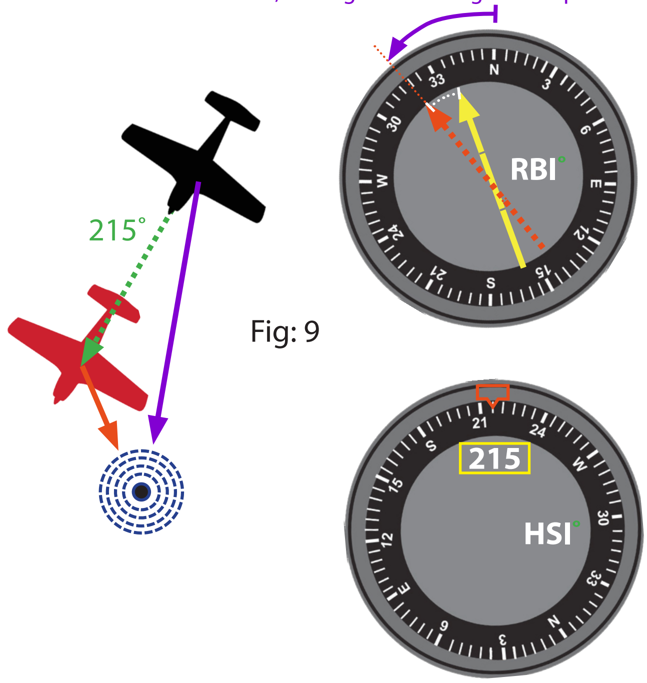


Fig: 9

The RBI needle tail starts left of the North position (yellow), but because the aircraft turns right, past 020˚ and onto 045˚, then the Heading is now pulling the Tail of the RBI. The actual flightpath is shown as the blue line below.

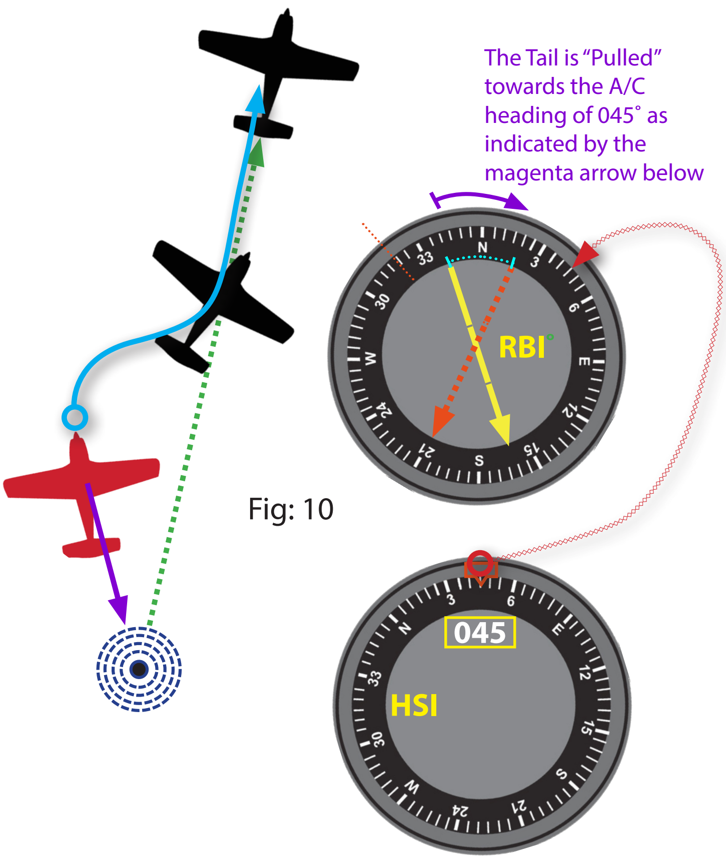


Fig: 10

In Fig 10. Imagine than an aircraft has flown over a beacon and initially has QDR radial FROM the beacon of 340˚ (*magenta arrow*). The Approach plate for this Beacon states that the Outbound track for this Approach is 020˚, indicated by the green dotted line.

This situation is represented on the RBI by the yellow needle and the position of the red aeroplane.

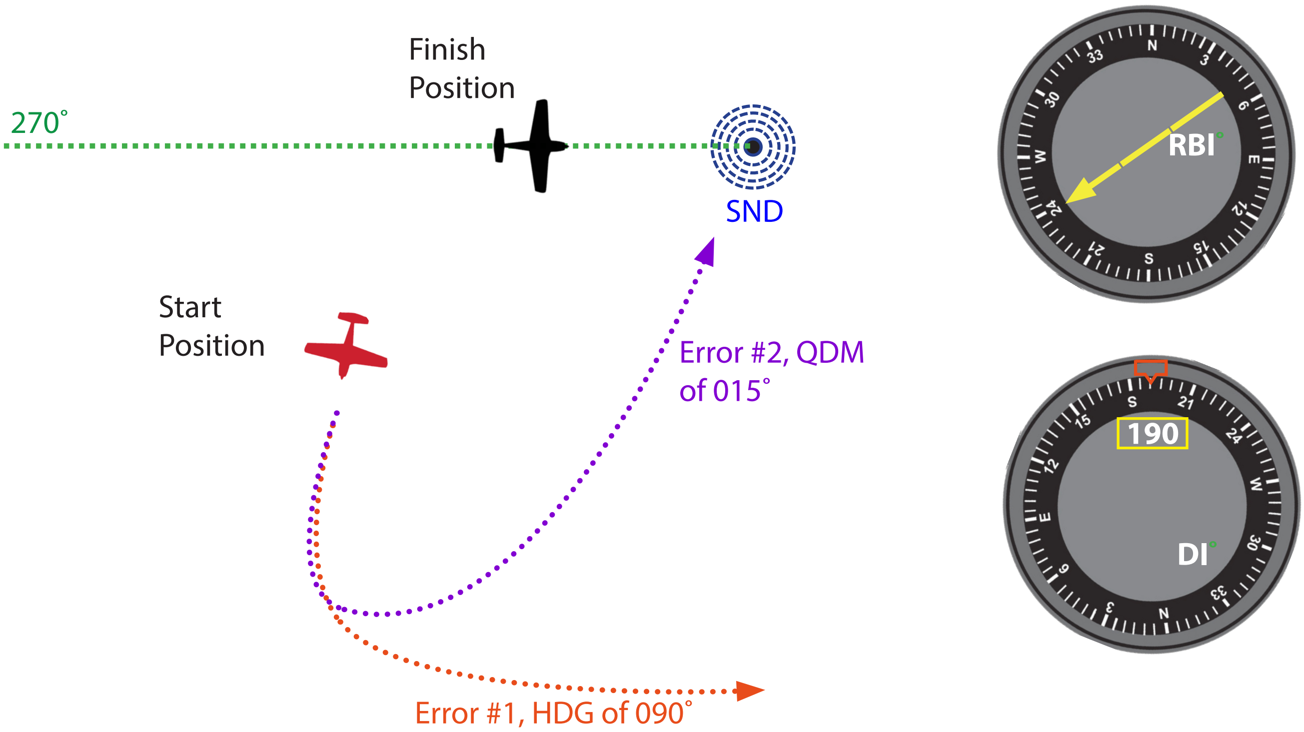
Therefore, from the plan diagram on the left, the aircraft must turn to the right by more than 40˚ (-20˚ thru' to +20˚) in order to intercept the 020˚ radial. So from a heading of 340˚ the aircraft must turn right onto an approximate heading of 045˚ to intercept the 020˚ radial.

This means that from a pilots perspective looking at the RBI, they must "pull the tail" of the RBI from 340˚ to 020˚ with the RBI needle ending up in the orange needle position.

If you follow the red-dotted arrow on the left from the HSI heading around to the RBI, you will see that your Heading is "pulling the tail" from the initial 340 to final 020˚, The pilot can then turn onto a heading of 020˚ to track outbound on the corrected radial.

Interception with an RBI

One of the skills of a Radio Navigation Pilot is intercepting a radial (a QDR) or an inbound track (a QDM) to a Beacon. Take a look at the set up in the diagram below. Here an aeroplane is heading 190˚ to the south. ATC call the pilot and tell them intercept the 270˚radial for SND and fly inbound to the beacon.



How do we approach this situation? Lets start with some facts. You have been asked to intercept a radial, which is a QDR, but the Controller wants you to fly Inbound, now that's a QDM, so first-things-first, convert QDR to QDM.

You need to be easily able to convert the two which will always be 180˚ apart. *Remember this trick*:

- add 200 then minus 20, or
- minus 200 and add 20

This makes it easy, so using QDR270˚ as an example: 270 minus 200 is 70. 70 plus 20 is 90, or 090˚

Try this again with a QDM of 125, what is the QDR?

125 plus 200 = 325, and 325 minus 20 is 315˚, so the QDR for QDM125˚ is 315˚

So the pilot is actually being asked to flying inbound to the SND beacon on 090˚. Looking at the diagram above with North at the top and the answer is obvious, but in the plane, maybe not. So the task is get some situational awareness and plot a course to get from the position of the red plane to the black plane.

Before we go further lets look at two common mistakes.

Error #1. You get confused by ATC and turn right onto a heading of 090˚. This is shown as the orange dotted track.

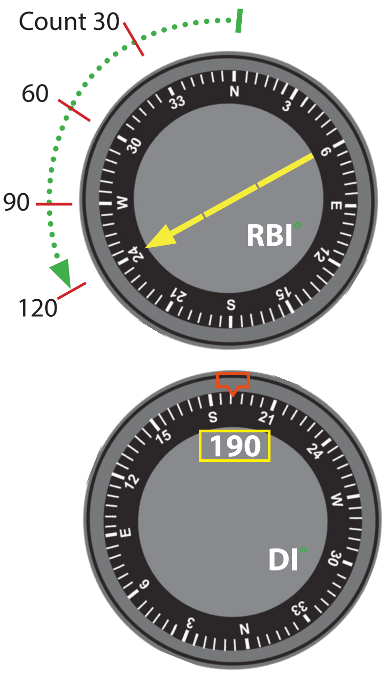
Error #2: You turn right and track towards the beacon. Wrong again, yes you are tracking towards the beacon, but not on a QDM of 090˚, as in the case of the purple track above, more like 015˚.

Understand the Picture

So does the pilot turn left to intercept the QDM or turn right? To answer that we need to really understand what the needles are telling us.

💡 Revelation time! The Compass Rose is a circular calculator.

The Big Numbers on the Compass Rose are 30˚ apart. So that's 000˚, 030˚, 060˚, 330˚, 300˚ etc.
The next size divisions are 10˚ and the really small ones are 5˚ apart.



Method #1 QDM: What is the QDM? Look at the RBI needle and count (in this example anti-clockwise) the "big numbers" from the top of the RBI around to the head of the needle: "33, 30, W, 24".

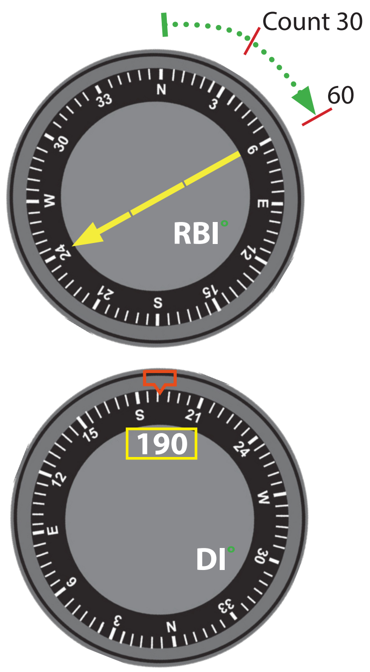
Each one is 30˚, so actually count them up in your head by adding 30's together like this: *"30, 60, 90, 120"*. (or 1,2,3,4 so 4x30 is 120)

The heading is 190˚ (*from the DI below*), so 190˚ minus 120˚ is 070˚

Therefore the QDM is 070˚ to the beacon.

To work out the QDR from the beacon, it is 70 +200 => 270.
270-20=>250˚

So the QDR is 250˚



Method #2 QDR: What is the QDR? Look at the RBI needle and count the "big numbers" from the top of the RBI around to the Tail of the needle: "3, 6".

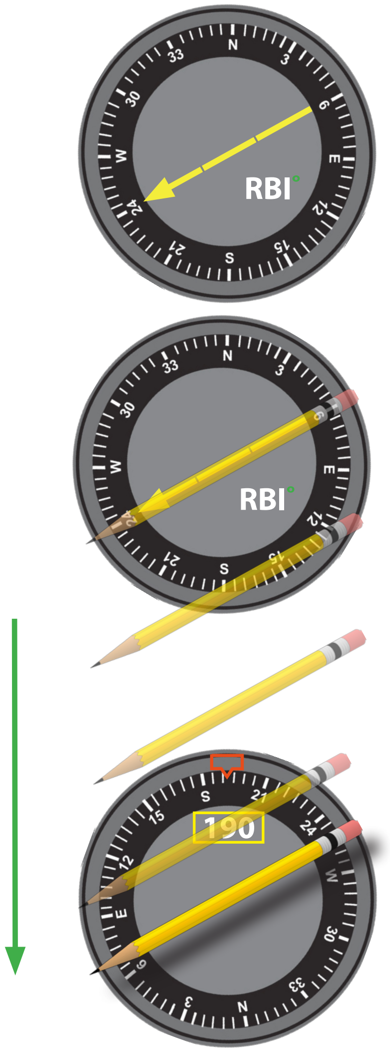
Each one is 30˚, so actually add them up in your head by adding 30's together like this: 30, 60. (or "1,2" so 2x30 is 60)

The heading is 190˚ (*from the DI below*), so 190˚ plus 60˚ is 250˚

Therefore the QDR is 250˚ to the beacon.

To work out the QDM to the beacon, it is 250 - 200 => 50.
50+20=>070˚

So the QDM is 070˚



Method #3 Pencil Method: What is the QDM? Look at the RBI needle and place your pencil over it aligned with the Head of the needle.

Very carefully parallel your pencil across to your DI/HSI and the head of the pencil will point at the QDM, which in this case is 070˚

To work out the QDR from the beacon, it is underneath the pencil eraser at 250˚

So the QDR is 250˚

Do not be ashamed if the mental arithmetic of Method 1 and 2 are confusing and you have to resort to the Pencil method to start with. Most people won't admit to it, but they usually start this way.

However with practice the "penny will drop" and you will start to actually "see" what the picture is telling you without the aid of a prop such as the Pencil.

But for now, if the Pencil works for you, use it.

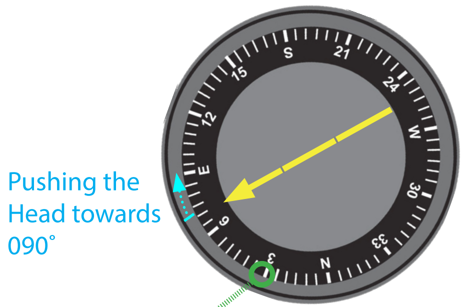
As Ford Prefect once said of the Infinite Improbability Drive, "Don't knock it, it works!"

How to Intercept.

If you now imaging replacing the pencil with the RBI needle (see left) we remember that we must "push the head".

The Head is currently pointing at 070˚, but we need to "push" it to 090˚.

That means we need to turn to the right, as this will push the needle.



But what heading should we use to Push the Head?

There is no hard and fast answer, but I recommend 60˚ as a starting point. This is not an exam-testable item so if its 55˚ or 65˚ it doesn't really matter, but for reasons that will become obvious later, 60˚is a good place to start.

The QDM remember is 090˚, so minus 60˚ is 030˚. So in this case turn right and start flying on a heading of 030˚

If you look at where 030˚ is on the DI/HSI, then you see that this will indeed start to push the head, towards 090˚.

Once the aircraft has turned right onto a heading of 060° the needle of the RBI will start to be pushed towards 090°, the target QDM.

From the diagram on the right, when the aircraft has reached point X the RB points at 010°

Therefore the QDM is 10 + 60=> 070°

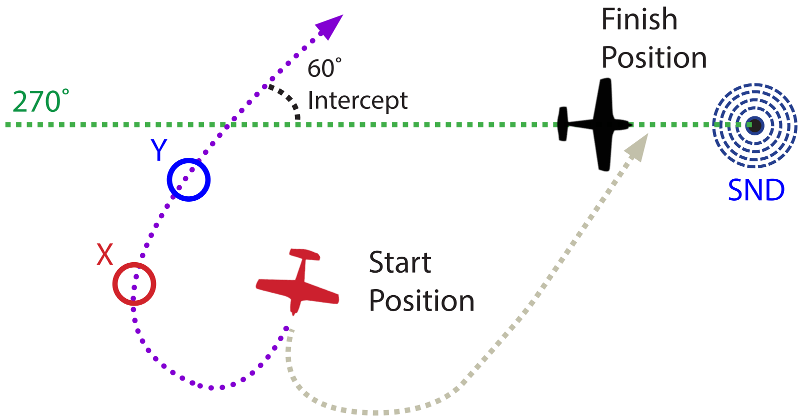
You will reach the desired QDM of 090° when the RBI points at 030°, as 060° + 030° => 090°

Time to get out the stopwatch and time how long it takes for the RBI Needle to fall 5°, say from 010° to 015°

If the answer is <*say*> 40 seconds, then we know we are intercepting at a rate of 5° per 40 seconds.

This is important as we don't know how far we are away from the beacon.

However, if we know our closing rate (5° per 40s), then we can calculate when to turn inbound onto the QDM of 090°



RB at point X

RB at point Y

So how do we know this? Well earlier I suggested we intercept at 60°.

A Rate-One turn is 3° per second. So it takes 20 seconds to turn through 60°.

If we know our closing rate because we timed it, then we know that when the RB is at 25°(that is 5° to go) it will take a further 40 seconds to reach the QDM.

We know it will take 20 seconds to complete the 60° turn from the Intercept Angle to the QDM.

So what we do is wait until the needle points at 25°, we know it will take 40seconds to intercept the QDM, but 20 seconds to turn, so 40 minus 20 is 20. Therefore when the RB reaches 25° start the stop watch and count 20 seconds, at the end of 20 seconds start the turn, at Rate-One, towards the beacon.

When you roll out, you should be very close to the desired QDM.

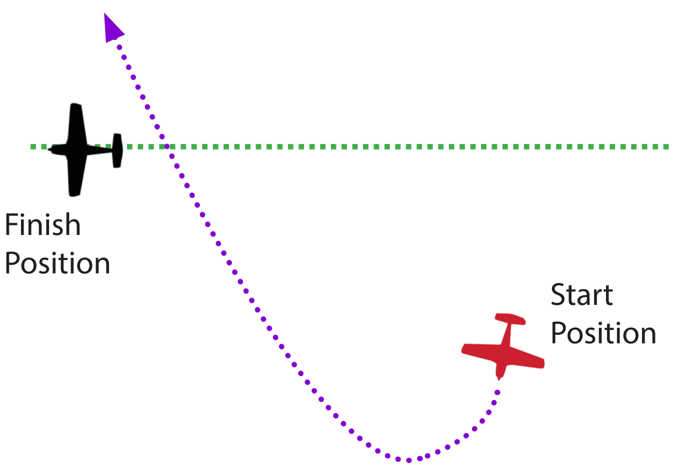
It wont be exact in real-life as wind and of course the fact that the aircraft is following a curved path will conspire to introduce errors, but it will be close enough and any corrections can be made once the aircraft is stable.

Now you understand how the intercept works, you may ask the question. "*Why turn right and not left, so long as you intercept at 60°it shouldn't make any difference*".

The simple answer is there is no "right" or "wrong", however if you suspect that you are close to the beacon, you may be unable to intercept the QDM before passing the beacon. See grey dotted line above. So by turning away from the beacon you give yourself more space and time to intercept correctly. However, given sufficient distance, both will work equally well and turning left is might be more efficient.

Interception with an RBI - Part 2

Take a look at the set up in the diagram below. As before a aeroplane is heading 190˚ to the south. ATC call the pilot and tell them intercept and track out on the 270˚radial from SND and fly outbound from the beacon.



In this scenario, the pilot needs to look at the radial or QDR. No need to convert this time, ATC have given us the QDR and want us to fly out on a QDR.

Find 270˚ on the Direction Indicator / HSI, using the pencil method, we can see we have a QDR of:

050˚ (Tail of the Needle) plus 190˚ => 240˚.

We need to "pull the tail" of the RBI needle (or the pencil eraser) towards 270˚, the desired QDR.

So turn right onto a heading that is 60˚ more than the desired QDR of 270˚, therefore 330˚

Once the turn is complete, the Tail of the RBI needle will be reading approximately -70˚ or an aprox QDR of 290˚.

Your heading of 330˚ is now "pulling the tail" towards 300˚, which is 60˚ to the left.

Once it reaches 60˚left (or -60˚ if you want to look at this way), then the QDR is 330˚ - 60˚ => 270˚, the desired QDR.

As before check the rate of QDR change, so in this case if the rate is <say> 5˚ per 50 seconds, you can calculate the timing of the start of the turn.

In this example when the Tail of the needle reaches 295˚ (5˚ to go), then a 60˚ turn takes 20 seconds to complete.
Start the stopwatch at 295˚, then count for 50-20=> 30 seconds then start to turn right, at Rate-One onto the QDR of 270˚

Needle Dip

For the more astute among you, there is one thing we have not taken into account in the previous two examples of Interception and that is Needle Dip.

The question is, do we need to be concerned with Needle Dip?

The answer is a qualified "no". I say "no" on the proviso that the aircraft when flown on the 60˚intercept heading is kept straight and level. If this the case then the NDB will not suffer Dip and will give a true reading. If there is a lot of turbulence or you do not fly with the wings-level, then Dip will be induced and it will considerably harder to interpret the RBI.

However, temporarily, as the aircraft turns onto the QDM or QDR from the Interception track, there will be some Dip, until the wings become level again.

As the turn was initiated based on Time, this should not affect the outcome.

Conclusion

The RBI is considerably more difficult to interpret for the novice than the magnetically slaved, and superior RMI.

However the RBI is far more common that than the RMI, is also simpler, cheaper, more robust and more reliable than its RMI cousin, so if you find yourself flying a variety of different aircraft, then you are more likely to come across the RBI than the RMI.

That said, once you are well practiced with using the RBI, then switching to an RMI is a very easy, however for those with little or no experience of the RBI, the reverse cannot be said. This introduction has focussed on a single instrument, but the skills are completely transferable to the ADF -RMI, VOR-RMI and HSI.

If you can understand the fundamental principals of using the RBI and you train yourself to the point where you can instinctively interpret its readings, then I promise you will never get lost again.

Whether we like it not, Single-Needle tracking is an integral part of the Instrument Rating. Although in mainland Europe many NDB's are being decommissioned in favour of GNSS, above 70˚ North and South, NDB's may be the only form of navigation.

With the recent discovery by C4ADS of the existence of portable GPS-Spoofing devices, and their use by Governmental agencies, there has been a quiet shift in the opinions of some Aviation Authorities that the pace of decommissioning of NDB's and VOR's should be slowed, whilst solutions to such interference can be found. https://www.bbc.com/news/technology-47786248

For this reason, NDB's might be with us longer than you think.

As a final thought, NDB's work on the Long-Wave and Medium wave frequencies where many commercial radio stations operate. It is quite possible to listen to the radio using your ADF receiver and if you know the location of the transmitting Antenna, use it as an uncertified beacon, if all else fails!

In the next in the series, Holds, I will introduce the effects of wind and how to correct your heading to maintain Track using single-needle tracking.

Stephen Evans
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