Understanding VOR's, VORTAC's and How To Use Them

by Hal Stoen Used by California Airlines (CAX) with permission from Hal Stoen

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INTRODUCTION

The practical aspects of understanding and using the VOR are so simple that it is confusing. When I used to flight instruct I would use a variety of ways to explain how it all worked until "click" and the light bulb went on. Hopefully I will be able to accomplish the same in written form. So if it all seems "Greek" to you, please plow on and I'll do my best to find the switch to that bulb.

JUST WHAT IS A VOR, VORTAC ETC.?

The VOR system is the backbone of air navigation in the United States and most other countries. You may have seen them from the air, while driving through the country or at an airport. They usually are round buildings, about thirty feet in diameter with a cone sticking out the top. Many are painted in a red and white checkerboard pattern.

VOR is an acronym for Very high frequency Omni Range. VORTAC is the same with TAC standing for TACAN, a military designation for it's distance information on a VOR signal. VOR/DME is a VOR with Distance Measuring Equipment co-located at the site.

When you tune in a VOR the DME will automatically display the distance to or from the station. Notice however that you must select which VOR signal you want the DME to display: Nav 1 or Nav 2. There is no other action required on the pilots part to receive distance information. In X-Plane all VOR's have DME.

In addition there are various classes of VOR's that relate to the distance the signal is usable. The lowest powered of these is the TVOR (Terminal VOR) and the highest powered are those used for the high altitude structure- above FL180. This class is noted on charts with an "H". This is an over simplification, but will suffice for this discussion.

HOW DO THEY WORK?

The VOR radiates an omnidirectional signal- in other words it goes out in all directions.
This, versus an ILS signal which is "beamed" in a very narrow sector. The VOR signal is electrically phased so that the received signal is different in various parts of the 360 degree circle. For simplicity's sake in this discussion I will refer to the VOR as if it had 360 radials. In reality the signal is infinitely variable.

LET'S GET ORIENTATED!

Try picturing yourself standing in a large expansive area. It's dark, and you don't know where you are. But you have a friend in this dark expanse that will use a navigational signal. Your friend will fire off a strobe light and then turn on a flashlight that is pointed right at due magnetic North. Your friend slowly rotates in place with his flashlight taking six minutes to complete a full circle. At that time he fires off the strobe light and starts all over again.

You see the strobe go off and start counting.....at 45 seconds into your count the flashlight sweeps by. Now you know where you are relative to your friend in that dark room- 45/360 from due North, or 045 degrees. And, that is only place that you can see that flashlight sweep by 45 seconds after the strobe.

That is a really simple way to think of how directional information works in VOR navigation. Like spokes in a wheel the "radials" of a VOR radiate out from the center of the station providing azimuth information to the pilot in his aircraft. Each radial is referred to by its direction of emanation from the VOR. In other words the radial going

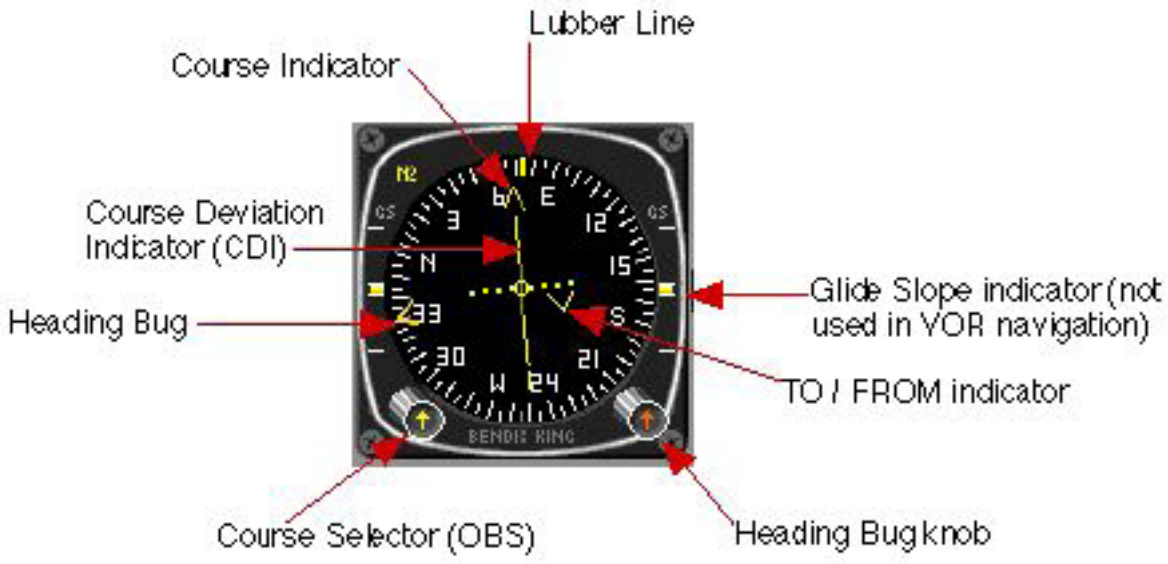
out straight East is the 090 degree radial. The one pointed straight South is the 180 degree radial and so on.

If you are due Northeast of a VOR you are on the 045 degree radial. It does not matter which direction you are headed. If you are pointed Northeast you are on the 045 degree radial. If you are pointed Southwest you are still on the 045 degree radial. The VOR receiver in the aircraft has absolutely no idea of the aircraft heading- and does not care. The information is displayed as if you were in a saucer-shaped aircraft, without a front or a rear.

There is a potentially confusing word used in VOR discussions and that is "bearing". Bearing is a relative word. For example the right wing tip is 90 degrees to your right as you sit in the front office, the left wing tip is 90 degrees to your left. The use of the word was carried over from sailing days into the aviation lexicon. It is used in VOR work to describe some of the controls of the display, for instance the Omni Bearing Selector- the OBS. The OBS was given its name from the beginning and although it may be confusing if taken literally, just accept it as a term.

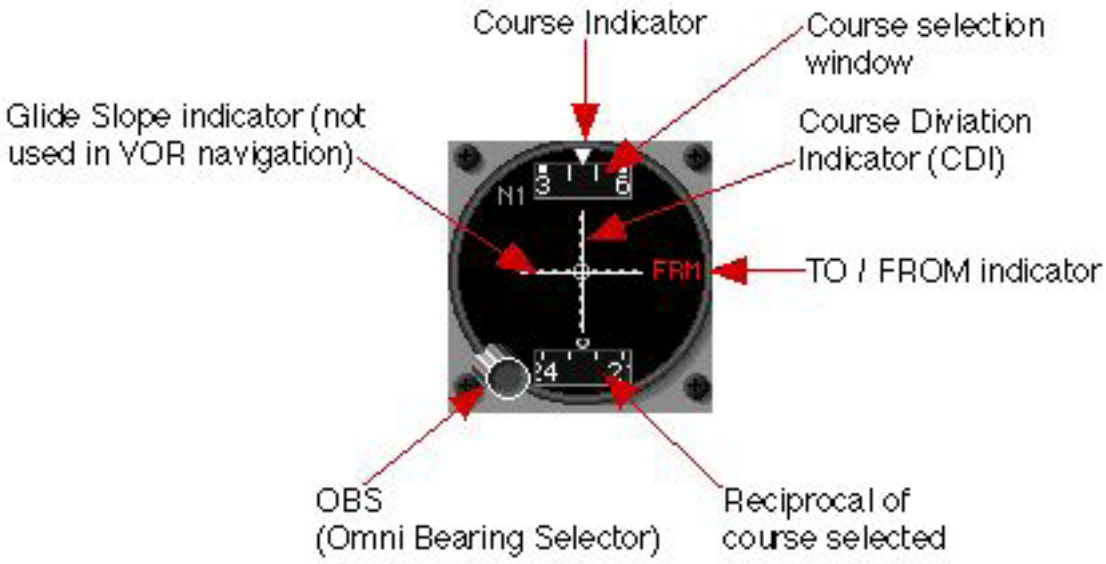
THE DISPLAYS

There are several choices of displays in X-Plane, in this discussion we will use the ones in the Cessna 172. These displays consist of two different types, the HSI and the VOR head. In VOR navigation they both provide the pilot with the same information, just in a slightly different format.
The HSI:



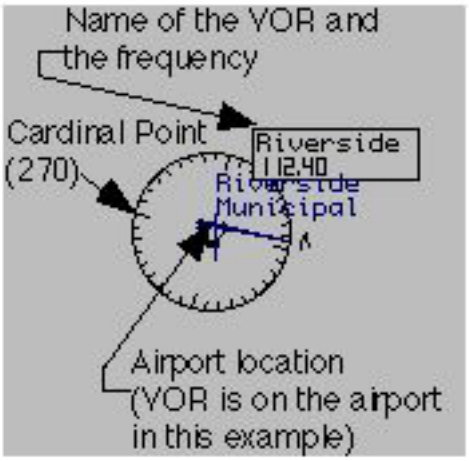
(For complete information on this display see the HSI.)

The VOR head:

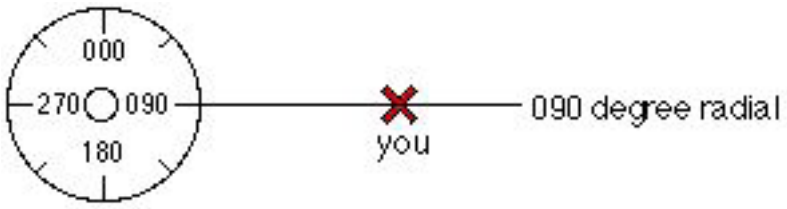


ORIENTATION AND OVER-VIEW:

This is how X-Plane represents VOR's. For this discussion we will use the Riverside, California VOR. First, notice the frequency- 112.4. If you want to use this VOR for navigation that is the frequency you tune in on your navigation receiver. In addition, notice that the compass rose is orientated with the 000/360 radial pointed at magnetic North. Also note that the "ticks" for the four cardinal points of the compass (000, 090, 180 and 270) are slightly larger than the 10 degree "ticks".



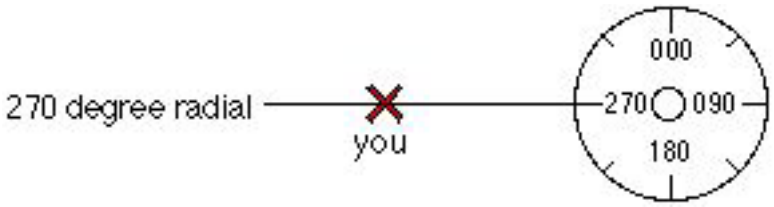
So let's look at an overhead view of an airplane that is out there, in that dark room, with a pilot that is trying to figure out just where he is in relationship to the VOR. It may help if you can imagine yourself in a saucer shaped aircraft rather that a conventional one with a "front" and a "rear".



In the above situation if you turn the OBS it will center in two locations: 090 degrees and 270 degrees. When the CDI is centered at 090 degrees the TO/FROM indicator will read "FROM". This makes sense when you think about it as you are indeed on the "090 degree radial from the VOR". In addition, if you were to fly a heading of 090 degrees and track the CDI you would be flying from the VOR.

When the CDI is centered at 270 degrees the TO/FROM indicator will read "TO". If you were to fly a heading of 270 degrees and track the CDI you would be flying to the VOR.

In the above example no matter what heading you fly, or what you have the OBS turned to, one fact remains: you are located on the 090 degree radial.



In the above situation if you turn the OBS it will center in two locations: 090 degrees and 270 degrees. When the CDI is centered at 270 degrees the TO/FROM indicator will read FROM. This makes sense when you think about it as you are indeed on the 270 degree radial from the VOR. In addition, if you were to fly a heading of 270 degrees and track the CDI you would be flying from the VOR.

When the CDI is centered at 090 degrees the TO/FROM indicator will read TO. If you were to fly a heading of 090 degrees and track the CDI you would be flying to the VOR.

In the above example no matter what heading you fly, or what you have the OBS turned to, one fact remains: you are located on the 270 degree radial.

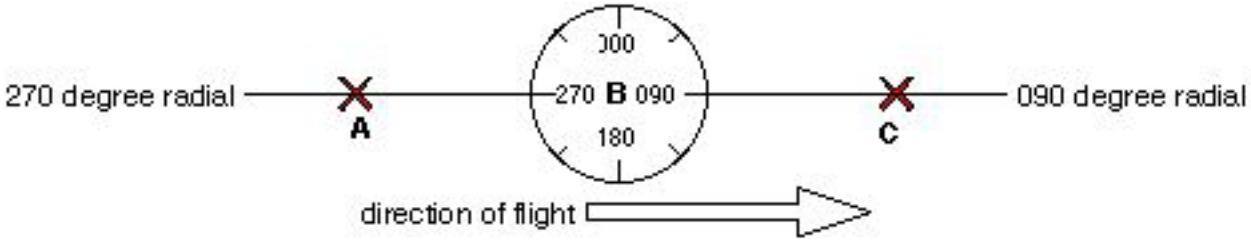
In the above situation if you have the OBS set to 090 the TO/FROM indicator will read FROM. The CDI will be to the right of center indicating that the 090 degree radial is to your right assuming that you are flying a 090 degree heading, or a close approximation. Actually, the crossover point for the CDI to read reverse information is 90 degrees on either side of your OBS selection- in this case it would be 000 and 180.

In the above situation if you have the OBS set to 270 the TO/FROM indicator will read TO. The CDI will be to the left of center indicating that the 270 degree radial is to your left assuming that you are flying a 270 degree heading, or a close approximation. Actually, the crossover point for the CDI to read reverse information is the same as above, 90 degrees on either side of your OBS selection- 000 and 180.

So, in navigating with VORís the practice to keep in mind is that the OBS heading and the aircraft heading should be in the same sector. If you are flying East (090) you would tune the OBS to 090 degrees and track the CDI from the VOR.

Let me put the cart before the horse for just a minute and then we will come back to VOR orientation.

VOR NAVIGATION, part 1:



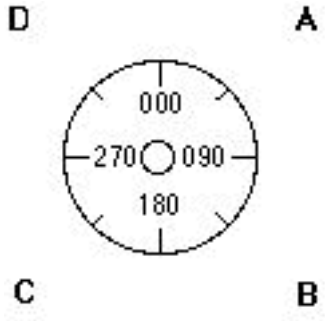
In the above example you are flying from West to East using a single VOR for navigation. When you are at "A" the OBS would be set to 090 degrees and you would be East bound on the 270 degree radial. The CDI would be centered and the TO/FROM indicator would read TO. If you drifted off course to the North the CDI would be to the right of center indicating that your course is to the right. If you drifted off course to the South the opposite would apply. You have the OBS set to 090 degrees because that is the course you are flying and the direction you are headed.

As you cross the VOR at B several things happen. The CDI will usually peg out to either the far left or right of the indicator. This happens because all of the azimuth information is concentrated into such a small area that it is virtually impossible to keep the CDI centered over the VOR. This area is also cryptically know as "the zone of confusion". So don't go chasing the needle as you get close to the VOR- the heading that got you there will work for you as you cross over.

O.K., now you have crossed B and are flying towards C. What happens? Nothing. Your course is still East bound so the OBS setting remains at 090. As you cross over the VOR the TO/FROM indicator will change from TO to FROM. Also, before you crossed the VOR you were navigating to the VOR inbound on the 270 degree radial and now you are navigating from the VOR outbound on the 090 degree radial. And, just as before, if you drift off course to the North the CDI will be to the right of center to indicate that your desired course is to the right, and the opposite applies if you drift to the South of course.

Now someone is saying "Hmm, what if I flew from point A to point B and set the OBS to 270 degrees instead of 090 degrees?" Outside of confusing the living heck out of yourself the answer is "nothing". Can you do it? Sure, but all course indications from the CDI would be opposite readings. Navigation can be difficult enough as it is without going out of your way to confuse yourself.

BACK TO ORIENTATION :



Going back to basic orientation now, letís see if this all makes sense to you.

If you are at point A and turn the OBS to 090 degrees what will the display be? Turn yourself to a heading of 090. The 090 degree radial is off to your right, and that is where the CDI would be to indicate that your selected course, 090, is to the right. What about the TO/FROM indicator? If you were to draw a line 90 degrees on either side of the selected course (180 and 000) you would find that you are on the 090 degree side from the VOR and therefor the flag indicator would read FROM.

If you are at point A and turn the OBS to 180 degrees what will the display be? Turn yourself to a heading of 180.

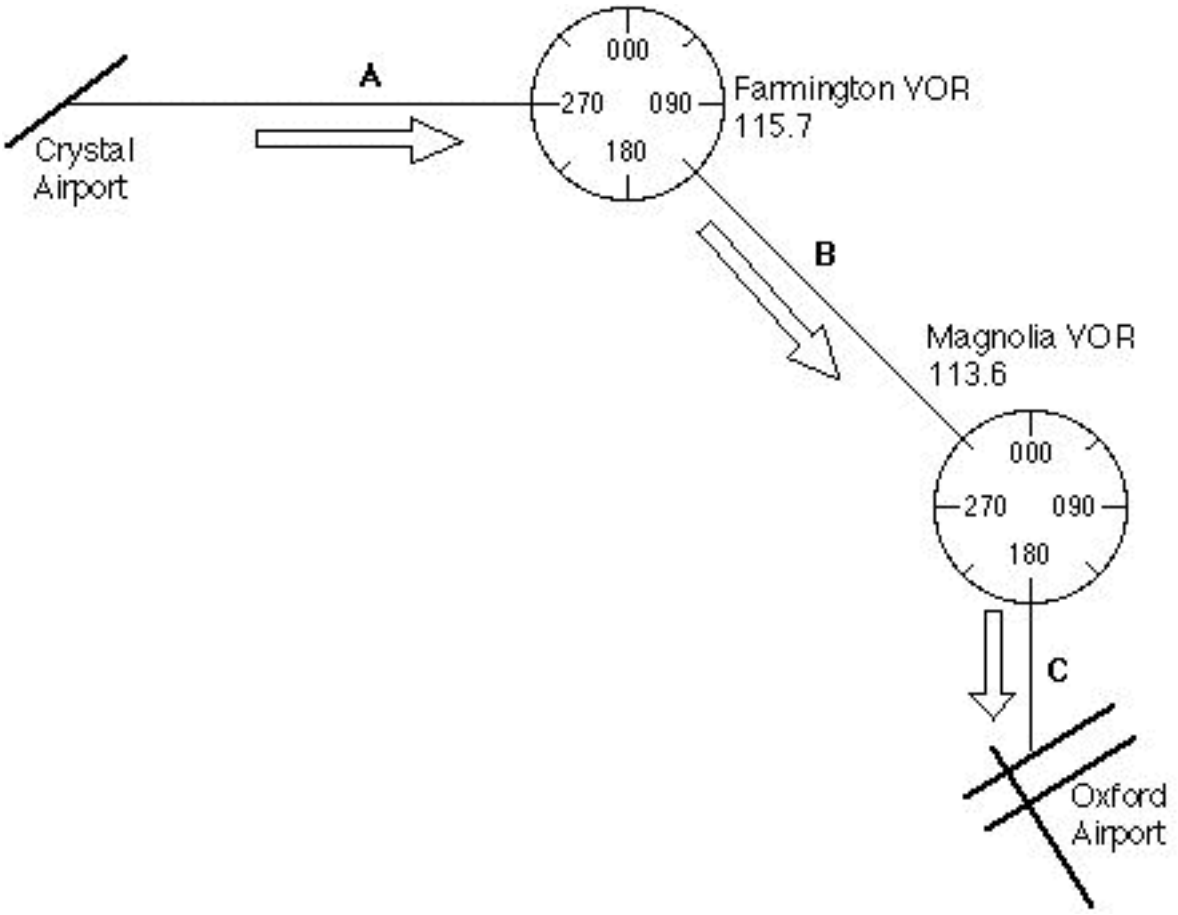
The 180 degree radial is off to your right, and that is where the CDI would be to indicate that your selected course, 180, is to the right. What about the TO/FROM indicator? If you were to draw a line 90 degrees on either side of the selected course (270 and 090) you would find that you are on the 000 degree side from the VOR and therefor the flag indicator would read TO.

If you are at point B and turn the OBS to 270 degrees what will the display be? Turn yourself to a heading of 270. The 270 degree radial is off to your right, and that is where the CDI would be to indicate that your selected course, 270, is to the right. What about the TO/FROM indicator? If you were to draw a line 90 degrees on either side of the selected course (180 and 000) you would find that you are on the 090 degree side from the VOR and therefor the flag indicator would read TO.

If you are at point C and turn the OBS to 180 degrees what will the display be? Turn yourself to a heading of 180. The 180 degree radial is off to your left, and that is where the CDI would be to indicate that your selected course, 180, is to the left. What about the TO/FROM indicator? If you were to draw a line 90 degrees on either side of the selected course (090 and 270) you would find that you are on the 180 degree side from the VOR and therefor the flag indicator would read FROM.

If you are at point D and turn the OBS to 180 degrees what will the display be? Turn yourself to a heading of 180. The 180 degree radial is off to your left, and that is where the CDI would be to indicate that your selected course, 180, is to the left. What about the TO/FROM indicator? If you were to draw a line 90 degrees on either side of the selected course (090 and 270) you would find that you are on the 000 degree side from the VOR and therefor the flag indicator would read TO.

VOR NAVIGATION, part 2:



In the above illustration you are at the Crystal Airport and wish to fly to the Oxford Airport using VOR navigation.

Through clever measuring on your part you know that the Farmington VOR is exactly 090 degrees from Crystal, the Magnolia VOR is 135 degrees from the Farmington VOR and that the Oxford airport is 180 degrees from the Magnolia VOR.

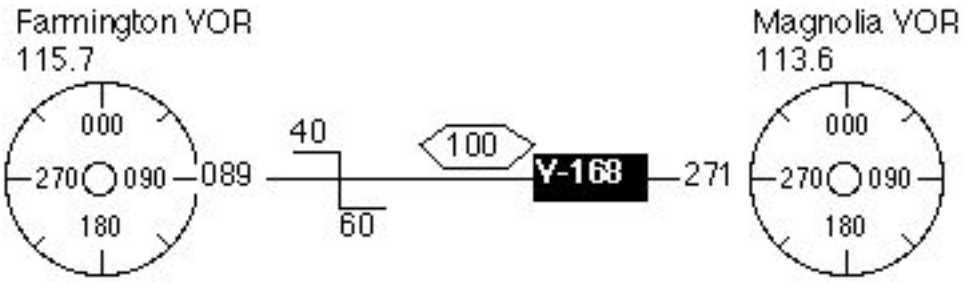
Before takeoff at the Crystal Airport you tune in the Farmington VOR on your navigation receiver and set your OBS to 090 degrees. Airborne, you listen to the VOR and verify that you have the correct station. As long as you are not flying on a designated airway it is perfectly acceptable to recenter the CDI if necessary. Fly to the Farmington VOR and when the TO/FROM indicator flips to FROM turn to a new heading of 145 degrees to intercept to 135 degree radial outbound. Next turn the OBS to 135 degrees and intercept the radial. The TO/FROM indicator will indicate FROM.

If the Magnolia VOR was not too distant from Farmington and a good signal was received it would be perfectly acceptable to eliminate tracking outbound from Farmington and instead tune in Magnolia and fly directly to it. For illustration purposes though let's say that Magnolia is too far to receive a decent signal when you are at Farmington. Track outbound from Farmington on the 135 degree radial until you are halfway to the Magnolia VOR. At this point Tune in the Magnolia VOR, identify, center the CDI with the OBS and fly to Magnolia. The TO/FROM indicator will read TO.

In actual practice, as long as you have two VOR receivers onboard, you would tune Nav-2 to Farmington and Nav-1 to Magnolia. Near the halfway point you would verify the Magnolia VOR on Nav-1 and note that the CDI was near center with 135 degrees set in the window. At the halfway point you would select Magnolia with Nav-2.

Upon reaching the Magnolia VOR turn the OBS to select the 180 degree radial. Turn to intercept the radial and track it until you reach the Oxford airport.

FLYING AN ESTABLISHED AIRWAY:



As I stated at the beginning this is not meant to be an IFR primer. For complete and thorough IFR lessons see Andrew Ayerís IFR Tutorial. Having said that, let's take a brief peek at how an airway looks and how you would fly it.

In the above illustration the established route between the Farmington and Magnolia VOR's is Victor 168. It is 100 nautical miles between the stations. For some reason unknown to us the point where we switch VOR's to navigate on is not at the halfway point of 50 miles but is instead at 40 miles from Farmington and 60 miles from Magnolia. This may be because Farmington is a low powered VOR, obstructions that degrade the signal quality, etc.

Flying from East to West you will be tracking outbound on the 271 degree radial from the Magnolia VOR and inbound on the 089 degree radial to the Farmington VOR. Inasmuch as this is an established airway, Victor 168, you would fly these radials if you were operating IFR.

Whoa, let's back up a second here. Is that correct? Outbound on the 271 radial, and inbound on the 089? Shouldn't that be "Outbound on the 271 and inbound on the 091"? Well, Grasshopper, you would think so. And, that would be true were it not for the Magnetic North Pole. There are lines of magnetic variation across our globe, and compass readings must be "adjusted" as your angle from the Magnetic North Pole increases or decreases. This is most notable when flying East/West routes, and less so when flying North/South routes.

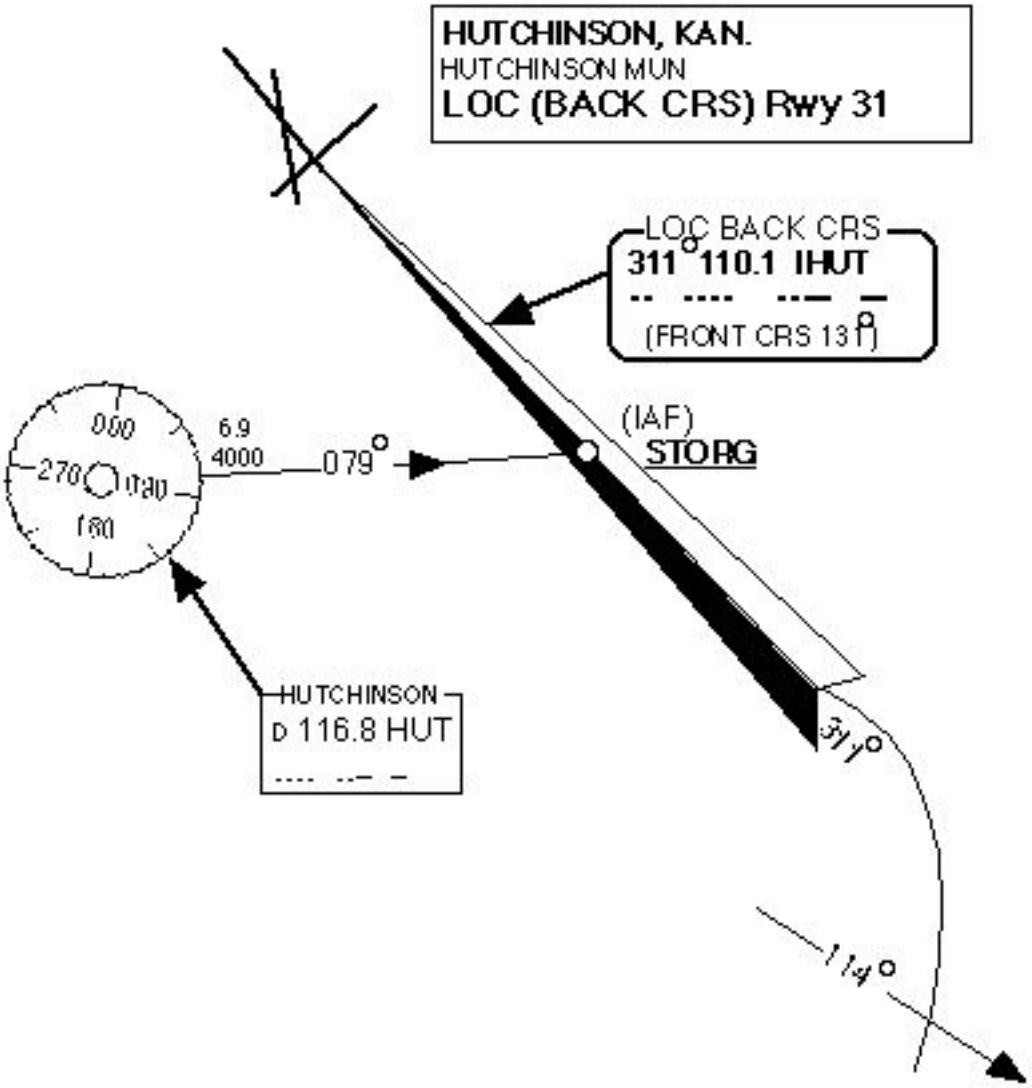
If you were operating VFR you are under no obligation to fly the established airway. In fact, many pilots fly the

airways with a several mile "offset" to decrease the chances of conflicting traffic.

Flying from Magnolia you would set your outbound course to 271 degrees and the TO/FROM indicator will read FROM. When 60 miles out from Magnolia you would change over to the Farmington VOR for navigation and set the course indicator to 269 degrees, the reciprocal of 089. The TO/FROM indicator will read TO. On navigation charts the radial is always the course shown.

USING THE VOR AS AN AID IN AN APPROACH:

Once again I invoke the "read the IFR tutorial clause". This illustration is just to help you get orientated in using the VOR as an approach aid.



Note that the 114 degree radial from the HUT VOR is used as a lead-in indicator. If you were flying the approach you might be assigned a DME arc by ARTC. As you fly the arc, based in this case off of the HUT VOR, you would have your Nav 2 receiver tuned to the ILS frequency of 110.1 and the course indicator set to 131 degrees (your Nav 2 display is an HSI and this is how you set up a back course on that type of display). Your Nav 1 receiver would be tuned to the HUT VOR and the course indicator would be set to 114 degrees. The TO/FROM indicator would read FROM, assuming you are in the Southeast quadrent. As the CDI on Nav 1 starts to center

(from left to right) you would be preparing to turn to 311 degrees and intercept the localizer back course approach.

Note also that the IAF (Initial Approach Fix) STORG is based on the 079 degree radial from the HUT VOR. At some point while intercepting and tracking the localizer you would reset the course indicator on your Nav 1 display from 114 degrees to 079 degrees.

As you approach STORG on the approach the CDI will be displaced to the left side of the display and then begin moving towards center. The TO/FROM indicator would read FROM. When the CDI reaches the exact center point of your display you are at STORG and would begin your descent as appropriate.

SUMMATION:

I hope that I was able to find that "switch" that made understanding VOR's click in your mind. Once you understand how they operate and are used in aviation navigation they truly do become easy to utilize.

As always I request that if you find any errors in this presentation, or if I didn't make things clear enough, that you please contact me so that I may make corrections.

Thank you.

Hal Stoen

2 December, 1998

revised: 10/06/00

 Click to return to the index. Return to "Flying the coupled approach".