Very Large Container Ships
Difficulties and Potential from the Hydrodynamic Standpoint

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Abstract

In this paper the past, present and future of container ship design is briefly discussed. Hydrodynamic aspects such as propulsion concepts, rudder cavitation and parametric rolling are discussed. Current trends in container ship design are demonstrated on the basis of model tests performed at the Hamburg Ship Model Basin (HSVA) throughout the last decades. Alternative concepts to overcome current limits in ship size and speed are given.

Keywords

Container Ship, VLCS, ULCS, Hull Lines, Propeller, Rudder, Cavitation, Stability

1 Introduction

During the last four decades the loading capacity of container ships has increased from a few hundred TEU for the first full container ship to more than 8,000 TEU for the most modern vessels now in operation. Over this period of development numerous design and construction problems associated with the increasing size of the vessels and their propellers were overcome. The demand for sufficient stability, higher speeds and low vibration levels has led to new hull forms specific to this type of vessel.

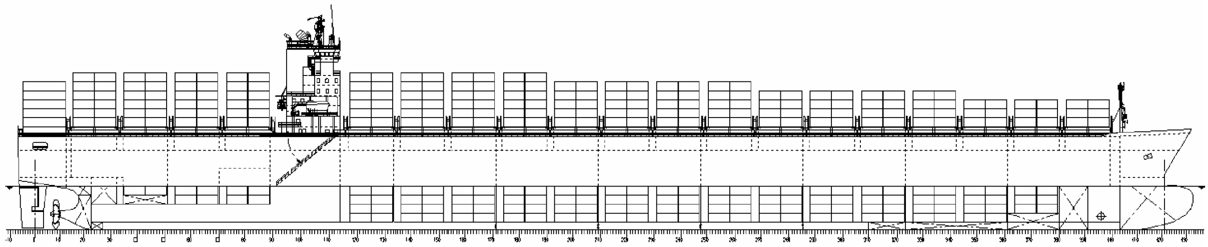

Fig. 1.1 – Side View of an 8,200 TEU ULCS (Source: Aker Ostsee)

What has not changed over the years is the propulsion concept consisting of a single propeller driven directly by a two-stroke diesel engine. This has been the optimal solution with regards to both investment cost and overall efficiency. However, with increasing ship size and speed, new hydrodynamic problems are appearing as a result of the higher propeller loading. This can make it interesting to consider alternative propulsion concepts for these ships.

In this paper certain hydrodynamic aspects concerning very large container ships are discussed. These include propeller design requirements for low vibration excitation, rudder cavitation problems, parametric roll motions and more. The causes of these problems are addressed and some hints are given regarding how to avoid them.

Furthermore the paper discusses the pros and cons of further possible propulsion alternatives for ultra large container ships from the hydrodynamic point of view. These include twin screw propulsion, single screw with additional podded drive arranged behind the single propeller, single screw with additional twin pod drives and more.

In this paper we use the acronym VLCS (Very Large Container Ship) for all Post-Panmax ships with a container capacity up to 8,000 TEU. For container ships with a capacity exceeding 8,000 TEU we use the acronym ULCS (Ultra Large Container Ship).

Quite often the container capacities found in the literature as well as in ship descriptions are theoretical or geometrical figures. Sometimes these figures must be reduced by about 10% to get the real container capacity.

2 History

In 1956 the first container line started from Port Newark to Houston, Texas with a converted World War II T2-tanker. The ship’s name was “Ideal X” and she was able to carry 58 35’ containers. The benefits from the much shorter loading and harbour times were so convincing that American ship owners converted more and more old vessels to carry the new kind of cargo. Fig. 2.1 gives an impression of this first mile stone in container shipping. The first container ship without ship borne loading gear was the “Sea-Land Venture”, which entered service only a few years after the “Ideal X” made her maiden voyage as a container ship.

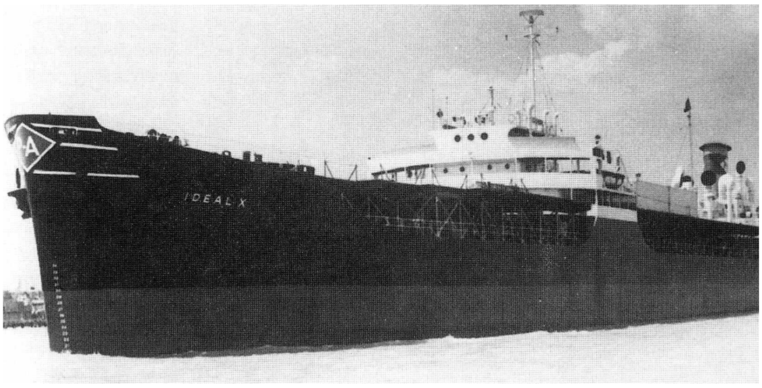

Fig. 2.1 – „Ideal X“, First Container Ship (Source: Witthöft, 2001)

As container shipping was invented in the USA, it is clear that the dimensions of the first containers followed American standards. Later on the ISO defined a standard container with a length of 20 ft (6.035 m), a width of 8 ft (2.435 m) and a height of 8 ft (2.435 m). This container is the basis for the world-wide used TEU (Twenty Feet Equivalent Unit).

The success of the new transport concept was exceptional and the container ships grew very quickly in size and container capacity. In the beginning the ships were classified using the generation concept:

1st Generation with about 1,000 TEU occurred for the first time in about 1966,

2nd Generation with about 2,000 TEU occurred for the first time in about 1969,

3rd Generation with about 3,000 TEU occurred for the first time in about 1972.

For the following ships with higher container capacities the generation classification concept was no longer used. However the ships still grew and especially the geometry of the locks of the Panama canal was limiting the ship size. The “Panmax” container ship was born and had the following principle dimensions:

Length over all:	max. 294.1 m
Width:	max. 32.3 m
Draught:	max. 12.0 m

Panmax container ships have a maximum container capacity of about 4,500 TEU. This limit was reached in the late 1970’s. It took about one further decade before the first container ships were built which could not pass the Panama canal. These ships were consequently called “Post-Panmax” container ships. Nowadays all container ships with a capacity exceeding about 5,000 TEU are Post-Panmax ships.

Fig. 2.2 shows the currently world largest container ship. It is the “OOCL Shenzhen” with an official container capacity of 8,063 TEU.

Fig. 2.2 – „OOCL Shenzhen“, 8,063 TEU, World Largest Container Ship

The next geographical limits for the size of container ships are given by the dimensions of the Suez canal. The Suezmax dimensions are defined as follows:

- Width x Draught < 820 m²,
- Width < 70 m,
- Draught < 21.3 m.

Within these limits container ships with a capacity up to about 13,000 TEU are feasible.

Generally the width of container ships is defined by the number of container stacks in the transverse direction. Thus, the width of the ships increases in steps of about 8 ft. Up till now a width of 43 m corresponding to 17 container stacks abreast has been built. In the cargo rooms nine layers of containers are stowed, while seven layers are usual on deck. The draught increased to a maximum of about 14.5 m. Here the limiting factor is the water depth in the harbours which are economically reasonable and capable of serving the very large container ships. Only few harbours are on this list nowadays,. and for future ultra large container ships the list is even shorter.

In Tab. 2.1 the main particulars are summarised for some historical container ships.

Year	Capacity [TEU]	Name	Yard	L [m]	B [m]	T [m]	V [kts]	P_B [MW]
1956	58 (35')	Ideal X	(U.S.)	(174.2)	(23.6)	?	(18.0)	(2x ?)
1968	730	ELBE EXPRESS	B&V	171.0	24.5	7.9	20.0	?
1981	3,430	FRANKFURT EXPRESS	HDW	271.0	32.28	11.5	23.0	2x 20.0
1991	4,407	HANNOVER EXPRESS	Samsung	281.6	32.3	13.5	23.0	36.5
1995	4,832	APL CHINA	HDW	262.0	40.0	12.0	24.6	48.8
1996	(6,000 ?)	Regina Maersk	Odenese	302.3	42.8	12.2	24.6	54.9
2001	7,506	HAMBURG EXPRESS	Hyundai	304.0	42.8	14.5	25.0	68.6
2003	8,063	OOCL Shenzhen	Samsung	308.0	42.8	14.5	25.2	68.6

Tab. 2.1 – Main Particulars of Historical Container Ships

3 Possible Developments for Future ULCS

Today it is likely that the size of container ships will continue to increase within the near future. Ships with a capacity of 8,400 TEU are under construction.

Furthermore, it is likely that the upcoming giant container ships will be single screw vessels. Due to economic reasons twin screw vessels are currently not competitive.

The larger the container ships are, the faster they have to sail from port to port in order to maintain acceptable container line schedules and to successfully compete with smaller container ships (see Fig. 6.1). Nowadays the largest two stroke diesel engine with 12 cylinders offers a brake power of 68.6 MW. With this installed power it is possible to have an 8,000 TEU container ship sailing at a service speed of about 25.2 kts. Generally this speed is considered to be too low for the anticipated container service.

With increasing size of the container ships the required brake power of the main engines increases too. Tab. 3.1 gives a rough overview of the ship capacities and the corresponding required ship speeds and engine powers.

Capacity [TEU]	Required Service Speed [kts]	Required Engine Power (MCR) [MW]	No. of Required Cylinders
8,000	25.4	74	13
9,000	25.6	80	14
10,000	25.7	86	15
11,000	25.8	93	16
12,000	26.0	100	18

Tab. 3.1 – Single Screw, ULCS, Required Power

In Tab. 3.2 the main particulars of some projects for future ULCS are summarised. Comparing these data with the data from Tab. 3.1 it is obvious that none of the projected container ships is likely to reach the required service speed.

Capacity [TEU]	Type	Source	L [m]	B [m]	T [m]	V [kts]	P_B [MW]
8,000	Single Screw	HDW	325.00	46.00	13.00	25.3	68.6
9,000	Single Screw	Samsung	334.00	45.60	13.00	25.0	68.6
10,000	Single Screw	HSVA	360.00	50.00	14.00	25.5	80.0
10,000	Single Screw	MARIN-Wärtsilä	349.00	49.00	14.00	25	80.0
12,000	Single Screw	MAN B&W	380.00	52.50	14.60	25.5	85.8
12,000	Twin Screw	MAN B&W	380.00	52.50	14.60	25.5	2x 42.8
12,500	Twin Screw	BV / K.E. Hansen	378.00	54.20	14.50	?	2x 40.0
18,000	Twin Screw	MAN B&W	450.00	60.00	15.70	25.5	2x 51.4

Tab. 3.2 – Possible Main Particulars for Future ULCS

4 Hull Lines

The hull lines of very large container ships (VLCS) have developed within the 40 year history of container ship design. The hull lines designs evolved continuously from the first design to the latest new buildings throughout all generations. In principal no special hull lines are needed for the VLCS. The single screw container ship is currently the one and only concept for this ship type which can be operated economically. However, due to the very highly loaded propellers the aft body should be designed very carefully with respect to the quality of the wake field.

Fig. 4.1 shows the measured wake field of a 8,100 TEU container ship model which is considered to be sufficiently good.

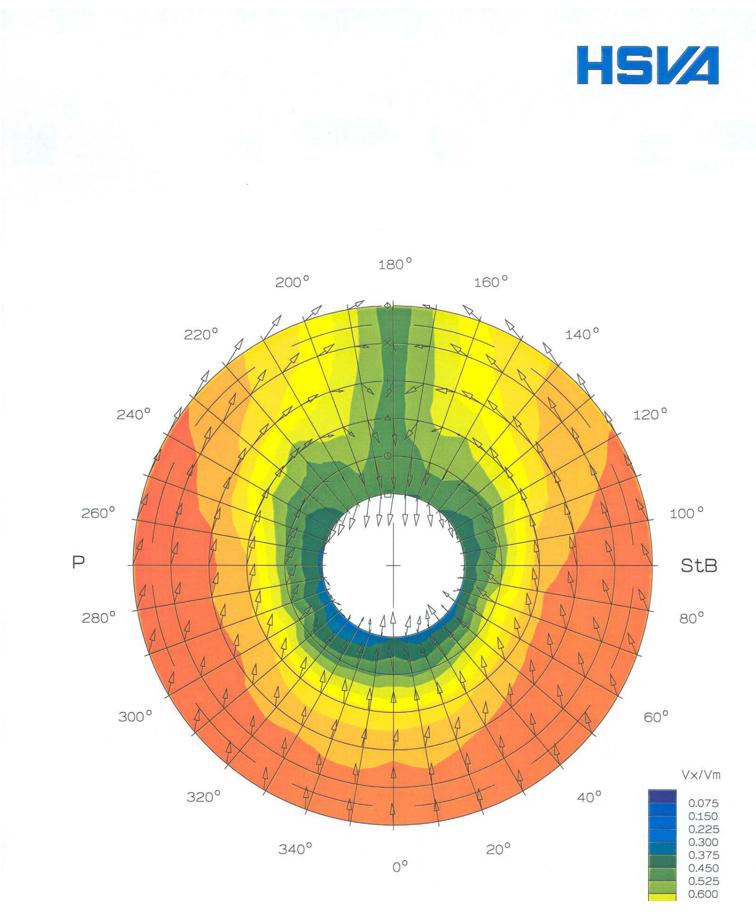

Fig. 4.1 – Typical Wake Field of a ULCS – 8,100 TEU

Fig. 4.2 shows a body plan typical for an 8,000 TEU container ship. In Fig. 4.3 to Fig. 4.5 the block-coefficient, the water-plane coefficient and the longitudinal centre of buoyancy are plotted in relation to the displacement volume of container ships investigated at HSVA. These values do not change significantly as a function of the ship size. The mid-ship section coefficient is independent of the ship size and has a value of about 0.98. With increasing delivered power the vertical propeller tip clearance increases and should be more than 35% for an 8,000 TEU ship (see Fig. 4.6).

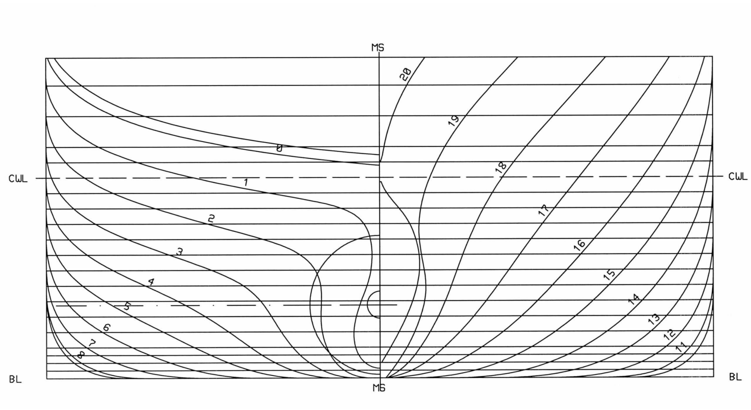

Fig. 4.2 – Typical Hull Lines of a ULCS – 8,100 TEU

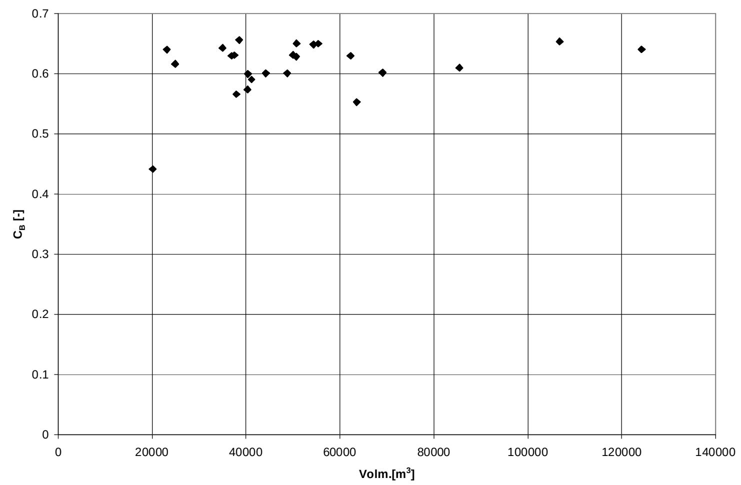

Fig. 4.3 – C_B = f(Volume)

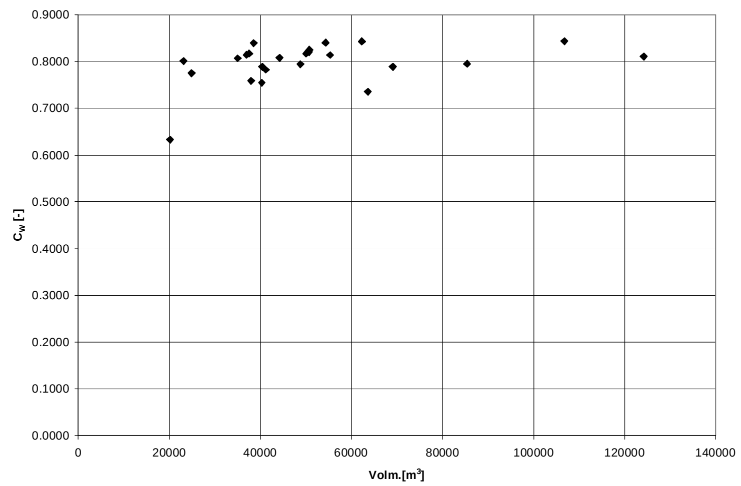

Fig. 4.4 – C_{WP} = f(Volume)

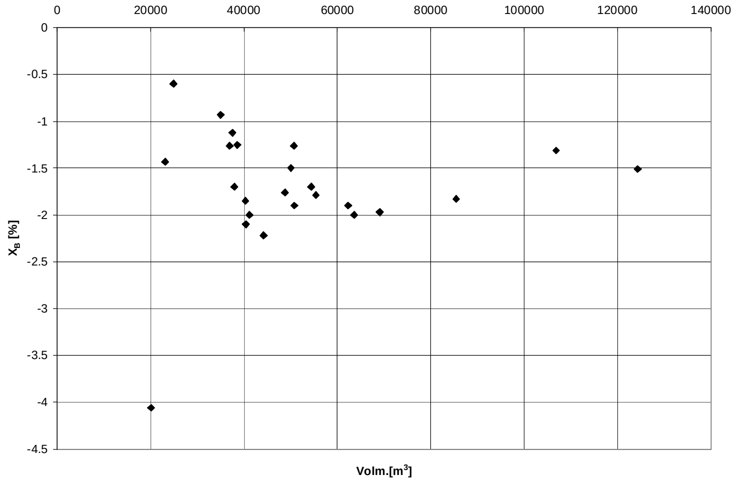

Fig. 4.5 – LCB = f(Volume)

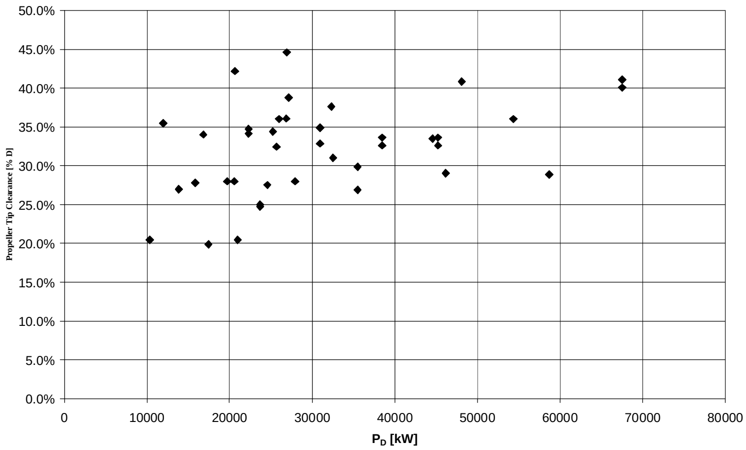

Fig. 4.6 – Vertical Tip Clearance in Percent of the Propeller Diameter

5 Propeller and Rudder

From the hydrodynamic point of view the propeller and the rudder are the most problematic elements of a very large container ship.

Fig. 5.1 presents the power density and tip speed of container ship propellers as functions of the container capacity. For an 8,000 TEU vessel the power density is about 1,100 kW/m². The corresponding tip speed is about 44 m/s. These values are extremely high and require a very thorough design of the propeller as well as of the rudder, which lies in the slip stream of the propeller.

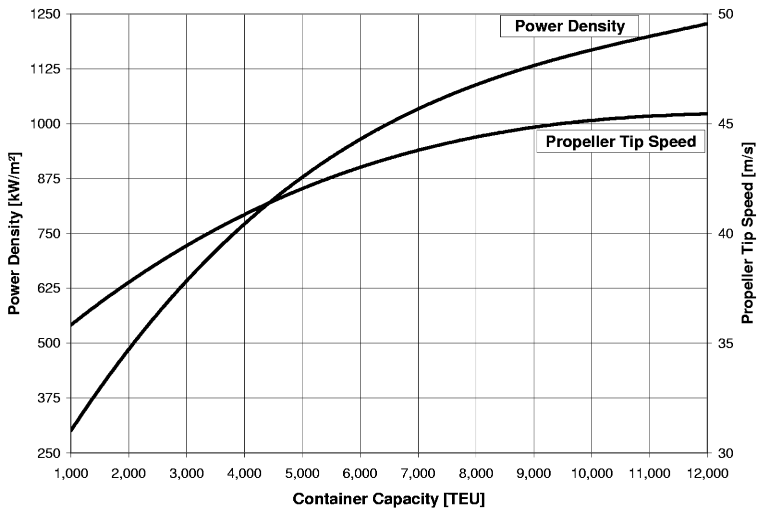

Fig. 5.1 – Power Density and Propeller Tip Speed for Container Ships (Courtesy of MMG)

In Fig. 5.2 to Fig. 5.4 some geometric properties of built propellers for large container ships are plotted in relation to the delivered power. The largest propeller diameter is about 9.0 m. The number of propeller blades increases for larger ships and delivered powers. Nowadays six bladed propellers for VLCS are state-of-the-art. In order to manage the high delivered powers a blade area ratio of about 80-90% are required.

One of the limiting factors for the size of the propeller is the casting weight which clearly exceeds 100 t for a 9.0 m propeller. Another limit is set by the draught of the container ships which is usually a maximum of 14.5 m (scantling draught) for container ships with more than 6,000 TEU. The demand for high propeller efficiency, acceptable pressure pulses and the absence of erosive cavitation lead to new and sophisticated propeller blade geometries. Only few propeller designers world-wide are able to deliver such high level propeller designs.

Fig. 5.5 shows the design propeller speed for large container vessels in relation to the delivered power. The design propeller speeds for very large container ships are either 94 rpm or 102 rpm, depending on the type of the installed main engine (see section 6).

The rudder is located directly behind the propeller. Due to the high propeller slipstream speeds the rudders of large container ships are highly loaded. Thus these rudders are endangered with regard to cavitation and erosion (see section 7). The rudder for very large container ships cannot be built just following geometrical rules. It must be designed like a propeller. Asymmetric leading edges and special designs for all gaps in the propeller slipstream are required to avoid erosion. The latest trend is to use spade rudders which avoid by principle any gaps in the highly loaded areas.

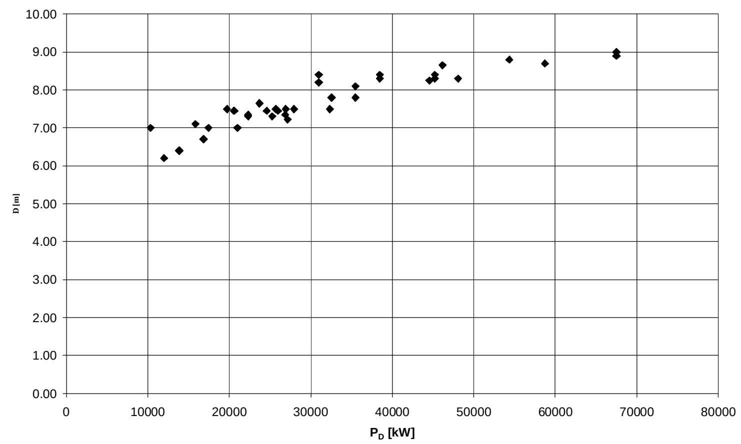

Fig. 5.2 – Propeller Diameter $D_P = f(P_D)$

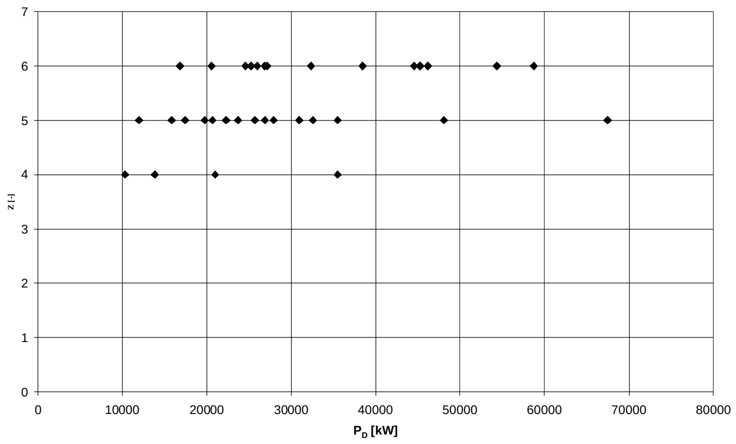

Fig. 5.3 – Blade Number z = f(P_D)

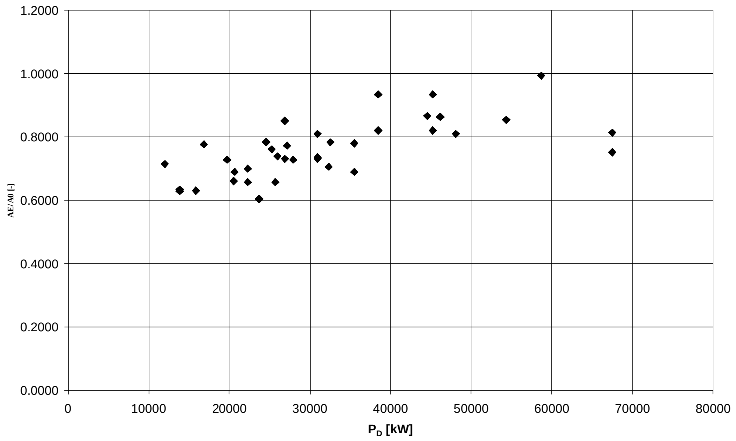

Fig. 5.4 – Expanded Blade Area Ratio A_E/A_0 = f(P_D)

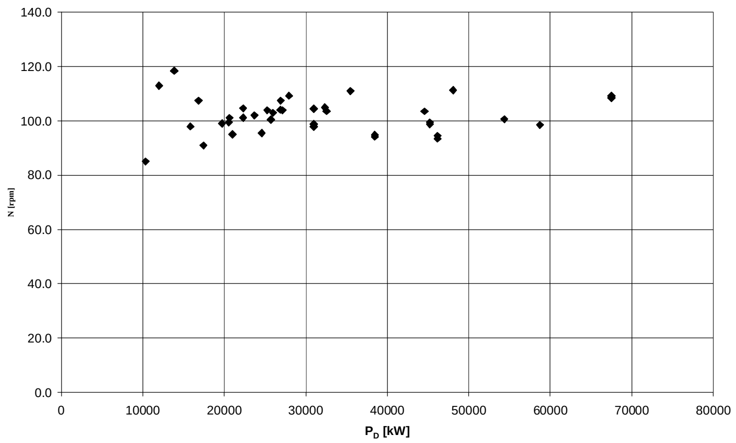

Fig. 5.5 – Propeller Speed n = f(P_D)

6 Speed and Power

Container ships with higher container capacities have to sail at higher speeds than those ships with lower capacity, if they want to be competitive. The reason is simply the longer time in the harbour which is needed to load and unload the high number of containers. This is the reason why the ship speed is of so enormous importance for large container ships. Container ships carrying more than 6,000 TEU have to sail with service speeds of more than 25 kts.

Nowadays two-stroke engines drive the propeller directly. Thus, the available most powerful main engine limits the speed of very large container ships. Currently this most powerful motor is the 12K 98MC designed by MAN B&W and is built by

Hyundai. The twelve cylinders of this motor develop a brake power of 68,640 kW at 94 rpm. Hyundai also offers this motor with up to 18 cylinders. But these motors have not been built up till now. A motor with 18 cylinders would offer a brake power of 102,960 kW.

The competing motor 12RTA96C from Sulzer offers a brake power of 68,640 kW at 102 rpm.

During service not the theoretical maximum power (MCR) is available at the propeller, but a much lower power. The example in Tab. 6.1 shows that during sea trials only about 71% of the installed engine power is taken into account at the propeller for the determination of the service speed.

MCR (100%)		68,640 kW	= $P_{B,max}$
NCR (e.g. 90% MCR)	=0.9 x MCR	61,780 kW	
- Losses in Coupling, Shaft and Gear (e.g. 1%)	-0.01 x NCR	-620 kW	
Max. Delivered Power (Service Condition)	= 0.9 x 0.99 x MCR	61,160 kW	= $P_{D,Service}$
- Sea Margin (e.g. 20% $P_{D,Service}$)	-0.2 x $P_{D,Service}$	-12,230 kW	
Max. Delivered Power (Trial Condition)	= 0.8 x 0.9 x 0.99 x MCR	48,930 kW	= $P_{D,Trial}$

Tab. 6.1 – Exemplary Calculation of the Delivered Power P_D

Fig. 6.1 presents the required ship speed and the corresponding required delivered power as functions of the container capacity of single screw container ships. It also shows that due to the limited available power of the main engine nowadays only container ships with less than about 7,300 TEU can be operated with the required ship speed. Larger vessels cannot sail fast enough to offer a competitive container line service until more powerful main engines are built and become available.

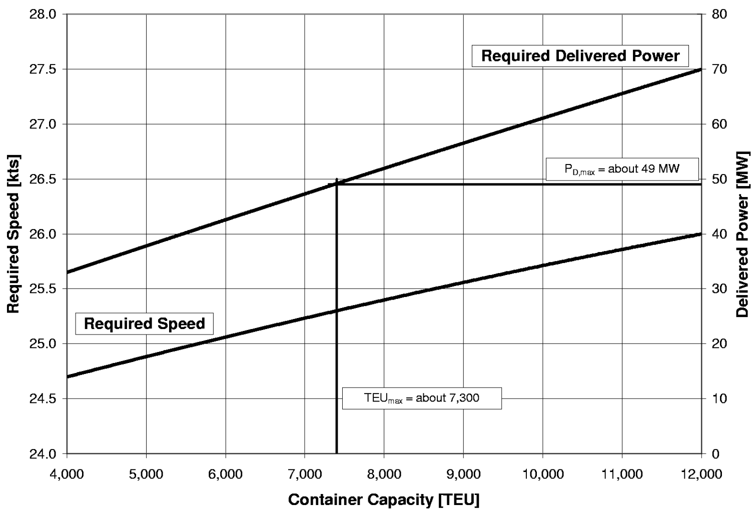

Fig. 6.1 – Required Speed and Delivered Power for LCS

Fig. 6.2 and Fig. 6.3 show the delivered power (trial conditions) and the specific delivered power as functions of the displacement volume with the ship speed as parameter. These diagrams are suitable for a rough estimation of the required power for new project vessels. But for actual projects the block coefficient and the prismatic coefficient should be taken into account as well as the quality of the hull lines and the propeller. Furthermore, the interaction of ship hull, propeller and rudder must be considered.

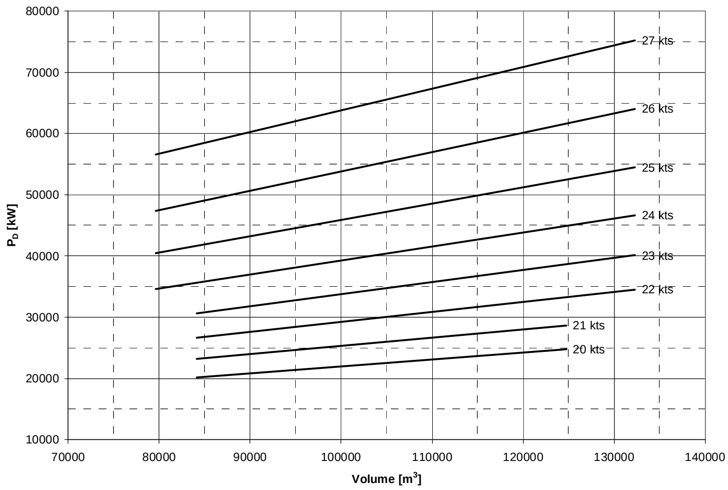

Fig. 6.2 – Power Requirement of VLCS

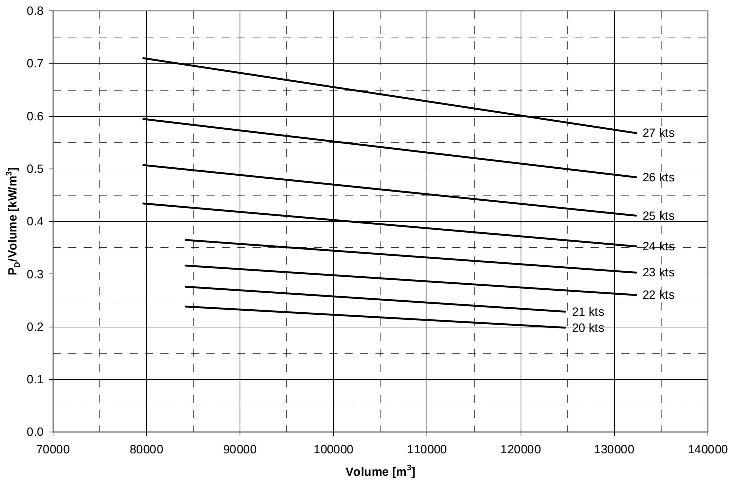

Fig. 6.3 – Specific Power Requirement for VLCS

Fig. 6.4 shows the relationship between ship speed and displacement volume of container ships that have already been built. While small container ships with a displacement of about 40,000 m³ (about 2,500 TEU) sail with at most 23 kts, the speed increases to more than 25 kts for ships with a displacement of about 80,000 m³ (about 6,000 TEU).

Fig. 6.5 to Fig. 6.9 present the thrust deduction fraction, the wake fraction, the relative rotative efficiency, the propeller efficiency and the overall propulsive efficiency at service speed as functions of the displacement volume (container ships only). These data are derived from model tests with actual design propellers at HSVA. The values are valid for the design draught.

The following table summarises the propulsion coefficients for an 8,000 TEU container ship.

Speed	abt. 25.2 kts
t	0.13 to 0.15
w_T	0.18 to 0.20
η_R	1.02 to 1.04
η_0	0.66 to 0.68
η_D	0.72 to 0.75

Tab. 6.2 – Propulsion Coefficients, 8,000 TEU VLCS

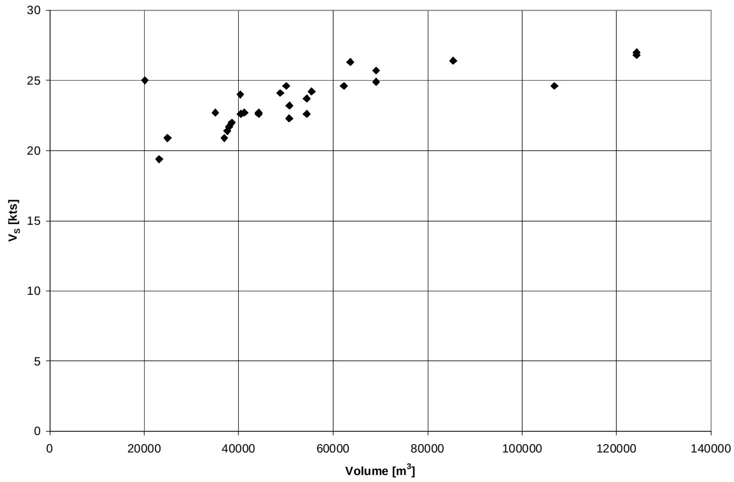

Fig. 6.4 – Service Speed V_S = f(Volume)

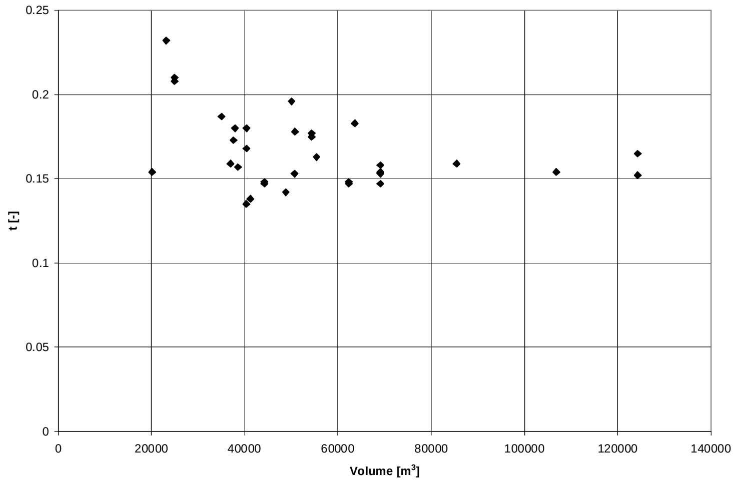

Fig. 6.5 – Thrust Deduction Fraction at Service Speed t = f(Volume)

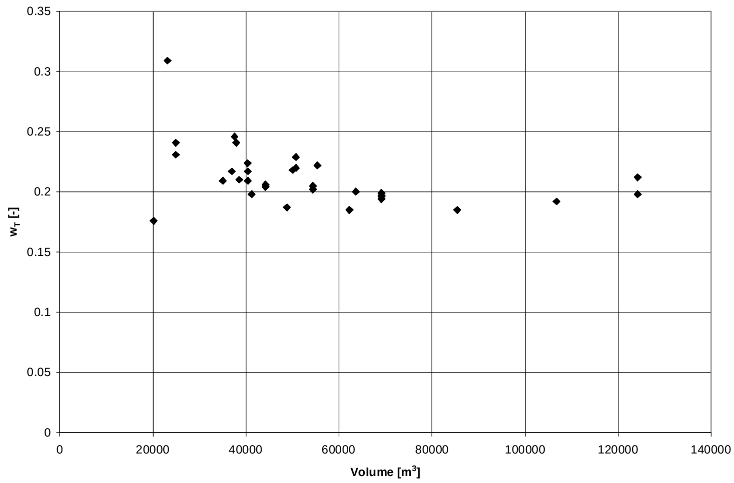

Fig. 6.6 – Wake Fraction at Service Speed w_T = f(Volume)

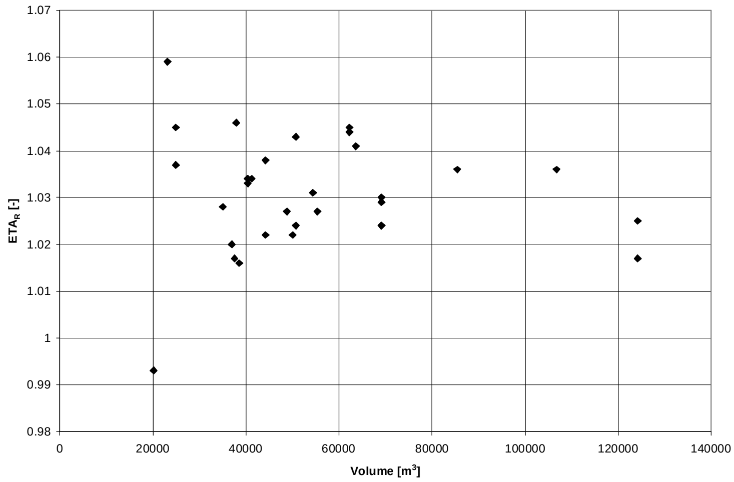

Fig. 6.7 – Relative Rotative Efficiency at Service Speed η_R = f(Volume)

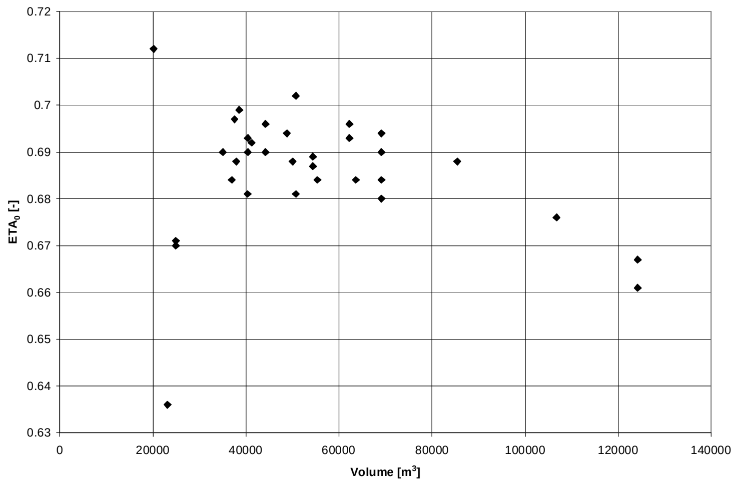

Fig. 6.8 – Propeller Efficiency at Service Speed η_0 = f(Volume)

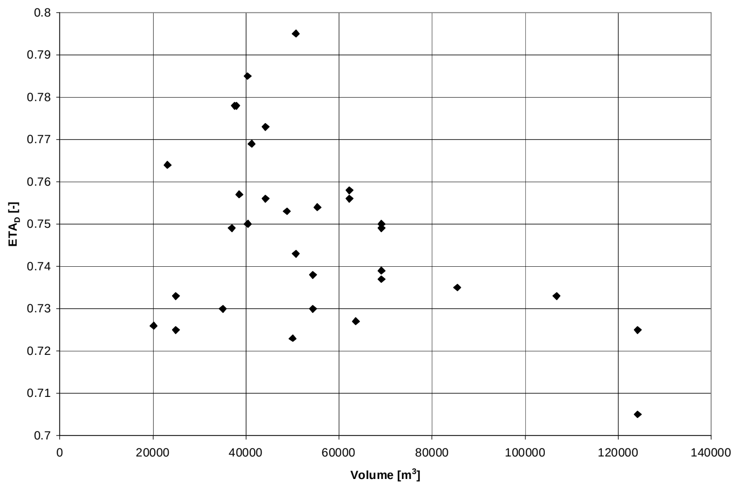

Fig. 6.9 – Propulsive Efficiency at Service Speed η_D = f(Volume)

7 Special Hydrodynamic Problems of VLCS and ULCS

7.1 Propeller Cavitation

Propeller cavitation is not a special problem of very large container ships alone. But due to the very high power density the propellers of VLCS and ULCS are more endangered from cavitation than those of smaller container ships.

In Fig. 7.1 the pressure pulses of the first harmonic are presented in relation to the delivered power of container ships. These pressure pulses were measured during cavitation tests in HSVA's large cavitation tunnel HYKAT. For the vibration excitation of the ship hull structure the second and the third harmonics are important, too.

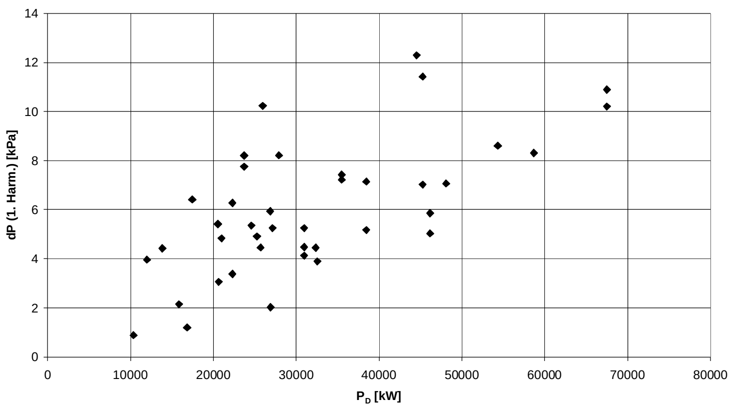

Fig. 7.1 – Measured Pressure Pulses, 1st Harmonic

7.2 Rudder Cavitation

Not only the ultra large container ships themselves and their propellers are huge, but also the rudders are incredibly large. The movable part of the most commonly used semi-balanced rudders is up to 12 m high and often more than 7 m long. Due to the high ship speed and the enormous amount of energy transmitted from the propeller to the water, the rudders are put to a high risk for cavitation even at small rudder angles. These small rudder angles occur very often during service, since small course corrections are required to keep the ship on track. Thus the rudders are highly endangered from cavitation induced erosion. Erosive damages often occur after the first voyages. These problems can be avoided and overcome if the rudder is designed carefully.

In the last years the number of rudder cavitation investigations in HSVA's HYKAT facility has increased significantly. These tests prove that the rudder cavitation problems can be minimised with a well designed rudder. Fig. 7.2 presents sketches of the observed cavitation pattern on the suction side of the rudder of a very large container ship at rudder angles of 4 and 10 degrees.

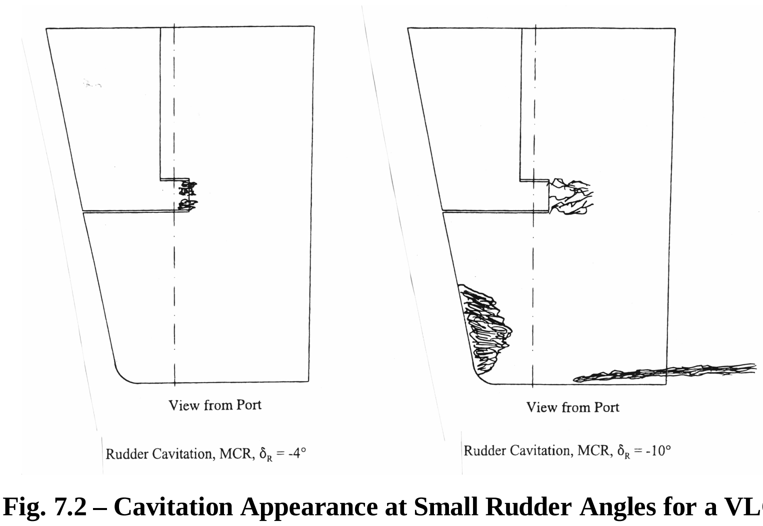

Fig. 7.2 – Cavitation Appearance at Small Rudder Angles for a VLCS

7.3 Parametric Rolling

Parametric roll motions occur when the wave length of head or following seas is close to the ship length. Due to the significant changes of the ship stability (high stability in the wave trough and low stability on the wave crest, see Fig. 7.3) massive roll motions can be induced if the exciting period is a multiple of the ship's half natural period. Under these conditions the roll motions reach the highest amplitudes. In extreme cases the ship may capsize.

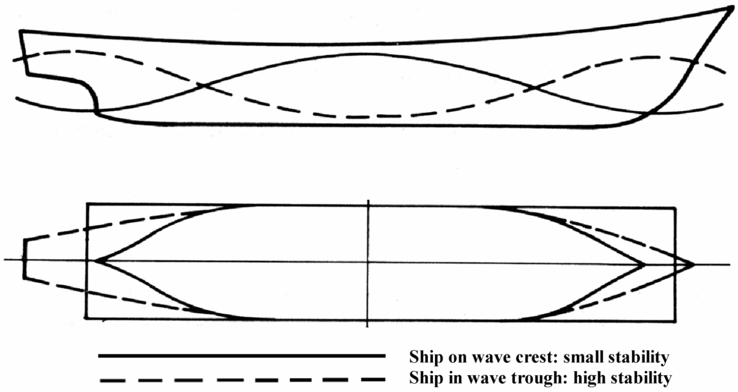

Fig. 7.3 – Ship Stability on Wave Crest and in Wave Trough (Source: Schneekluth, 1988)

In principle the phenomenon of parametric rolling applies to all ships. But very large container ships are especially endangered, since their principle dimensions nicely fit to the ocean’s waves. Furthermore, the container ships have very low metacentric heights, i.e. a low transversal stability.

Parametric rolling could be counteracted with special hull forms, especially at the ship ends, and active roll damping devices like fin stabilizers or roll damping tanks.

Furthermore, higher metacentric heights could be achieved by correct distribution of cargo and ballast water. And last but not least the risk of parametric rolling can be reduced by choosing the right course and ship speed.

Fig. 7.4 shows an example for damaged cargo due to parametric rolling.

Fig. 7.4 – Cargo Damages after Parametric Rolling

7.4 Speed and Power

The most powerful main engine which is currently available is a two stroke diesel engine with 12 cylinders and a brake power of 68,640 kW. With this engine the required service speed for single screw container vessels can be realised for ships with up to about 7,300 TEU. Fig. 7.5 presents the relationship between the required and the achievable speed as a function of the container capacity. It clearly shows that for very large container ships with about 8,000 TEU, every tenth of a knot is essential.

In order to achieve the very high ship speeds the hull lines as well as propellers and rudders of ultra large container ships must be optimised most thoroughly. Although the most modern CFD-tools and the whole know-how collected in ship model basins, design bureaus and ship yards are used for the design and optimisation of the hull lines design, intensive model test series are still required to gain the last tenths of a knot in ship speed in order to fulfil the contract speed in combination with an acceptable cavitation performance. Often the final optimisation is limited to local improvements of the bulbous bow, the aft body, the rudder design, the arrangement of the rudder and propeller as well as the investigation of additional devices for improving the propulsion efficiency, e.g. rudder bulbs.

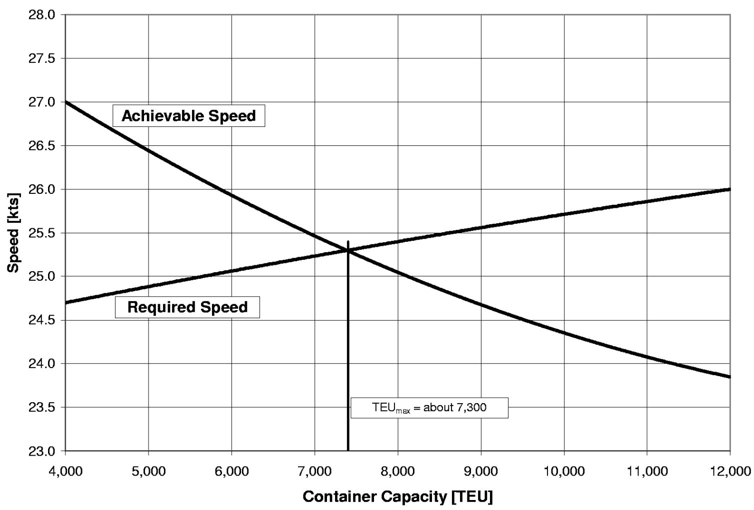

Fig. 7.5 – Required and Achievable Speed for Single Screw Container Ships with the Most Powerful Main Engine (P_B = 68,640 kW) Currently Available

Tab. 7.1 summarises the final optimisation steps for a very large container ship. Tab. 7.2 shows the corresponding calculation of the achieved cost reduction for a 7,500 TEU container ship based on a reduction of the power consumption by 5%. The cost reduction of about 500,000 USD per year and ship is much more than the costs for the optimisation by CFD-calculations and model tests.

Modification	**ΔP_D [%]**	**ΔV [kts]**
1. Transom extension 2 m	1.2	
2. Transom extension 4 m	1.9	
3. Transom extension 2 m, Rudder 0.8 m aft	0.1	
4. Transom extension 2 m, Rudder 0.8 m aft, Propeller 0.8 m aft	3.9	
5. Same as 4. with rudder bulb 1	3.6	
6. Same as 4. with rudder bulb 2	5.0	
Speed gain with 6.		≈ 0.26 kts

Tab. 7.1 – Optimisation of a 7,500 TEU Container Ship

Daily consumption	200 t
Daily gain	-10 t
Annual gain	= -10 t *250 = 2,500 t
Possible annual cost reduction	500,000 USD

Tab. 7.2 – Cost Reduction due to 5% Lower Power Consumption

8 Further Future Developments for ULCS

Nobody is able to predict the future, but with knowledge about history it is possible to identify trends which might extend into the future.

Within the last 10 years the capacity of a single container ship increased by about 30% from 6,000 TEU to more than 8,000 TEU. Nowadays the motor required to drive a single screw container ship with 10,000 TEU at a speed of more than 25 kts. is not available. But the past has shown that the limits have been continuously pushed towards higher and higher power levels.

In the following sections some alternative propulsion concepts for ultra large container ships are presented.

8.1 Single Screw – Larger Engine

The most likely option is the development, manufacture and installation of more powerful two-stroke diesel engines (see section 6).

8.2 Single Screw – Lower Speed

It seems that the most reasonable alternative is the reduction of the ship speed. As an example: For a speed of 23 kts a ship requires about 25-30% less power than for a speed of 25 kts. However, according to the statements of ship owners this alternative is not feasible since the ULCS's would not be competitive in comparison with the smaller container ships.

Nonetheless the authors think that a significant increase in the cost for fuel oil would result in the realisation of this variant.

8.3 Twin Screw

If the trend to higher container capacities is maintained, the twin screw container ship will be chosen. Due to the higher investment costs a twin screw container ship can only be operated economically nowadays if it can carry more than 12,500 TEU. The ships of this type will be very wide (B > 50 m) in order to be within the limits for the draught. These very wide bodies will give the designers the chance to develop hydrodynamically good concepts, e.g. twin skeg arrangements, with propulsion efficiencies as good as or better than single screw arrangements. For the designers of the ship hull as well as for the propeller designers this is a very interesting and challenging task.

An example of a body plan for a twin skeg container ship with a capacity of 12,500 TEU is shown in Fig. 8.1.

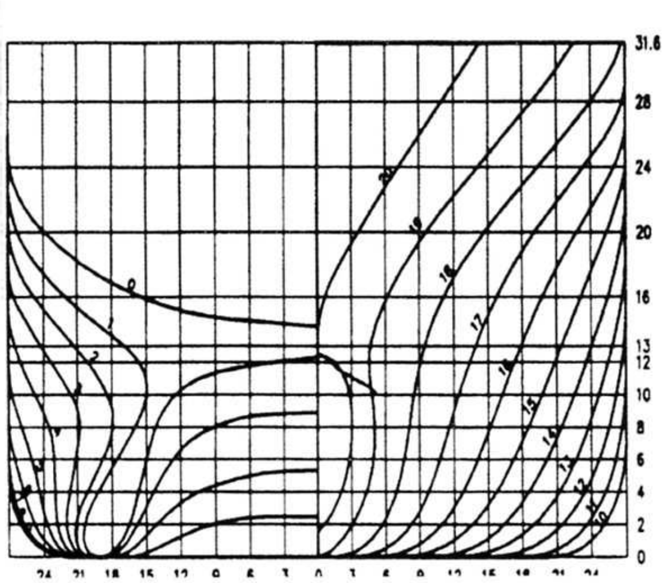

Fig. 8.1 – Possible Hull Lines of a 12,500 TEU Twin Screw ULCS (Source: Zamburlini, 2003)

In Fig. 8.2 the total transportation costs per TEU and trip for shipping of containers for a single screw container ship are compared with those for a twin screw vessel. The single screw vessel with 8,000 TEU is as expensive as a twin screw ship with a container capacity of 12,500 TEU. The twin screw vessel is never cheaper than the single screw vessel and with increasing ship size the possible savings decrease.

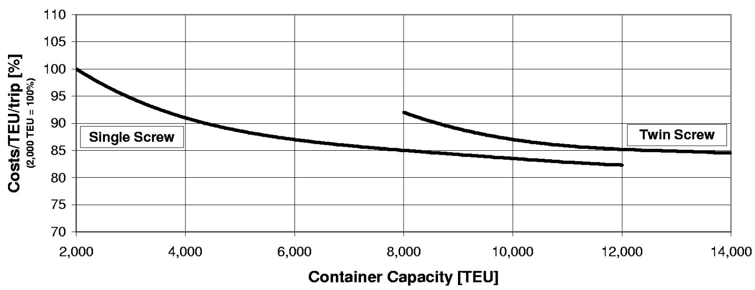

Fig. 8.2 – Economy of Scale, Relative Costs per TEU

8.4 Pod-Drive behind Main Propeller

Another possibility to increase the power for a "single screw" ship is the installation of an additional electric pod drive behind the main propeller (instead of the rudder). Presently pod drives with up to 20 MW are available. Fig. 8.3 shows such an installation with contra-rotating propellers at model which was tested at HSVA. The tests proved that this configuration is very efficient in terms of power consumption. However, the cavitation test with the whole model in HSVA's HYKAT showed that the pod drive is highly endangered by cavitation and erosion can be expected. Especially since the pod drive is used to keep the ship on course, it will be exposed to oblique flow with continuously changing angles and high energy content.

Furthermore, high investment costs for the installation have to be considered.

Fig. 8.3 – Pod Drive Behind Main Propeller

8.5 Two Fixed Pod-Drives as Boosters

Instead of the installation of one pod drive behind the main propeller, the next alternative is characterised by the installation of two fixed pod drives of maximal 2x 20 MW in addition to the main propeller (see sketch in Fig. 8.4).

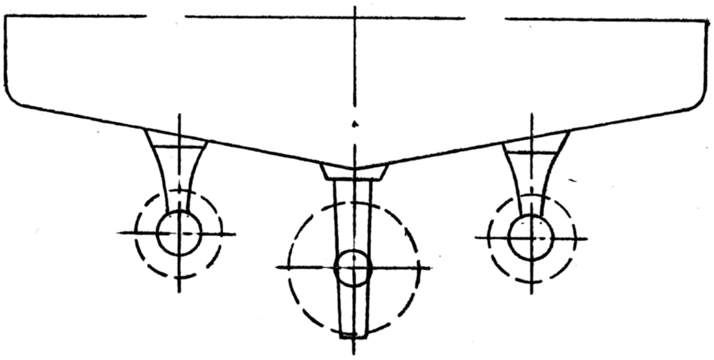

Fig. 8.4 – Two Pod Drives in Addition to the Main Propeller

This configuration results in a triple screw vessel with a separate rudder, for which the investment costs are considered to be higher than for a conventional twin screw vessel. Nonetheless this concept could be a good solution for the conversion of an existing single screw vessel.

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