Rethinking the pivot point

Dr Seong-Gi Seo
Senior Lecturer, Warsash Maritime Academy, Southampton Solent University

Traditionally, the pivot point of a ship has been defined as the centre of the ship's rotation. This reduces the ship's motion to a simple question of surge and yaw. The simplicity of this concept has been very useful in helping to analyse the manoeuvring of a ship, and the term is used extensively in teaching the essential techniques of ship handling. However, as ships have become bigger in size and forced to operate in relatively smaller port or harbour areas, more precise and skilled manoeuvring is needed. The traditional concept of the pivot point is no longer accurate enough for these purposes.

In this article the pivot point is regarded as an apparent centre of rotation, taking the centre point at mid-ship as the actual centre of the ship's yaw motion. A few basic ship manoeuvres are described in the light of this new definition and some frequently encountered manoeuvres which were difficult to explain using the traditional pivot point definition are also discussed.

Because a ship's motion in a small confined area is at least a general planar motion involving surge, sway and yaw, it is not possible to calculate the position of the pivot point with any accuracy using the traditional method. According to the traditional method of calculation, the pivot point is assumed to be located at a third (quarter) of ship length from the bow (stern) when moving ahead (astern). If the pivot point is regarded as an **apparent centre of rotation**, taking the centre point at midships as the actual centre of ship's yaw motion, a much greater level of accuracy is possible when calculating a ship's manoeuvres.

How does the pivot point occur?

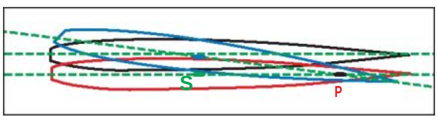
Ship's motion in 3-D space has six degrees of freedom, namely, surge, sway, heave, roll, pitch and yaw. The slow motion of a ship carefully handled in a small confined area, however, could be modelled as a general planar motion (in 2-D plane) for practical purposes, in which only two translations (surge and sway) and one rotation (yaw) are considered.

Each elemental motion is linear in nature, and these motions can be superimposed to give the combined effect. For the purpose of analysis, a ship's motion needs to be broken down into the elemental motions and each element is treated individually. All of the elemental motions are then combined to give the resultant motion.

It is usual for mariners to feel ship's movement relative to the surrounding, that is, to the water surface or fixed objects such as land or buildings. This gives rise to the terms *Motion through Water* and *Motion over Ground*. In the following discussion, the water is assumed to be stationary.

When a ship is following a curved path, surging, drifting and turning happen simultaneously. In Figure 1 the drifting motion (in black) and the turning motion (in blue) are shown individually. As the two kinds of motion occur simultaneously, a unique point is noted. The point P, where the two kinds of motion cancel each other, will remain stationary, whereas **the turning motion (yaw) itself happens about point S**. With the surge motion added, point P will have only the forward motion, giving an observer on board the illusion that the ship is pivoting about this point – hence the name.

Taking point S as the actual centre of rotation (yaw motion) and pivot point P as the point on the ship's centre plane at which the displacement due to drift and yaw cancel each other out, we can establish the following equation:



▲ Figure1: The Pivot Point

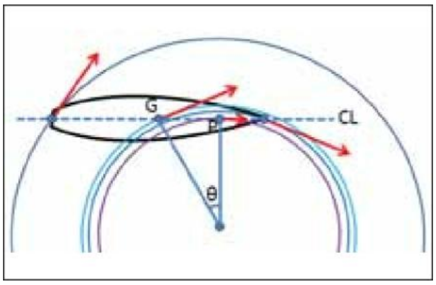
$V + (X_p \times r) = 0$ (Equation 1)

- where, V(m/s): sway speed of S
- P: Pivot Point
- X_p(m): distance to P from S
- r(rad/s): yaw Speed

A geometrical observation (Figure 2) would now allow a few descriptive definitions. The pivot point is the point on a ship's centreline:

- which **appears** to be the centre of rotation to the observer on board ship – that is, **the apparent centre of rotation**;
- which gives the **shortest turning circle radius**.
- at which the **drift angle is zero**.
- whose **motion vector** is in line with the ship's current heading.

In Figure 2, the four points shown on the centreline of the ship are the bow, the pivot point, the centre of gravity and the stern. The red arrows show the direction of the motion vector of each point. (The magnitudes are not shown.) The angles between the motion vectors and the ship's centreline are called the *drift angle* if the point is chosen as the reference point for the coordinate system. As shown in the diagram, the circle passing through the pivot point has the shortest radius.



▲ Figure 2: Local drift angle and pivot point

How does the pivot point move?

From Equation 1, we obtain,

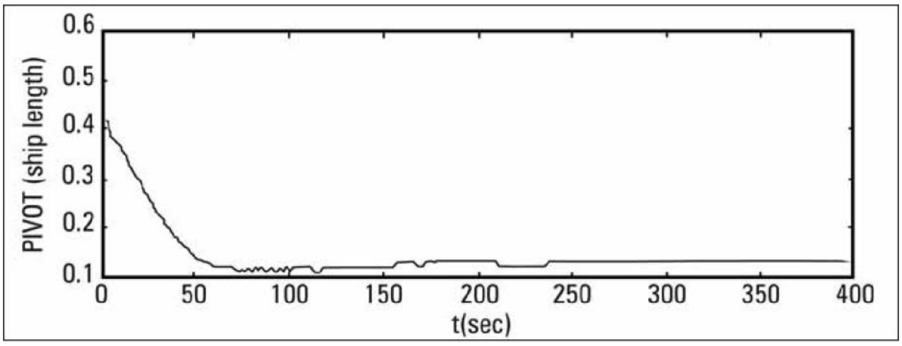
$X_p = -V/r$ (Equation 2)

This expression implies a few aspects of the pivot point:

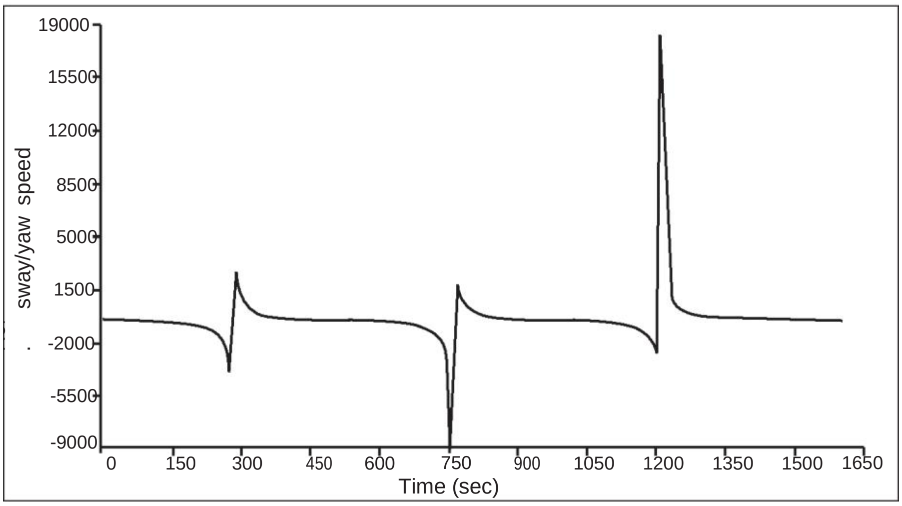
- The pivot point cannot be defined without a rotational motion.
- If a rotational motion precedes the sway motion, the pivot point first appears at

point S and shifts to point P as the ship approaches a steady state. This can happen when the rudder is first set at an angle to the ship's centreline. An example is shown in Figure 3. In this case ship trial data testifies that the turning moment – the force of which is far removed from the ship's centre of gravity – takes effect prior to the sway when the rudder is set at an angle to the centreline. In Figure 3, the graph shows the distance of the pivot point from the bow as a fraction of ship's length. The pivot point is shown to gradually shift from the midship to a location about 13 per cent of ship length from the bow.

- If a sway motion precedes the rotational motion, the pivot point first appears at infinity and very quickly arrives at a single point (P). This happens every time the rudder changes from starboard to port or vice versa, as shown in Figure 4. This is expected as there will be a point in time when the ship has zero yaw speed while swaying, when it changes the direction in which it is turning from starboard to port or vice versa. In Figure 4 the spikes indicate that the pivot point was momentarily at infinity and the horizontal part of the line shows the steady position of the pivot point. The spikes alternate direction, first down and then up, which means the pivot point disappears into forward infinity and then reappears at aft infinity before returning to the steady location, decelerating as it goes.



▲ Figure 3: Distance of pivot point from bow, starting from actual point of rotation.



▲ Figure 4: Pivot Point from Infinity

Motion with yaw but no headway or sway

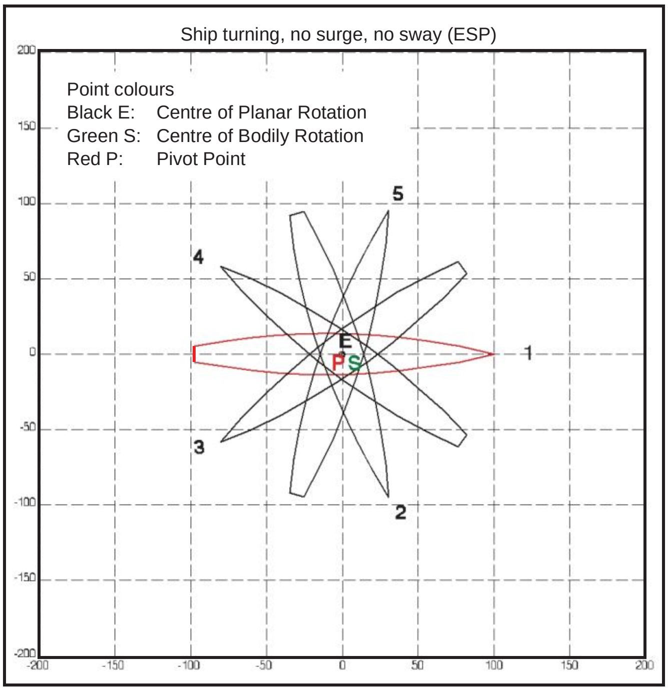
This occurs when the ship is turning about its own centre of rotation (S) – as when the bow thrusters and stern thrusters are operating in opposite directions. The ship is not moving ahead/astern, nor is it swaying. In this case all three points coincide – as shown in Figure 5.

Motion with yaw and sway only

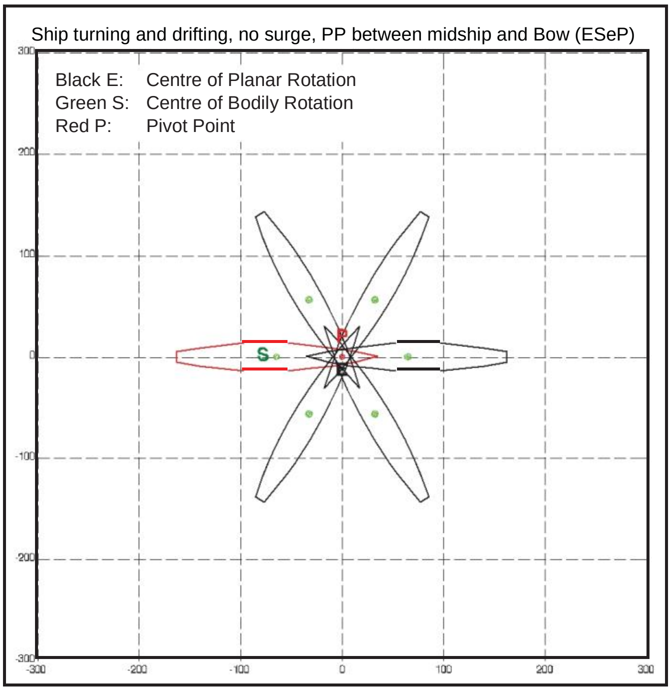
In the absence of any longitudinal movement (ie where there is no surge), if the ship is both drifting and turning, and if the pivot point is between S and the bow, the centre of planar rotation (E) and the pivot point (P) will coincide, as shown in Figure 6.

If the pivot point is ahead of the bow, the motion shown in Figure 7 will result.

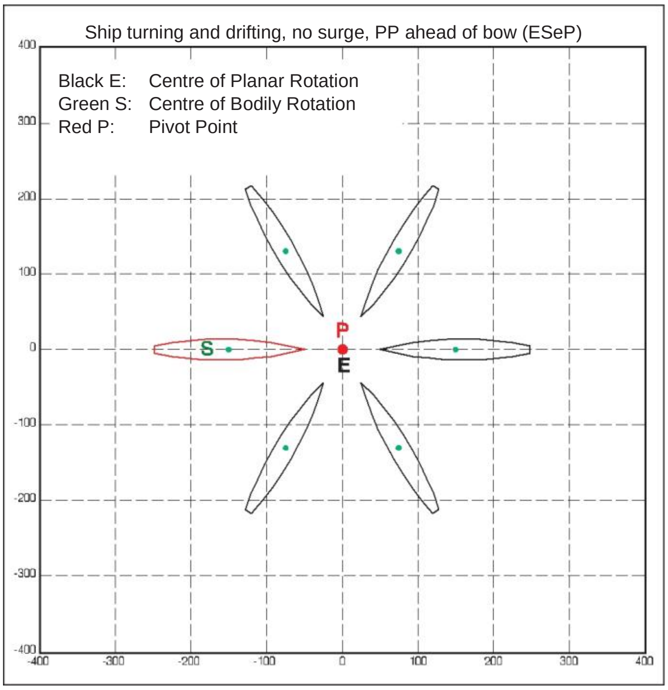
The two points E and P are at the same location. This manoeuvre could be produced using the stern thruster. In practice however, the same manoeuvre could be produced by a combination of all three elemental motions (see 'walking sideways' below).



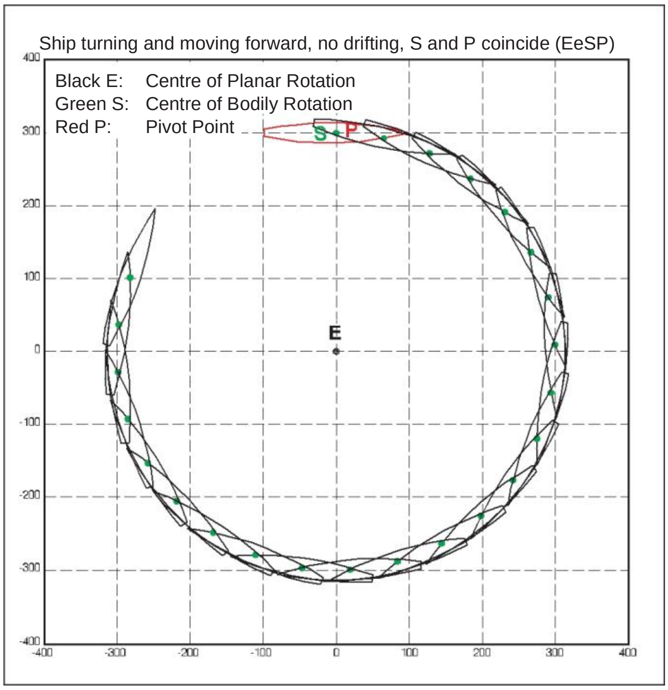
▲ Figure 5: Yaw only



▲ Figure 6: Yaw and sway



▲ Figure 7: Yaw and sway



▲ Figure 8: Yaw and surge

Motion with yaw and surge only

If the ship moves ahead while turning but without any sway motion, the resulting movement will look like the one shown in Figure 8. In this case, the pivot point will be on top of point S. This manoeuvre could be produced with both bow and stern pods deflected. This manoeuvre does not cause the stern to swing out as long as there is no drift. It is therefore suitable for use in restricted waters.

Motion with heading, drifting and turning

When all the three motions (surge, sway, yaw) are present, all the three distinctive points (E, S, P) will exist separately as shown in Figure 9. In this particular case, the stern swings out sweeping a bigger arc, as all skilful ship handlers are aware.

Most ship motions fall into this category. The amount of swing out is directly related to the position of the pivot point.

Can the pivot point be ahead of the bow?

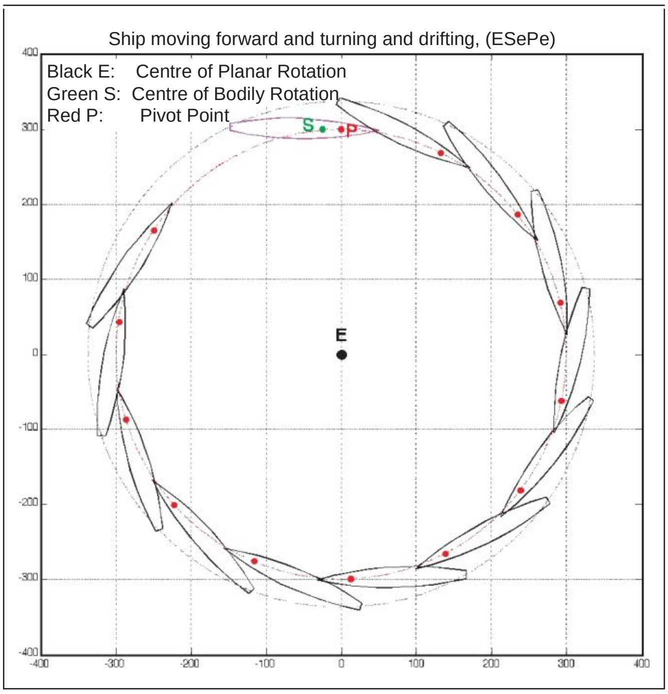
The converged position of the pivot point could be ahead of the bow, if:

- the drift angle of point S, $\theta > \sin^{-1}(L/2R)$;
- the turning circle radius $R > (L/2\tan\theta)$

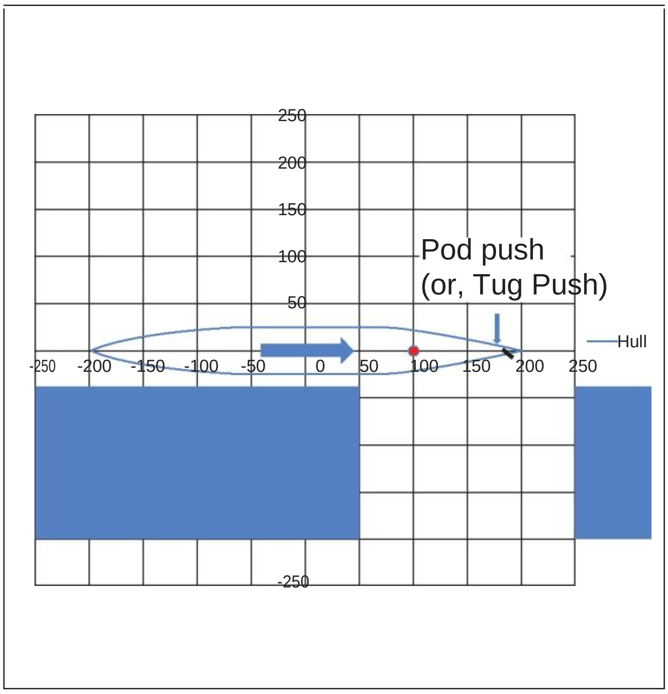
where ı is the drift angle of S when P is at the bow;

- the ship circles with a curvature less than $(2\tan\theta/L)$.

Also from Equation 2, $\mathbf{X_P} = \mathbf{-V/r}$, $\mathbf{-V} > 0.5Lr$ for the pivot point to be ahead of bow.



▲ Figure 9: General planar motion



▲ Figure 10: Docking astern into slip

Walking sideways'

When the propeller starts to turn with the rudder set to an angle, the ship starts to surge followed by sway and yaw. If the forward motion is kept small, and if enough time is allowed for the drifting and turning motions to manifest, the combination of motions may force the ship to move sideways in a circular path centred on the pivot point ahead of the bow. Imagine a ship positioned at the bottom of a chart heading upwards and kick started. After a short time, the ship will have moved forward, drifted and turned. If the ship has moved in a circular path sideways, the distance moved forward is the same as the vertical distance of the circular path from a horizontal starting datum line. The combined result would be the same as moving the ship sideways in a circular path without surge motion, as shown in Figure 7.

Docking astern into a cut

Figure 10 demonstrates how the definition of the pivot point discussed above enables better understanding of certain phenomena. Here, the traditional definition of the pivot point – considered to be located somewhere aft of midship – is shown as a red dot. The ship has been moving astern. The stern is now pushed (by the pod, for example) to turn into the slip. However, no experienced ship handler would attempt this manoeuvre as shown, as it would not work unless the manoeuvre is assisted by the bow thruster. According to the new definition, the pivot point is much further away from the stern, making it necessary to push the bow away (by the bow thruster, for example) from the pier, to safely dock the stern into the slip.

Standing turn from stationary position

When rounding a corner as tightly as possible, experienced mariners would use kick ahead with the rudder at 35°. This technique is employed according to the traditional description of pivot point characteristics which says that the pivot point would move instantly to about a third/quarter of the ship's length from the bow, thus hoping to generate the motion shown in Figure 9 for the first 90° of the turn. However, these attempts often fail to clear the corner even when the ship's stopped position is well ahead of the corner at the starting point. Those failures imply that existing assumptions about the pivot point are erroneous. In reality, the pivot point first appears at midship since the turning motion manifests prior to the drifting motion. It then moves gradually forward as the drift motion sets in. Therefore, the gap between the ship and the pier should be carefully chosen for each individual ship.

In summary:

- The pivot point is not the actual centre of rotation, but just appears to be so. Nevertheless, it is a useful concept for ship handlers to visualise the movement of a ship.
- The pivot point does not move instantly, but rather gradually corresponding to the changing hydrodynamic surroundings.
- A surge motion alone can not create the pivot point.
- The pivot point is a geometrical property, not a physical quantity