body plans are given in Table 2.3, Figure 2.4 and Figure 2.5 respectively.

Several authors have studied the manoeuvrability of these VLCCs, such as the participants of the Tokyo CFD Workshop [58], Toxopeus [143] (KVLCC2M, V&V), Simonsen and Stern [126, 127] (KVLCC2, deep/shallow water, V&V), Broglia et al. [17] (KVLCC2, blockage during PMM), Carrica and Stern [23] (KVLCC1, DES coupled with body motions), Cura Hochbaum et al. [30] (KVLCC1 / KVLCC2, virtual PMM), Toxopeus and Lee [149] (KVLCC2, virtual PMM), Muscari et al. [95] (KVLCC2, RANS coupled with body motions), Stern et al. [132] (KVLCC2, DES at large drift angles) and Phillips et al. [107] (KVLCC2, virtual PMM). More information about the KVLCC results obtained at SIMMAN 2008 can be found in Stern et al. [131].

2.5.4 HTC

Figure 2.6: Teresa del Mar (source: www.shipphotos.es/teresadelmar.htm)

The Hamburg Test Case (HTC) is a model of the container ship built by Bremer Vulkan in 1986 as *Ville de Mercure*, and subsequently named *Teresa del Mar*, see Figure 2.6. *Teresa del Mar* was sold in 2010 and renamed *Maria*. After the *Ville de Mercure* a number of other container ships with the same hull form were built. One of the sister vessels, *Catalina del Mar*, is still sailing.

Captive model experiments were conducted on the HTC within the VIRtual Tank Utility in Europe (VIRTUE) project by Hamburgische Schiffbau-Versuchanstalt (HSVA) in order to provide additional material for CFD validation. These tests comprised force measurements for the bare hull, the hull with rudder and the hull with propeller and rudder. Furthermore, PIV measurements were conducted for the model equipped without rudder, with the model sailing at steady rotational motion. These experiments were reported in VIRTUE deliverable D3.1.3, see Vogt et al. [161]. The scale of the model λ was 1:24 during the HSVA tests. The water depth to ship's draught ratio of $h/T_m = 14$ represented deep water conditions.

The HTC has been studied numerically by several authors, such as Drouet et al. [37], Gao and Vassalos [54] and Toxopeus [144, 145, 148].

Hull form

In Table 2.4, the main particulars of the HTC are presented. Both model scale and full scale (prototype) values are given.

Table 2.4: Main particulars of HTC

		HTC			
Description	Symbol	proto	model		Unit
Scale	λ	1:1	1:24	1:30.02	-
Length between perpendiculars	L_{pp}	153.700	6.404	5.120	m
Breadth max. moulded	B	27.500	1.1458	0.916	m
Draught moulded fore	T_f	10.300	0.4292	0.343	m
Draught moulded aft	T_a	10.300	0.4292	0.343	m
Displacement volume moulded	∇	28342	2.0500	1.048	m^3
Wetted surface area bare hull	S_{wa}	5567	9.6640	6.177	m^2
Position centre of buoyancy forward of midship	x_B	-0.571			$\%L_{pp}$
Block coefficient	C_b	0.650			-
Length-Breadth ratio	L/B	5.582			-
Breadth-Draught ratio	B/T	2.673			-
Length-Draught ratio	L/T	14.922			-

The body plan of the HTC is presented in Figure 2.7. A photograph of the HTC during the model tests at HSVA is presented in Figure 2.8.

The model was tested fixed in all degrees of motion. It was not equipped with bilge keels. For the measurements of the model with rudder, the rudder forces were measured separately. Turbulence was stimulated in all tests. Therefore, in the viscous-flow calculations it was assumed that the flow was fully turbulent.

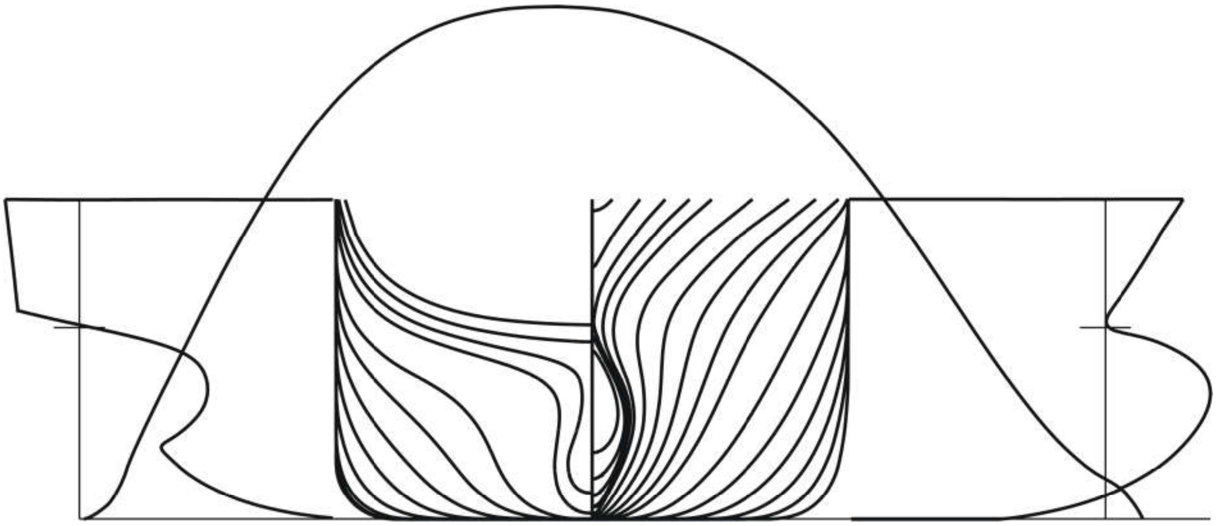

Figure 2.7: Body plan of HTC

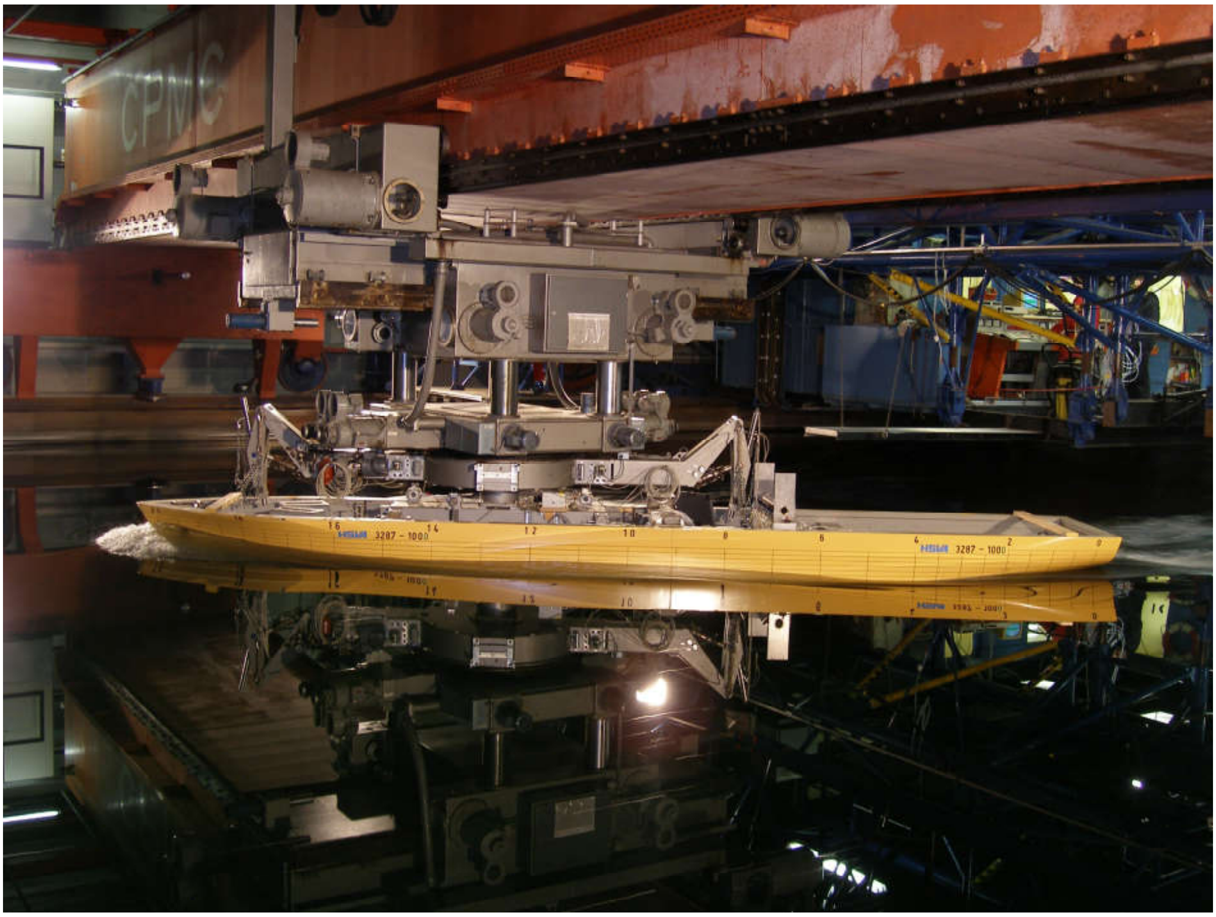

Figure 2.8: HTC model during oblique motion test using CPMC (photograph by HSVA)

Propeller

The particulars of the propellers of the prototype HTC and of the model test propellers (scaled to prototype values) are specified in Table 2.5.

Table 2.5: Main particulars of the HTC propeller

DESIGNATION	SYMBOL	MAGNITUDE			UNIT
		Prototype	Model Scale		
Propeller Id.		-	HSVA 2208	MARIN 5286R	
Diameter	D_p	6.105	6.101	6.100	m
Pitch at $0.7R$	$P_{0.7}$	4.884	4.994	4.642	m
Pitch ratio at $0.7R$	$P_{0.7}/D_p$	0.800	0.818	0.761	-
Expanded blade area ratio	A_E/A_0	0.569	0.580	0.568	-
Number of blades	Z	4	4	4	-
Direction of rotation	-	clockwise when looking ahead			-

Rudder

For the model tests, the rudder was divided into a movable and a fixed (headbox) part in order to allow turning of the rudder without touching the hull surface. The particulars of the rudder and a drawing are presented in Table 2.6 and Figure 2.9.

Table 2.6: Particulars of the HTC rudder

Description	Symbol	Magnitude	Unit
Projected total rudder area	$A_{R,\text{tot}}$	39.76	m^2
Projected movable rudder area	A_R	29.03	m^2
Rudder span	$h_{R,\text{tot}}$	9.20	m
Rudder span of movable part	h_R	7.20	m
Average rudder chord	c_R	4.32	m
Total area ratio	$A_{R,\text{tot}}/L_{\text{pp}}T$	2.51	%
Movable area ratio	$A_R/L_{\text{pp}}T$	1.83	%

2.5.5 Other cases

Other publications presenting data that can be used to validate the forces and moments predicted with viscous-flow calculations for manoeuvring purposes are e.g. the prolate spheroid [24], the NACA 0012 profile (2D case) [1], ONR Body 1 [138, 10], DTMB 5415 [130, 119, 93, 167, 118] and recently the NNemo [112, 33, 117, 55, 108].

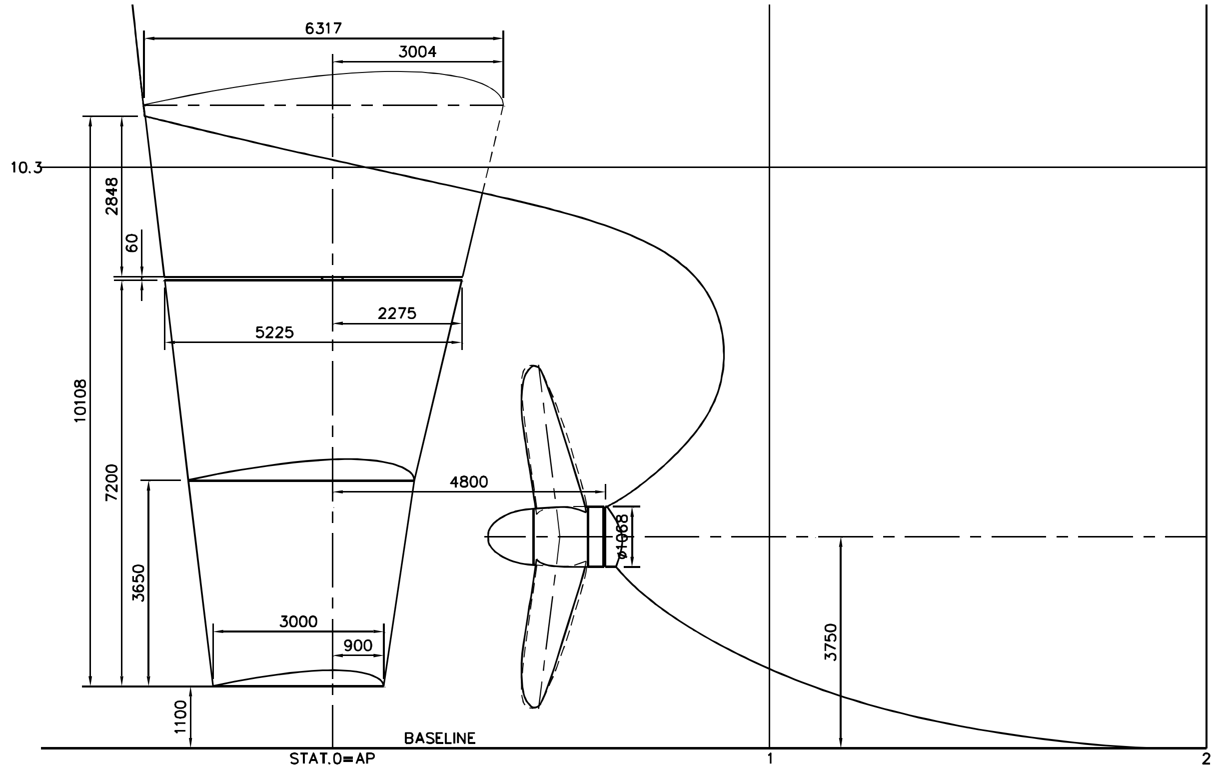

Figure 2.9: Drawing of the HTC rudder, T=10.3 m, dimensions in mm

2.6 Validation cases for free sailing manoeuvring

For validation of the predicted manoeuvres, results from free sailing manoeuvring tests or full scale trials are required. This section presents some of the test cases that are available in literature for which free sailing manoeuvring data is present.

2.6.1 Esso Osaka

The *Esso Osaka* received ample attention due to the existence of well-documented trials in deep and shallow water published by Crane [26], and it was recommended by the 22^{nd} International Towing Tank Conference (ITTC) that this ship was used for validation of force predictions and manoeuvring simulations. However, due to the fact that the hull form is rather outdated and some doubts arose regarding the scatter in the results during analysis of different model test campaigns [25], the interest in this validation case has diminished in the last few years.

Recent studies in which the viscous-flow around the *Esso Osaka* for captive conditions was simulated were published by e.g. El Moctar [46], Simonsen [122], Simonsen and Stern [123, 124, 125] and Van Oers and Toxopeus [155].