Steerable Propulsion Units: Hydrodynamic issues and Design Consequences

by Tom van Terwisga, Frans Quadvlieg and Henk Valkhof (MARIN, Wageningen, The Netherlands)

Paper written on the occasion of the 80th anniversary of Schottel GmbH & Co;
Presented on 11 August 2001

Introduction

The last three decades have shown a strong development in the market for steerable propulsion units. This paper addresses several main developments and places them in a historic perspective. The major objective of the paper is to present a review of issues relevant to steerable propulsor units. These issues are essentially of a hydrodynamic nature. Although it is thought that hydrodynamic issues often have a heavy impact on the design, the professional background of the authors rather than anything else prompts the choice for an emphasis on hydrodynamic aspects. Starting from the hydrodynamic aspects, we draw several conclusions towards the design and operations of vessels equipped with steerable propulsion units.

Steerable propulsion units refer here to those units that are able to actively deliver a steering moment by rotating the thrust vector through the rotation of the thruster. Such propulsion units may occur in different concepts. The most renowned example and one of the oldest products in this range is the steerable thruster unit (Figure 1).

Recently, since the early nineties, a distinct concept has made its way into the marine world. This new concept is referred to as podded propulsor (or in short: pods) and is distinguished from the original thruster in that its prime mover is an electric motor, situated in the hub underneath the strut, directly driving the propeller (Figure 2).

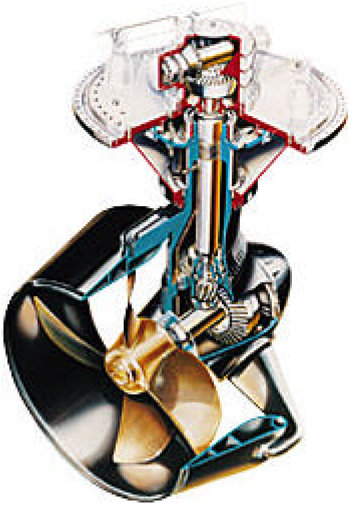


Figure 1 Steerable thruster unit

Figure 2 Podded propulsor

Apart from the steerable thruster and the pod, a number of other steerable propulsor units exist. One of the oldest is the Voith Schneider Cycloidal propeller (see Figure 3). This propeller is characterised by a number of foils rotating about a vertical axis, with a blade angle that depends on the blade position. The blade angle is controlled by a mechanical actuator mechanism, which essentially determines the thrust/torque ratio in every position.

A special type of waterjet that is worth mentioning is the Schottel Pumpjet, which distinguishes itself by the combination of intake, pump and nozzle in one rotatable unit (see Figure 4). The gain in space and the consequent flexibility in the ship design are obvious.

Figure 3 Voith Schneider Propeller

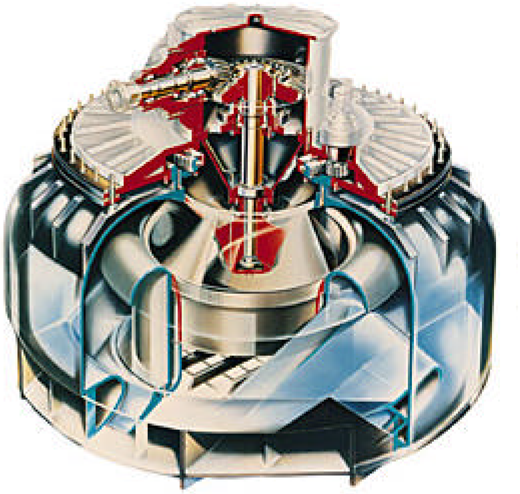


Figure 4 Schottel Pump Jet

The paper first aims at providing some historic background to the development of steerable propulsion units. This is followed by a discussion on hydrodynamic issues and design consequences for perhaps the two most popular steerable propulsors: the steerable thruster and the podded propulsor.

Historic development

An early example of a propulsor applying the principle of the vectored thrust is the German *Voith Schneider Propeller*. The development of the Voith Schneider Propeller started in 1926 and the first application powered an inland waterway vessel in 1929. The first tug with the VSP Cycloidal propeller installed (Figure 5) was launched in 1950.

Figure 5 First VSP Tractor Tug in 1950

Schottel has played an essential role in the history of *azimuthing thrusters*. Some 50 years ago, Schottel introduced the Schottel Rudder Propeller SRP. This rudder propeller could be rotated over 360 deg (vertical axis), where the full propulsive power could be used for any angle (Figure 6). These days, azimuthing thrusters are available up to some 6 MW, allowing for a wide range of applicability (Figure 7).

Figure 6 First Schottel Rudder Propeller launched in 1950

Figure 7 Largest Schottel Rudder Propeller

The popularity of steerable thruster units can be explained by the various applications of Dynamic Positioning (DP) or Dynamic Tracking (DT), both in the offshore industry, as well as in other areas of seagoing activities. The conventional thruster unit which is widely applied in DP/DT applications, makes use of a mechanical power transmission, where the prime mover (mostly a diesel engine or an electric motor) is connected with the propeller through one or two right angle gears (designated respectively L or Z drive).

The increase in popularity of the conventional thruster in the early seventies was caused by several factors, according to Nienhuis [8]. "In the offshore industry activities were shifting towards increased water depths which in some cases prohibit the use of conventional passive mooring systems. The flexibility and mobility of DP systems led to its application for the exploitation of marginal oil fields, with the added advantage that assistance of anchor handling vessels is no longer necessary. This latter advantage is also beneficial for cable or pipe laying vessels, which nowadays may be fitted with dynamic tracking (DT) systems. Indeed there seems to be a trend for oil companies to require the use of actively controlled ships in the vicinity of subsea pipe lines to avoid the risk that these may be damaged by the use of anchors." Other applications of DP or DT systems can be found in dredging vessels (e.g. trenching, stone dumping, beach replenishment) and naval ships (mine hunters in hunting or hovering mode, frigates in mine sweeped areas, replenishment at sea operations).

The number of applications of the rotatable thruster for other ship types also grew. This was a.o. promoted to a large extent by Bussemaker [1], who proposed tractor tugs with azimuthing propellers. In the mean time the application of rotatable thrusters has grown to many other ship types, such as double-ended ferries, stern drive tugs, inland passenger ships, mine hunters and offshore workships.

The traditional stronghold of the azimuthing thruster is the application where good manoeuvrability at low speeds is essential, such as e.g. for DP and DT. With the maturing of the concept of the azimuthing thruster and the availability of electric motors with a high power density, the thruster with an electric motor in the pod came within reach. The first so-called *podded propulsors*, using this design principle came into service in the early nineties. One of the main assets of this podded propulsor is probably that it has important consequences for the general arrangement of the ship as well, because of the different layout of the propeller-shafting-engine chain. Other important aspects refer to the overall propulsive efficiency and the manoeuvrability.

The idea of placing the electric propulsion motor inside a submerged azimuthing propulsor arose in the late 1980s by Kvaerner Masa-Yards, together with ABB Industry. A 1.5 MW unit was first installed in 1990 on the Finnish waterway service vessel Seili [7].

Over the last five to six years, podded propulsors have become more and more important. Particularly on cruise liners, the units have proven to be of major importance as a means to reduce cavitation and vibration and hence have lead to a new standard for a high comfort class of cruise ships. At MARIN, it all started with the request of Kvaerner Masa-Yards and

Carnival Cruise Lines to compare the results of the twin screw open shaft Fantasy class of ships with similar ships provided with pods.
Based on encouraging results with pods as main propulsor, Carnival Cruise Lines decided to select ABB Azipod® propulsion on the last two passenger cruise ships of the Fantasy class. "Elation", delivered in early 1998 from Kvaerner Masa Yards' Helsinki Yard was thus the first cruise ship fitted with electric azimuthing propulsion units. Two units were installed with pulling propellers in the front end of the pods. The electric motors feature a power output of 14 MW each and a rotation rate range from 0-146 rpm. At present, the largest podded drives that are offered by the industry go up to powers of about 30 MW.

The podded propulsor (with the electric motors placed in the pod) have proven to offer a number of benefits, "such as a remarkably increased manoeuvrability. The crash stop for instance was half of the original, and the vessel remains manoeuvrable during a crash stop. Other benefits are less fuel consumption, reduced engine room size and flexible machinery arrangement, as well as low noise and vibrations. The need for long shaftlines, conventional rudders, CP-propellers and reduction gears are eliminated, resulting in space and weight savings and reduced need for maintenance." [7].

In the meantime, all major propulsor manufacturers have developed their own podded propulsor (Figure 8, Figure 9 and Figure 10). A noteworthy deviation from the mainstream pod design is the Siemens - Schottel Propulsor (SSP, see Figure 11).

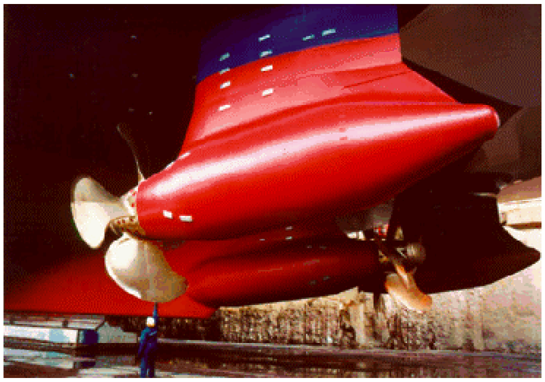


Figure 8 Azipod from ABB

Figure 9 Dolphin from John Crane-Lips

Figure 10 Mermaid from Rolls-Royce Kamewa

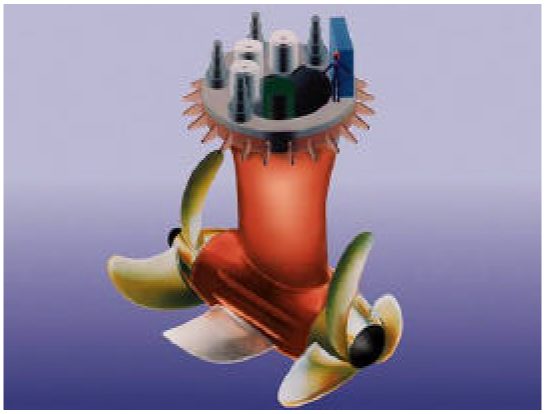


Figure 11 SSP from Siemens-Schottel

The hydrodynamic design of the SSP is characterised by two propellers, rotating in the same direction. By dividing the total thrust over two propellers, a number of potential advantages occur:

- The mass flow through the propeller disk is increased when compared to only one propeller. This is caused by the contraction of the streamtube due to the acting propeller when going downstream. The wake of the first propeller at the downstream propeller has therefore a diameter that is smaller than the propeller diameter. Consequently additional massflow is ingested, leading to a higher efficiency.

- The loading over the blades is lower when the thrust is divided over two propellers, causing improved cavitation characteristics. Alternatively, at comparable cavitation behaviour, the blade area ratio can be decreased which decreases the frictional drag contribution to the torque.
- At a lower loading per blade, there is room to decrease the propeller rotation rate, also resulting in smaller frictional drag contributions to the torque.
- Decreasing the propeller rotation rate leads to larger rotational losses in the wake. These losses can largely be recovered when a proper stator (such as the stator fins and the strut on the SSP) is placed, downstream or upstream of the propeller.

The above tendencies may lead to improved powering performance, which is almost always a trade off between efficiency and the risk of vibration hindrance and erosion. These potential advantages do however not automatically lead to an improved overall performance of the ship. Much will depend for example on the constraints with regard to propeller diameter.

A derivative of the hydrodynamic considerations is that it will be important to have a high-power-density electric motor. This motor should be able to operate at low rotation rates, or at the same rotation rate at a reduced pod diameter. The SSP was the first podded propulsor fitted with a Permanent Magnet Motor, allowing for a high power density

Thrusters: Hydrodynamic issues and design consequences

This section touches upon some of the more dominant hydrodynamic issues in the design and operation of thruster units: thrust effectiveness, maximum thrust density and manoeuvrability.

Thrust effectiveness

Perhaps the most important issue in DP, DT or low speed manoeuvring is knowledge on the effective forces that the thrusters exert on the ship in the encountered conditions. These forces determine the thruster effectiveness for a given input power and consequently affect the selection of the type of thruster, its size and the overall thruster layout.

Thruster effectiveness does not follow simply from a consideration of a thruster in open water conditions. The thruster always operates in the vicinity of the hull and of other propulsors in an environment determined by waves and the motions of the ship.

Nienhuis [8] acknowledged the following disturbing factors: "In the first place, unsteady conditions are inherent due to the low-frequency motions, the variable thrust vectors as well as the first-order ship motions. Secondly, the low speeds encountered may lead to inflow directions, which deviate significantly from the alongship direction. Further, it may be expected that other propellers operating in the vicinity of the considered thruster or propeller will not only alter its effective inflow velocity, and hence its thrust, but will also affect the net force which this thruster exerts on the ship. Next, the effect of wind and waves, which more often than not dominates the current, leads to thrust levels of the propeller which are not in balance with the current forces. This is similar to a tug in towing condition. Finally, restricted water (shallow water or the presence of quays) is often encountered, changing the performance of the propulsion devices."

These phenomena all combine to the fact that for a proper design and operation of a vessel operating at low speeds, it is not sufficient to know the bollard pull of each of the propellers. Still relatively little knowledge is available for conditions inherent to DP, tracking or low speed manoeuvring. These conditions being:

- low propeller inflow speeds
- drift angle varying from 0 to 360 degrees
- thrust vectors largely uncorrelated with the current force vector
- widely varying propulsion arrangements
- restricted water

- unsteady dynamic behaviour as a function of waves and low and high frequent ship motions."

The effectiveness of a whole DP/DT system is often presented in a so-called DP capability prediction. Such a prediction aims at providing the sustainable conditions for a ship with a given thruster configuration. The sustainability is then defined in a simple way by determining the static balance between excitation forces imposed by the environment and reaction forces by the thrusters (Figure 12). As explained above, the conditions for a DP operated ship are highly dynamic and due to amongst others the effect of large inertia and damping forces and second order wave drift forces, this static approach suffers from severe limitations. Wichers et al. [11] conclude that static analysis (for a monohull) is inadequate in determining the DP capability of a 3 axis weathervaning vessel.

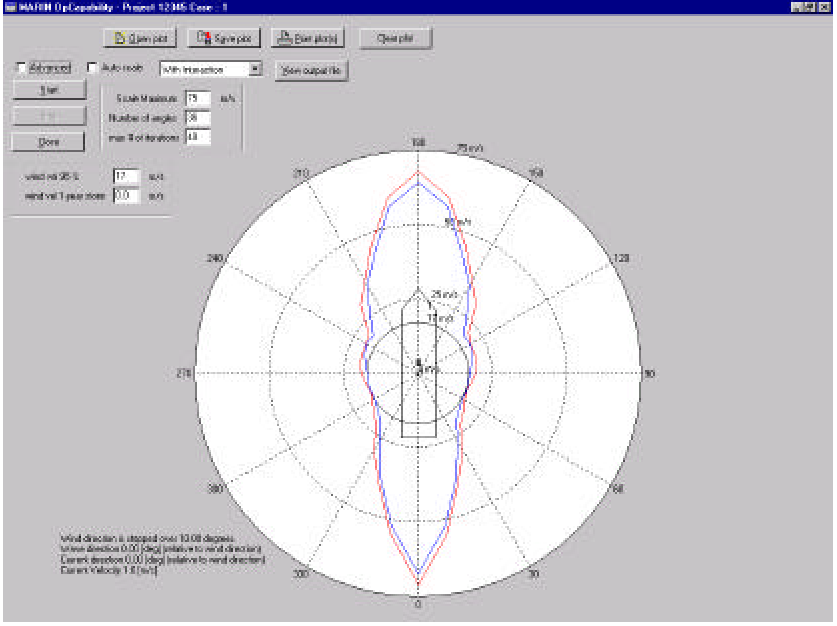


Figure 12 Example of a DP Capability plot showing the reduction in capability by thruster - hull and thruster – thruster interaction. In this case, 6 azimuthing thrusters were applied, each of 200 kN bollard pull.

Another complication in the use of DP capability predictions is the large variety of computational models that are used, each with their own simplifications and neglects. In many cases for example, no interaction effects with other thrusters or with the hull are used. In even more cases the effects of e.g. bow tunnel thruster degradation in waves are neglected. These are mostly outside the scope of the DP Capability programs, whereas these effects can have an important bearing on the capability.

To fully incorporate the above effects and other non-linear effects such as the second order wave drift forces on the hull, one should apply a simulation model that solves the equations of motion in the time domain (see e.g. Wichers et al. [11]).

Maximum thrust density

Because of structural considerations, the size of a thruster is usually heavily constrained. This constraint, together with the desire to keep the number of thrusters as low as possible, has posed the issue of the maximum thrust density (thrust per unit propeller disk area). Although it is recognised that the thruster efficiency decreases with increasing thrust density in general, there is nevertheless a drive toward higher thrust densities for DP as a result of the overall design problem.

The minimum dimensions of thrusters are however limited by cavitation induced thrust breakdown, cavitation-induced vibrations, erosion and possibly mechanical constraints imposed by the construction. Simple rules of thumb are mainly used in practice by engineers and propeller manufacturers to determine the minimal propeller size in an early design stage.

These rules mostly use a propeller tip speed criterion or a power density criterion. More refined criteria, deduced from model experiments, such as proposed by Auf'm Keller [3] and Holtrop [2], show that parameters as blade area ratio and number of blades should also be taken into account. Current computational tools such as lifting surface or panel codes are able to also show the effect of blade geometry on the maximum thrust density.

Van Rijsbergen and Van Terwisga [10] review methods to determine the minimal propeller diameter originating from full-scale experience, model-scale experiments and theoretical and computational considerations. Their paper focuses on thrust breakdown due to the presence of a certain amount of sheet cavitation on the propeller blade. Other types of cavitation, such as Propeller Hull Vortex (PHV) cavitation and erosive bubble cavitation can also impose a limit on the thrust density, but are not yet amenable to computational analysis.

It was concluded from this study that the minimum propeller is determined by two criteria: A non-dimensional thrust density criterion K_T/σ_n, and a non-dimensional tip speed criterion σ_n. Dimensional equivalents of these criteria are less reliable because they show too large a dependency on shaft immersion and efficiency. Furthermore, the thrust capability of a propulsor was pointed out to be dependent on wake field, propulsor type (open propeller, ducted propeller or waterjet) and propeller design. These parameters should preferably be incorporated in the criteria.

Manoeuvrability

One of the most important goals of the azimuthing thrusters is to have the ability to direct the thrust in all directions. This allocation offers an excellent freedom in manoeuvrability and is of great use for the offshore industry, especially for the purpose of dynamic positioning. Also for other ships, it turned out to be a good solution.

The large amount of tugs that are presently equipped with azimuthing propellers is a good example of ships that are combining on-the-spot manoeuvrability with the required vectored thrust ability at low and high speeds. The nozzle on the steerable propeller combines this good manoeuvrability with a good bollard pull. A good example is the ship type Azimuthing Stern Drive (ASD) tug. The number of azimuthing stern drive tugs that are delivered in the recent years is enormous. The Azimuthing Stern Drive tug is hereby developed as the standard tug type, taking over from the tractor tugs and the conventional tugs. Even a new type of tug is developed and equipped with Schottel thrusters. This is the Rotor® tug [5], of which an impression is given in Figure 13.

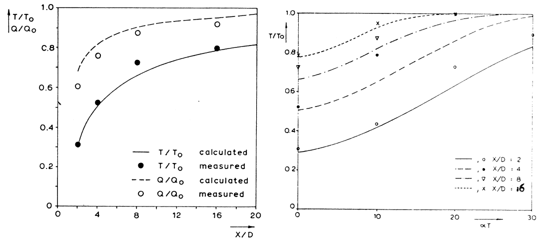
Figure 13 The Rotor Tug

The concept of three thrusters under the vessel without skegs yielded an enormous freedom in manoeuvrability (Figure 14), allowing even pure sideways movements of up to 6 knots (Figure 15).

Figure 14 Turning on the spot

Figure 15 Sidestepping at 6 knots

For ships equipped with thrusters and their manoeuvrability, it becomes an issue whether the human helmsman is able to control the ship. This manoeuvring problem is in a way related to the control of the jet fighter F16. The F16 system in itself is course unstable and so manoeuvrable that one human cannot handle it. Placing a computer between the controls of the pilot and the actual steered flaps on the F16 formed a good solution. For the Rotor Tug, Schottel developed also such a device, called the Master-Pilot. Also for the ships equipped with DP capabilities, such computer systems are required to allocate the thrusts of the propellers in such a way that the environmental loads can be withstood, not only effective, but also efficient. This means that the DP job has to be done with as little power use as possible. During all these manoeuvres, it is important that the thrusters will have as little mutual interaction as possible. One thruster, blowing in the direction of a second thruster, reduces the effectivity of the leeward thruster to a large extent, see Figure 16 from Nienhuis [8].



thruster-thruster interaction under a flat plate as: a) a function of distance between the two thrusters; b) a function of azimuth angle of the forward thruster

Figure 16 Mutual interference between thrusters

For manoeuvring and course keeping purposes, one is interested in the characteristics of the propellers in oblique flow at relative high speeds. The side force and the longitudinal force as function of larger forward speeds and oblique inflow angles are discussed in [6]. With decreasing skeg sizes and in some cases no skeg at all, the aspect of the course stability becomes more critical. For the above mentioned Rotor-tug, it was found that for small angles of attack, the side force generated by an operating thruster with nozzle is of the same order of magnitude as a typical skeg. This is illustrated in Figure 17 from [5]. These smaller angels of attack (say up to 15°) are important for course keeping. For an important part, the course stabilising effect is due to the nozzle. The following example of a double-ended ferry illustrates that for thrusters without nozzle, the situation is different.

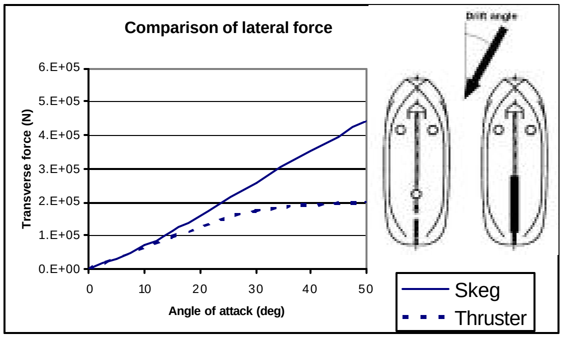


Figure 17 Comparing the lateral forces working on the ship due to thrusters or skeg

Sufficient course keeping ability with rotatable propulsors is not trivial. Double-ended ferries are sometimes equipped with thrusters without nozzles. In Figure 18, reported in [4] an illustration is given of two hull forms. While the upper hull form (initial design) suffered from an unacceptable course instability, the lower hull form appeared to show an acceptable behaviour. In this case, stability obviously has to come from both the hull form and the propulsors.

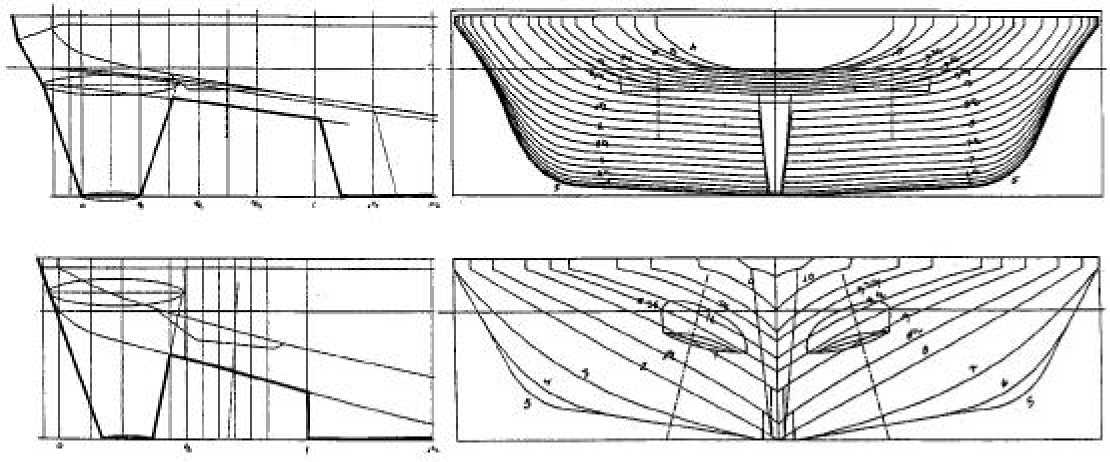


Figure 18 Hull form design consequences for sufficient course keeping ability

Pods: Hydrodynamic issues and design consequences

With every new development, new uncertainties occur that need to be controlled. Hydrodynamic issues that arose during the development of pods were uncertainty about scale effects in the power-speed prediction based on model tests, and the loads and stresses that occur on the pod during its operational life. MARIN has recognised these problems in an early stage and has invested in developing and validating an extrapolation method to scale the power-speed relation from model to full scale. This is reflected in the pod models used for hydrodynamic testing and in a Joint Industry Project on Pods in Service. The objectives and a description of the monitoring campaign are given later.

A number of design questions arose with the advent of the pod:

- Will pods save money and will they show lower fuel consumption?
- Will they lead to higher passenger and crew comfort, achieved by lower propeller induced hull pressures and excitation forces through better cavitation properties?
- What about the manoeuvrability and the course keeping ability?
- What about the safety and reliability of the new systems?
- What are the hydrostructural loads under operational and extreme conditions?
- Will they cavitate due to steering angles during course keeping?

- Can they replace stern thrusters?

Some general trends referring to these questions are given below. These trends were found from some 50 commercial and research projects on podded ships that were carried out at MARIN during the last 5-6 years. Due to an early investigation of the hydrodynamic issues, We are proud to say that some 80% of the commercial researches towards pods are carried out at MARIN. This includes the very prestigious projects towards the Eagle class of cruise vessels (Figure 19) and the Queen Mary II (Figure 20).

Figure 19 Eagle class cruise vessel

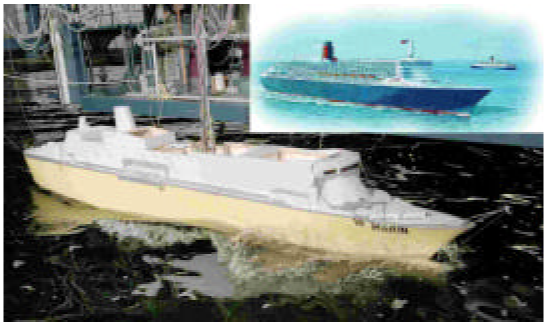


Figure 20 Queen Mary II

Propulsive Efficiency
Before establishing the power speed relation, one should make sure that the pods are ideally positioned in the flow, respecting possible design constraints. It has become clear that the optimisation of the so called tilt and rudder angles and transverse and longitudinal position in combination with the best rotational direction can lead to power savings of about 3-5%. Although some trends between optimal position and hull form can be distinguished, the optimum position strongly depends on the shape of the hull, the aft body fullness and the L/B ratio of the ship.

Assuming that the pod configuration has been optimised, predicted power improvements relative to conventional propulsion configurations in the range of 7-12% are not unusual. Up to now, MARIN was able to validate her power predictions with the trial results of some 7 ships. These results showed that the predicted power is close to the full-scale measured power, with a slight tendency to be somewhat conservative.

Comfort
Addressing the comfort issue, it can be stated that the minimisation of propeller induced pressure fluctuations is of utmost importance. Especially for cruise liners and ferries this is an important issue. The increase in cruising and crossing speeds over the last decade and the growing importance of passenger comfort has led to a decreasing feasible design space for propellers in a conventional shaft arrangement. Large propeller-hull clearances and highly skewed, tip unloaded propellers were the result. The deterioration of propulsive efficiency was thereby accepted.

With pods, excellent inflow characteristics and small cavitation extents on the propeller blades have been observed. Even the complete absence of cavitation has been observed. A consequent reduction of propeller induced hull pressure fluctuations and excitation forces was measured, even under steering angles of about plus or minus 7 degrees. It is therefore expected that in the near future, more sophisticated wake adapted propellers on pods can gain a few percent in efficiency without sacrificing the excellent vibration levels of the ship.

Manoeuvrability and course keeping

The introduction of podded propulsors with electric motors in the hub introduced the vectored thrust in a new market segment: the very large powers. This allowed for example cruise ships to be equipped with pods. The need for this was also obvious. Besides the already present trend to go for an All Electric Ship, there was a need for better manoeuvrability with cruise ships. Cruise ships are becoming larger and larger while ports stay at similar sizes and marine traffic becomes denser. A further improvement in controllability of cruise ships should therefore be pursued. The application of the podded propulsors stimulated this enormously. Besides the almost standard application of pods for cruise vessels, nowadays pods are also applied in other ships. The first application of the SSP was on a chemical tanker, but there are other applications possible such as heavy load ships.

Equipping ships with podded instead of conventional propulsion can improve the manoeuvring characteristics of a ship considerably. However, the use of the word can should be emphasised here: worsening is also possible. Several manoeuvring aspects are dealt with in the following.

Low speed manoeuvring

For manoeuvrability at low speeds, the pod developments are the necessary leap forward. Due to the use of new materials and client requirements towards all balcony ships, the superstructure of modern cruise vessels and ferries is becoming very high. The resulting wind loads are enormous. Therefore, more powerful bow and stern thrusters are required. Especially stern thrusters have insufficient power. Now, the all-turnable podded propulsors are overcoming this in the aft ship. The most recently observed trend is that the amount of bow thruster power is the limiting factor in reaching the vessels' low speed manoeuvring targets.

Course keeping ability

A design consequence of the application of pods is that freedom is obtained to design a very flat aft ship. This is often favourable from a resistance point of view, and creates a very homogeneous flow towards the pod, which is good to avoid cavitation and vibrations. Especially when three or four pods are used, this freedom is also needed from a design and construction point of view. References are the Queen Mary II and the Eagle class of cruise vessels. The open aft ship does not have much lateral resistance and hence the course keeping ability will be small. The podded propulsors are furthermore in general without nozzle. It was already stipulated in this paper that non-ducted propellers have inherently much lower course keeping stability than ducted propellers. Together, this makes that podded ships are in general more course unstable than conventional ships (see Figure 21). The recent trends of applying pods to full ships (such as tankers and LNG carriers) can become a real challenge from the course keeping point of view.

The possible operational consequences of an insufficient course stability is serious:

- Not fulfilling the IMO resolution A751(18) towards course keeping ability,
- Excessive steering actions imposed by the autopilot, causing wear and tear of the bearings and steering engine, increased resistance, loss of propulsive efficiency and possible cavitation.
- An increased risk of broaching due to the loss of directional and transverse stability in stern quartering waves.
- Increased risk of collisions due to the inability of the ship to counteract turns adequately.
- Increased required power because of the additional hull resistance resulting from the non-zero drift angles.

Excessive steering in calm water or waves should be avoided at all times from a cavitation point of view. The consequences are a constantly varying loading of the propeller, resulting in many peak loadings. There is an increased risk for adverse effects by cavitation on the propeller (when the propeller is in oblique flow, the cavitation inception speed is lower). Ships at higher speed may additionally suffer from cavitation on the struts of the pods.

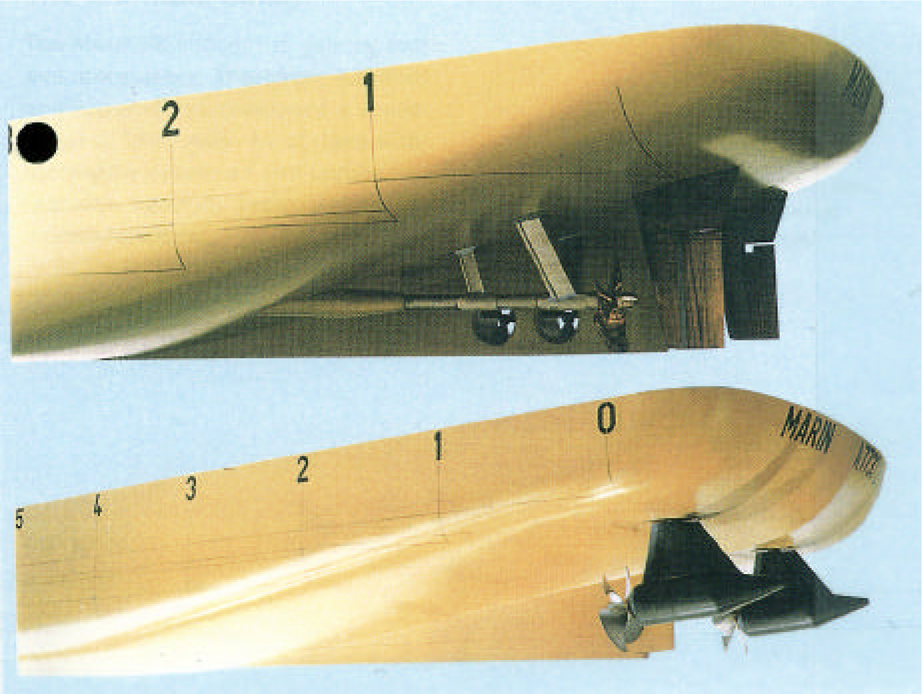


Figure 21 Aft ship equipped with conventional propulsion arrangement and a pod arrangement

Based on the above, it is the firm belief of MARIN that the course keeping ability and directional stability should be investigated thoroughly before building the ship. More important than ever seems here that the behaviour and performance of the vessel is the result of a marriage of the hull form with the propulsor.

Heel angles

A third important aspect of steering with pods is the occurrence of large heel angles. The pods are very powerful steering tools. The side force that can be generated is so large, that the steered vessel can suffer from very large heel angles. At MARIN, heel angles of up to 25° have been measured with ship models due to regular steering. Knowing that the panic limit for passengers is at some 7°, it is obvious that this is undesired. The design consequences are that the hull form will have to be modified to assure that the heel angles will stay within acceptable values. It is important to check this with model tests before the ship is build.

Practical operation of pods and thrusters

Experience from past projects learns that crew training is becoming very important when ships are equipped with podded propulsors, which is true for steerable thruster units as well. Operating pods is a different way of sailing. The manoeuvring capabilities of vessels equipped with pods are potentially high, but full use of these capabilities requires crew training, preferably on a manoeuvring simulator in order to cover also propulsion emergencies. Examples of such projects are e.g. the cruise vessels built at MeyerWerft in Papenburg, who had to sail through the Ems to reach open sea. Very accurate steering is necessary and the slightest mistake will cause a risk on the loss of the ship. Other examples are the training of tugmasters, the handling of double-ended ferries such as for the PSD ferries and the TESO ferries. Figure 22 gives an illustration of a training for tugmasters on the handling of a tug while escorting large vessels.

Figure 22 Master training in tug handling at MARIN's simulator centre

Safety and structural loads

To get an appreciation of the structural loads that are met during operations with pod propelled ships, a large European project was initiated by MARIN. The reliability and safety of pods under operational conditions had to be monitored on full scale. This Joint Industry Project was designated "Pods In Service" and has the following objectives:

1. Assess the reliability and safety of pods under operational conditions
2. Evaluate the operational performance and benefits for the ship owners
3. Develop design, construction and classification methods.

In this Joint Industries Project, 25 parties are collaborating world-wide. Besides MARIN, these are the cruise line operators, navies, the pod manufacturers ABB Azipod, KaMeWa, Siemens-Schottel, shipyards and classification societies and VTT Finland (see Figure 23).

Figure 23 Participants in the Pods in Service Project (Kvaerner Masa-Yards meanwhile also joined the project)

During this project, four vessels will be monitored on full-scale during a period between 6 to 12 months of their operational life. The measured ships are the Summit (Millenium-class), the TT-line's Nils Holgerson, RCCL's Radiance of the Seas and the Finnish Botnica. During the monitoring campaign, there is a focus on structural excitation and response. To this end, the following signals are measured continuously: strains in shaft, gear and pod housing, hull pressure fluctuations, hull accelerations and vibrations and propeller blade strains. Simultaneously, the conditions are monitored continuously by registration of azimuth shaft torque and angle, input power and propeller rpm, ship draft, motions, speed and track and wind, waves and current. For one of the vessels, the underwater-radiated noise will be measured.

From the measured quantities, important feed back is obtained. This is not only hydrodynamic feed back with respect to the efficiencies and vibrations. Much structural feed back is presented and classification societies are using this to upgrade or determine the rules for the classification of podded vessels. A special work group consisting of all classification societies is developing and verifying computational and design methods for pod and hull strength.

The first ship, the Botnica, owned by the Finnish Maritime Administration, experienced a extreme severe storm situation (15 m significant waves) during the monitoring campaign. The results are being analysed during the first months of 2001. Then it also will become clearer what happened during that extreme event. But of course also the other information will be of importance to increase the knowledge related to the behaviour of the ship and its POD system during a longer period of time.

Final remarks

This paper gives a review of current issues in the design and application of steerable thrusters and podded propulsors. One can conclude from this review that the concept of steerable thrusters and its design space is relatively well known territory, yet leaving a number of pitfalls for the designer. The concept of the podded propulsor is relatively new, and relatively little empirical knowledge has yet been accumulated. Hence, designers and operators have to rely on model tests, supplemented with CFD calculations that require relatively little empiricism. For pods, one can state that the necessary empirical knowledge is generated more quickly than was the case with the steerable thruster some 50 years ago. This is achieved through sophisticated model tests supplemented with CFD computations and comprehensive full-scale measurement campaigns.

On podded propulsors, different applications and more sophisticated designs can be expected. An extension of the pod applications can be expected toward full block vessels and container ships. Research programs are already initiated for this. A higher degree of sophistication of the design seems especially possible in an optimisation of the combined hull form – pod system design (e.g. adaptation of hull lines) and in further reductions of the pod diameter and the optimisation of the stay (strut arm of the pod). In addition, the propeller optimisation will lead to a further improvement in efficiency and in cavitation and vibration reduction. It is expected that the range of applications will also grow with increasing insight in course keeping properties in calm water and waves.

Although this paper has dealt especially with hydrodynamic issues, we cannot evade the ever-important issue of economics. Even hydrodynamicists can see that a reduction of the price of the pods will definitely be beneficial toward extension of its use.

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