Grant Agreement No:	605221
Project Acronym:	SHOPERA
Project Title:	Energy Efficient Safe **SH**ip **OPERA**tion

Deliverable D4.1

Test Matrix

Due date of deliverable: *30-04-2014*

Actual Submission date: *30-04-2014*

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CO[1]	
-dissemination level-	

Status of Deliverable: *Draft/<u>Final</u>*

Document Reference Number: *SHOPERA-T-WP4-TK4.1–rev07*

[1] **dissemination level**	
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Document History

Document ID.	Date	Description
SHOPERA-T-WP4-TK4.1–rev01	22nd April 2014	Draft version for discussion
SHOPERA-T-WP4-TK4.1–rev07	30th April 2014	Final version

Document Control Sheet

Title: D4.1. Test Matrix
Abstract This document contains deliverable *D4.1. Test Matrix*, which specifies the test matrix, test conditions, values to be measured in the tests and data exchange format of experimental results for WP3. The deliverable is a result of the work in Task 4.1. Test Matrix (partners: GL, UDE, NTUA, DNV, SU, DTU, TUB, IST, VTT and LR). The work is based on the ship types, safety criteria and validation requirements of numerical methods, defined in WP1. Input to this task was provided through tight interaction with WP1 (safety criteria and ship types) and WP2 (characteristics of the developed numerical tools). Output of this task provides specifications for WP3, including test matrix, test conditions and values to be measured. Measurement data from model tests will be further used in WP4 for the validation of numerical tools and for benchmarking of numerical simulation methods for selected cases, including external participants.
Summary Report: **Introduction.** This report provides matrix of model tests to be conducted within WP3 of the SHOPERA project. The tests to be conducted should address the required developments of numerical methods for manoeuvrability in waves and provide validation data for these developments. **State of the Art:** One of the largest gaps in the present SoA is the absence of validated numerical methods for the computation of drift forces in waves. Although some measurements are available for the longitudinal component of drift force, both at zero and non-zero speeds, most data are available for head waves only; virtually no measurements are available for the added resistance in oblique waves, as well as for side drift force and yaw drift moment, especially for non-zero forward speed. For simulations of manoeuvres in waves, simplified models of rudder forces in waves are required. Two aspects are to be taken into account: forces due to waves and forces on rudder in propeller slip stream in off-design conditions. Experimental data for the validation of such models are not available yet. Finally, validation of the proposed criteria for manoeuvring in waves will be carried out using direct transient simulations of manoeuvres in time domain. Such simulations in turn require validation by comparison with experiments; in the open literature, only limited amount of such experimental results is available. **Value added to SHOPERA:** Specifications for model tests to be carried out in WP3, including test matrix, test conditions and values to be measured. Measurement data from model tests will be further used in WP4 for the validation of numerical tools and for benchmarking of numerical simulation methods for selected cases. **Achievements:** Matrices for model tests and numerical simulations. **Not achieved:** NA **Input from other Deliverables:** D3.1. Specification of model tests **Exploitation of results:** Output of this task provides specifications for WP3, including test matrix, test conditions and values to be measured. Measurement data from model tests will be further used in WP4 for the validation of numerical tools and for benchmarking of numerical simulation methods for selected cases, including external participants. This executive summary may be published outside the SHOPERA consortium. *YES*/*NO*

Work carried out by	**Approved by**
Vladimir Shigunov Germanischer Lloyd SE	*Name of internal reviewer and date of acceptance:* Vladimir Shigunov, 2014-04-29
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1 Summary

This document contains deliverable *D4.1. Test Matrix*, which specifies the test matrix, test conditions, values to be measured in the tests and data exchange format of experimental results for WP3. The deliverable is a result of the work in Task 4.1. Test Matrix (partners: GL, UDE, NTUA, DNV, SU, DTU, TUB, IST, VTT and LR). The work is based on the ship types, safety criteria and validation requirements of numerical methods, defined in WP1. Input to this task was provided through tight interaction with WP1 (safety criteria and ship types) and WP2 (characteristics of the developed numerical tools). Output of this task provides specifications for WP3, including test matrix, test conditions and values to be measured.

Measurement data from model tests will be further used in WP4 for the validation of numerical tools and for benchmarking of numerical simulation methods for selected cases, including external participants.

2 Definition of Required Tests

This report provides matrix of model tests to be conducted within WP3 of the SHOPERA project. The tests to be conducted should address the required developments of numerical methods for manoeuvrability in waves and provide validation data for these developments. In addition, RANSE simulations required to provide input data for manoeuvring simulations are also defined.

2.1 Drift Forces, Added Resistance and Propulsion in Waves

One of the largest gaps in SoA is the absence of validated numerical methods for the computation of drift forces in waves. Although there are some measurements available for the longitudinal component of drift force (added resistance), both at zero and non-zero speeds, most data are available for head waves only. There are virtually no measurements available in the open literature for the added resistance in oblique waves. Another gap to be addressed concerns side drift force and yaw drift moment, important for manoeuvrability in waves: whereas some limited data are available for these components of drift forces at zero forward speed, there are no measurements available in the open literature for non-zero forward speed. Therefore, to address these gaps, measurements of drift forces in waves, including added resistance, are required, covering head and following waves as well as oblique and side waves for the entire speed range relevant for manoeuvring in waves. The usual approach to the computation of drift forces in waves is the spectral method, following which, drift forces are computed in regular waves, and estimated in irregular waves assuming their proportionality to the squared amplitudes of seaway components. Because of the practicality of this method, it will be used in SHOPERA. Thus, model tests should provide drift forces in regular waves for the validation of numerical methods. However, to check the accuracy of the spectral assumption, several additional tests should be carried out: first, drift forces will be measured for several wave heights for selected wave directions and periods and, second, added resistance will be measured directly in irregular waves in few selected seaways. Another uncertainty in the numerical models for manoeuvring in waves relates to thrust deduction and wake fraction in waves. Although the scope of SHOPERA does not allow for a dedicated study to define thrust deduction and wake fraction in all relevant seaways for all typical hull forms, an investigation is required to quantify the uncertainties related to the assumption of these parameters as independent of waves. To do this, a limited amount of propulsion tests in regular waves should be carried out. Finally, in order to subtract calm-water effects from the measurements in waves, resistance and propulsion tests should be also performed in calm-water conditions.

2.2 Rudder Forces

Accuracy of simulations of manoeuvres in waves strongly depends on the models of rudder forces. There are available simplified models for rudder forces in calm water conditions; to simulate rudder forces in waves, two aspects should be taken into account: first, forces due to waves on the rudder and second, forces on rudder in propeller slip stream in off-design conditions. To provide data for the development and validation of such models, two types of tests should be carried out: measurement of rudder forces (side and longitudinal) in regular waves, and rudder forces in propeller slip stream during bollard pull.

2.3 Manoeuvring

The approach to norming manoeuvrability in waves is addressed by fulfilling two requirements: (a) prescribed minimum advance speed and (b) course-keeping; both requirements are to be fulfilled in waves and wind from any directions. Although fulfillment of these requirements indirectly implies the ability of ship to change course in a limited time in waves and wind from any direction, validity of this implication should be verified using direct simulations of manoeuvres in time domain. To provide validation data for such simulations, transient manoeuvres in regular waves should be performed. The most suitable manoeuvre is turning circle, because it allows to minimize the influence of the initial conditions, if sufficiently large number of circles is performed. Note that simulation of manoeuvres in waves requires, as input, manoeuvring derivatives in calm water, which can be derived from standard PMM tests (or simulations).

2.4 Summary of Recommended Tests

Summarising, the following model tests should be performed in deep and shallow water to provide validation data for the developed numerical models:

- Drift forces including added resistance in regular waves
- Added resistance in irregular waves
- Propulsion and speed loss in regular waves
- Resistance and propulsion in calm water
- Rudder forces in regular waves
- Rudder forces in bollard pull
- Turning circle in regular waves
- Zig-zag manouevers in regular waves
- PMM tests in calm water

3 Vessels and Loading Conditions

It has been agreed upon within the consortium that open ship lines are favourable, since this enables publication of data and open benchmarking as planned in WP4. Furthermore, consensus has been reached that a reasonably large number of tests per model is favourable over a large variety of model types with only limited tests per type. Three vessel types of different hydrodynamic characteristics were selected to provide a sufficiently broad variety of hull types for the validation of numerical tools: a VLCC tanker, a post-panamax container ship and a RoPax ferry. For two ship types, open lines are available: for the KVLCC2 tanker designed by MOERI and the Duisburg Test Case (DTC) container vessel designed by the Institute of Ship Technology, Ocean Engineering and Transport Systems (ISMT) at the University of Duisburg-Essen. For the RoPax vessel, data cannot be made publicly available but can be used for validation by SHOPERA partners. The main particulars of the vessels are summarised in Table 1; hull surface geometry is shown in Fig. 1.

Table 1: Main particulars of the vessels used in tests

Ship	KVLCC2	DTC	RoPax
Length between perpendiculars L_{pp} [m]	320.0	355.0	90.0
Waterline breadth B_{wl} [m]	58.0	51.0	17.82
Design draught T_d [m]	20.8	14.5	4.19
Volume displacement V [m³]	312622	173467	3752
Wet surface without appendages S [m²]	27194	22032	1763
Block coefficient C_B [-]	0.8098	0.661	0.56

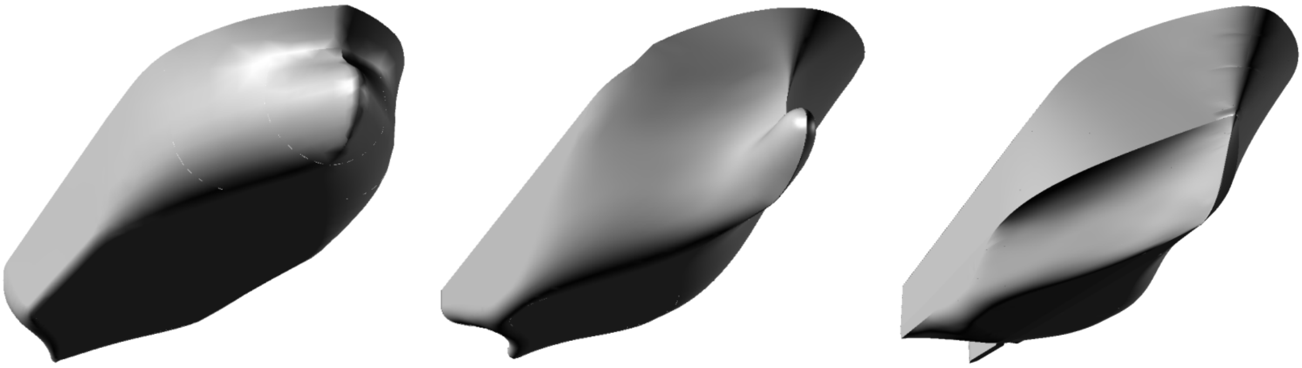

Fig. 1: Hull surface geometry of KVLCC2 (left), DTC (middle) and RoPax (right) vessels

Tankers and container ships sail in various loading conditions: tankers usually either in full load or ballast, whereas container ships at any loading condition between scantling draught and ballast draught. Because hydrodynamics is very different between full load and ballast, two loading conditions should be studied for KVLCC2 (full load and heavy weather ballast) and for DTC (design draught and ballast). Instead of ballast, a slightly greater draught can be used for DTC if arrangement of all devices onboard the model is difficult in ballast. Besides, for container ships, also lateral windage area strongly differs between design draught and ballast because of cargo load, Fig. 2. For RoPax ferries, on the other hand, draught changes only slightly in operation, therefore for RoPax, only one loading condition is tested (design draught). Parameters of loading conditions are summarised in Table 2.

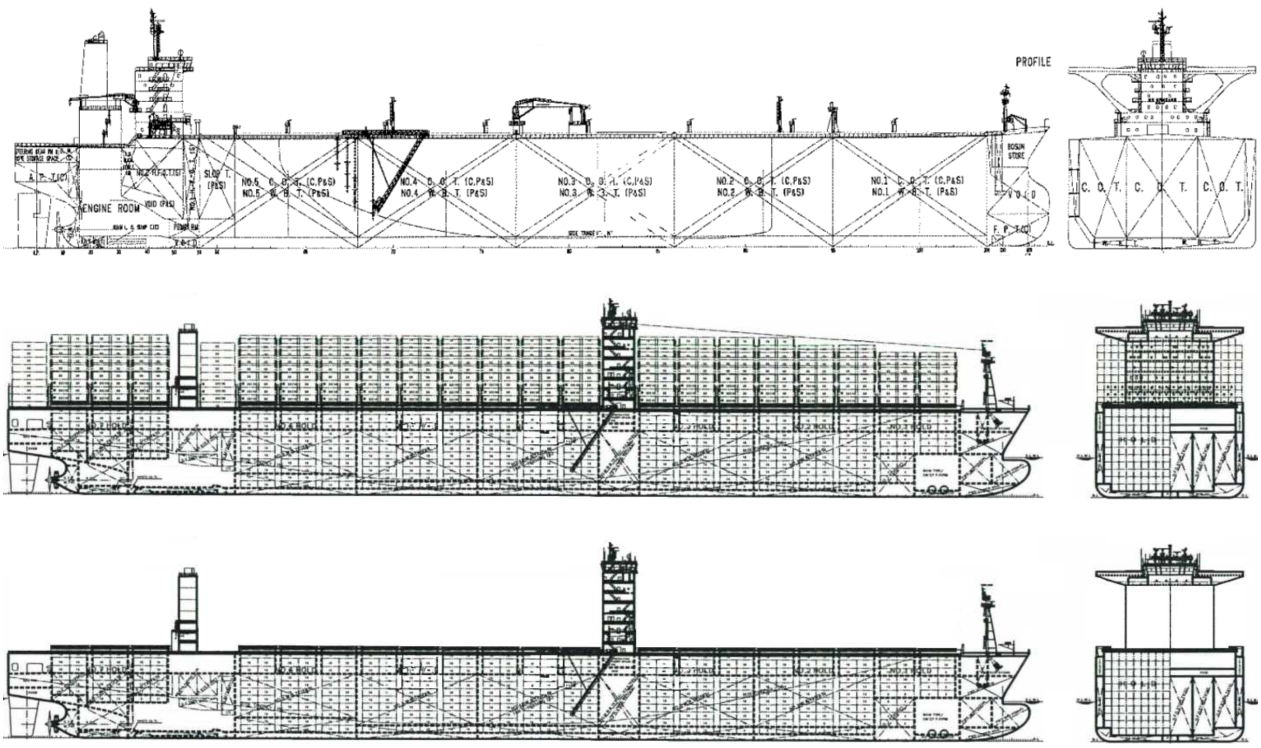

Fig. 2: GA for (top to bottom) KVLCC2, DTC in design loading condition, DTC in ballast loading condition and RoPax ferry

Table 2: Parameters of loading conditions

Ship	KVLCC2		DTC		RoPax
Loading condition	Full Load	Heavy Weather Ballast	Design Draught	Ballast	Design Draught
Definition	LC1	LC2	LC1	LC2	
Draught at forward perpendicular Tfp [m]	20.8	8.2	14.5	5.9 (7.8)	4.089
Draught at aft perpendicular Tap [m]	20.8	11.5	14.5	9.8 (11.0)	4.296
Mass displacement [t]	320438		177804		3846
Longitudinal position of CG LCG [m]	171.1				40.765
Transverse metacentric height GM [m]	5.71	21.4	5.1	18.4 (12.4)	2.397
Longitudinal radius of inertia r44 [m]	23.2	23.2	20.3	21.0 (20.1)	6.3
Transverse radius of inertia r55 [m]	80.0	80.0	87.3	88.1 (87.4)	22.5
Vertical radius of inertia r66 [m]	80.0	80.0	87.4	89.2 (87.7)	22.5

4 Test Matrix

4.1 Added Resistance in Regular Waves

Ship/LC	**Water Depth**	**Speed [knots]**	**Wave Heading [°]**	**Wave Period**
DTC/design	deep	0	0 & 180	7 periods
		6	0 & 180	7 periods
		16	0 & 180	7 periods
DTC/design	intermediate	0	180	7 periods
		6	180	7 periods
		16	180	7 periods
DTC/design	shallow, depth 1	0	180	7 periods
		6	180	7 periods
		16	180	7 periods
DTC/design	shallow, depth 2	0	180	7 periods
		6	180	7 periods
		16	180	7 periods
DTC/ballast	shallow, depth 1	0	180	7 periods
		6	180	7 periods
		16	180	7 periods
KVLCC2/scantling	deep	0	0 & 180	5 periods
		6	0 & 180	5 periods
		12	0 & 180	5 periods
KVLCC2/scantling	shallow, depth 1	0	180	7 periods
		6	180	7 periods
		12	180	7 periods
KVLCC2/scantling	shallow, depth 2	0	180	7 periods
		6	180	7 periods
		12	180	7 periods
KVLCC2/heavy ballast	deep	0	0 & 180	5 periods
		6	0 & 180	5 periods
		12	0 & 180	5 periods
RoPax/design	deep	0	0 & 180	7 periods
		5	0 & 180	7 periods
		14	0 & 180	7 periods

Notes:

- Tests are performed at the maximum feasible wave steepness for all wave periods; additionally, waves of 0.5 and 0.7 of maximum steepness are used for two wave periods (RAO peak and the shortest wave)
- Where possible, the wave steepness should be kept constant (for quadratic RAO)

- Variables to be measured: heave, pitch, surge, longitudinal force, undisturbed wave, pressure near the fore shoulder; videos for selected scenarios
- Short waves down to the ratio of wave length to ship length of about 0.1, long waves up to the ratio of wave length to ship length of about 1.8

4.2 Drift Forces in Regular Waves

Ship/LC	Water Depth	Speed [knots]	Wave Heading [°]	Wave Period[1]
DTC/design	deep	0	30, 60, 90, 120, 150	7 periods
		6	30, 60, 120, 150	7 periods
DTC/design	shallow	0	30, 60, 90, 120, 150	7 periods
DTC/ballast	shallow	0	30, 60, 90, 120, 150	7 periods
KVLCC2/scantling	deep	0	30, 60, 90, 120, 150	5 periods
KVLCC2/scantling	shallow	0	30, 60, 90, 120, 150	7 periods
KVLCC2/heavy ballast	deep	0	30, 60, 90, 120, 150	5 periods
KVLCC2/heavy ballast	shallow	0	30, 60, 90, 120, 150	7 periods
RoPax/design	deep	0	30, 60, 90, 120, 150	7 periods
		5	30, 60, 120, 150	7 periods

Notes:

- Tests are performed at the maximum feasible wave steepness for all wave periods; additionally, waves of 0.5 and 0.7 of maximum steepness are used for two wave periods (RAO peak and the shortest wave)
- Where possible, the wave steepness should be kept constant (for quadratic RAO)
- Variables to be measured: heave, pitch, roll, surge, sway and yaw, longitudinal force, drift force, yaw moment, undisturbed wave, pressure near the fore shoulder; videos for selected scenarios
- Short waves down to the ratio of wave length to ship length of about 0.1, long waves up to the ratio of wave length to ship length of about 1.8

4.3 Added Resistance in Irregular Waves

Variables to be measured in these tests are heave, pitch, roll and surge motions, longitudinal force, undisturbed wave and pressure near the fore shoulder.

Ship/LC	Water Depth	Speed [knots]	Wave Heading [°]	Wave Period
DTC/design	deep	6	180	3 irregular seaways
KVLCC2/scantling	deep	6	180	3 irregular seaways

4.4 Propulsion and Speed Loss in Regular Waves

Ship/LC	Water Depth	rpm	Wave Height	Wave Heading [°]	Wave Period
DTC/design	deep	75%	max. & 0.7 max. steepness	180	5 periods
DTC/design	shallow, depth 1	30%	max. steepness	180	7 periods
		75%	max. steepness		7 periods
		100%	max. steepness		7 periods
DTC/design	shallow, depth 2	30%	max. steepness	180	7 periods
		75%	max. steepness		7 periods
		100%	max. steepness		7 periods
KVLCC2/scantling	deep	75%	max. & 0.7 max. steepness	150, 180	5 periods
KVLCC2/scantling	shallow, depth 1	30%	max. steepness	180	7 periods
		75%	max. steepness		7 periods
		100%	max. steepness		7 periods
KVLCC2/scantling	shallow, depth 2	30%	max. steepness	180	7 periods
		75%	max. steepness		7 periods
		100%	max. steepness		7 periods
RoPax/design	deep	75%	max. & 0.7 max. steepness	180	5 periods

Notes:

- Tests are performed at the maximum feasible wave steepness for all wave periods; additionally, waves of 0.5 and 0.7 of maximum steepness are used for two wave periods (RAO peak and the shortest wave)
- Where possible, the wave steepness should be kept constant (for quadratic RAO)
- Variables to be measured: thrust, torque, forward speed, heave, pitch, undisturbed wave, pressure near the for shoulder; videos for selected scenarios
- Short waves down to the ratio of wave length to ship length of 0.1, long waves up to the ratio of wave length to ship length of about 1.8

4.5 Propulsion and Speed Loss in Irregular Waves

Ship/LC	Water Depth	rpm	Wave Heading [°]	Wave Period
DTC/design	deep	75%	180	3 irregular seaways
KVLCC2/scantling	deep	75%	180	3 irregular seaways

Notes:

- Variables to be measured: thrust, torque, forward speed, heave, pitch, undisturbed wave, pressure near the for shoulder; videos for selected scenarios
- Autopilot should be used for course keeping

4.6 Resistance in Calm Water

Note that the initial part of the test will be used as surge acceleration test. Variables to be measured in these tests: resistance, trim and sinkage, pressure near the for shoulder, wave profile by photographs.

Ship/LC	Water Depth	Speed [knots]
DTC/design	deep	6, 16
DTC/design	shallow, depth 1	6, 16
DTC/design	shallow, depth 2	6, 16
DTC/ballast	shallow, depth 1	6, 16
KVLCC2/scantling	deep	6, 12
KVLCC2/heavy ballast	deep	6, 12
KVLCC2/scantling	shallow, depth 1	6, 12
KVLCC2/scantling	shallow, depth 2	6, 12
RoPax/design	deep	5, 14

4.7 Propulsion in Calm Water

Variables to be measured: propeller torque, propeller thrust, trim and sinkage, pressure near the for shoulder, wave profile by photographs.

Ship/LC	Water Depth	Rpm [%]
DTC/design	deep	75
DTC/design	shallow, depth 1	30, 40, 50, 65, 75, 85, 100
DTC/design	shallow, depth 2	30, 40, 50, 65, 75, 85, 100
KVLCC2/scantling	deep	75
KVLCC2/scantling	shallow, depth 1	30, 40, 50, 65, 75, 85, 100
KVLCC2/scantling	shallow, depth 2	30, 40, 50, 65, 75, 85, 100
RoPax/design	deep	75

4.8 Rudder Forces in Regular Waves

Ship/LC	Depth	Speed [knots]	Wave Steepness	Wave Heading [°]	Wave Period	Rudder Angle
DTC/design	deep	6	max. & still water	60, 120	1 period	from 0 to 35°
KVLCC2/scantling	deep	6	1 height	60, 120	1 period	from 0 to 35°

Notes:

- Variables to be measured: longitudinal and side rudder forces, rudder stock moment, undisturbed wave, propeller thrust, propeller torque, ship motions
- Where possible, the wave steepness should be kept constant

4.9 Bollard Pull in Calm Water

Variables to be measured: longitudinal and transverse rudder forces, rudder stock moment, propeller thrust, propeller torque.

Ship/LC	Water Depth	rpm [%]	Rudder Angle
DTC/design	deep	30, 75, 100	from 0 to 35°
DTC/design	shallow	30, 75, 100	from 0 to 35°
KVLCC2/scantling	shallow	30, 75, 100	from 0 to 35°

4.10 Turning Circle in Regular Waves

Two series of tests are planned, both for DTC at design draught in deep water:

(1) 75% rpm, initial headings 0, 90, 180 and 270°, rudder angle 35°, 3 wave periods, maximum wave steepness
(2) 75% rpm, initial headings [90 and 180] °, rudder angle 35°, 1 wave period, maximum wave steepness, 1 wind speed, 1 current speed

4.11 PMM Tests in Calm Water

PMM tests include standard tests: steady drift motion, harmonic sway, harmonic yaw, harmonic combined sway and yaw and harmonic variation of rudder angle. Part of PMM results will be taken from SIMMAN database, part will be taken from numerical PMM simulations, and part from the tests carried out in SHOPERA model experiments.

Ship/LC	Water Depth	Speed [knots]	Notes
DTC/design	deep	6	GL numerical simulations
		16	GL numerical simulations
DTC/design	intermediate	6	TUB model experiments
		16	TUB model experiments
DTC/design	shallow, depth 1	6	SHOPERA model experiments
		16	SHOPERA model experiments
DTC/design	shallow, depth 2	6	SHOPERA model experiments
		16	SHOPERA model experiments
DTC/ballast	deep	6	GL numerical simulations
		16	GL numerical simulations
KVLCC2/scantling	deep	6	SIMMAN database
		12	SIMMAN database
KVLCC2/scantling	shallow, depth 1	6	SHOPERA model experiments
		12	SHOPERA model experiments
KVLCC2/scantling	shallow, depth 2	6	SHOPERA model experiments
		12	SHOPERA model experiments
KVLCC2/heavy ballast	deep	6	UDE numerical simulations
		12	UDE numerical simulations
RoPax/design	deep	5	TUB numerical simulations
		14	TUB numerical simulations

4.12 Other Tests

A number of other tests are to be performed, including, first, additional manoeuvring tests requested by different partners and, second, calibration tests to define parameters of models.

Ship/LC	Water Depth	Test	Conditions
DTC/design	deep	Turning circles in calm water	75% rpm, 35° rudder angle
DTC/design	deep	Zig-Zag manoeuvre in calm water	75% rpm, 20°/20° rudder angle
DTC/design	deep	Zig-Zag manoeuvre in regular waves	Wave direction 180°, 75% rpm, 2 wave periods, 2 initial conditions, 20°/20° rudder angle
KVLCC2/dcantling	deep	Circular motion tests in calm water	
KVLCC2/scantling	deep	Circular motion tests in regular waves	
DTC/design DTC/ballast KVLCC2/scantling KVLCC2/heavy ballast RoPax/design	air	Dry moments of inertia	Pendulum tests in air
DTC/design DTC/ballast KVLCC2/scantling KVLCC2/heavy ballast RoPax/design	deep	Definition of GM	Static heeling tests
DTC/design DTC/ballast KVLCC2/scantling KVLCC2/heavy ballast RoPax/design	deep	Wet moments of inertia and roll damping	Roll decay tests

5 Values to be Reported

5.1 Test Conditions

The following values are to be reported for all tests:

(1) Water temperature, density, viscosity
(2) Where relevant, air temperature, density, viscosity
(3) Dry moments of inertia of the models
(4) Draughts at forward and aft perpendiculars and initial metacentric height of the models
(5) Roll decay tests

5.2 Time Histories

Time histories are to be reported as ASCII files for the following filtered and not filtered variables:

(1) Hull forces and moments including inertia terms
(2) Hull forces and moments with removed inertia terms
(3) Rudder forces (side force, longitudinal force and rudder stock moment)
(4) Propeller thrust and torque
(5) Forward speed
(6) Undisturbed free surface elevation
(7) Ship motions

5.3 Post-Processed Time Histories

The following post-processed results are to be reported:

(1) Complex transfer functions
(2) Average forces and moments over time
(3) Quadratic transfer functions of hull forces and moments
(4) Error margins for each variable

6 Data Exchange Format

6.1 General

Data are supplied in ASCII format.

6.2 Coordinate System

The following coordinate system is used for ship motions and forces: coordinate origin at the intersection of waterline, central plane and midship section; x-axis parallel to waterline, positive forward, y-axis parallel to waterline, positive to port; z-axis positive upwards. Rudder angle to port is positive.

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