Report of the Selected Vessels and Operational Data

Work Package 1

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GATERS Innovation Action Project is sponsored by the EC H2020 Programme (ID: 860337) with the independent aim and objectives. The project has an official sub-license agreement with Wartsila Netherlands BV to utilise the Gate Rudder Patent (EP 3103715) at specific retrofit projects of vessel sizes below 15000 DWT.

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Abstract

Deliverable D1.1 presents the geometrical and operational data for several actual vessels (existing) to be used in WP1 to develop and apply the best retrofit design and analysis procedure for the Gate Rudder System (GRS). Also, a ship database and ship data are presented for the application of the GRS for broader ship types and their operations in WP5 and WP6.

For the above purposes, the deliverable included the data for three key vessels including; "*Sakura*": 2400GT (400TEU) Japanese coastal container vessel fitted with a conventional rudder system (CRS); "*Shigenobu*": also another 2400GT (400TEU) Japanese coastal container vessel but fitted with a gate rudder system (GRS) which is sister to *Sakura; and* "*M/V Erge*": 5500DWT European general cargo vessel, currently, fitted with a CRS but will be retrofitted by a GRS as the "Target Vessel" of the GATERS project. The data presented for these vessels involved the detailed descriptions of their hulls, rudders and propeller geometries, including the digital format. The trials data of these vessels in terms of the power-speed and manoeuvring (Turning Circle and Zig-Zag) are also presented.

For the further applications of the GRS for broader ship types to be explored in WP5 and 6 of GATERS, an extensive ship design/operation database for the European Short Sea Shipping and Oceangoing Shipping type vessels was introduced to retrieve the high-level data for these ship types applications. This was further complemented by introducing the data sources for the further three key vessels from the two shipowner partners of GATERS. These vessels are 4250 TEU container ship of Danaos, "*Zim Luanda*", together with the Newcastlemax class, "*Maharaj*" and Kamsarmax class, "*Star Laura*" of Star Bulk for the detailed investigations and impact analyses in WP5 and WP6, respectively.

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Executive Summary

Deliverable (D1.1) presents geometrical and operational data for several actual vessels (existing) to be used in WP1 to develop and apply the best retrofit design and analysis procedure for the Gate Rudder System (GRS). D1.1 also presents suitable database sources and selected ship types to further apply the developed GRS procedures to broader ships types and operations in WP5 and WP6.

Therefore, two main groups of data and data sources are presented in D1.1: (1) Data associated with three key vessels, which are selected for short sea shipping (SSS) operations, to develop and support the best design and analysis procedure for the GRS retrofit design; (2) Database associated with a large number of existing vessels to be accessed for the further applications of the GRS including SSS and oceangoing shipping (OS) type vessels as well as some selected vessel types for OS operations.

The deliverable includes the data associated with the 1st group (1) activities for the three key vessels. These are "*Sakura*": 2400GT (400TEU) Japanese coastal container vessel fitted with a conventional rudder system (CRS); "*Shigenobu*": another 2400GT (400TEU) Japanese coastal container vessel fitted with a gate rudder system (GRS) which is sister to *Sakura; and* "*M/V Erge*": 5500DWT European general cargo vessel, currently, fitted with a CRS but will be retrofitted by a GRS as the "Target Vessel" of GATERS project

The data presented for the two Japanese vessels involve the detailed description of the hull, rudder and propeller geometries, including their digital versions as well as the trials data of these vessels in terms of the power-speed and manoeuvring (Turning Circle and Zig-Zag). The data provided will form a basis for numerous model tests and CFD analyses to be conducted in WP1 to help the development of the best design and analysis procedure of the GRS. Similar to the Japanese vessels, the data presented for M/V Erge with CRS also involve the detailed description of hull, rudder and propeller geometry, including their digital versions and the trails data for the power-speed and manoeuvring (i.e. turning circle and zig-zag) characteristics.

Since the retrofit GRS design for M/V Erge is one of the main objectives of GATERS, the preliminary geometrical data for the GRS were determined as part of the WP1 activities and included in D1.1. Therefore, the provided data for the GRS and CRS will form the basis for the model tests and CFD analysis tasks in WP1 which will eventually lead to the detailed design, manufacture and installation of the retrofit GRS on MV Erge in WP3 and WP4.

In order to address the 2nd group (2) activitie1.1 also presents an extensive ship design/operation database) for the European SSS and OS type vessels to retrieve the high-level data (i.e. main particulars and basic operational data) to be used for the analyses in WP5 and WP6. Furthermore, three suitable OS type vessels that belong to the two shipowner project partners are presented to apply the GRS for more detailed impact analyses. These vessels are 4250 TEU container ship of Danaos, "*Zim Luanda*", together with the Newcastlemax class, "*Maharaj*" and Kamsarmax class, "*Star Laura*" of Star Bulk for the detailed investigations in WP5 and WP6, respectively.

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Abbreviations

CRS	Conventional Rudder System
GRS	Gate Rudder System
OS	Oceangoing Shipping
SSS	Short Sea Shipping
JCV	Japanese Container Vessels

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1. Introduction

This deliverable (D1.1) is the first output of WP1. It presents geometrical and operational data for several actual vessels (existing) to be used in WP1 to develop and apply the best design and analysis procedure for the Gate Rudder System (GRS). Also, it presents suitable ship types and database sources to further application of the developed GRS procedures in broader ships types and operation in WP5 and WP6.

Therefore, two main groups of data and data sources are presented in this deliverable: (1) Data associated with three key vessels, which are for short sea shipping (SSS), selected to develop the best design and analysis procedure for the GRS design; (2) Database associated with a large number of existing vessels to be accessed for the further applications of the GRS including SSS and oceangoing shipping (OS) type vessels.

The deliverable itself does not cover the entire data and database referred to, as some of these data and databases are in digital format and cannot be contained in this report. However, the report guides the reader for this purpose. Furthermore, some of the selected ship data, which will be used in the second group (2) activities (i.e. for further application of the GRS in WP5 and WP6), may be modified or replaced by other ship types in the future that may offer better option.

Following this introduction section, Section 2 of the deliverable includes the data associated with the 1st group (1) activities for three key vessels. These are "*Sakura*": 2400GT (400TEU) Japanese coastal container vessel fitted with a conventional rudder system (CRS); "*Shigenobu*": 2400GT (400TEU) Japanese coastal container vessel fitted with a gate rudder system (GRS) which is sister to *Sakura; and* "*M/V Erge*": 5500DWT European general cargo vessel, currently, fitted with a CRS but she will be retrofitted by a GRS as the "Target Vessel" of GATERS project [1].

As far as the two Japanese vessels are concerned, the data presented in Section 2.1 involves the detailed description of the hull, rudder and propeller geometries, including the digital version and the trials data in terms of the power-speed and manoeuvring (Turning Circle and Zig-Zag). The data provided, in collaboration with a Japanese Consortium, will form a basis for numerous model tests and CFD analyses to be conducted in WP1 to help the development of the best design and analysis procedure of the GRS.

As far as the Target Vessel data is concerned, similar to the Japanese vessels, the data presented in Section 2.2 involves the detailed description of hull, rudder and propeller geometry, including the digital version, for M/V Erge with CRS. The trails data for this vessel in terms of Power-Speed, Manoeuvring (i.e. Turning Circle and Zig-Zag) are also included. The digital versions of the data for the three key vessels are stored in the GATERS Project ShareFile system.

Since the retrofit GRS design for M/V Erge is one of the main objectives, the preliminary geometrical data for the GRS in terms of the rudder blades and propellers were derived as part of WP1 activities and included in Section 2.2. The provided data for the GRS, together with CRS, will form the basis for the model tests and CFD analysis tasks in WP1 which will eventually lead to the detailed design, manufacture and installation of the retrofit GRS on MV Erge in WP3 and WP4.

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Section 3 of this deliverable includes identifying a suitable European ship database source and selecting vessel types from this source and other two shipowner partners' sources in the GATERS Project.

For the above purpose, in Section 3.1 the extensive ship design/operation database of the GATERS Partner (LLI) for the European SSS and OS type vessels is introduced. This database will be accessed to retrieve the high-level data (i.e. main particulars and basic operational data) for the suitable vessel types to be used for analyses in WP5 and WP6. In the database, the main particulars of almost 34000 ships for the SSS and OS as such; for the SSS containing product tankers (including combined prod/chem), general cargo carriers, RoRo (excluding specialised vehicle carriers), bulk carriers and container carriers are included; while for the OS types, the data comprises mainly Tankers 20-60K DWT, Bulkers 35-100K DWT and Container carriers 3-10K TEU.

In section 3.2 of the deliverable, the databases and suitable OG vessel types that belong to the two shipowner project partners, Danaos and Start Bulk, are presented to apply the GRS and conduct impact analyses in WP5 and WP6. The partner DANAOS Shipping is a leading international owner of 65 containerships ranging from 2.2K to 131K TEU, while the partner STAR BULK provides high-quality transportation services for dry bulk cargoes by 120 modern vessels built-in world-class shipyards. The review of their databases and consultations with them indicated that 4250 TEU container ship of Danaos, "*Zim Luanda*", (IMO: 9403229) would be the most suitable type for OS to explore for the GRS application. Within a similar framework, two classes of bulk carriers, i.e. the Newcastlemax class, "*Maharaj*" and Kamsarmax class, "*Star Laura*" of Star Bulk were identified for the detailed investigations in WP5 and WP6, respectively.

Section 4 of the deliverable presents a short summary of the tasks conducted in the report.

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2. Selected vessels and associated data for methodology development and demonstration of GRS

WP1 includes tasks for the development of the best design and analysis procedures as well as the CFD and other numerical and experimental tool developments to retrofit or design a ship with the GRS. For the methodology development and demonstration of GRS, there are three vessels to be examined in physical tests and with computational methods. The first two of these ships are Japanese container ships called SAKURA and SHIGENOBU, as sister ships. The most important characteristic difference between these sisters is; Sakura has a Conventional Rudder System (CRS) whilst Shigenobu has Gate Rudder System (GRS). The general dimensions of these ships are given in Table 2-1 and Table 2-2.

The other subject ship to investigate is the Target Vessel “M/V ERGE”, which will be retrofitted with a GRS in the GATERS project. The original rudder of M/V ERGE is a CRS with a flap, and when she is fitted with a GRS, the power-speed, manoeuvring and URN (Underwater Radiated Noise) measurements will be conducted with M/V ERGE and for both rudder arrangements. The general particulars of M/V ERGE are given in Table 2-3.

Table 2-1 Main dimensions of Sakura for design draught

SAKURA			
Length overall	L_{OA}	(m)	111.40
Length between perpendiculars	L_{BP}	(m)	106.40
Breadth	B	(m)	17.80
Design Draught (midship)	T	(m)	5.24
Displacement	Δ	(ton)	4794
Service Speed	V_S	knots	15.5
Rudder			CRS

Table 2-2 Main dimensions of Shigenobu for design draught

SHIGENOBU			
Length overall	L_{OA}	(m)	111.40
Length between perpendiculars	L_{BP}	(m)	106.40
Breadth	B	(m)	17.80
Design Draught (midship)	T	(m)	5.24
Displacement	Δ	(ton)	4794
Service Speed	V_S	knots	15.5
Rudder			GRS

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Table 2-3 Main dimensions of target ship M/V ERGE for design draught

M/V ERGE			
Length overall	L_{OA}	(m)	89.95
Length between perpendiculars	L_{BP}	(m)	84.95
Breadth	B	(m)	15.40
Design Draught (midship)	T	(m)	6.46
Displacement	Δ	(ton)	7280
Service Speed	V_S	knots	12.0
Rudder Type			CR

2.1 Japanese Container Vessel Sakura & Shigenobu

The GRS was applied for the first time on a 2400 GT full-scale, new-built coastal container "Shigenobu", which has entered into service in November 2017, supported by Nippon Foundation. This first application was to demonstrate the vessel's performance, especially her excellent manoeuvrability performance. The comprehensive speed and manoeuvring trials with this vessel and her sister ship "Sakura", which had the same hull form and engine size with a conventional flap-rudder, indicated that the vessel with GRS was 14% more efficient at the design speed than her sister.

Detailed ship characteristics and general views of the Japanese Container Vessels (JCV), which were calculated with MaxSurf, are given in Table 2-4 and shown by Figure 2-1, respectively. Propeller and rudder characteristics for both vessels are also given in Table 2-5.

Figure 2-1 Japanese Container Ships Sakura (Left) and Shigenobu (Right)

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Table 2-4 Ship characteristics of Sakura and Shigenobu for sea trial draught

Parameter	Symbol	Unit	SAKURA	SHIGENOBU
Length overall	L_{OA}	(m)	111.4	
Length between perpendiculars	L_{BP}	(m)	106.4	
Breadth	B	(m)	17.8	
Draught (midship)	T	(m)	4.175	
Draught (AP)	T_A	(m)	4.5	
Draught (FP)	T_F	(m)	3.85	
Displacement	Δ	(ton)	4794	
Block coefficient	C_B		0.591	
Prismatic coefficient	C_P		0.613	
Midship area coefficient	C_M		0.965	
Waterplane area coefficient	C_{WP}		0.697	
Longitudinal centre of buoyancy	LCB	(m) (+ fwd)	0.153	
Longitudinal centre of floatation	LCF	(m) (+ fwd)	-2.683	
Longitudinal centre of gravity	LCG	(m) (+ fwd)	-4.650	
Verticle centre of gravity	VCG	(m)	-1.846	
Speed	V_S	knots	15.5	
Rudder Type			CRS	GRS

Table 2-5 Rudder and Propeller characteristics of Sakura and Shigenobu

Parameter	Symbol	Unit	SAKURA	SHIGENOBU
Main Engine Rated Power		(kW)	3309	
Max Propeller Speed		(RPM)	220	
Propeller diameter	D	(m)	3.50	3.30
Blade number	Z		4	
Pitch diameter ratio (mean)	P/D		0.69	0.835
Blade area ratio	BAR		0.63	0.512
Rudder Type			CRS	GRS
Rudder Total Area	A_R	(m^2)	9.25	11.2(5.6×2)

The full-scale ship CAD models are part of this document, and digital data are distributed to the interested parties in GATERS (i.e. for model tests and CFD studies) and also stored in the project Files Sharing System. According to their location on the hulls, the associated propeller and rudder arrangements are presented in Figure 2-2. As it is shown in Figure 2-3, the propeller plane location of Shigenobu is 0.30 m aft of Sakura's propeller plane, while the rudder stock position of the GRS is 0.80 m away from the centre line of each gate rudder blade and 1.335 m forward of the conventional rudder stock. All the project partners who will be using the Japanese Container Vessels data were informed about the availability of the data in digital format at the GATERS Share File System [2].

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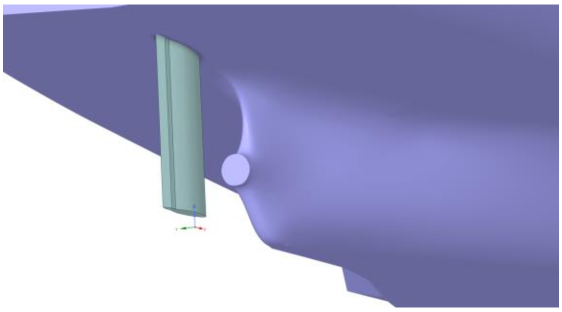
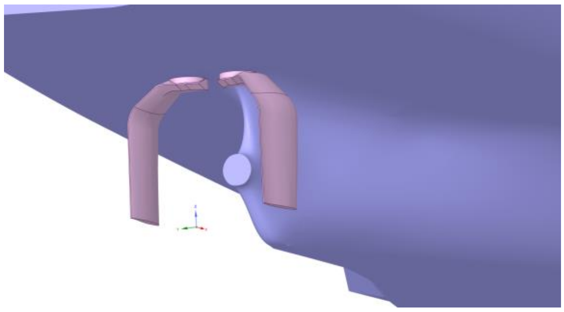
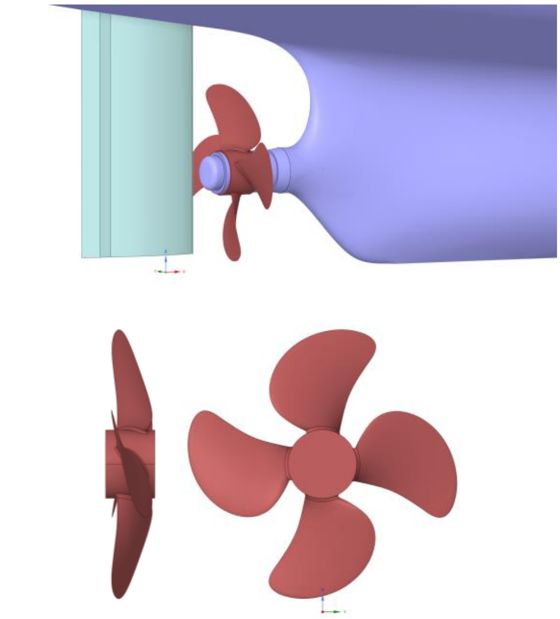
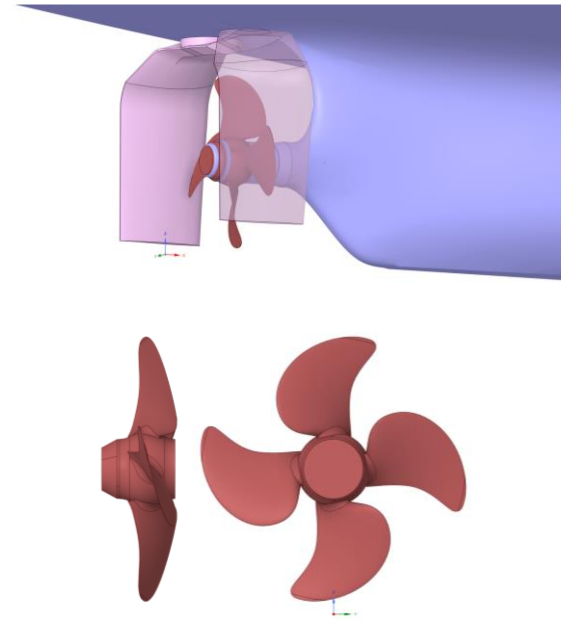
	Sakura	Shigenobu
Rudder		
Propeller		

Figure 2-2 Rudder and propeller orientation on the Japanese container vessels

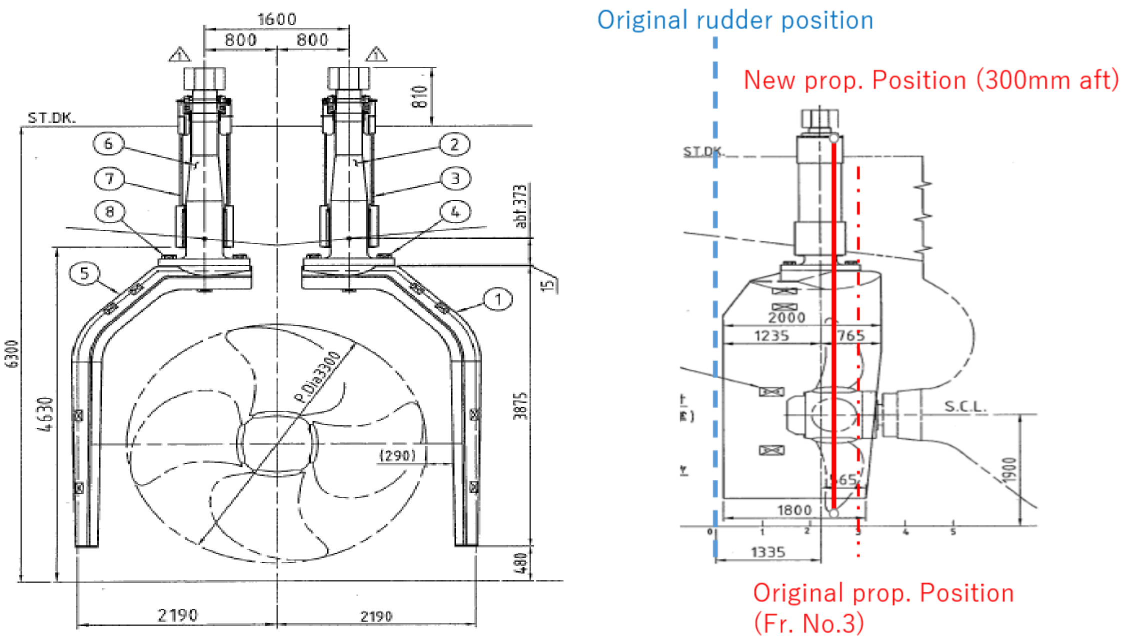


Figure 2-3 General arrangement of GRS for Shigenobu

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The Shigenobu and Sakura have an appendage (as a blister) on either side of their fore and aft bows, as shown in Figure 2-4. These appendages are added into the main hull to increase the cargo capacity of the vessels.

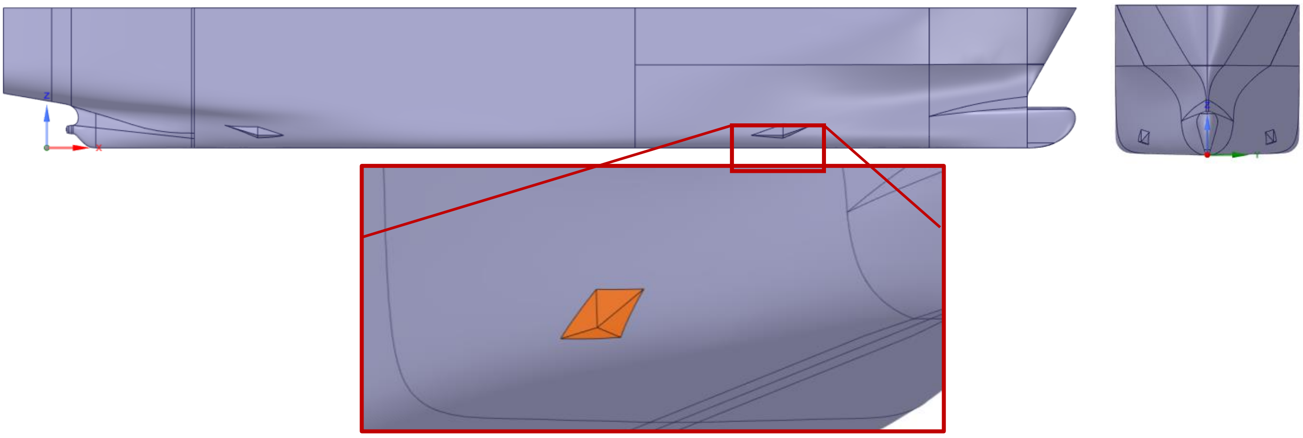

Figure 2-4 JCS Hull appendage detail

2.1.1 Power-Speed Trial Results

A set of joint sea trials was conducted with both vessels on 30 December 2020 to eliminate all the uncertainties that can be related to the trial location and weather [3]. The speed trials were conducted by running the vessels closely with minimum time lags with the following details in Table 2-6.

Table 2-6 Japanese Container Ships Shigenobu (GRS) and Sakura (CRS) Power Speed Trial Results

Run No	Measured Shaft Power (kW)	Sakura (CRS) Speed Over Ground (Knots)	Shigenobu (GRS) Speed Over Ground (Knots)
1	2500	14.4	15.35
2	2750	14.9	15.65
3	3000	15.4	15.9

2.1.2 Circle Tests

The circle test measurements results are given in Table 2-7 and Table 2-8 for Sakura with CRS and Shigenobu with GRS, respectively. While the turning circle tests for Sakura are straightforward with the limited rudder angle/speed arrangements, following standard manoeuvring test procedures, these tests for Shigenobu were conducted at various rudder angle/speed configurations to achieve a relative comparison between the two rudder systems. This is due to the large angle control range of the GRS, as shown by Figure 2-5.

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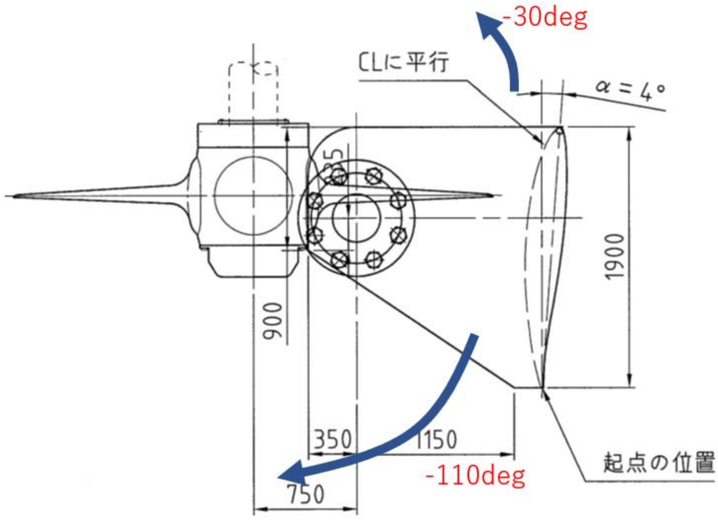

Figure 2-5 GRS angle convention

Table 2-7 Japanese Container Ship Sakura with Conventional Rudder System Circle Trial Results

M.E Load	4/4	4/4
Rudder Angle	35°	35°
Named M/E Speed (rpm)	220	220
Blade Pitch Angle	17.6°	17.6°
Direction	PORT	STBD
Time (90°), sec	47.9	48.9
Time (180°), sec.	94.2	103.9
Time (270°), sec.	147.1	166.9
Time (360 0), sec.	201.0	221.8
Initial Speed (kn)	16.2	16.2
Advance (m)	287	298
Transfer (m)	-	-
Test time (s)	201.0	221.8
Tactical dia. (m)	217	253
Turnin dia. (m)	-202	235
Max. healing angle (deg)	4° Right	5° Left

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Table 2-8 Japanese Container Ship Shigenobu with Gate Rudder System Circle Trial Results

<table>
<tr><td>M.E Load</td><td colspan="2">4/4</td><td colspan="2">4/4</td><td colspan="2">4/4</td><td colspan="2">4/4</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td></tr>
<tr><td rowspan="2">Rudder Angle</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td><td>Port</td><td>Stbd</td></tr>
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<tr><td>Named M/E Speed (rpm)</td><td colspan="2">220</td><td colspan="2">220</td><td colspan="2">220</td><td colspan="2">220</td><td colspan="2">195</td><td colspan="2">195</td><td colspan="2">195</td><td colspan="2">195</td><td colspan="2">194</td><td colspan="2">194</td><td colspan="2">194</td><td colspan="2">194</td><td colspan="2">194</td></tr>
<tr><td>Blade Pitch Angle</td><td colspan="2">21.2°</td><td colspan="2">21.2°</td><td colspan="2">21.2°</td><td colspan="2">21.2°</td><td colspan="2">0° > 9°</td><td colspan="2">0° > 9°</td><td colspan="2">9°</td><td colspan="2">9°</td><td colspan="2">12°</td><td colspan="2">12°</td><td colspan="2">12°</td><td colspan="2">0° > 12°</td><td colspan="2">0° > 12°</td></tr>
<tr><td>Direction</td><td colspan="2">PORT</td><td colspan="2">STBD</td><td colspan="2">PORT</td><td colspan="2">STBD</td><td colspan="2">PORT</td><td colspan="2">STBD</td><td colspan="2">PORT</td><td colspan="2">STBD</td><td colspan="2">PORT</td><td colspan="2">PORT</td><td colspan="2">STBD</td><td colspan="2">PORT</td><td colspan="2">STBD</td></tr>
<tr><td>Time (90°), sec</td><td colspan="2">57.7</td><td colspan="2">61.6</td><td colspan="2">59.1</td><td colspan="2">53.2</td><td colspan="2">153.9</td><td colspan="2">162.6</td><td colspan="2">90.9</td><td colspan="2">104.9</td><td colspan="2">91.5</td><td colspan="2">95.4</td><td colspan="2">93.8</td><td colspan="2">130.1</td><td colspan="2">148.4</td></tr>
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<tr><td>Time (360 0), sec.</td><td colspan="2">257.9</td><td colspan="2">245.4</td><td colspan="2">252.6</td><td colspan="2">251.3</td><td colspan="2">484.1</td><td colspan="2">505.6</td><td colspan="2">428.7</td><td colspan="2">442.8</td><td colspan="2">559.0</td><td colspan="2">363.8</td><td colspan="2">355.7</td><td colspan="2">429.2</td><td colspan="2">441.0</td></tr>
<tr><td>Initial Speed (kn)</td><td colspan="2">16.06</td><td colspan="2">16.06</td><td colspan="2">16.06</td><td colspan="2">16.06</td><td colspan="2">0.0</td><td colspan="2">0.0</td><td colspan="2">9.0</td><td colspan="2">9.0</td><td colspan="2">9.0</td><td colspan="2">9.0</td><td colspan="2">9.0</td><td colspan="2">0.0</td><td colspan="2">0.0</td></tr>
<tr><td>Advance (m)</td><td colspan="2">377</td><td colspan="2">376</td><td colspan="2">387</td><td colspan="2">357</td><td colspan="2">152</td><td colspan="2">98</td><td colspan="2">285</td><td colspan="2">270</td><td colspan="2">340</td><td colspan="2">337</td><td colspan="2">342</td><td colspan="2">88</td><td colspan="2">53</td></tr>
<tr><td>Transfer (m)</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Test time (s)</td><td colspan="2">257.9</td><td colspan="2">245.4</td><td colspan="2">252.6</td><td colspan="2">251.3</td><td colspan="2">484.1</td><td colspan="2">505.6</td><td colspan="2">428.7</td><td colspan="2">442.8</td><td colspan="2">559.0</td><td colspan="2">363.8</td><td colspan="2">355.7</td><td colspan="2">429.2</td><td colspan="2">441.0</td></tr>
<tr><td>Tactical dia. (m)</td><td colspan="2">392</td><td colspan="2">381</td><td colspan="2">344</td><td colspan="2">350</td><td colspan="2">189</td><td colspan="2">196</td><td colspan="2">280</td><td colspan="2">283</td><td colspan="2">350</td><td colspan="2">295</td><td colspan="2">289</td><td colspan="2">144</td><td colspan="2">127</td></tr>
<tr><td>Turnin dia. (m)</td><td colspan="2">-366</td><td colspan="2">368</td><td colspan="2">-321</td><td colspan="2">328</td><td colspan="2">-186</td><td colspan="2">184</td><td colspan="2">-267</td><td colspan="2">257</td><td colspan="2">-326</td><td colspan="2">-271</td><td colspan="2">261</td><td colspan="2">-75</td><td colspan="2">47</td></tr>
<tr><td>Max. healin angle (deg)</td><td colspan="2">3°</td><td colspan="2">2.5°</td><td colspan="2">3°</td><td colspan="2">2.5°</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="2">2</td></tr>
</table>

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2.1.3 Zig-Zag Manoeuvre Tests

The course keeping ability is the most important factor for the manoeuvrability of a container ship to avoid accidents and cargo loss during severe weather conditions because the rolling motion of a container ship is strongly affected by poor seakeeping ability. Japanese container ships' Zig-Zag Manoeuvre test measurements are given in Table 2-9 and Table 2-10 for Sakura with conventional rudder and Shigenobu with gate rudder, respectively.

Table 2-9 Japanese Container Ship Sakura with Conventional Rudder System Zig-Zag Manoeuvre Test Results

Item	10° Right - Left Angle (degree)	10° Left - Right Angle (degree)	20° Right - Left Angle (degree)
1st overshoot angle	8.0°	7.4°	16.2°
2nd overshoot angle	9.6°	10.5°	15.8°

Table 2-10 Japanese Container Ship Shigenobu with Gate Rudder System Zig-Zag Manoeuvre Test Results

Item	10° Left - Right Angle (degree)	10° Right-Left Angle (degree)	20° Left Angle (degree)
1st overshoot angle	3.0°	3.7°	14.6°
2nd overshoot angle	7.4°	8.2°	10.5°

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2.2 Target Ship M/V ERGE

M/V ERGE (Ex-JOERG N) is one of the eight sister multi-purpose dry-cargo ships which were originally commissioned and owned by a Germain Consortium (See Figure 2-6). These vessels were specially strengthened at their hold regions to carry wind turbine blades, hence having unusually large square holds with extra-strong covers. It was designed by a German design firm ABH (ABH INGENIEUR TECHNIK GMBH) and was built by the Chinese shipyard WEIHAI DONGHAI in 2010-11 for a German Consortium of shipowners.

Figure 2-6 Target Vessel; M/V "ERGE"

In 2015, the partner CAPA purchased two of these vessels named M/V ERGE for the target vessel and her sister ship M/V ERLE. After CAPA acquired M/V ERGE, her capacity was increased from 4500DWT to 5500 DWT by increasing her draft approximately by 0.65m without any engineering modifications to the main hull or propeller or the engine. The capacity increase calculations were approved by Bureau Veritas. The main particulars of M/V ERGE after the capacity increase are given in Table 2-11, while the main engine and gearbox details are listed in Table 2-12, respectively.

Table 2-11 Ship characteristics of Erge for ballast and full load operating conditions

Parameter	MV Erge			
	Symbol	**Units**	**Ballast Load**	**Full Load**
Length overall	L_{OA}	(m)	89.95	
Length between perpendiculars	L_{BP}	(m)	84.95	
Breadth	B	(m)	15.4	
Draught (midship)	T	(m)	3.30	6.46
Draught (AP)	T_A	(m)	3.80	6.46
Draught (FP)	T_F	(m)	2.80	6.46
Displacement	Δ	(ton)	3585	7280
Block coefficient	C_B		0.806	0.859
Prismatic coefficient	C_P		0.823	0.862
Midship area coefficient	C_M		0.994	0.997
Waterplane area coefficient	C_{WP}		0.854	0.944
Longitudinal centre of buoyancy	LCB	(m) (+ fwd)	43.363	43.495
Longitudinal centre of floatation	LCF	(m) (+ fwd)	44.128	40.495
Longitudinal centre of gravity	LCG	(m) (+ fwd)	43.006	43.036

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Verticle centre of gravity	VCG	(m)	3.23	6.095
Speed	V_S	knots	12	

Table 2-12 Main Engine and Gearbox characteristics of MV Erge

Parameter	Unit	Value
Main Engine Type		MAN Diesel 8138/32A
Rated Power	(kw)	1960
Rated Main Engine Speed	(RPM)	775
Gear Box Ratio		5.263:1
Propeller Type		FPP
Propeller Speed	(RPM)	147.25
Propeller rotational direction		Left-handed

The original propeller of M/V ERGE was cropped after the initial trials. It is suspected that this was done to reduce the torque of the propeller to match the power rating of the Main Engine while no clear evidence exists. The main characteristics of the original and cropped propeller are given in Table 2-13 and Table 2-14, respectively, while Table 2-15 presents the section details of the original propeller (before cropping).

Table 2-13 Original Propeller characteristics of M/V ERGE

Parameter	Symbol	Unit	value
Propeller diameter	D	(m)	3.60
Blade number	Z		5
Pitch diameter ratio (mean)	P/D		0.79
Blade area ratio	BAR		0.66
Skew		(mm)	26.05
Rake		(mm)	5.5

Table 2-14 Cropped Propeller characteristics of M/V ERGE

Parameter	Symbol	Unit	value
Propeller diameter	D	(m)	3.42
Blade number	Z		5
Pitch diameter ratio (mean)	P/D		0.83
Blade area ratio	BAR		0.61
Skew		(mm)	26.05
Rake		(mm)	5.5

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Table 2-15 Original Propeller section details of M/V ERGE

r/R	Radius (mm)	Chord (mm)	Pitch (mm)	P/D	CLE (mm)	Rake (mm)	Thickness (mm)	Camber (mm)	Skew (mm)
0.19	333	527.8	2536	0.704	212.2	15.67	160.7	57.9	51.7
0.23	387	568.3	2594	0.721	260.4	28.12	153.5	55.7	23.75
0.26	450	615.2	2655	0.738	319.1	41.52	145.3	53.0	-11.5
0.32	540	682.3	2733	0.759	402.8	58.53	133.9	48.9	-61.65
0.42	720	816.5	2858	0.794	546.5	85.09	112.5	40.6	-138.25
0.53	900	895	2943	0.818	627.1	101.7	92.74	32.8	-156.5
0.63	1080	962.8	2993	0.831	651.9	108.3	74.68	26.6	-127.4
0.74	1260	1002.5	3013	0.837	611	105	58.3	22.8	-54
0.84	1440	996.4	3006	0.835	483.8	91.66	43.6	21.5	77.7
0.95	1620	876.2	2977	0.827	252.5	68.38	30.59	15.3	271
1.00	1710	418.7	2956	0.821	78.99	53.01	24.72	12.4	386.3

The rudder details of M/V ERGE are also shown in Table 2-16, including its arrangement at the aft end of M/V ERGE, as shown in Figure 2-7.

Table 2-16 Rudder characteristics of M/V ERGE

Parameter	Unit	Erge
Rudder Type		Flapped Rudder
Total Rudder Area	(m^2)	8.51
Flap Area	(m^2)	2.03
Max Rudder Angle	(degree)	45
Max Flap Angle	(degree)	55

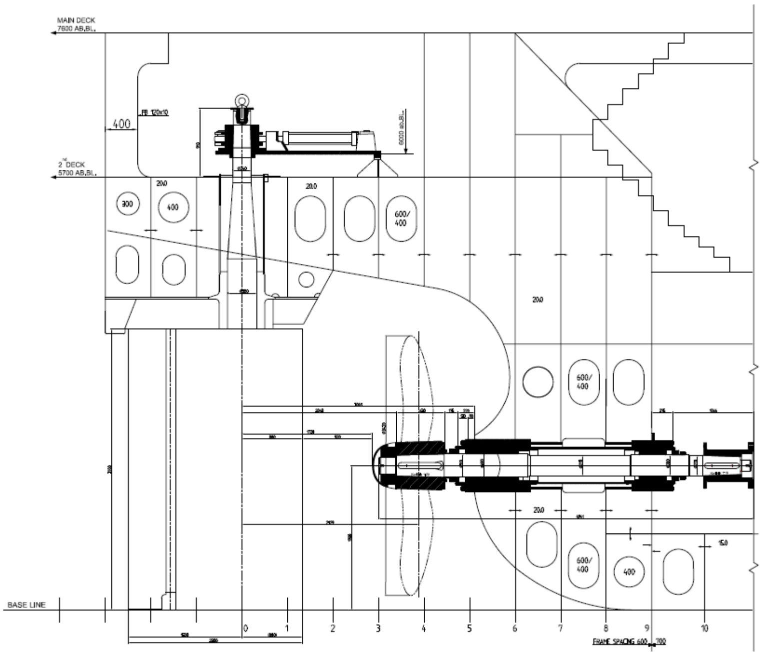

Figure 2-7 Stern gear arrangement of M/V "ERGE"

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2.2.1 Power and Performance Trials

Following her built, the initial trials were carried out at the Yellow Sea of China during the Feb 5th-6th, 2010. The sea trial campaign included the measurements of ship speed, shaft-power, hull performance and manoeuvring tests. The weather-related environmental and vessel's loading conditions during the trials are shown in Table 2-17, while the speed-power data are given in Table 2-18.

Table 2-17 M/V ERGE Sea Trial Ship and Environmental Conditions

Location	Yellow Sea
Weather	Fine
Wave condition	DOUGLAS 3
Air Pressure (Pa)	1020 mbar
Air Temperatre	2°C
Water Temperature	4°C
Draught Forward	2.80 m
Draught mean	3.30 m
Draught Aft	3.80 m

Table 2-18 M/V ERGE Power Performance Trial Results

Run No	Named M/E Load	Track Heading	Ground Speed (Knots)	Measured Shaft Power (kW)	Propeller Speed (rpm)	Average Speed (kn)	Average P_{Shaft} Power (kW)
1	75%	291° (NW)	12.3	1348	132.89	11.6	1350
2	75%	111° (SE)	11	1352	133.11		
3	85%	111° (SE)	11.4	1518	138.51	12	1500
4	85%	291° (NW)	12.6	1482	138.86		
5	100%	291° (NW)	12.8	1695	144.42	12.5	1707
6	100%	111° (SE)	12.1	1720	145.3		

Notes:

1) Ship speed is indicated as "Ground Speed" on the table and is the speed relative to the ground. A minimum delay between runs was maintained in order to minimise any variations in tide and wind conditions

2) Shaft power is assumed to equal the delivered power

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2.2.2 Turning Circle Manoeuvring Trials

A turning circle manoeuvre was performed to both starboard and port. The rudder helm angle was set at the maximum design rudder angle of 35 degrees during turning circle manoeuvring trials, with the main engine running at 775RPM. Figure 2-8 shows the main parameters involved in a typical circle manoeuvring test, and Table 2-19 includes the measured data related to these parameters during the tests for M/V ERGE.

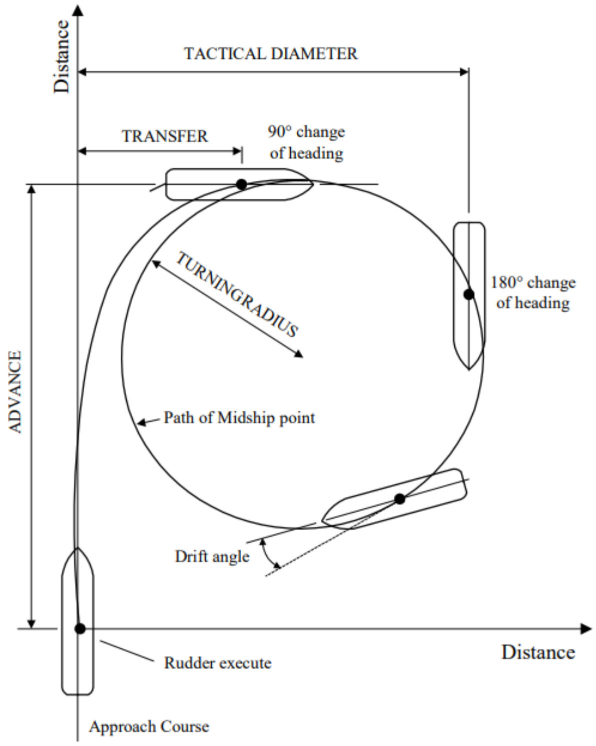

Figure 2-8 Elements of turning circle manoeuvre trial

Table 2-19 M/V ERGE turning circle manoeuvring trial results

M.E Load	IOO%MCR	IOO%MCR
Named M/E Speed (rpm)	775	775
Direction	PORT	STBD
Time (90°), sec	72	68
Time (180°), sec.	120	118
Time (270°), sec.	167	164
Time (360 0), sec.	214	210
Initial Speed (kn)	12.2	12
Advance (m)	304	259
Transfer (m)	109	104
Test time (s)	214	210
Tactical dia. (m)	198	184
Turnin dia. (m)	144	122
Max. heelin angle (deg)	4	5

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2.2.3 Zig-Zag Manoeuvring Trials

A zig-zag test was performed by applying a specified rudder angle (10 degrees for 10/10 zig-zag test to an initially straight approach as the "first execute"). Once the change of heading reached this specified value (10 degrees), the rudder is then immediately deflected to the opposite side with the same angle, as shown in Figure 2-9 with the main characteristics of this particular test.

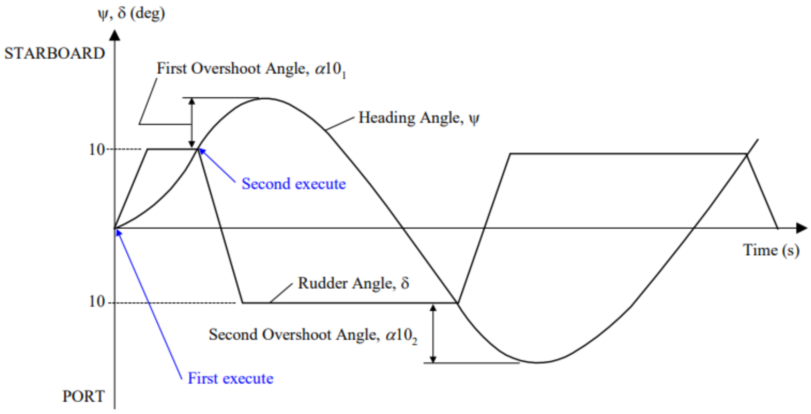

Figure 2-9 Elements of 10/10 Zig-zag Manoeuvre

Figure 2-10 and Table 2-21 shows the measured data in graphics and tabulated format, respectively, for M/V ERGE following this test.

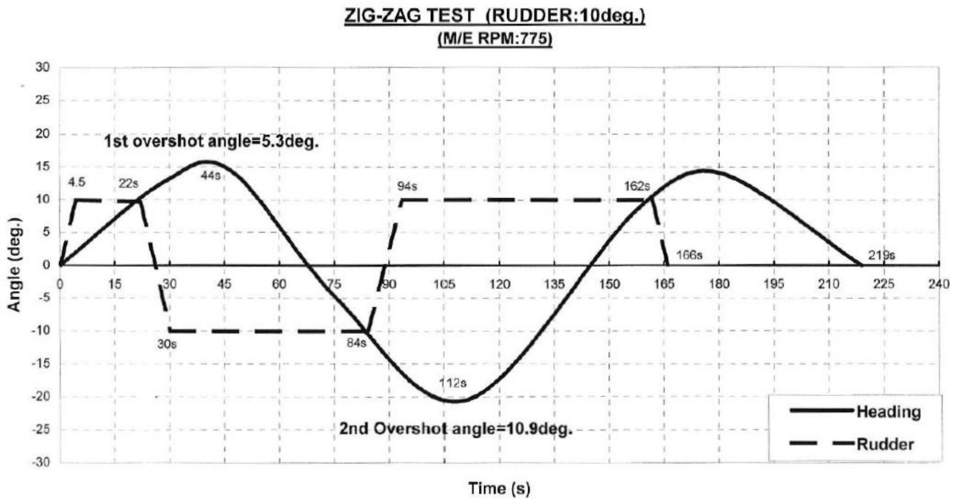

Figure 2-10 Zig-zag Manoeuvre Results of M/V ERGE (10/10)

Table 2-20 Tabulated Zig-zag Manoeuvre Results of Erge

Parameter	Value, (degrees)	Time (second)
First overshoot angle	5.3	44
Second overshoot angle	10.9	112

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2.2.4 GRS Design for Target Ship M/V Erge

As stated in the introduction section, one of the main objectives of GATERS is to design, manufacture and retrofit an effective GRS for M/V ERGE and demonstrate its effectiveness during the project lifetime. For this purpose, during the first four months of the project, a preliminary retrofit GRS was designed for M/V ERGE, and the main particulars of the GRS are presented in this section to form a basis for the model tests, CFD analyses, as well as to kick-off the actual detailed design activities.

The preliminary design work for the GRS of M/V ERGE was conducted in WP1 by the partner UoS based on the combination of the approaches below:

i. Initial trials data of M/V ERGE

ii. Speed-Power data collected during M/V ERGE's service

iii. Geometrically similar hull R&P model test data obtained from partner ITU

iv. Accumulated design knowledge from the Japanese vessels with GRS

v. Low-fidelity and high-fidelity CFD studies conducted with the model and full-scale versions of M/V ERGE

While the above approach was applied to determine the size of the GRS components (i.e. rudder blades, propeller and shafting), an important decision was made on the reference design data of M/V ERGE regarding her current propeller, which was cropped and having the current diameter of 3.42m. The UoS believes that the decision to crop M/V ERGE's propeller from 3.6m to 3.42m was not justified with the data available for this vessel, and hence the ship has been underperforming. Therefore, it was decided to conduct the GRS design as optimum as possible (i.e. aimed for 3.6m diameter) and compare the vessel's performance with the retrofit GRS and CRS, based on an enlarged (near optimum 3.6m) propeller and NOT with the existing cropped propeller of 3.42m diameter. This would provide a fairer comparison of the performances of M/V ERGE to assess the effect of the GRS .

By following the initial design activities, the main dimensions of the gate rudder blade and associated propeller are shown in Table 2-21 and Table 2-22, respectively.

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Table 2-21 M/V ERGE Gate rudder data

Parameter	Unit	Value		
Rudder Post from AP	(m)	1.60		
Rudder Post from CL	(m)	0.80		
Top Height from BL	(m)	4.20		
Middle Height	(m)	3.10		
Bottom Height	(m)	0.50		
Top Chord	(m)	1.30		
Top Chord (in)	(m)	0.70		
Middle Chord	(m)	2.20		
Bottom Chord	(m)	1.55		
Rudder Sections		**Gate Rudder**	**Fore**	**Aft**
Rudder Area (Upper)	(m^2)	1.925	0.770	1.155
Rudder Area (Lower)	(m^2)	4.875	1.300	3.575
Total Rudder Area	(m^2)	6.800	2.070	4.730
Aspect Ratio		2.013	Balance	0.304

Table 2-22 M/V ERGE new propeller data

Parameter	Symbol	Unit	Value
Propeller diameter	D	(m)	3.6
Blade number	Z		5
Pitch diameter ratio (@ 0.7R)	P/D		0.77
Blade area ratio	BAR		0.45
Skew		(mm)	25.0
Rake		(mm)	0.0
Boss Ratio			0.185
Boss Length		(mm)	0.70

The section details and some other geometric features of the gate rudder blades are shown in Figure 2-11.

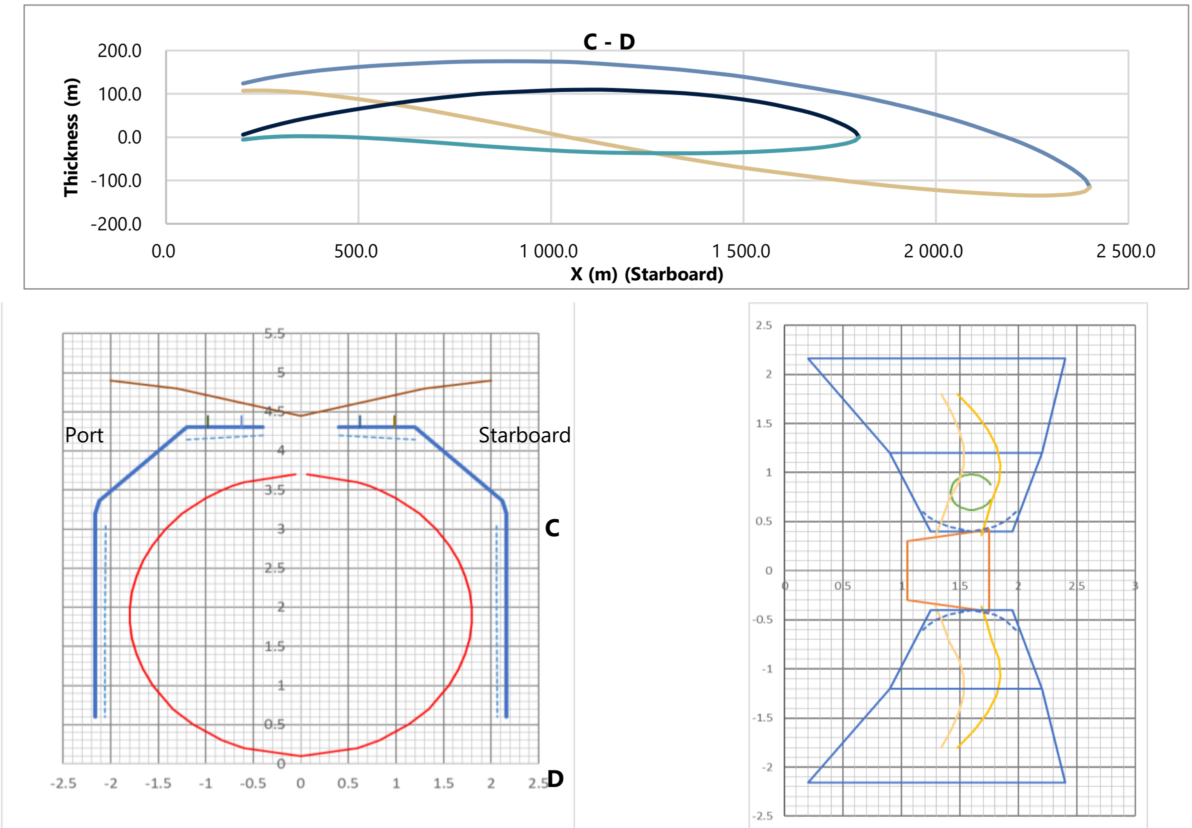

Figure 2-11 M/V ERGE Gate Rudder sections and draft design

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Having determined the initial geometric details of the GRS, these changes are reflected on the general arrangement of M/V ERGE and the preliminary design details of the GRS are shown in Figure 2-12.

Because of the limitations in the steering gear room, it was decided that the two steering gears will be located aft of the gate rudder stocks with an additional (1.6m) spacing between the two gate rudder stocks, as shown in Figure 2-12.

The new design arrangement with the introduction of the GRS indicated that the position of the new propeller with the GRS would be shifted further back compared to the original propeller position with the CRS. By keeping the CRS (stock) axis as the reference frame (i.e. AP), the gate rudders' axes will be located at 1.4m forward of AP, as shown in Figure 2-12. This also implied that the propeller shaft with the GRS would be extended; hence a suitable cover had to be designed to provide a smooth flow to the propeller at the stern tube region.

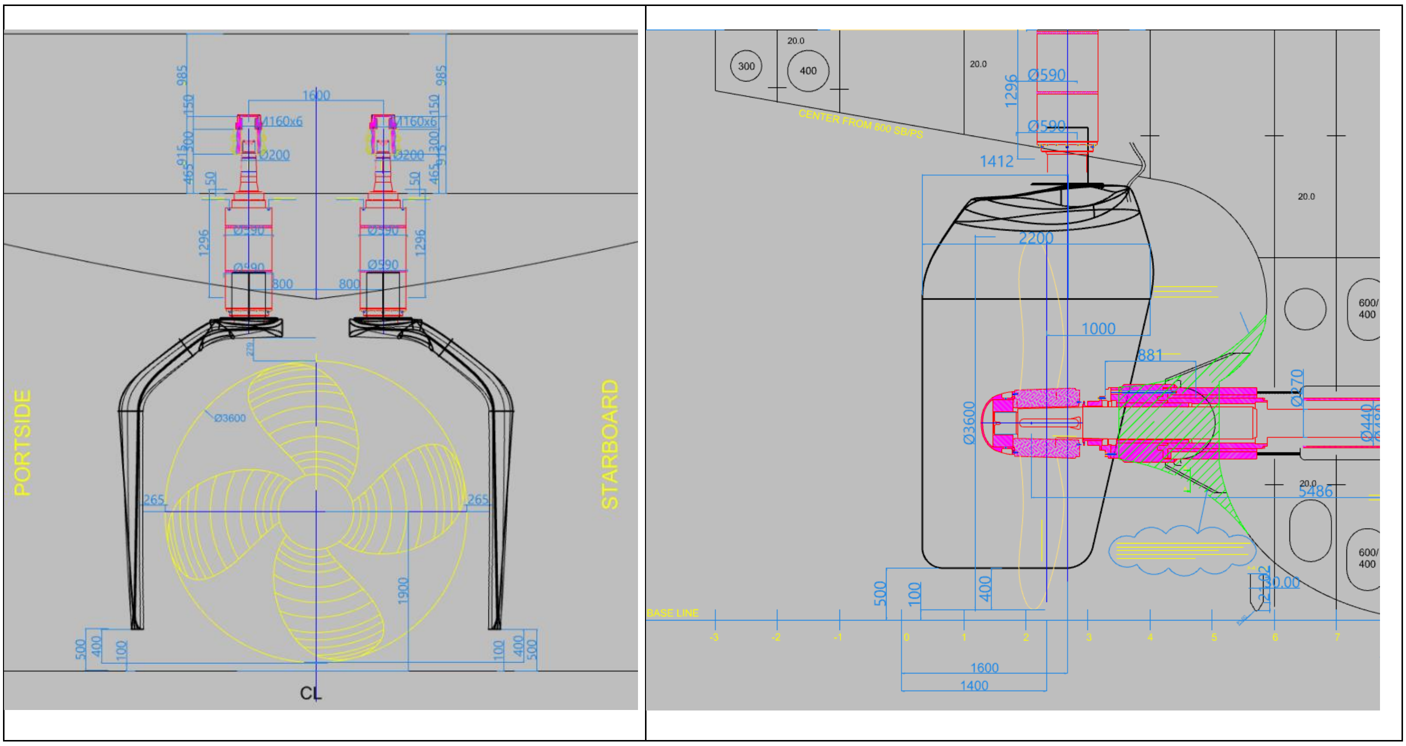

Figure 2-12 M/V ERGE GRS installation drawing

Thereby, as shown in Figure 2-13, the shaft extension cover is designed based on the water lines of the ship to provide a smooth transition around the shaft (the frames that support the cover sheet do not represent the final structure).

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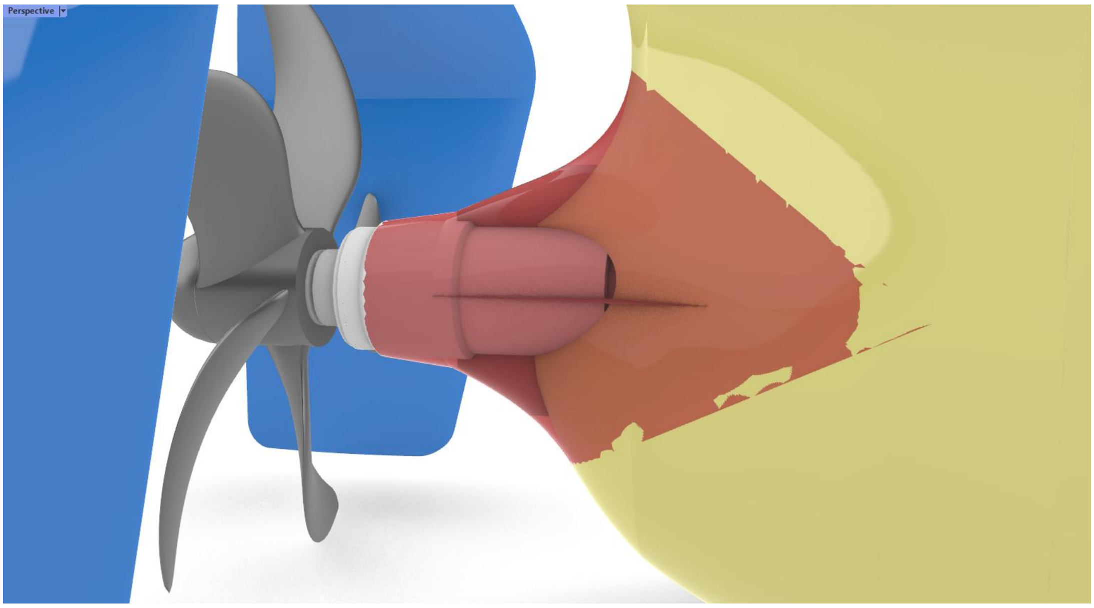

Figure 2-13 M/V ERGE shaft extension cover for GRS configuration

Based on the experience with the Japanese container ships, the stocks of the Gate Rudder blades should be properly covered by designing streamlined trunks to avoid potential flow shedding vibrations during the straight-ahead and manoeuvring conditions. Therefore, the GRS trunks were designed to implement shown in Figure 2-14.

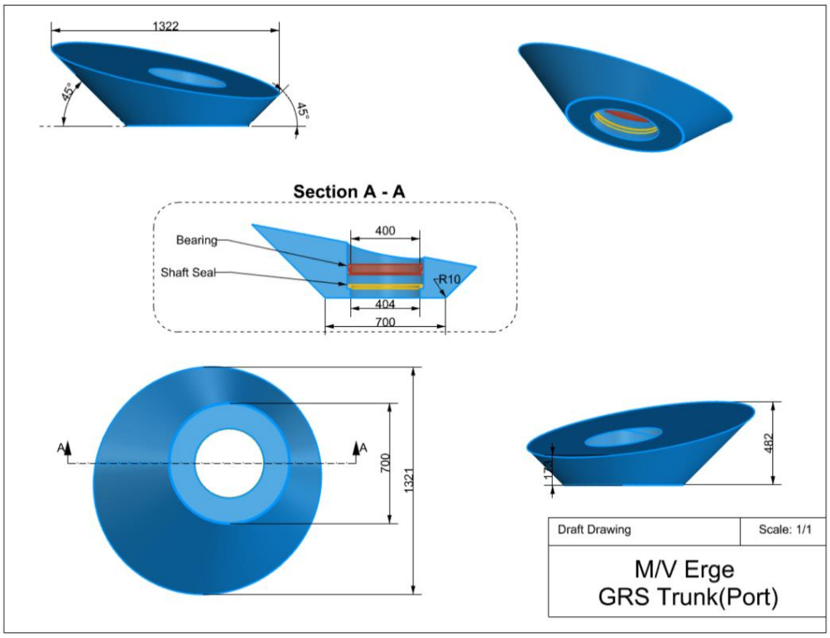

Figure 2-14 GRS Shaft trunk draft mechanic drawing

Based on the initial design activities conducted, the main components of the newly designed GRS for M/V ERGE are shown in Figure 2-15 by rendered figures. All the project partners who will be using the M/V ERGE data were informed about the availability of the data in digital format at the GATERS Share File System [4].

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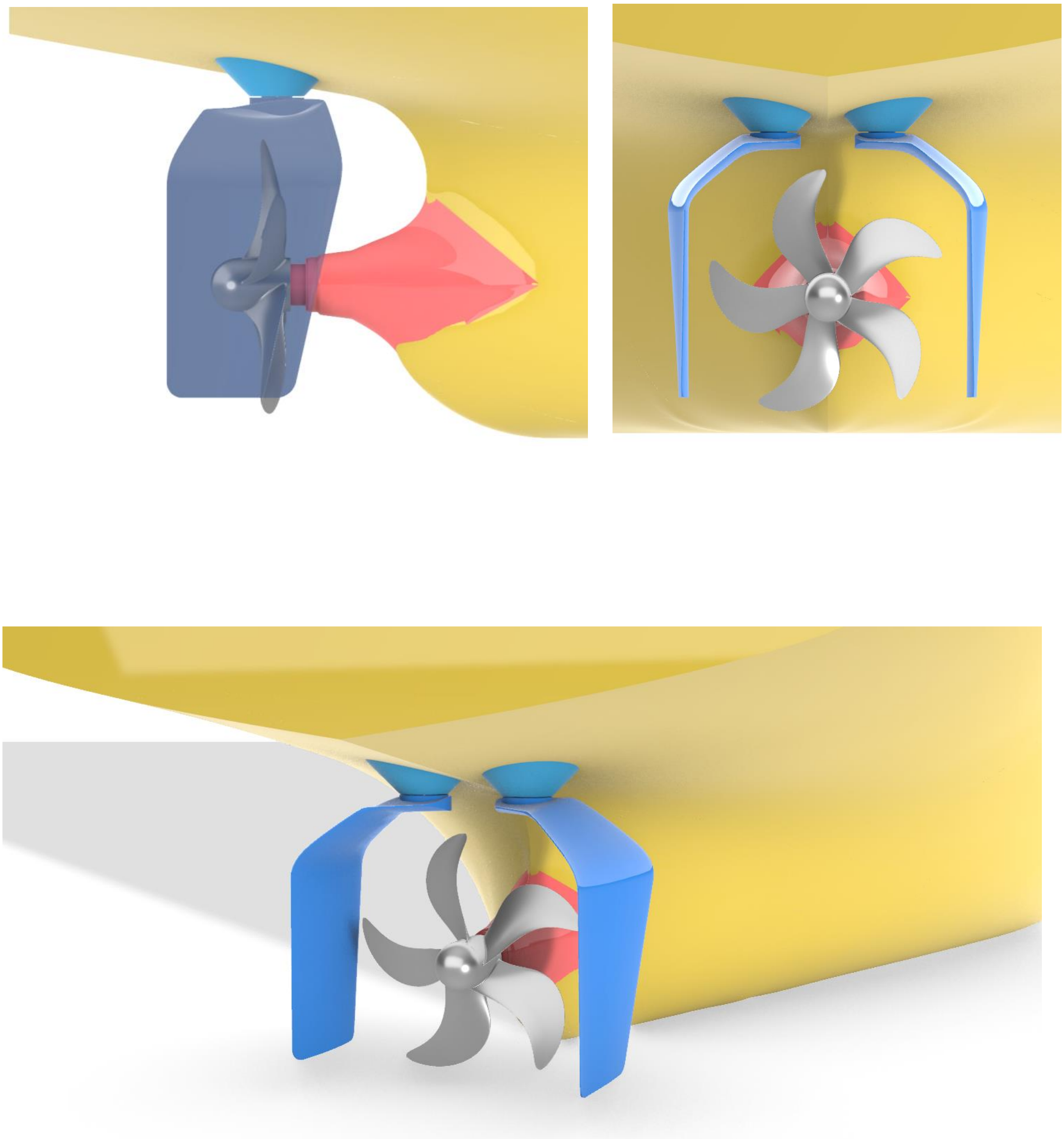

Figure 2-15 M/V ERGE GRS Configuration rudder fairing were prepared and shared.

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3. Database and selected vessels for further application and exploitation of GRS

The developed best design procedures and tools for the GRS design and analysis will be used for the broader ship type applications of GRS in the later stages of the GATERS project. In WP5 and WP6 of GATERS, retrofit applications for the selected major and broader ship types for the European Short Sea Shipping (SSS) and the Oceangoing Shipping (OS) operations will be explored for their impact assessments regarding the existing and forthcoming international and regional regulations such as IMO's Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII), EU local regulations concerning the emissions and air pollution and the life cycle cost for the selected vessels.

The aforementioned assessments will be conducted at two levels, namely:

(i) Relatively high (concept) level design/analysis and impact assessment for representative European fleet (covering different types of fleet members). This is based on the fleet members' main particulars and operation conditions for SSS and the OS vessels by considering the CRS and GRS alternatives for the chosen members. This analysis will be based on the preliminary design and analysis tools developed in WP1.

(ii) More detailed (but still concept) level design/analysis and impact assessment of the vessel types based on the available data (i.e. detailed hull forms, propellers, rudders, operational profiles and tank tests data) to be collected from the GATERS Shipowner and Design consultant partners. The data are expected to represent the most common vessel types (i.e. workhorses of the shipowners' fleet). This analysis will be conducted by using the high-fidelity design and analysis tools developed in WP1, WP5 and WP6.

In order to conduct the above two levels of impact analysis, the candidate vessel types/classes need to be selected in consultation with the appropriate GATERS partners. The selected types and associated preliminary data are described in the following two sub-sections.

3.1 High-level European Fleet Data for Impact Assessment

For this purpose, the extensive ship design/operation database of the GATERS Partner (ILL) for the SSS and OS vessels will be accessed.

In the database, the main particulars of 33,689 ships containing product tankers (including combined prod/chem), general cargo carriers, RoRo (excluding specialised vehicle carriers), bulk carriers and container carriers are included.

The Oceangoing ships (OS) comprise Tankers 20-60K DWT, Bulkers 35-100K DWT, Container carriers 3-10K TEU. The Short Sea Shipping (SSS) vessels are generally smaller than 10K DWT and mainly composed of general cargo vessels, similar to GATERS target vessel M/V ERGE, and Product Tankers. Table 3-1 present the range of this database.

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Table 3-1 High level European SSS oand the Oceangoing shipping fleet data

Row Labels	Deep Sea	Short Sea	Grand Total
Products/-chem	**2 241**	**5 807**	**8 048**
B 20'-60'dwt	2 241		2 241
D -10'dwt		4 625	4 625
X <1'dwt		1 182	1 182
General cargo		**14 385**	**14 385**
B -10'dwt		10 277	10 277
X <1'dwt		4 108	4 108
Roro		**510**	**510**
B -1,999 lm		200	200
X <1'dwt		310	310
Pure Chemical		**1 299**	**1 299**
C -10'dwt		1 097	1 097
X <1'dwt		202	202
Bulker	**7 636**		**7 636**
C 60'-100'dwt	3 988		3 988
D 35'-60'dwt	3 648		3 648
Container	**1 811**		**1 811**
C 5'-10'teu	1 014		1 014
D 3'-5'teu	797		797
Grand Total	**11 688**	**22 001**	**33 689**

3.2 Detailed Vessel Data for Application of Developed GRS Design Methodology

GATERS project is fortunate to have two major shipping companies as partners in the consortium. The partner DANAOS is one of the largest independent owners of modern containerships, while the partner STAR BULK is presently one of the major dry bulk shipping companies with 37 million metric tons of cargo capacity per year. This enables crucial feedback from the leading shipping industry partners and access to two major OS vessel types, Containerships and Bulk carriers.

3.2.1 Selected Vessel from GATERS Partner Danaos' Fleet

The partner DANAOS Shipping is the owner of 65 containerships ranging from 2200 to 13100 TEU, as shown in Figure 3-1. Danaos' containerships fleet on the water were built using the latest innovations in ship design. This presents a unique challenge to demonstrate any improvement with the GRS implementation of their state-of-the-art modern ships.

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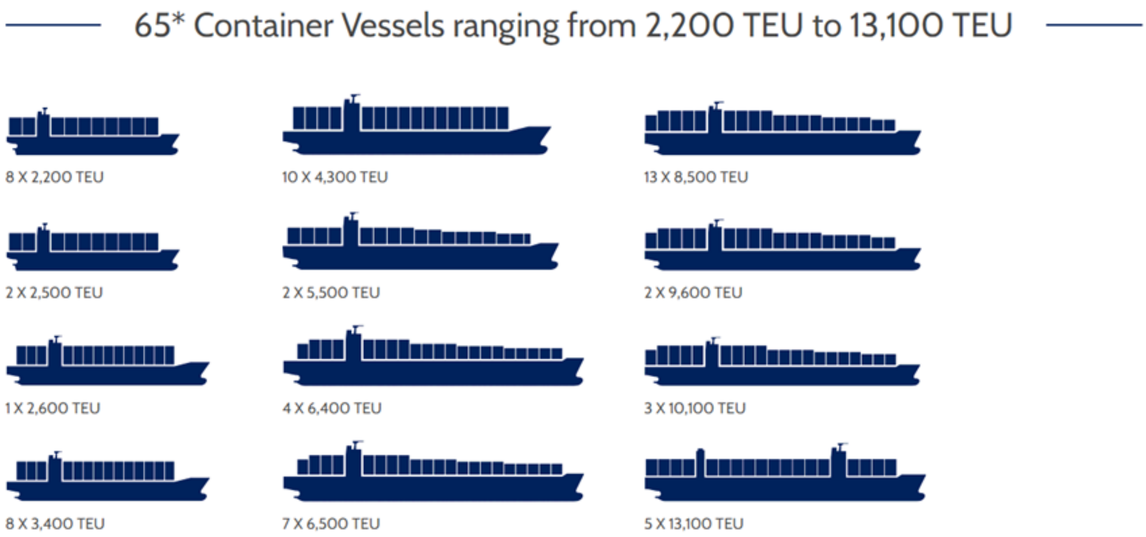

Figure 3-1 Danaos' containership fleet

The review of the Danaos' fleet database and investigation of the operational profiles for the various size containerships indicated that 4,300 TEU segment is an ideal candidate to scrutinise the developed GRS design methodology further. On this basis, "Zim Luanda", (IMO: 9403229) is selected by considering other facts, including the readily available comprehensive ship hull, propeller, rudder, operational profile and tank tests data.

Zim Luanda was built in 2009 and is sailing under the flag of Malta. Its carrying capacity is 4253 TEU, and the design draught is 12.6 meters. Her length overall (LOA) is 260.05 meters, and her width is 32.25 meters, as shown in Table 3-2.

Table 3-2 Main dimensions of Containership Zim Luanda (IMO: 9403229)

Zim Luanda			
Length overall	L_{OA}	(m)	260.05
Length between perpendiculars	L_{BP}	(m)	244.8
Breadth	B	(m)	32.25
Design Draught (midship)	T	(m)	12.6
Displacement	Δ	(ton)	50826
Container capacity		TEU	4253
Maximum Continuous Engine Rating		kW	37046

The required data for the impact analysis study with the implementation of the GRS are in hand, as confirmed by Danaos, and will be shared with the respected partners for the analyses.

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3.2.2 Selected Vessels from GATERS Partner Star Bulk's Fleet

The GATERS partner STAR BULK is a global shipping company that provides high-quality transportation services for dry bulk cargoes. The Star Bulk fleet comprises 120 modern vessels built-in world-class shipyards and with an average age of 7.9 years. Star Bulk's fleet composition is highly diversified, ranging from Supramax vessels to Newcastlemax vessels and has a total capacity of more than 13 million DWT as presented by Figure 3-2.

Figure 3-2 bulk carrier fleet of Star Bulk

The review of the Star Bulk's fleet database and investigation of the operational profiles for the various size bulk carriers indicated that Newcastlemax and Kamsarmax are ideal candidates for scrutinisation of the developed GRS design methodology. Amongst the Newcastlemax and Kamsarmax segment bulk carriers, "Maharaj" and "Star Laura" have been selected for detailed investigation for each category, and their general particulars are presented in Table 3-3 and Table 3-4, respectively.

Table 3-3 Main dimensions of Newcastlemax bulk carrier Maharaj

Maharaj			
Length overall	L_{OA}	(m)	300
Length between perpendiculars	L_{BP}	(m)	295.50
Breadth	B	(m)	50
Design Draught (midship)	T	(m)	18.43
Displacement	Δ	(ton)	209472
Hold capacity		(m^3)	227362
Maximum Continuous Engine Rating	MCR	(kW)	15250

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Table 3-4 Main dimensions of Kamsarmax bulk carrier Star Laura

Star Laura				
Length overall	L_{OA}	(m)	228.99	
Length between perpendiculars	L_{BP}	(m)	222.00	
Breadth	B	(m)	32.26	
Design Draught (midship)	T	(m)	14.43	
Displacement	Δ	(ton)	82192	
Hold capacity		(m^3)	97186	
Maximum Continuous Engine Rating	MCR	(kW)	9800	

The required data for the impact analysis study to implement the GRS are in hand, as confirmed by the partner Star Bulk and will be shared with the respected partners or the analyses.

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4. Summary

As deliverable D1.1, the report presented the geometrical and operational data for several actual vessels (existing) to be used in WP1 to develop and apply the best design and analysis procedure for the Gate Rudder System (GRS) and its applications for broader ships types and operations in WP5 and WP6.

For the above purpose, the report included the data for three key vessels including; "*Sakura*": 2400GT (400TEU) Japanese coastal container vessel fitted with a conventional rudder system (CRS); "*Shigenobu*": 2400GT (400TEU) Japanese coastal container vessel fitted with a gate rudder system (GRS) which is sister to *Sakura; and* "*M/V Erge*": 5500DWT European general cargo vessel, currently, fitted with a CRS but will be retrofitted by a GRS as the "Target Vessel" of GATERS project. The data presented involved the detailed description of the hull, rudder and propeller geometries, including the digital format as well as their trials data in terms of the power-speed and manoeuvring (Turning Circle and Zig-Zag).

For the further applications of the GRS for broader ship types in WP5 and 6 of GATERS, an extensive ship design/operation database for the European Short Sea Shipping and Oceangoing Shipping type vessels was introduced to retrieve the high-level data for the broader ship type applications. This was further complemented by the introduction of three further key vessels from the shipowner partners. These vessels are 4250 TEU container ship of Danaos, "*Zim Luanda*", together with the Newcastlemax class, "*Maharaj*" and Kamsarmax class, "*Star Laura*" of Star Bulk for the detailed investigations in WP5 and WP6, respectively.

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5. References

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