<u>Monitoring turns when large drift angles are present.</u>

Captain Paul Chapman FNI

Planning and monitoring turns generally involves determining then comparing the vessel's heading at positions along the turn. Concentric Indexing is a radar technique that achieves this in a reverse manner, determining where a fixed object should be relative to the vessel's head. With concentric indexing, the turn is continuously monitored using the path of a reference point along an offset range ring. Detailed information on this technique can be found at http://www.niqld.net/ni_presentations_planned_turns.html).

The presence of external forces causing sway confounds monitoring methods that use the vessel's heading. The resulting drift angles change the vessel's heading for her respective position in the turn.

Starting the turn.

With Concentric Indexing, the turn is started when the Reference Point nears the offset Variable Range Marker (VRM) (figure 1). As the offset is abeam of the pivot point, the turn is started in the same position regardless of vessel size or scanner location. During the turn, there is no drift angle at the pivot point (definition of dynamic pivot point)(figure 2).

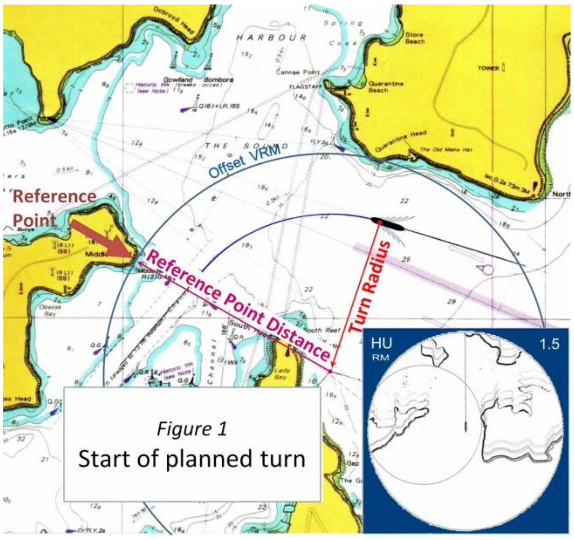


Figure 1
Start of planned turn

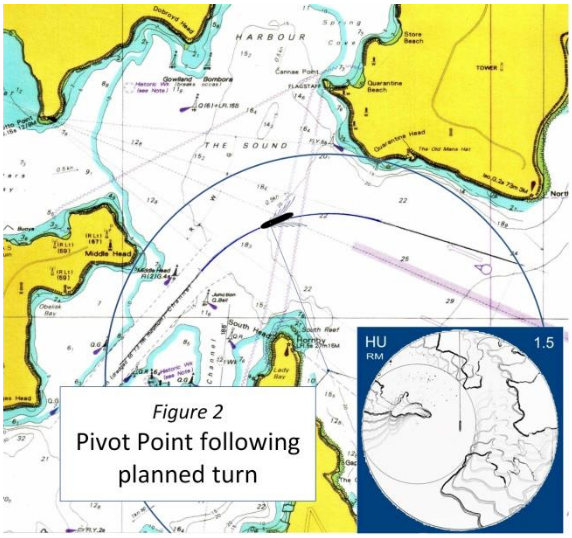


Figure 2
Pivot Point following planned turn

If the vessel has a drift angle, the heading will not be co-incident with the course made good and the offset VRM will be displaced by an angle equal to the drift angle. As a result, the turn will be started earlier (figure 3) or later (figure 4) than planned.

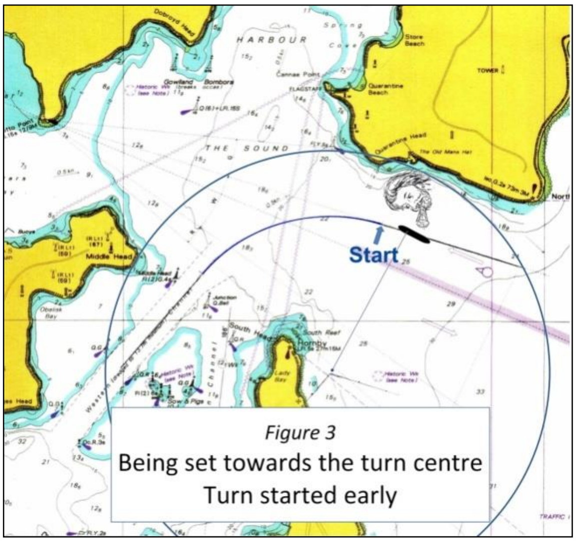


Figure 3
Being set towards the turn centre
Turn started early

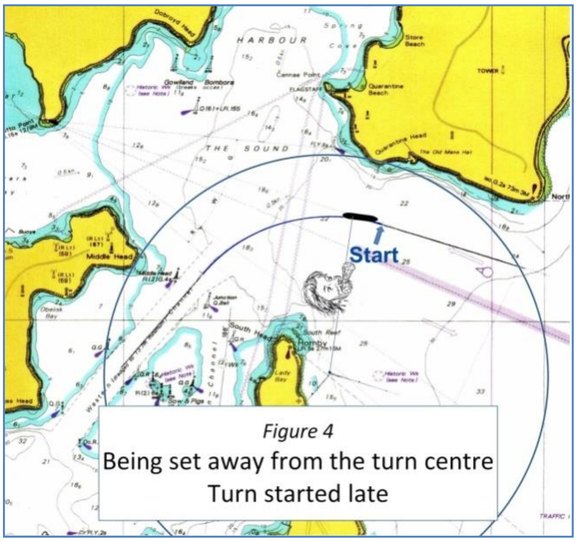


Figure 4
Being set away from the turn centre
Turn started late

For good passage track keeping, turns should be started at the planned position. Prudence commends using more than one method to identify the wheel over position.

Following the turn

Any component of sway that is concentric to the reference point will not be picked up by the offset VRM as the offset remains at the same distance from the reference point. This is an important limitation of concentric indexing. Viewing the preceding figures, the offset VRM can be considered to be rolling around the reference point. Such departures from the planned turn can be picked up with a secondary reference point (the northern headland, Quarantine Head, in this case) or if using a ranged stabilised Electronic Bearing Line (EBL), the side ways movement of the reference point from the ranged EBL.

Correcting for Set

Set, the direction of the external influence, wind or current, determines the required water track needed to closely follow the planned track (over ground). There are two perpendicular components to be considered, set along the axis of the turn's bisector and set perpendicular to the bisector. For clarity, these components will be discussed individually.

The following diagrams show the water track (in blue) to achieve the ground track (in brown) that will closely follow the planned turn. In all examples, the drift (the velocity imparted on the vessel from the external influence) is 30% of the vessel's speed through the water. The set is indicated by a wind man and light blue arrow. For scalability, all measurements other than angles are in percentages.

Set along the bisector of the turn

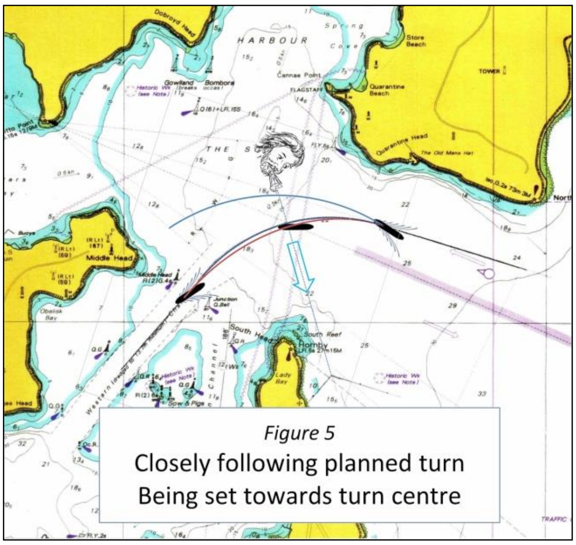


Figure 5
Closely following planned turn
Being set towards turn centre

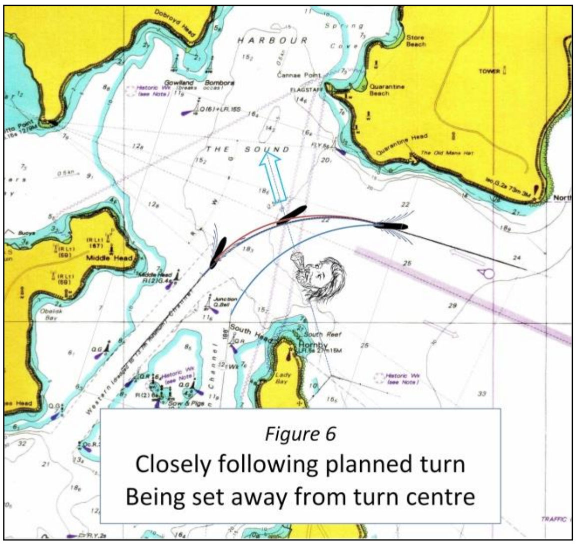


Figure 6
Closely following planned turn
Being set away from turn centre

Set along the bisector of a turn causes a drift angle that is on the same side throughout the turn (figures 5 & 6). The maximum drift angle is experienced near midway through the turn and the average drift angle is very close to when the set is on the vessel's beam. The drift angle at the start and end of the turn are very similar (14½°).

With set along the bisector, concentric indexing can be used with the VRM offset at the planned turn radius at an angle from the beam equal to the average drift angle (16½°). (figures 7 & 8)

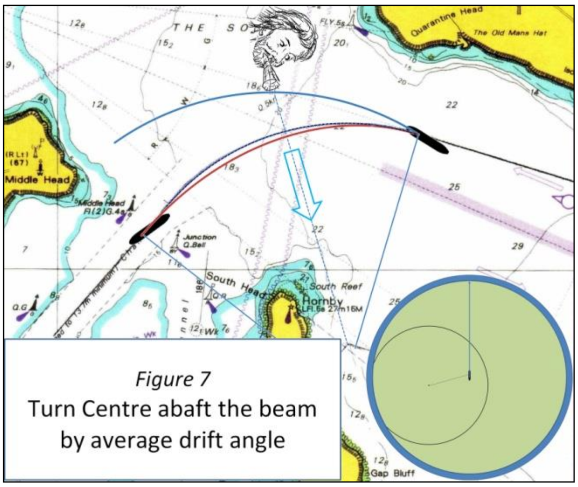


Figure 7
Turn Centre abaft the beam
by average drift angle

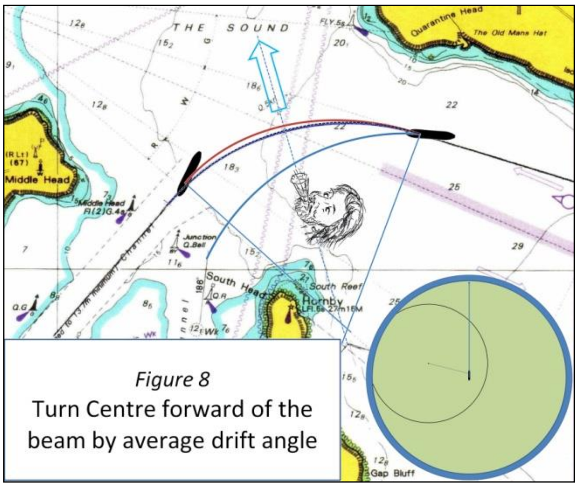


Figure 8
Turn Centre forward of the
beam by average drift angle

Set Perpendicular to turn bisector.

Set perpendicular to the turn bisector causes drift angles that reverse during the turn. The maximum drift angle is at the start and finish of the turn (10°). There is no drift angle in the middle of the turn. The change in heading during the turn is equal to the change in course plus or minus double the maximum drift angle. (Figures 9 & 10) For this reason, the vessel's turn through the water and apparent turn on the radar are quite different from the charted turn and requires a different radius.

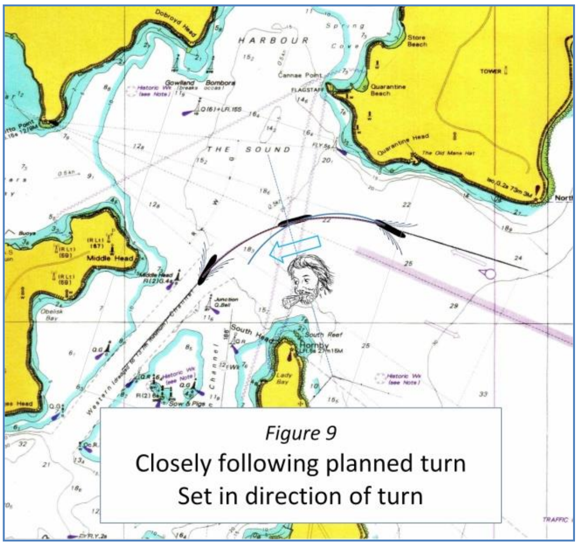


Figure 9
Closely following planned turn
Set in direction of turn

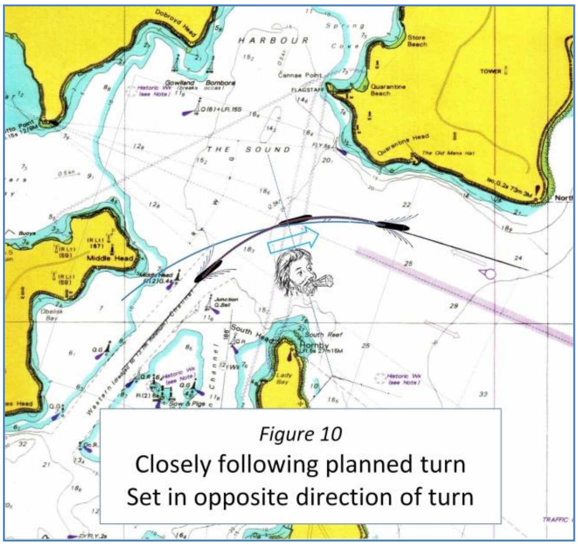


Figure 10
Closely following planned turn
Set in opposite direction of turn

The planned turn into the harbour has a change in course of -68°. With the set in the direction of the turn, the change in heading is -88°. With the set in the opposite direction of the turn, the change in heading is -48°.

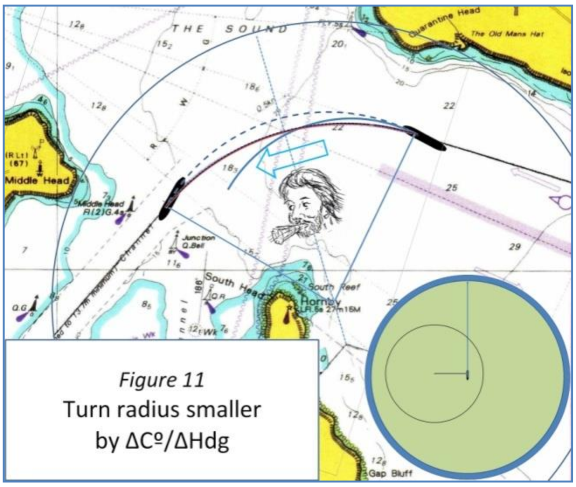


Figure 11
Turn radius smaller
by ΔCº/ΔHdg

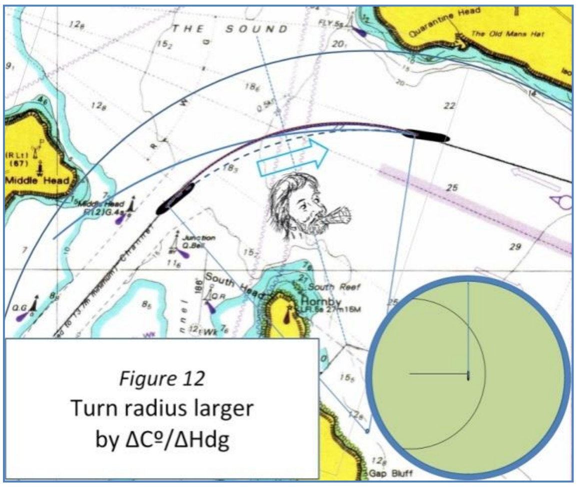


Figure 12
Turn radius larger
by ΔCº/ΔHdg

Conveniently, the change in the turn radius is equal to the change in course divided by change in heading. With the set in the direction of the turn, the new turn radius is 68°/88°, equalling 78% of the planned radius (figure 11). With the set in the opposite direction of the turn, the new turn radius is 68°/48°, equalling 140% of the planned turn (figure 12).

Rate of Turn

With set perpendicular to the turn bisector, the relationship of required rate of turn to speed and radius is substantially modified. Firstly, the rate of turn is adjusted by the change in heading (ΔHdg) divided by the change in course (ΔCº). If the change in heading is greater than the change in course, a greater rate of turn is required. Secondly, the rate of turn is adjusted by the change in speed made good. The greater the speed made good, the greater the turn rate required. There is a very close relationship between the speed made good and speed through the water x (ΔHdg/ΔCº).

$$RoT \approx \left(Speed \times \left(\frac{\Delta \mathrm{Hdg}}{\Delta \mathrm{C}^{\underline{o}}} \right) \right) \div \left(\mathrm{Radius} \times \left(\frac{\Delta \mathrm{C}^{\underline{o}}}{\Delta \mathrm{Hdg}} \right) \right)$$

$$RoT \approx \left(\frac{Speed}{Radius} \right) \times \left(\frac{\Delta \mathrm{Hdg}}{\Delta \mathrm{C}^{\underline{o}}} \right)^2$$

The water track radius is very close to the planned radius x $(\Delta C^{\underline{o}}/\Delta Hdg)^2$.

Set from any direction

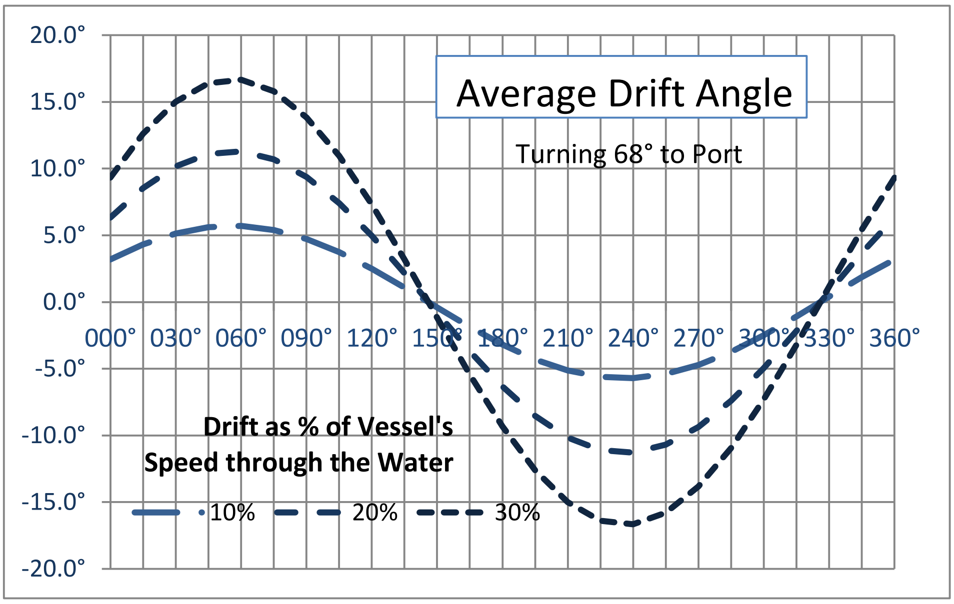
When monitoring turns using concentric indexing, it has been shown that;

- set along the turn bisector is accommodated by adjusting the offset VRM by the angle of the average drift angle
- set perpendicular to the turn bisector is accommodated by adjusting the distance of the offset VRM.

Set from any other direction is accommodated with a combination of these two adjustments. The two determinants of these adjustments have semicircular values relative to the set.

Average Drift Angle Adjustment (Graph 1)

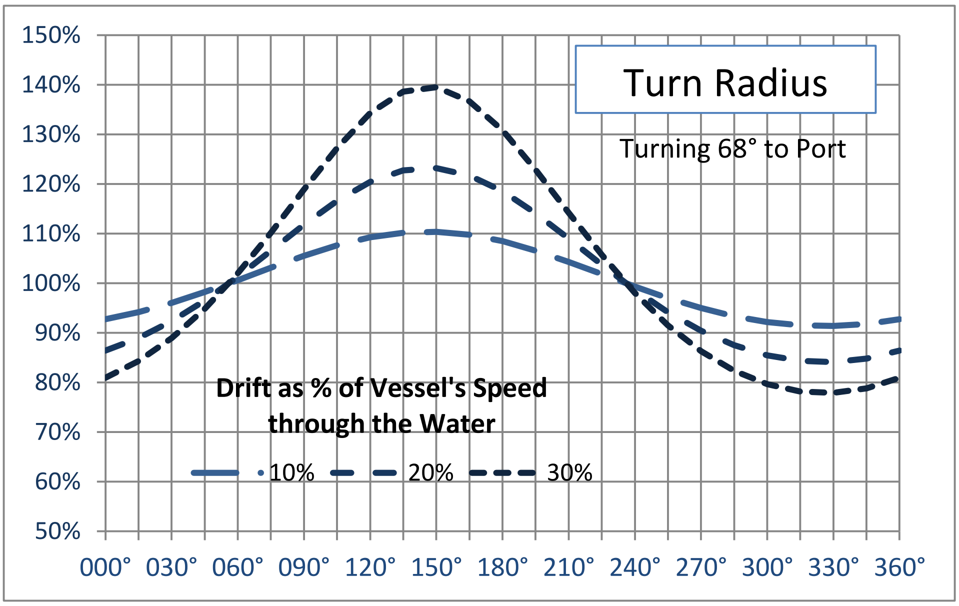
- The average drift angle is proportional to the sine of direction of set minus half the course change.
- The average drift angle co-efficient is equal to arctangent of drift divided by vessel speed.



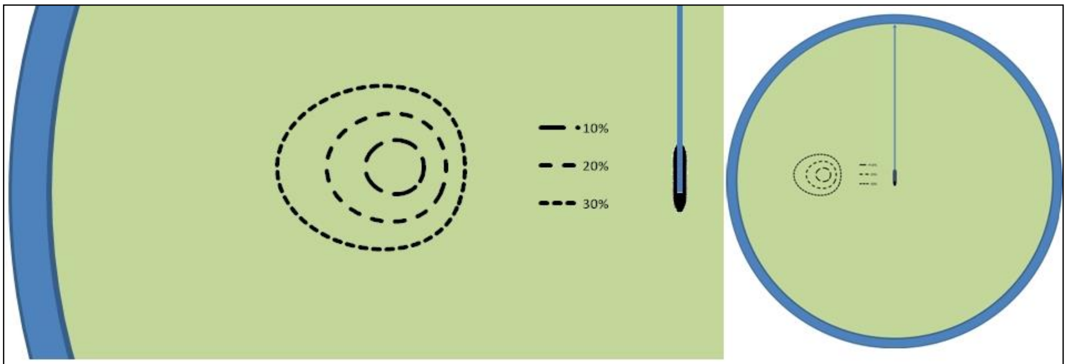
Graph 1: X axis – Set relative to initial course   Y axis - Average drift angle

Turn Radius Adjustment (Graph 2)

- The difference in change in heading from change in course is proportional to the cosine of direction of set minus half the course change
- The co-efficient of change in heading from change in course is arcsine (sine half the course change multiplied by drift divided by vessel speed)



Graph 2: X axis – Set relative to initial course   Y axis – Turn Radius Adjustment



Loci of turn centre adjustments for different values of set

By example, if the relative set was 000° at a drift of 30% of the vessel's speed through the water, from the Graph 1, the Average Drift Angle Adjustment would be 9° forward of the beam and from Graph 2, the Turn Radius Adjustment would be 81%.

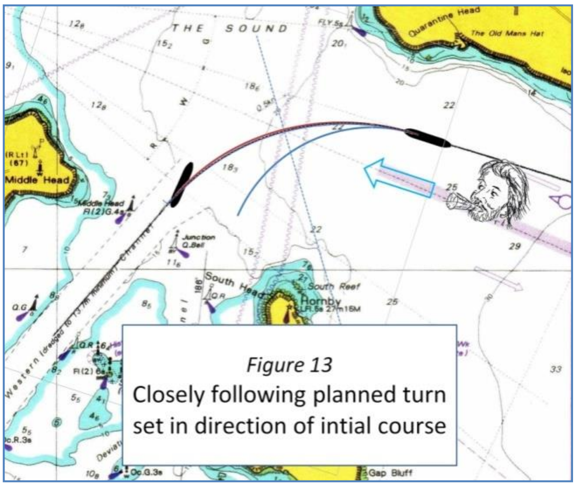


Figure 13
Closely following planned turn set in direction of intial course

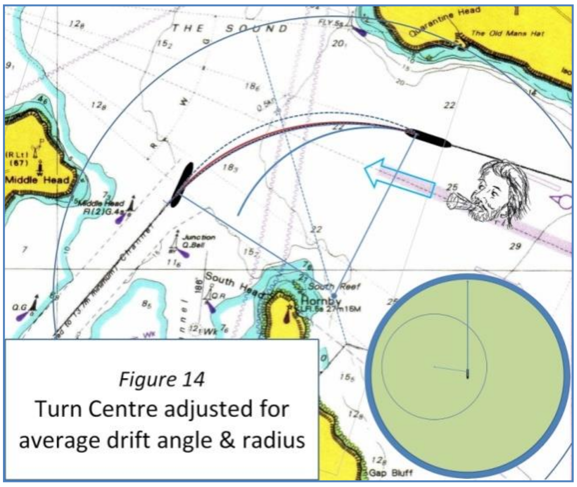


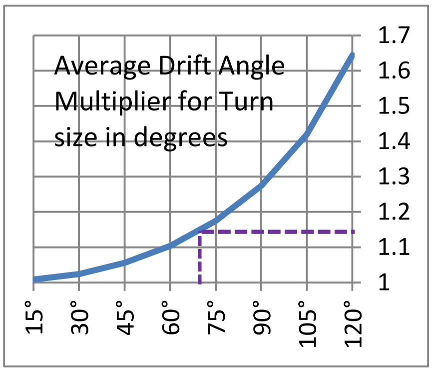
Figure 14
Turn Centre adjusted for average drift angle & radius

Practical Application of Adjustments

It has been shown that the effects of drift angle can be accommodated with concentric indexing if the set and drift is known. However the values of set and drift typically will not be known.

Fortunately for the mariner, the adjustments can be established from the drift angle on the initial course and the anticipated drift angle on the next course.

The average drift angle adjustment will be the sum of the two drift angles divide by two multiplied by a Turns Multiplier. The Turn Multiplier (Graph3) is to determine the average drift angle through the turn from the initial and final drift angles.



Graph 3

In the turn just considered the Average Drift Angle adjustment would be 1.14 x (0°+16°)/2 = 9°

The Turn Radius adjustment will be as previously discussed (figures 11 & 12). In the turn just considered, the initial drift angle is 0° and the final drift angle is +16°. The turn radius adjustment would be -68°/(-68° + 0° - 16°) = 81%

In pilotage applications, a table can be made up for specific turns with rows for initial drift angle and columns for the expected drift angle on the next course.

Reference Point Distance

The final radar adjustment is the reference point distance. If there is no adjustment to the radius, no adjustment to the reference point distance is required. If the turn radius has been adjusted, the reference point distance must also be adjusted.

In practice, a simple method is to adjust the VRM to the reference point when the vessel is at the start of the turn. (refer to composite method at http://www.niqld.net/ni_presentations_planned_turns.html)

The new charted turn centre can be marked on the chart using the intersection of the turn bisector and arc of the new turn radius from the start of the turn. From the new turn centre, the new reference point distance can be measure.

An excel spreadsheet is available at http://niqld.net/resources/turn_adjustments.xlsx which will calculate the required settings for specific initial course drift angle and anticipated next course drift angle as well as generate tables for the combinations of drift angles.

Conclusion

Navigating with large drift angles requires close attention. Conducting turns with large drift angles requires very close attention.

If the drift angle on the next course is known or well estimated, concentric indexing can be used to monitor the turn. The monitoring may not have the still water accuracy but will give a good indication for track keeping and should be combined with a parallel index line for the next track. The combination of these radar techniques should help achieve the goal of a steady rate of turn to bring the vessel onto the next track.

If using a rate of turn indicator, the required turn rate needs to be adjusted if the change in heading will be different from the change in course.

These adjustments to monitoring the turn are based on the expected drift angle on the next course. The drift angle experienced on the next course may not be as expected.

With set in the direction of the turn, it is very important to establish the greater than expected turn rate at the start. If the required turn rate is not established at the beginning of the turn, a much higher turn rate will be needed at the end.

Acknowledgement

I would like to thank the Corporation of the Lower St Lawrence Pilots for not only bringing to my attention that large drift angles frustrate concentric indexing, but also the opportunity to use their simulator at Maritime Simulation and Resource Centre (www.pilot-sim.com) to explore a remedy.

I would particularly like to thank Captain Alain Victor, author of the recently published “Parallel Index Techniques in Confined Waters”, for his interest and patience in helping develop a usable remedy to drift angles.