Hydrodynamic design challenges for very large container ships

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Introduction

A lot has been written about the development of container vessels from the first vessel, a converted World War II tanker, to the present largest ships in operation with capacities of more than 8000 TEU. Also market analysts believe that the tremendous growth in container carrying capacity has not yet come to an end. In all stages of the growth of the ships and the increase of ship service speed that came with it, demanding technical and operational challenges had to be overcome. The driving force behind this growth is the expected reduction in transportation cost per TEU (figure 1).

To look at the future hydrodynamic design challenges it is advisable to look at hydrodynamic problems of present ships. As hydrodynamics are only one aspect in ship design and cannot determine the hull and propulsion concept without consideration of other technical, operational and cost aspects, we also have to look at these.

Problems of present Very Large Container Ships related to ship Hydrodynamics

Today ships with a capacity of about 8000 TEU have approximate principle dimensions as shown below

LPP	320 m
B	42.8 m
T	14.5 m
CB	0.64
DP	8.8 m
PB	68.6 MW

They all have single screw propulsion and are designed for a service speed of 25 to 25.5 knots. To achieve this speed with the biggest engines that have been built until today, the resistance of the vessels is optimized in the usual manner. That means CFD analysis in combination with model testing are used. Fig. 2 shows a computed wave pattern. All large container ships built until today use slow

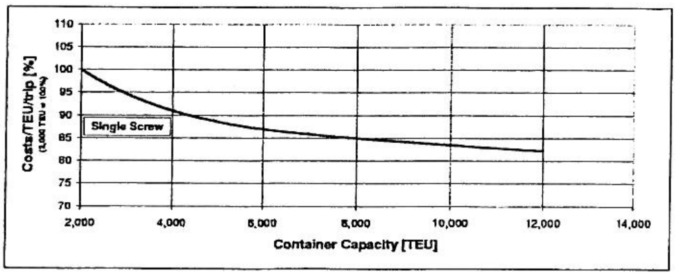

Fig. 1: Economy of scale, relative costs per TEU, according to Stopford, 2002

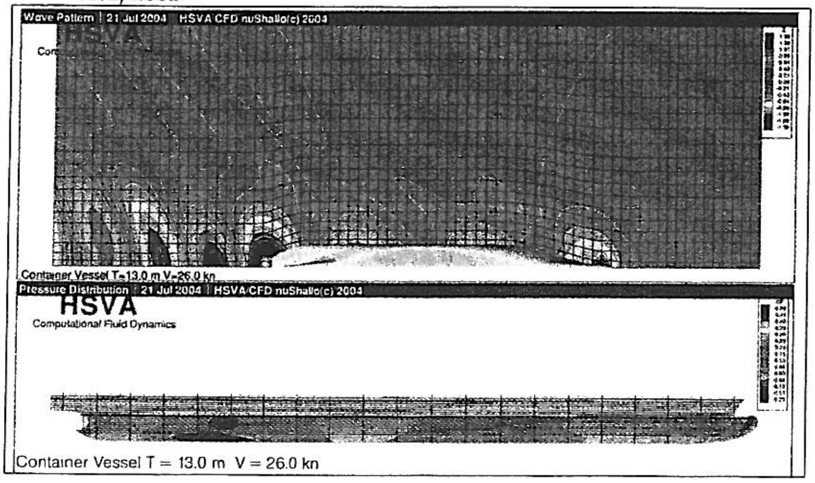

Fig. 2: Computed wave pattern for 8000 TEU ship at 26 knots is the basis for wave making resistance minimization

speed 2-stroke diesel engines as prime mover. The requirements for the propeller are as always efficiency, operation without erosive cavitation and low vibration excitation on the aft body. To fulfill these requirements the afterbody of the ship hull must be designed so that a good wake field (homogeneous inflow) and large tip clearance are achieved. Fig. 3 shows a typical wake field. The propeller tip clearance of large ships is typically between 35 % and 40 %.

A propeller tip speed of 46 m/s in combination with a power density of more than 1000 kW/m² definitely presents a challenge to the propeller designer. Blade area ratios in the order of 1.0 and 5 to 7 propeller blades are therefore selected for the propellers, leading to propeller weights in the order of 100 tons. Fig. 4 shows a typical cavitation pattern observed in HYKAT.

So far in all large container ships in operation semi spade rudders have been used for steering. While these rudders give sufficient manoeuverability, the operation behind the highly loaded propeller at 25 knots ship speed causes cavitation damages in many areas (Friesch, FAST 2003). Fig. 5 shows a rudder after about 12 months of operation. Model tests (fig. 6) show the reason for the damages. The propeller tip and hub vortices and the flow in the gaps around the pintle are the reasons for the erosive cavitation. Stainless steel plaiting seems to have reduced the problems in some cases. Change of material alone will however not be a long term solution. Modification of the leading edge spoilers etc. may help to improve the situation. Twisted leading edge spade rudders could help to solve the problems, see below.

When the first Post-Panmax vessels were built nobody anticipated any sea keeping problems – until the first problems with severe roll angles where reported on pacific crossings. Several ships have suffered high losses in cargo (fig. 7). The occurrence of high roll angles is related to parametric roll. Parametric roll occurs under the following conditions:

- the wave length is about 1 to 1.5 ship lengths.
- the ship heading its bow or stern into the waves.
- the ship natural roll period is approximately 0.5, 1 m 1.5 times the period of encounter.
- the ship initial stability varies significantly between the positions ship on the wave crest, ship in the wave trough.

The last condition holds true for all large container vessels with their large bow flare sections and wide afterbody, which lead to varying waterline shapes as illustrated in fig. 8. Wave lengths in the order of 300 m to 400 m exist in Pacific swells.

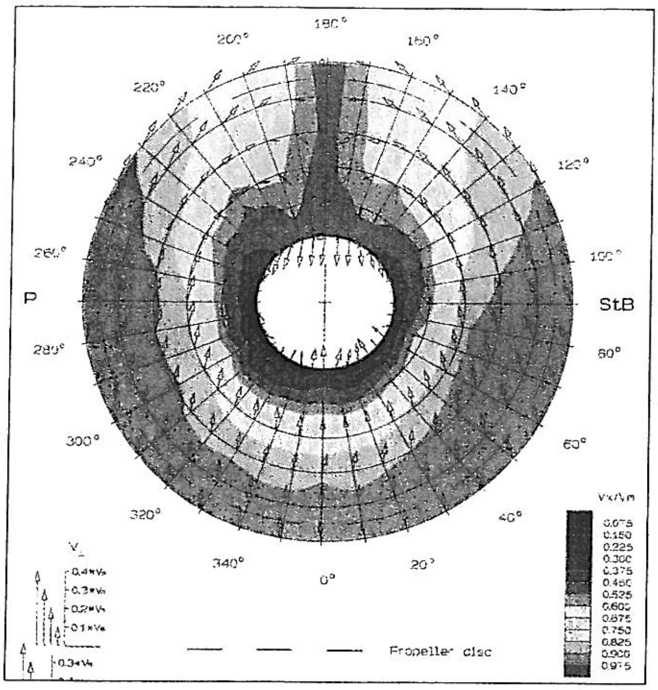

Fig. 3: Achsial and transverse flow in the propeller plane from model measurements

Steaming against the waves with 20 to 25 knots critical conditions may occur, when the metacentric height is between 2 and 3.5 m, which are typical values for such ships. Of course these simple estimates are not sufficient for a prediction of the roll angles and critical wave heights, where these conditions can occur. Even the frequencies are shifted due to nonlinear effects. However model tests and time-domain simulations can give more accurate insight. The type of countermeasures that can be considered are:

Operational measures: Avoid critical condition. Based on simulation results and wave spectra evaluation based on radar signals ship board systems are under development to warn the crew when they enter possible critical conditions.

Modified hull forms. As the basic mechanism for parametric roll excitation is well understood, hull forms can be designed, which are much less critical to parametric roll excitation.

- Increase of metacentric height.
- Increase of freeboard.
- Increase of passive damping (larger bilge keels).
- Active damping by stabilizer fins.

Development of ultra large container vessels

Economy of scale is driving the development to even larger container vessels. At the same time the required service speed is gradually increasing. To keep the same turn around times as smaller ships, although more time for cargo handling is needed, requires an increased service speed. Therefore it is likely that the desirable service speed may further increase to 26 or 27 knots.

From the hydrodynamic point of view a further increase in hull draft is also wanted for minimum power requirement. A study by Jensen und Kraus (The Naval Architect, 2004) has shown that optimum dimensions for a 13300 TEU Container Vessel with a design speed of 26 knots are approximately:

LOA	396.00 m
LPP	380.00 m
B	54.25 m
T	15.70 m
H	30.00 m
CB	0.66

Whether or not the draft will really increase, will depend on the development of container ports and terminals in the near future. For a design draft of 14.5 to 15 m the optimum breadth of the vessel is increased by one container width.

The required power to drive these ships obviously increases with ship size and speed. Thus the question of prime movers and propellers has to be newly addressed. So far all large container ships are single engine, single fixed pitch propeller driven. Engine Manufacturers will be able to provide main engines with output of more than 80 MW in the foreseeable future. In addition or alternatively electric power take ins can be considered (fig. 9), where a large diesel generator provides power for an electric motor driving the main shaft via a reduction gear box or directly in the shaft line. All known developments for increased main engine power are however expected to have a shaft speed of about 100 rpm. From the hydrodynamic point of view an increased propeller diameter at reduced rpm is recommended. An increase of diameter without reduction of the rpm will further increase the tip speed of the propellers with associated cavitation problems.

Successful propeller designs can only be achieved for hulls generating a wake distribution, which is as homogenous as possible. Optimising a propeller from the cavitation point of view has less chances once the wake pattern is unfavourable. Different types of profile shapes have been considered, mainly to delay cavitation inception and therefore to reduce the amount of cavitation for the main operation point of the ship. On these high powered container ships the amount of cavitation (extent and volume) are quite large. Optimisation from the cavitation inception point of view will lead to a significant reduction of cavity volume and therefore to reduced hull pressures. But there are hints from model tests in HYKAT in combination with full scale experiences showing that these measures may create an even higher risk of erosion and more fluctuating cavitation, increasing higher order pressure fluctuations.

A special tip geometry, which has been reported to increase propulsive efficiency, is the KAPPEL propeller (Friesch, NAV 2003). This concept »bents« the tip to the suction side, thus introducing a curved generator line in the tip area. MARIN reports comparable results for applying local tip rake to the pressure side. Both concepts claim improvements in efficiency with somewhat smaller pressure fluctuations.

Another point to be looked at more deeply is the risk of rudder erosion. From

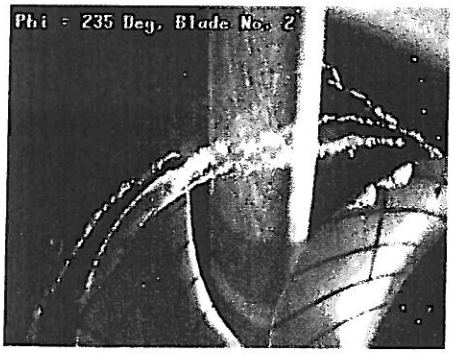

Fig. 4: Typical cavitation pattern observed in HYKAT

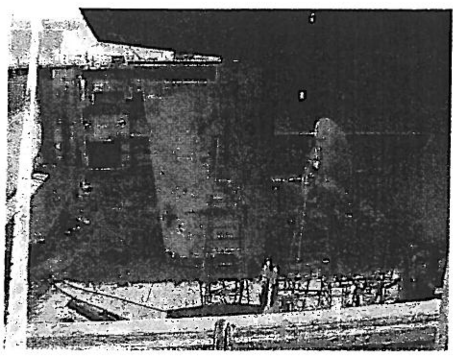

Fig. 5: Serious rudder damages caused by cavitation

Fig. 6: Cavitation patterns on a semi-balanced rudder

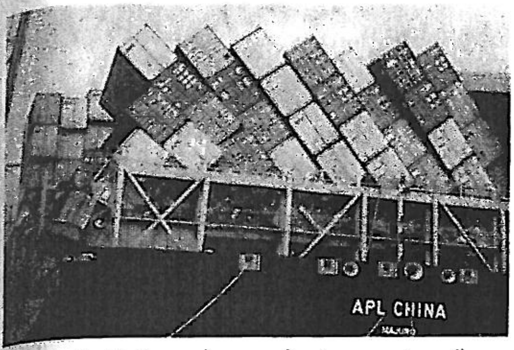

Fig. 7: Cargo damage due to excessive roll motion

the feed back from ship owners, it appears that there is a strong need to avoid cavitation erosion on the rudders. There are different types of rudder cavitation, such as bubble, sole, gap, propeller tip vortex, propeller-hub vortex cavitation and cavitation caused by surface irregularities. This means that rudder erosion damages can either be caused by self induced cavitation or by the cavitating propeller tip and hub vortices. While the influence of the propeller related cavitation occurrences must be tackled by the propeller design, the self induced types of cavitation should be considered in the early design stage. If semi-balanced rudders are used, much more attention must be given to the area of the lower pintle, but the use of full spade rudders with asymmetric leading edges is strongly recommended for these types of ships.

Fig. 10 shows a comparison between the computed pressure distribution on the rudder surface with and without leading edge twist. Fig. 11 shows a corresponding model test. Several large container ships under construction now will be equipped with twisted edge rudders of Becker Marine Systems and will show whether the problems could be solved.

Several studies suggest twin screw arrangements for ultra large container ships. The statement is often found that apart from the higher investment cost also the fuel consumption will increase with the twin screw concept. According to HSVA estimates the latter may not be true. If twin skeg hull forms are optimized for resistance and propeller inflow the resistance difference is expected to be only a few percent. On the other hand the propeller diameter and pitch can be selected optimum with a significantly smaller thrust loading and much less design constraints due to the cavitation problem. Therefore an increased propeller efficiency is expected. Only detailed case studies can show whether that will compensate the disadvantages of twin screw propulsion.

An other alternative is the application of podded drives in combination with a single directly driven propeller. There are suggestions to integrate the pod behind the propeller for a Counter-Rotating-Propulsion system. In fact a very good propulsive efficiency can be expected from such a concept if the share of propulsive power in the pod is high enough. Of course the investment cost per kW are much higher for a pod drive than for a diesel drive,

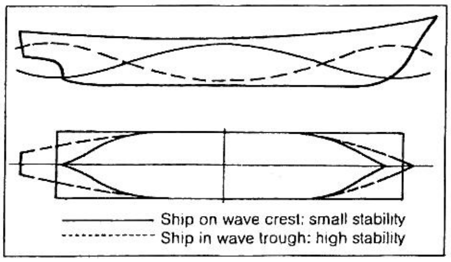

Fig. 8: Variation in waterline moment of inertia between wave crest and wave trough situation (Schneekluth, 1988)

which must be considered in the decision. Points that need to be considered in more detail are:

- check the optimum combination of load distributions.
- influence on the drag of the pod housing because of the contra-propeller arrangement.
- the cavitation behaviour of the aft propeller.
- the vibration and noise behaviour of both propellers in the higher frequency range.

Conclusion

The design of very large high powered container ships requires large efforts to design the best hull form and the most appropriate propeller in combination with the propulsion concept (single or twin screw) and with the selection of the main engine. Even if from the propulsion point of view for the single screw concept a large step forward seems to be difficult because of the problems related to efficiency, erosion and vibrations, because of the commercial advantages, this concept should be pushed ahead steadily. Twin screw propulsion or contra-rotating arrangements with a pod could be interesting solutions, but further research is needed to prove their feasibility and economy.

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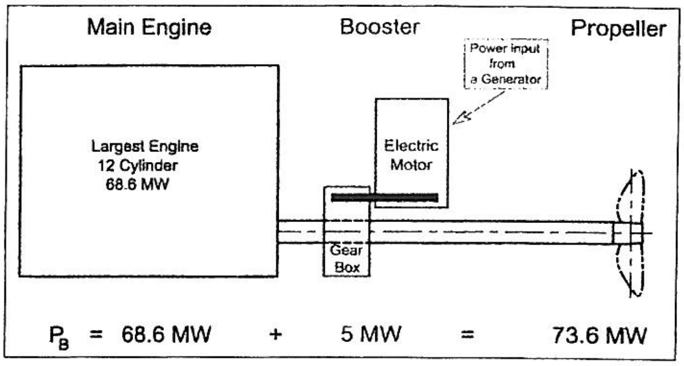

Fig. 9: Power-take-in / principle sketch

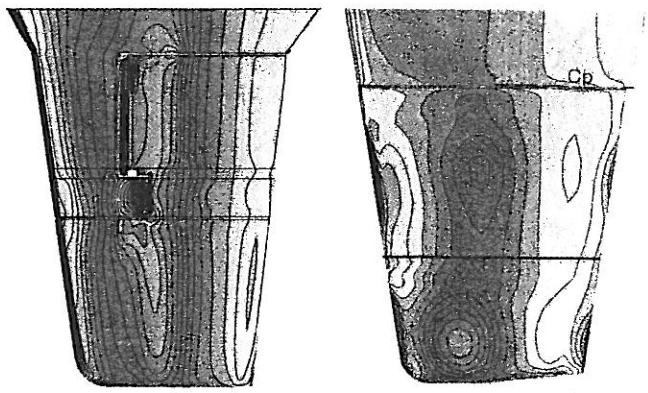

Fig. 10: Computed pressure distribution on different rudder geometries

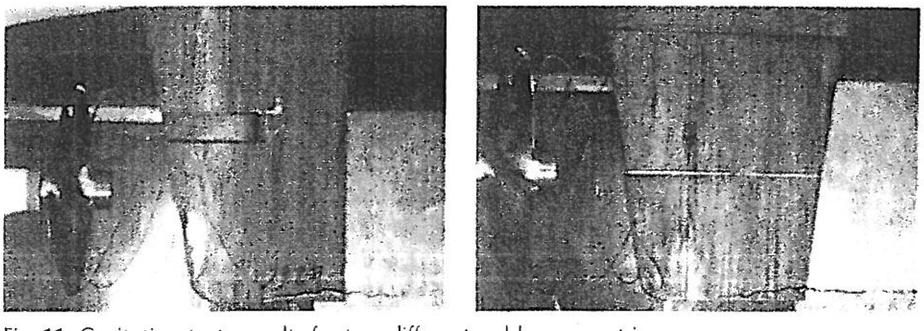

Fig. 11: Cavitation tests results for two different rudder geometries