Manoeuvring characteristics and interaction

Introduction

Each ship will have its own manoeuvring characteristics. The position of the pivot point will vary performance, while performance itself can be affected by numerous factors; not least, growth on the hull. The propellers, of such varied construction these days, can expect to generate increased thrust with reduced cavitation, while ‘slip’ and transverse thrust affects have as yet, not been eliminated from propeller activity.

Interaction inside the marine environment is noticeable in several forms, where a ship can experience a reaction from a land mass or another ship; typically, a parent vessel reacting with the smaller tug – the weaker element with the stronger. Interaction can be observed as squat, a bank cushion affect, or just an unexpected movement between two vessels in close proximity.

Whatever form interaction takes, it is generally seen as undesirable and unwanted. Mariners have become familiar with its effects over the years and the industry has gone some way to educate our seamen in anticipation of what to expect. Bearing this in mind, it would seem obvious to avoid the experience if possible, or if it is going to be encountered, then we should know how to counter its adverse effects.

Many factors are associated with interaction, not least speed of the vessel, depth of water, proximity of obstructions, the hull form and the manoeuvring aids operational to the vessel. Some influences can be avoided or even eliminated with awareness and training, while improved navigation practice must be expected to lessen the dangers and make ship handling safer to the individual and better for the environment.

The form of the land and the lack of underkeel clearance when vessels enter shallows will always be features worthy of special attention by the navigator and a ship’s Master. Pilotage will always be directly affected by the shallow water effect, while overall performance must encompass the elements derived from propeller action and the combined effects of the environment on the hull.
See Appendix B for the Maritime Coastguard Agency’s Marine Guidance Note on Dangers of Interaction – MGN 199.

### A ship’s performance factors

Ships are expected to meet their design speeds, and the propulsion units can only deliver the speed element provided all other related factors are also in place. Such elements as hull growth, corrosion or damage to a hull will clearly affect overall performance.

#### Corrosion

When a vessel is engaged in the regular employment of loading and unloading cargo, the ship’s hull is continuously in and out of the water between the load and light ship draughts. Such movement makes the hull form, susceptible to corrosive effects and allows rust to develop. As corrosive layers come away from the paint film, the hull is left indented and some parts are left proud. Such unevenness can generate hull resistance until overside maintenance can be applied – usually when the ship is in dry dock.

#### Hull growth

Where a vessel is frequently in port or operating in a river, it is highly probable that the hull will attract weed and similar organic growth. This provides additional resistance to the hull’s movement through the water and, unless regularly cleaned off in dry dock, could eventually cause a reduction in speed performance. This growth may also include barnacles attaching to the hull and to the propeller(s) – causing additional resistance which would affect propeller rotation speed and subsequent fuel burn.

#### Indentation hull damage

During a ship’s life, landing and berthing alongside docks and quaysides tend to take a toll on the smoothness of the hull’s lines. Such damage will affect the water flow around the hull, and further resistance to passage through the water will be encountered. Although seemingly minor at the time, this type of hull damage can and does accumulate over a period of time, which can again directly affect the ship’s performance.

#### Engine maintenance

Clearly it is well recognized that you cannot get out what you do not put in. An engine will only deliver peak performance from continuous high standards of maintenance. Fuel quality is also critical to the machinery output and subsequent propeller performance. Therefore, plant needs to be operated under a planned maintenance schedule where all elements are monitored on a regular basis; effective performance of machinery being linked directly to effective maintenance.

### Manoeuvring information

It is now recommended that manoeuvring information in the form of a ‘Pilot Card’, ‘Bridge Poster’ and ‘manoeuvring booklet’ should be retained on board ships. Such information should include comprehensive details on the following factors affecting the details of the ship’s manoeuvrability, as obtained from construction plans, trials and calculated estimates.
**Ships general particulars** – Inclusive of name, year of build and distinctive identification numbers; gross tonnage, deadweight, and displacement at summer draught; the principle dimensions, length overall, moulded breadth and depth, summer draught and ballast draught and the extreme height of the ship’s structure above the keel.

**Listed main manoeuvring features** – Main engine, type and number of units, together with power output; the number and type of propellers, their diameter, pitch and direction of rotation; the type and number of rudders with their respective areas; bow and stern thruster units (if fitted), type and capacity.

**Hull particulars** – Profiles of the bow and stern sections of the vessel and the length of the parallel of the middle body (respective to berthing alongside).

**Manoeuvring characteristics in deep and shallow waters** – Curves should be constructed for shallow and restricted waters to show the maximum squat values at different speeds and blockage factors, with the ship at variable draughts.

**Main engine** – Manoeuvring speed tables established for loaded and ballast conditions from trials or estimated; stated critical revolutions and maximum/minimum revolutions; time periods to effect engine telegraph changes for emergency and routine operational needs.

**Wind forces and drift effects** – The ability of the ship to maintain course headings under relative wind speeds, should also be noted; together with the drifting effects on the vessel under the influence of wind, when the vessel is without engine power.

**Manoeuvring characteristics in deep water**

**Course change performance** – Turning circle information from trials or estimates for various loaded/ballast conditions; Test condition results reflecting ‘advance’ and ‘transfer’ and the stated maximum rudder angle employed in the test, together with times and speeds at 90°, 180°, 270° and 360°; details should be in diagrammatic format with ship’s outline.

**Acceleration and speed characteristics** – Presentation of speed performance when the ship accelerates from a stopped position and deceleration from full sea speed to a position of rest, reflecting maximum rudder angles, for loaded and ballast conditions.

**Stopping capabilities** – Should include respective track stopping distances from:

- Full astern from a position of full ahead sea speed
- Full astern from a position of full ahead manoeuvring speed
- Full astern from half ahead
- Full astern from slow ahead
- Stopping the engine from a position of full sea speed ahead
Stopping from a position of full manoeuvring speed ahead
Stopping engine from half ahead
Stopping engine from slow ahead.

Relevant time intervals should also be recorded, reflecting the time to reach full ahead and positions of zero speeds, compatible with the above operations.

Information on the minimum speed (rpm) that the ship can retain steerage capability.

*Any other relevant information considered useful to the manoeuvring and handling capabilities of the vessel should be included in this 'Manoeuvring Booklet'.*

**The ship's pivot point**

The turning effect of a vessel will take effect about the ship’s ‘pivot point’ and this position, with the average design vessel, lies at about the ship’s Centre of Gravity, which is generally nearly amidships (assuming the vessel is on even keel in calm water conditions).

As the ship moves forward under engine power, the pivot point will be caused to move forward with the momentum on the vessel. If the water does not exert resistance on the hull the pivot point would assume a position in the bow region. However, practically the pivot point moves to a position approximately 0.25 of the ship's length (L) from the forward position.

Similarly, if the vessel is moved astern, the stern motion would cause the Pivot Point to move aft and adopt a new position approximately 0.25 of the ship’s length from the right aft position.

If the turning motion of the vessel is considered, with use of the rudder, while the vessel is moved ahead by engines, it can be seen that the pivot point will follow the arc of the turn.
When the vessel is moving ahead and turning at the same time, the forces on the ship take affect either side of the pivot point, as shown below:

The combined forces of water resistance, forward of the pivot point and the opposing turning forces from the rudder, aft of the pivot point, cause a ‘couple effect’ to take place. The resultant turning motion on the vessel sees the pivot point following the arc of the turn.

**The pivot point at anchor**

It should be noted that when the vessel goes to anchor the pivot point moves right forward and effectively holds the bow in one position. Any forces acting on the hull, such as from wind or currents, would cause the vessel to move about the hawse pipe position.

Use of the rudder can, however, be employed when at anchor, to provide a ‘sheer’ to the vessel, which could be a useful action to angle the length of the vessel away from localized dangers.
Turning circles and advice on turning

Turning circles are normally carried out during the sea trials of the vessel prior to handover from builders to owners. The fact that the manoeuvre may have to be carried out at sea, for collision avoidance purposes, makes this an item of ‘need to know’ for the ship’s Master and Watch Officers.

The ship’s trial papers and performance criteria will be placed on board the vessel prior to handover. Statements as to the ‘advance’ of the vessel and its ‘transfer’ will be stated, together with the ‘Tactical diameter’ and ‘Final diameter’ that the vessel scribes on trials. It should be realized that trials are generally conducted in relatively calm weather conditions with little wind. In reality, should it become necessary to execute a ‘round turn’, conditions are unlikely to be the same and, therefore, the criteria provided will not necessarily be the same as that provided in trial documents.

In the turning circle example shown on page 39 of a Cargo/Passenger Ferry vessel, the given helm was 35° hard over to each side for the respective turns to port and to starboard. The measurements for the Tactical and final diameters are indicated, as is the transfer on each of the respective turns. The ship was fitted with triple Controllable Pitch Propellers and conducted the turns at 20.3 knots (starboard) and 20.2 knots (port) from diesel (Sultzer) engines delivering 8000 h.p.

Turning circle – definitions and features

Once trials of a new ship are complete, operators will need to know how the vessel can expect to perform in a variety of sea conditions. The ship handler, for instance, should be aware of how long it will take for a vessel to become stopped in the water from a full ahead position or how far the vessel will advance in a turn. Turning circles and stopping distance (speed trials) provides such essential information to those that control today’s ships.

Advance – Defined by the forward motion of the ship, from the moment that the vessel commences the turn. It is the distance travelled by the vessel in the direction of the original course from commencing the turn to completing the turn. It is calibrated between the course heading when commencing the turn, to when the vessels head has passed through 90°.

Transfer – Defined by that distance which the vessel will move perpendicular to the fore and aft line from the commencement of the turn. The total transfer experienced during a turn will be reflected when the ship’s head has moved through a course heading of 180°. The amount of transfer can be calibrated against the ship’s change of heading and is usually noted at 90° and 180°.

Tactical diameter – Is defined by the greatest diameter scribed by the vessel from commencing the turn to completing the turn.

Final diameter – Is defined as the internal diameter of the turning circle where no allowance has been made for the decreasing curvature as experienced with the tactical diameter.
Details of ship and operation:

Cargo Passenger Ferry
Length OA 152 m
Breadth 21.7 m
Mean Draught 4.605 m
(Water depth for turn 90 metres)

Load Displacement 10322 T.
Lightship tonnage 7346 MT
Service speed 19.5 knots

Calm Weather.
No current.
Clean hull.
General information on turning circles
The conditions prevailing during the turning of a vessel will greatly affect the determined results. A major example of this would be experienced where a circle is considerably increased in size when conducted in very shallow waters, especially when compared with a turn conducted in deep waters. It would, therefore, be fair to assume that the turning rate of the quickest turn might not generate the tightest of turns.

It is also noted that the action of turning the vessel with hard over helm on, would cause the ship’s speed to decrease by a considerable amount. A drop of 30 to 40 per cent from full speed would not be seen as unexpected, assuming no direct reduction to the propulsion unit is applied. The rudder angle imposed, generating considerable drag effect during the turn, accounts for some loss of speed while the fore and aft component of hydrodynamic forces also cause a speed reducing affect, slowing the vessel down during the turn.

When conducting turns at high speed the only thing that is saved, is time, while the ‘rate of turn’ varies considerably. Such a factor may be critical in certain cases, especially where time is the important factor, as in the case of the man overboard situation.

Turning features – operational vessels
Once operational and a vessel has reason to perform a tight turn, e.g. Man Overboard, it should be realized that a deep laden vessel will experience little effect from wind or sea conditions, while a vessel in a light ballast condition, may experience considerable leeway with strong winds prevailing.

Another feature exists with a vessel that is trimmed by the stern. She will generally steer more easily, but the tactical diameter of a turn could be expected to decrease; while a vessel trimmed by the head will still decrease the size of the circle, but will be more difficult to steer.

Should the vessel be carrying a list at the time of conducting the circle, the completion time could expect to be delayed. Also, turning towards the list would expect to generate a larger turning circle than turning away from the list side, bearing in mind that a vessel tends to heel in towards the direction of the turn, once helm is applied.

It should also be realized that a ship turning with an existing list and not in an upright condition, especially in a shallow depth, could experience an increase in draught. Such a situation could also result in reduced buoyancy under the low side causing a degree of sinkage to take place. This increase in draught would not be enhanced if the turning action was also being conducted at high speed.

Additional considerations
The features associated with turning a vessel will be influenced by the type of rudder employed with the ship. This could be readily accepted if a conventional semi-balanced bolt axle rudder is considered against, say, a flap design rudder which would generate a substantially greater turning lever, producing a greatly reduced turning circle.

A narrow beam vessel like a warship, would also tend to make a tighter turning circle than a wide beam container vessel. So, respectively, the construction of the hull, the manoeuvring equipment together with speed of turn, draught, geographic water conditions, state of equilibrium are all relevant and must all be seen as influential factors relating to the effective turning of the vessel.
Influences on the turning circle
Modern day ships are built with a variety of manoeuvring aids. The previous example is unusual in that it had triple controllable pitch propellers. However, many ships are still being constructed with a righthand fixed propeller. Generally speaking, such vessels would turn tighter to port than to starboard, although weather conditions on the day of trials could influence this. Other factors will affect the rate of turn and size of the actual circle, namely:

a) Structural design and length of the vessel
b) Draught and trim of the vessel at the time of trials
c) The size and motive power of machinery employed
d) Distribution and stowage of any cargo
e) Whether the ship is on even keel or carrying a list
f) The geographic position of the turn and the available depth of water
g) The amount of rudder angle applied to complete the turn
h) External forces effecting the drift angle.

Structural design and ship’s length
Generally speaking, the longer the ship, the greater the turning circle. The type and surface area of the rudder will also have a major influence in defining the final diameter of the circle, especially the clearance between the rudder and the hull. The smaller the clearance between the rudder and the hull, the more effective will be the turning action.

Draught and trim
The deeper a vessel lies in the water the more sluggish will be her response to the helm. However, where a vessel is in a light condition and at a shallow draught then the superstructure is more exposed and would be more influenced by the wind. The trim of the vessel will influence the size of the circle considerably. Ships usually trim by the stern for ease of handling purpose but it should be noted that if the vessel was trimmed by the head during the turn the circle would be distinctly reduced.

Motive power
The relationship between power and the ship’s displacement will affect the turning circle and can be compared with a light-speed boat against a heavy ore carrier; the acceleration of the light-speed boat achieving greater manoeuvrability. Also, for the rudder to be effective, it must have a flow of water passing it. Therefore, the turning circle will not be increased by a great margin with an increase in speed because the steering effect is increased over the same common period.

Distribution and stowage of cargo
Ships’ trials are generally conducted on new ships and cargo stowage on board is rarely a factor to consider. However, if cargo is on board the vessel would respond more favourably if the loads could be stowed in an amidships position as opposed to in the extremities of the vessel. Where loads are at the ends of the vessel, any manoeuvre would be sluggish and slow in response to helm action.
**Even keel or listed over**

It would normally be expected that a new vessel completing sea trials would be on an even keel throughout, but such a condition cannot be guaranteed once the ship is in active service. In the event that the vessel is carrying a list when involved in a turn she can be expected to make a larger turn when turning towards the side carrying the list. The opposite holds good when turning away from the listed over side and tends to make a reduced turning circle.

**Available depth of water**

Turning circles for trials should always be carried out in deep water. Shallow water would be expected to cause a form of interaction between the hull and the sea bed causing the vessel’s head to yaw and it becomes more difficult to steer. Shallows could affect response time and so cause an increase in the advance and the transfer of the circle.

**Rudder angle**

A prominent feature of any turning operation and one where the optimum rudder angle is that which will cause a maximum turning affect with the reduced amount of drag. Where a large rudder angle is employed the turning circle would be tighter but it would be accompanied by a considerable loss of speed.

**Drift angle and influence forces**

When helm is applied and the bow responds, the stern of the vessel will traverse in an opposing direction. The resulting motion is one of a sideways movement at an angle of drift. When completing the turning circle, the stern of the vessel is outside the turning circle, while the bow area is inside the circle. In the majority of cases, it is the pivot point of the vessel which describes the perimeter of the turning circle.

**Propeller action**

Propellers are designed to produce maximum efficiency from the engine at the most economical fuel burn. However, the propeller itself gives rise to some drag effect and will have transverse thrust as a side effect. A degree of cavitation on the forward side of the blades can also be expected. Such effects continually reduce the propeller’s effectiveness and have associated side effects like generating excessive vibration and noise.

The rotation of the propeller and the generation of cavitation leads to a vortex being created in the region of the blade tips. This influences the slip value and hence the speed of the vessel. This action could cause damage through ‘pitting’ which could also affect propeller performance.

There are now many different types of propeller systems in operation. The right hand fixed blade propeller is still common but developments in controllable pitch propellers, contra-rotating propellers, multi-blade propeller systems, twin, triple and quadruple propeller sets, pod propulsion units, Kort nozzle systems and Azipod systems, have all taken market share in both commercial and warship construction. Active rudders with propellers attached are also an added feature, while Voith Schneider Propellers (VSP) have made advances with the Voith Cycloidal Rudder working in conjunction with cycloidal propulsion.
Distinct advantages with each system are advocated by the various manufacturers, but generally the performance with respect to the vessel design and the designate vessel function, lend to a specific choice of system, e.g. Azipod systems for Dynamic Positioned vessels.

**Transverse thrust**

Transverse thrust effects are a cause of the single propeller action where water is displaced to one side or another, causing a movement of the hull from the deflection of the water flow. The effects of transverse thrust when going ahead are so minimal they can generally be ignored but when operating astern propulsion, the water flow expels water in the forward direction. This in turn is deflected by the hull form causing a sideways push on the hull.

The ship handler should be aware of his or her own vessel’s performance when going astern and the diagram below goes some way to explaining the movement of the vessel with alternative propeller systems.

**Factors of propellers**

*Single fixed pitch propeller*

Fixed pitch propeller(s) are subject to drag effects and slip, when the vessel is moving through the water. Being usually constructed in a dissimilar metal to the steelwork of the hull, they are subject to pitting and corrosion effects necessitating, in most cases, the use of sacrificial anodes about the rudder propeller area. These anodes can themselves generate some frictional resistance.

In the event of damage to one of the blades of the propeller, it would become necessary to replace the whole propeller. Changing a propeller is expensive and will usually require the vessel to enter dry dock.

*NB. Historically smaller vessels could, and have been known to, change a propeller while alongside with the assistance of shoreside cranes and excessive forward trim.*
Controllable pitch propellers (CPPs)
These are more expensive to fit than fixed pitch propellers, especially if they are to be fitted retrospective to the building stage. They are subject to more maintenance but have distinct advantages over and above fixed pitch blades. If a blade is damaged it can be removed comparably quickly and replaced by a spare blade (usually carried by the ship itself). The whole propeller does not need to be replaced.

The CPP is also cost-effective in that, with a constant rotating shaft, shaft alternators can be used for electrical power generation without having to resort to the use of additional generators. Additional generator units require expensive auxiliary fuel, a necessity with fixed pitch propellers.

The benefits to the ship handlers are immediate bridge response to ship control, without having to go through engineers to obtain manoeuvring controls. However, the controllable propellers still generate an element of drag effect, especially at zero pitch and they are also subject to similar corrosion as the fixed pitch propellers, for the same reasons. They are generally subject to reduced slip values.

Nozzle propellers
When operating at high speed, these propellers experience a reduced value of slip but when at slow speed, under heavy load, may experience increased values of slip. They also experience erosion on the inside edge of the nozzle and at the blade tips, usually due to cavitation and vortex effects. The nozzle itself tends to be protective and tends to prevent debris hitting the actual propeller blades.

CPP construction. The circular base of CPP blades bolted onto the rotational base, set into the propeller shaft of a Controllable Pitch Propeller arrangement. Once the bolts are secured, they are strap welded together to prevent loosening through vibration.
Steerage problems may also be experienced, especially where the nozzle is short in length compared with diameter. Some more recent nozzles are fitted with a steerage vane and alternative nozzle lengths may have been fitted as alternative options.

Pitch angle of propellers

Pitch – Is defined as the axial distance moved by the propeller in one revolution, through a solid medium.

Measurement of pitch
Most modern shipyards would establish the pitch of a propeller by the use of an instrument known as a ‘Pitchometer’. However, if this was not available the pitch can be ascertained in dry dock from the exposed propeller.

Position the propeller blade in the horizontal position and place a weighted cord over the blades.
At different Radi R1, R2, and R3, measure the distances AC and BC as well as R1, R2, and R3.
The tangent of the pitch angle is then \( \frac{BC}{AC} \)

Therefore Pitch = \( 2\pi R \tan \theta \)
= \( \frac{2\pi \times R \times BC}{AC} \)

Example to calculate pitch angle of a propeller
In a four bladed propeller of constant varying pitch the following readings are obtained.

<table>
<thead>
<tr>
<th>Pitch Angle</th>
<th>Radi</th>
</tr>
</thead>
<tbody>
<tr>
<td>40°</td>
<td>0.5 m</td>
</tr>
<tr>
<td>25°</td>
<td>1.0 m</td>
</tr>
<tr>
<td>20°</td>
<td>1.5 m</td>
</tr>
</tbody>
</table>
Calculate the mean pitch of the blades.

Pitch of propeller = $2\pi R \tan \theta$

At radi 0.5 = $2\pi \times 0.5 \times \tan 40^\circ = 2.636$

At radi 1.0 = $2\pi \times 1.0 \times \tan 25^\circ = 2.929$

At radi 1.5 = $2\pi \times 1.5 \times \tan 20^\circ = 3.430$

Mean Pitch (Average) = 2.998 metres The theoretical distance the propeller will advance in one revolution.

**Examples of propeller slip**

**Real slip** – occurs as a result of physical conditions existing between the propeller and the water in which it is immersed. It should only be positive.

**Apparent slip** – is concerned with the same factors but in addition the effects of current and/or wind are taken into account. This may be positive or negative.

\[
\% \text{ Slip} = \frac{\text{Engine Distance} - \text{Ship's Distance}}{\text{Engine Distance}}
\]

**Further example of propeller slip**

Calculate the slip incurred by a vessel when given the R.P.M. = 125

And the pitch of the propeller is 6.0 m

The ship's run from Noon to Noon ship's mean time covers 540 nautical miles

Clocks are advanced 30 minutes during the day's run
Twin screw vessels

It should be realized from the onset, that when dealing with twin screw vessels, some basic information is directly linked to the behaviour when manoeuvring the vessel:

a) Fixed propellers are usually both outward turning (some tonnage still has inward turning, fixed pitch propellers).

b) Controllable pitch propellers are usually inward turning.

c) Configurations can be twin rudders or a single rudder.

d) Twin rudder configurations are generally accepted as being more responsive than a single rudder with twin propellers.

e) Twin propellers with a single rudder configuration tend to have a poor water flow pattern over the rudder area, making the rudder less effective.

f) Where the propellers and twin rudders are inset close to the fore and aft line, the turning ability of the vessel is often reduced; the turning effect being insignificant in some narrow beam vessels, such as some classes of warships.

g) The effects of transverse thrust are still present and should be related as the same to a single fixed pitch propeller. Though the effects are considered a poor turning element if the vessel is having to manoeuvre in confined waters.

h) The rudder(s) turning force when the vessel is operating ahead propulsion is usually considered as very good.

i) The wash from propellers when the vessel is operating astern propulsion will tend not to extend up the hull length, if the vessel is at high speed.

j) Some twin screw ships will respond well when only one engine is operational with the twin rudders working in tandem. While other vessels could find that the non-operational engine shields its respective rudder making it less effective. Alternatively, the constructional hull lines of the vessel could well influence the flow to the rudder surface and directly effect the turning ability to a lesser or greater degree.
k) Shaft alignment of twin propellers has a direct influence on turning ability of the vessel. Parallel shafts (to the fore and aft line) provide greater leverage about the pivot point. Angled shafts (slightly outboard) provide reduced leverage and subsequently reduced turning ability.

l) Twin screw vessels can be steered by engines with fine adjustments to the revolutions on respective shafts. Steerage would not be as accurate, or as steady as with rudder use, but would be manageable in an emergency.

**Twin screw arrangements**

*Twin screw arrangements. Twin controllable pitch propellers (CPPs) each fitted with ducting and flap rudders, designed either side of a single skeg stern structure. The vessel is also fitted with twin stern thrusters set forward of the propellers, on the centre line above the keel. Extensive use of sacrificial anodes have been used to reduce the corrosive effects in the stern area due to the construction in dissimilar metals, namely with tail end shafts, bronze propellers and the steelwork of the rudders and hull.*
Twin, four-bladed, fixed pitch propellers, positioned either side of a single balanced rudder. The arrangement seen fitted to the cable ship ‘Nexus’ exposed in dry dock.

Twin multi-blade propellers fitted in association with twin rudders aboard a vehicle ferry, seen exposed in dry dock.
Machinery ‘Pod’ propulsion (Pod propulsion units)

Several cruise ships have recently moved towards ‘Pod propulsion units’ as a means of main power and many buildings in the ferry sector now reflect the potential use of ‘Pod Technology’ for vessels of the future. The compactness of the ‘pod’ and the associated benefits to passenger/ferry operations would seem to offer distinct advantages to ship handlers, operators and passengers alike.

Some of the possible advantages from this system would be in the form of:

1. Low noise levels and low vibration within the vessel.
2. Fuel efficiency with reduced emissions.
3. Good manoeuvring characteristics and tighter turning circle as when compared with a similar ship operating with standard shaft lines and rudders.
4. Reduced space occupied by bulky machinery making increased availability for additional freight or passenger accommodation.
5. Simpler maintenance operations for service or malfunction (pods are easy to remove and replace).

Machinery pods are usually fitted to the hull form via an installation block, each vessel having customized units to satisfy the hydrodynamics and the propulsion parameters. Propeller size and the rpm would also need to reflect the propulsion requirements to the generator size with electric ‘Azipod Units’.

The direction of the shaft line is acquired from a hydraulic steering unit giving the versatility of directional thrust to port and starboard as well as ahead or astern.

For extremely high speed steering a 360° rotation pulling pod with a rudder flap has been designed.

Control means is provided by flap movement with the complete ‘Pod’ turning.

Azipod propulsion systems provide the action of pulling, rather than pushing the vessel through the water. A typical twin propeller azipod configuration would consist of three main diesel generators driving an electric motor to each propeller,
with full bridge control transmission. Power ranges start from about 5 MW up to 38 MW dependent upon selected rpm (adequate built-in redundancy is accounted for by providing three generators for only two propellers).

The Azipod propulsion system makes ship handling easier and turning circles are comparatively tighter than where vessels are fitted with conventional rudders – speeds of 25 knots ahead, 17 knots astern and 5 knots sideways provides excellent harbour manoeuvring. Varieties of pod designs are rapidly entering the commercial market supported by associated new ideas to improve fuel efficiency and provide better performance.

Many are water cooled, eliminating the need for complex air cooled systems, while the Siemans-Schottel Propulsion (SSP) system has propellers at each end of the pod rotating in the same direction.

The Passenger vessel ‘Amsterdam’ fitted with twin azipod propeller units either side of the centre ‘skeg’, seen exposed in the dry dock environment. Alternative arrangements are constructed with a centre line Controllable Pitch Propeller with azipods set to either side.

High Speed Craft (HSC)
Chapter 2 of the High Speed Craft Code draws attention to the potential hazards that may affect high speed design craft, when manoeuvring at speed:

1. Directional instability is often coupled to roll and pitch instability.
2. Broaching and diving in following seas, at speeds near to wave speed is applicable to most types of craft.
3. Bow diving and craft on the plane, both in mono-hulls and catamarans, is due to dynamic loss of longitudinal stability in relatively calm seas.
4. Reduced transverse stability with increased speeds in mono-hulls.
5. Pitching of craft on the plane (mono-hulls) being coupled with heave oscillations can become violent (similar to a porpoise action).
6. Chine tripping, being a phenomenon of mono-hulls on the plane occurring when the immersion of a chine generates a strong capsize moment.
7. Plough-in of air cushion vehicles either longitudinally or transversely as a result of bow or side skirt tuck, under or sudden collapse of skirt geometry, which in extreme cases could cause capsize.
8. Pitch instability of SWATH (small water plane area twin hull) craft, due to the hydrodynamic moment developed as a result of the water flow over the submerged lower hulls.
9. Reduction in the effective metacentric height (roll stiffness) of surface effect ship (SES) in high speed turns compared to that of a straight course, which can result in sudden increases of heel angle and/or coupled roll and pitch oscillations.
10. Resonant rolling of SES in beam seas, which in extreme cases could cause capsize.

Specific design features incorporated at building can go some way to overcome the above affects and enhance safer stability conditions and manoeuvring aspects.

**High speed craft**

**HSC categories**
The IMO, HSC code was introduced in 1994 and had mandatory implementation in 1996. Under the auspices of the code, High Speed Craft were placed into one of three categories:

**Category ‘A’ craft**
Defined as any high speed passenger craft, carrying not more than 450 passengers, operating on a route where it has been demonstrated to the satisfaction of the flag or port state that there is a high probability that in the event of an evacuation at any point of the route, all passengers and crew can be rescued safely with the least of:

i. time to prevent persons in survival craft from exposure causing hypothermia in the worst intended conditions;

ii. the time appropriate with respect to environmental conditions and geographical features of the route, or

iii. four hours.

**Category ‘B’ class**
Defined as any high speed passenger craft other than a Category ‘A’ craft, with machinery and safety systems arranged such that, in the event of damage, disabling any essential machinery and safety systems, in one compartment, the craft retains the capability to still navigate safely.

**A cargo craft class**
Defined as any high speed craft other than a passenger craft and which is capable of maintaining the main functions and safety systems of unaffected spaces, after damage in any one compartment on board.

**Maximum speed formula**
Speed must be equal to, or exceed 3.7 times the displacement corresponding to the design waterline in metres cubed, raised to the power of 0.1667 (metres per second).
Applicable to most types of craft, corresponds to a volumetric Froude number greater than 0.45.

*High speed craft*

The bow wave and generated wake made by a small high speed pilot craft operating in calm open waters. Such water disturbance can affect other small craft which may be in close vicinity.

A high speed passenger ferry operating off the Spanish coastline in calm, but restricted water. The dangers from the generated wake when operating at speed can be hazardous for craft being single-handedly manned by fishermen or yachtsmen.
Waterjet propulsion systems

![Diagram of a waterjet propulsion system]

**Waterjets**

With the increased development in high speed craft, especially in the Ferry sector of the industry, waterjet propulsion systems have been incorporated into vessels either as a main propulsion system or alongside conventional propeller units to provide additional power and/or manoeuvring capability.

Some caution must be used with these systems when in confined waters as the jet wake generated can be powerful and could cause interaction with other traffic or coastline structures.

**High Speed Craft and Safe Speed (Ref., Regulation 6, ColRegs)**

It should be realized from the onset that the Collision Regulations are applicable to all vessels inclusive of HSC. This application also includes Regulation 6 ‘Safe Speed’, which in turn must also be construed in conjunction with the other relevant remaining regulations.

The question of what constitutes a safe speed is probably irrelevant until an accident occurs. The fact remains that a high speed vessel must still retain the ability to move out of trouble just as a conventional vessel needs to avoid close quarter situations. The letter of the law within the ColRegs is designed to avoid close quarter situations and many of these can be avoided by not only a reduction of speed but also an increase of speed.

Such a statement is not meant to be controversial, but is meant to highlight that an increase of speed can be just as effective to avoid a close quarter encounter as a decrease in speed. Such action, however, should not be taken without long range radar scanning beforehand, and should not be sustained for an indefinite period. Neither should a decision of this nature be made without a full appraisal of the immediate environment.

The use of high speed in good visibility can, and is, well used to take early action to avoid close quarter situations. However, in the event of poor visibility being encountered, watch officers should to be aware of the need to be able to stop their vessel within half of the visible range, bearing in mind that a high speed craft on the ‘plane’ at over 40 knots, which encounters poor visibility, may reduce to say fifteen (15) knots.
In so doing, her mode changes to that of full displacement, and she can no longer assume the same manoeuvrability as when she is operating at increased speed.

Again this option is not being advocated by this author. On the contrary, to bring the vessel to a dead stop can, in some circumstances, be more hazardous than maintaining
ship manoeuvrability. What is being highlighted is that stopping, or increasing speed, are alternative actions to decreasing speed and should not be dismissed out of hand. They are and remain, options, and the circumstances of each scenario will dictate what is considered prudent at the time.

**Comment:** Watch Officers are reminded, however, that Regulation Six is not a stand alone regulation, and the ColRegs also stipulate that: ‘Assumptions should not be made on the basis of scanty information, especially scanty radar information’.

**Wheel over points**

The dangers of interaction are prevalent in many different situations, but none more so than when the vessel enters shallows and is in close proximity to the land. Tight manoeuvres must be anticipated through rivers, canals and when making land falls. The large vessel must anticipate that the position of the way point is rarely coincident with the time at which the helm will be applied. Masters would be expected to ensure that passage plans include ‘wheel over points’ when vessels are approaching positions of course alteration.

*Wheel over point. This example shown for a 60° alteration of course. Advance and transfer details can be referenced from the ships sea trials and performance documentation.*
**Canal and river movements**

Rivers and canals by their very nature have restricted water compared to open sea conditions. When the ship is in transit through a canal, the vessel occupies a volume of the canal space causing effectively a blocking restriction to water movement.

**Squat and blockage**

**Blockage factor illustrated**

The illustration above shows that because the underkeel clearance is small, the volume of water under the keel is small and would not have the same buoyancy affect on the hull as noted in deeper water; bearing in mind that the position of buoyancy is defined as the geometric centre of the underwater volume. If the vessel is heeled by external forces the water plane will increase, the position of ‘B’ would move upwards but, at the same time, also outwards towards the angle of heel. This leaves the low side, at the turn of the bilge, liable to contact with the ground.

**Blockage Factor** = \[
\frac{\text{that proportion of a midship's section}}{\text{cross sectional area of the channel, river or canal}}
\]

When two ships are passing in the channel the blockage factor is increased and the value of squat experienced can expect to nearly double.

Practically the vessel may expect to encounter steerage problems caused by squat and the proximity of the canal bottom in relation to the position of the keel. Speed of movement would be critical and the vessel must expect to move at a greatly reduced speed. The use of tugs, fore and aft to effect steerage control must also be anticipated as being an absolute necessity.
Squat – ship’s response

The behaviour of a ship in shallow water, where the forces of buoyancy are reduced, can expect to be totally different to the behaviour of the same ship in deeper water, where the buoyancy forces will have a much greater affect. Factors affecting the actual value of squat will vary considerably but could expect to include any or all of the following:

a) Draught/depth of water ratio. A high ratio equates to a greater rate of squat.

b) The position of the longitudinal centre of buoyancy (LCB) will determine the trimming effect and have a direct relation to the squat value.

c) High engine revolutions can expect to increase stern trim.

d) The speed of the vessel is related to the value of squat in that the value is influenced by speed$^2$. The faster the ship moves the greater the squat value.

e) The type of bow fitted effects the wave making and pressure distribution on the under water volume.

f) The length/breadth ratio can cause an increase or decrease of the squat value, i.e. short-tubby ships tend to squat more, than the longer narrow beam vessel.

g) The breadth/channel width ratio affects the squat value. A high ratio causing an increased value of squat.

h) Vessels with a large block coefficient $C_b$ will experience greater effects from squat.

i) Greater effects of squat are experienced when a vessel is trimmed by the bow than by the stern.

Evidence of squat

The indication that a vessel is experiencing squat will show from the steering being affected. Waves from the ship’s movement will probably increase in amplitude and the wake left by the vessel will probably be mud stained. Some vibration may also occur with a decrease in speed and a reduced rpm.
A large tanker manoeuvres in close proximity to an FPSO in offshore regions. Such close manoeuvres between vessels and fixed or floating structures are known to generate interactive forces which tend to hamper ship handling operations.
Where a vessel is brought into close proximity of a bank, as in a canal or river, it may experience a pressure build up between the hull and the obstructing bank, known as ‘bank cushion effect’. This pressure build up would effectively turn the bows of the vessel away from the bank and force the ship’s heading into the middle channel area, away from the restrictions of the channel sides.

*Interaction forces – vessels meeting ‘End On’ passing too close.*
In itself, this can be countered by applying helm, if it is expected and catered for. However, the movement from a bank cushion effect could have serious consequences if, say, the vessel is being overtaken or meeting an oncoming vessel moving in the opposite direction, the vessel close to the bank taking a sheer towards the oncoming traffic.

The pressure cushion generated cannot be avoided, but the violent reactive movement can be curtailed by reducing the speed of approach towards the bank. The speed of the vessel being reduced to steerage way only, will expect to minimize the outward turning effect of the vessel.

*Interaction forces – one vessel overtaking another, too close.*
Shallow water effect
When ships make a landfall from a deep sea position they may experience a form of interaction with the sea bed, known as ‘Shallow Water Effect’. It is especially noticeable where the shoals and the change in depth becomes abrupt and may cause the ship’s steering to be affected, the bows being pushed off course to either port or starboard as the vessel experiences a sharp change in underkeel clearance.

Interaction forces – bank cushion effect.

Bank cushion effect shown on a vessel where the rudder is retained in the midships position and the vessel sheers away from the bank with the pressure build up without any helm movement.
As the vessel approaches the shoal area, the interaction between the hull and the closeness of the sea bed may cause the vessel to sheer away. A reaction that can be quickly corrected by alert watchkeepers but could generate a close quarters situation if other traffic is in the near vicinity.

Negotiating bends in tidal riders. ‘P’ represents the position of the ship’s pivot point when going ahead.
**Interactive forces between tug and parent vessel**

With the following example a tug is to engage with a parent vessel on the starboard bow. Interaction between the smaller and larger vessels could generate a collision scenario. Prudent use of the helm and speed by the tugmaster will be crucial in collision avoidance.

The smaller tug experiences an outward turning effect along the parallel hull lines of the parent vessel. The outward turning effect can be countered by applying Port Helm in this example.

The tug experiences the maximum outward turning force at the shoulder position of the larger vessel. Because the tug is carrying Port Helm and still moving ahead, a loss of turning force is experienced under the flare of the ships bow. The tug could sheer across the bows of the larger vessel with inevitable collision.