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SIMMAN 2020

Sub report 1
Computed or submitted EFD based cases

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SIMMAN 2020

Sub report 1 – Computed or submitted EFD based cases

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Abstract

The present report describes the setup and the execution of simulation runs based on the 2018 manoeuvring models of the KCS and KVLCC2 for the shallow water cases of SIMMAN 2020.

Manoeuvreergedrag > Open water > Simulaties

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1 Overview

1.1 SIMMAN 2020

SIMMAN 2020 is the 3rd Workshop on Verification and Validation of Manoeuvring Simulation Methods. The previous ones were organized in 2008 and 2014. Originally the plan was to organize the workshop in 2019, but the project suffered from a two year delay and a new date was set: 6-8 April 2020.

The purpose of the workshops is to benchmark the capabilities of different ship manoeuvring simulation methods including systems- and CFD-based methods through comparisons with results for different hull form test cases. Systems based methods will be compared with free-model test data using provided PMM and CMT (circular motion mechanism/rotating-arm) data, whereas CFD-based methods will be compared with both PMM/CMT and free-model test data. The comparisons for the free-model tests will be blind in the sense that the free-model test data will not be provided prior to the workshop.

FHR participated in the 2014 workshop (see WL project 00_066):

- Both captive and free running tests were carried out with the KVLCC2 and the KCS;
- CFD computations were carried out with the KVLCC2;
- Different scientific papers were produced, among which a journal publication;
- Delefortrie, G., Eloot, K. and Van Hoydonck, W. attended the SIMMAN 2014 workshop in Denmark. Eloot, K. chaired the shallow water session.

The SIMMAN 2020 workshop will be hosted by KRISO, Korea, and is scheduled for 6-8 April, 2020. Three benchmark ships are selected for the workshop: KCS, KVLCC2 and the newly added ONRT (which was first added to the Tokyo 2015 CFD workshop). The disadvantage of the ONRT compared to the 5415M is the limited available dataset.

Participation of FHR in the 2020 workshop will be similar to the 2014 workshop participation:

- new model scale manoeuvring tests have been carried out with the KCS in 2017 (captive) and 2018 (free running), however, they are not included in the official SIMMAN set;
- a manoeuvring model has been built for the KCS based on the above test data. Both the tests and the manoeuvring models have been reported in project WL 16_023;
- some of the manoeuvring tests will be computed with CFD (KCS);
- the 2020 workshop will be attended.

According to the website: "All participants are supposed to deliver computed results for one or more of the test cases. These results will be compiled by the organizers and presented in a common format for easy comparison. The organizers will also make an assessment of the computations for each hull and present that at the workshop for general discussion. No papers will be presented at the workshop, but they will be included in the proceedings. At the workshop methods and computations will be presented in the form of posters.[…] Submitters are required to attend the workshop and represent their submissions."

The present report elaborates on the gathering and simulation execution, based on experimental research. In each of the chapters a different test case will be discussed.

1.2 Erratum found on the SIMMAN website

SIMMAN 2020 expects the results in the ship bound axis system, which is not common for regular manoeuvring simulations, but understandable when wave action is considered. However, the transformation formula they propose on the website contained a wrong matrix element. The correct version below

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} \cos\psi\cos\theta & \sin\psi\cos\theta & -\sin\theta \\ -\sin\psi\cos\phi + \cos\psi\sin\theta\sin\phi & \cos\psi\cos\phi + \sin\psi\sin\theta\sin\phi & \cos\theta\sin\phi \\ \sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi & -\cos\psi\sin\phi + \sin\psi\sin\theta\cos\phi & \cos\theta\cos\phi \end{bmatrix} \begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \\ \dot{z}_0 \end{bmatrix}$$

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\sin\theta \\ 0 & \cos\phi & \cos\theta\sin\phi \\ 0 & -\sin\phi & \cos\theta\cos\phi \end{bmatrix} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

has been communicated to the SIMMAN organizers. Anyway it is sufficient to deliver the results in the horizontal bound coordinate system. To move from a horizontal bound to a ship fixed coordinate system, the first equation simplifies to (ψ = 0°):

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ \sin\theta\sin\phi & \cos\phi & \cos\theta\sin\phi \\ \sin\theta\cos\phi & -\sin\phi & \cos\theta\cos\phi \end{bmatrix} \begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \\ \dot{z}_0 \end{bmatrix}$$

1.3 Ship's particulars

1.3.1 Overview

In the following paragraphs the main particulars and loading conditions as used on the towing tank are given for both benchmark ships.

1.3.2 KVLCC2

For the KVLCC2 only the captive model tests are considered, which were carried out at the loading condition presented in Table 1.

Table 1 – Ship's main particulars (T0Z06 – captive model)

Parameter	Model scale	Full scale
L_{PP} [m]	4.2667	320
B [m]	0.7733	58
T [m]	0.2773	20.8
$\overline{GM}$ [m]	0.047	3.49
I_{XX} [kgm²]	42.9	-
I_{YY} [kgm²]	837.2	-
I_{ZZ} [kgm²]	867.2	-
D_P [m]	0.1315	9.86
A_R [m²]	0.0199	111.7

1.3.3 KCS

The KCS is considered in this report with both the captive test results, carried out with the loading condition shown in Table 2, and the free running model test results, with loading condition presented in Table 3.

Table 2 – Ship's main particulars (C0401 – captive model)

	Model scale	Full scale
L_{PP} [m]	4.367	230.0
B [m]	0.611	32.2
T [m]	0.2051	10.8
$\overline{GM}$ [m]	0.0487	2.565
I_{XX} [kgm²]	13.9	-
I_{YY} [kgm²]	406.9	-
I_{ZZ} [kgm²]	422.6	-
D_P [m]	0.150	7.9
A_R [m²] Full Movable part	0.0196 0.0147	54.45 40.78

Table 3 – Ship's main particulars (C0404 – free running mode)

	Model scale	Full scale
L_{PP} [m]	4.367	230.0
B [m]	0.611	32.2
T [m]	0.2051	10.8
$\overline{GM}$ [m]	0.012 (±0.003)	0.62
x_G [m]	-0.067 (±0.002)	-3.53
I_{XX} [kgm²]	22.4 (±2)	-
I_{YY} [kgm²]	414.5 (±2)	-
I_{ZZ} [kgm²]	417.1 (±2)	-
D_P [m]	0.150	7.9
A_R [m²] Full Movable part	0.0196 0.0147	54.45 40.78

2 Test case 2.1

2.1 Overview

The background data of this case are the tests carried out at BSHC with the appended KVLCC2 at a scale factor of 1/45.714, corresponding to L_{PP} equal to 7.00 m. The setup of the tests is the same as similar tests executed at FHR (captive with free to heave and pitch).

The captive model tests have been carried out at Fr = 0.0514 (5.6 knots full scale), with turning propeller rate corresponding to a self-propulsion point at Fr = 0.0643. This self-propulsion point is at the same water depth and on a straight line (no yaw, no drift, no rudder action).

The different tests of this case are mentioned in Table 4.

Table 4 – Description of the captive model test cases[1] for the KVLCC2 in shallow water

Package	Drift angle (β=-atan(v/u))	Non-dimensional rate of turn r’	Requested quantities
Case 2.1.1	10°	0	X’, Y’, N’
	8°	0	X’, Y’, N’
	6°	0	X’, Y’, N’
	4°	0	X’, Y’, N’
	2°	0	X’, Y’, N’
	0°	0	X’, Y’, N’
	-2°	0	X’, Y’, N’
	-4°	0	X’, Y’, N’
Case 2.1.2, package 1	0°	0.1	X’, Y’, N’
	0°	0.2	X’, Y’, N’
	0°	0.3	X’, Y’, N’
Case 2.1.2, package 2	4°	0.1	X’, Y’, N’
	4°	0.2	X’, Y’, N’
	4°	0.3	X’, Y’, N’
Case 2.1.2, package 3	-4°	0.1	X’, Y’, N’
	-4°	0.2	X’, Y’, N’
	-4°	0.3	X’, Y’, N’

[1] http://simman2019.kr/contents/test_case_2.1.php

In this table the following dimensionless representations are used:

$$X' = \frac{X}{\frac{1}{2}\rho L T V^2} \quad (1)$$

$$Y' = \frac{Y}{\frac{1}{2}\rho L T V^2} \quad (2)$$

$$N' = \frac{N}{\frac{1}{2}\rho L^2 T V^2} \quad (3)$$

$$r' = \frac{r L_{PP}}{V} \quad (4)$$

Mind $\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{N}$ are only the hydrodynamic components of the forces. The ship velocity is equal to

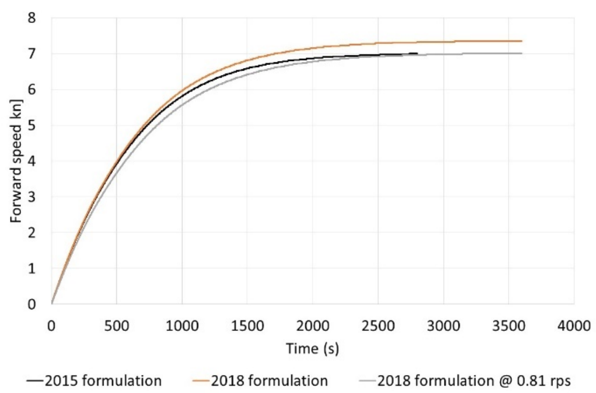
$$V = \sqrt{u^2 + v^2} \quad (5)$$

2.2 Determination of the self-propulsion point and the mathematical model

In the first place the self-propulsion point has to be determined. The scale of the BSHC ship model and the FHR model are different, however, here the FHR model scale will be used. The target speed for the propulsion determination is 7 knots full scale or 3.6011 m/s.

Initially COMPUTE fast time runs are carried out to localize the self-propulsion point and the mathematical model developed in 2015 for the KVLCC2 is used. In steps of 0.1 rps, the self-propulsion point is located between 0.8 and 0.9 rps, 0.85 rps seems the correct value (51 rpm). During a forced acceleration test, a speed of 3.6 m/s is obtained after 2800 s, see Figure 1.

Figure 1 – Acceleration test with KVLCC2 at 20% ukc, propeller turning at 0.85 rps (fresh water, no frictional resistance correction)



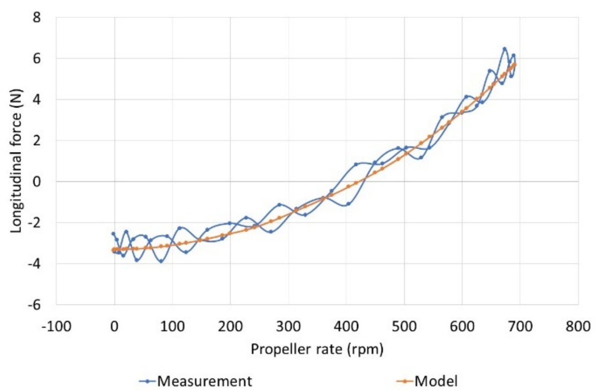
This exercise is repeated for the mathematical model of the KVLCC2 developed in 2018. The new formulations achieve a higher speed at 0.85 rps and the self-propulsion point is at 0.81 rps (48.6 rpm or 421 rpm model scale).

Mind that previously (SIMMAN 2014) a self-propulsion point of 0.77 rps (400 rpm model scale) was always assumed:

- this was apparently obtained by executing free running tests in 2010, however, these test results cannot be found (only the regular SIMMAN tests);
- however: the longitudinal force measured in captive tests T0Z02A03 (2010) is negative (hence more rate is needed);
- in 2015, the self-propulsion point was also determined for SHOPERA tests at 20% ukc a velocity of 0.41 m/s (6.9 knots) was obtained at 420 rpm, however the PID controller used rudder angles up to 10°.

The self-propulsion point of the captive tests seems to correspond with the simulated results, based on the 2018 formulation (see Figure 2). The new 2018 formulation is deemed superior and will be used for the following computations.

Figure 2 – Measured and modelled longitudinal force, 20% ukc, 0.416 m/s (7 knots full scale), for different propeller rates



2.3 Case 2.1.1

The case 2.1.1 is simulated in fast time, by means of the COMPUTE simulation in fresh water and without frictional resistance correction. The used input data for the COMPUTE autopilot file can be found in Figure 3.

Figure 3 – COMPUTE commands for case 2.1.1

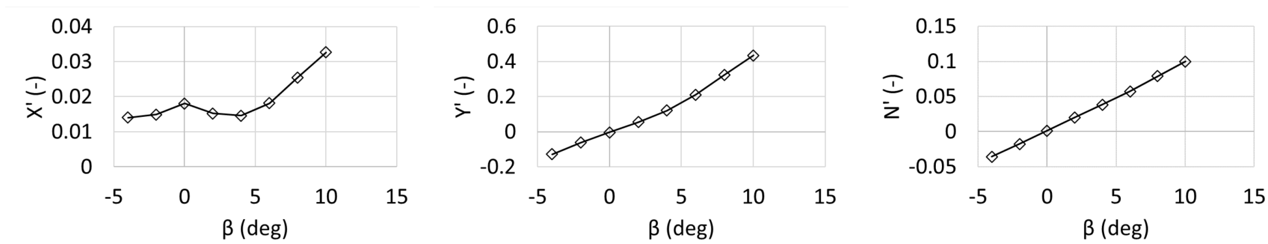
```
<row>1;2.8371217133445;-0.500261105616463;0;0.81;0;0;0</row>
<row>101;2.85285227625905;-0.400942240188064;0;0.81;0;0;0</row>
<row>201;2.86510707812318;-0.301134888400413;0;0.81;0;0;0</row>
<row>301;2.87387118834852;-0.20096065013752;0;0.81;0;0;0</row>
<row>401;2.87913392921679;-0.100541572278049;0;0.81;0;0;0</row>
<row>501;2.88088888888889;0;0;0.81;0;0;0</row>
<row>601;2.87913392921679;0.100541572278049;0;0.81;0;0;0</row>
<row>701;2.87387118834852;0.20096065013752;0;0.81;0;0;0</row>
<row>800;2.87387118834852;0.20096065013752;0;0.81;0;0;0</row>
```

The simulation results are summarized in Table 5 and Figure 4. Mind that an uncertainty assessment is recommended, but this is not done here as it requires Monte Carlo simulations.

Table 5 – Results of case 2.1.1

β (°)	r'(-)	X' (-)	Y' (-)	N' (-)	γ (°)	χ (°)
10	0	0.032674576	0.435359	0.099851	0	180
8	0	0.025474747	0.324884	0.078839	0	180
6	0	0.018143524	0.211509	0.057171	0	180
4	0	0.014576005	0.121392	0.03814	0	180
2	0	0.015233394	0.054287	0.020186	0	180
0	0	0.018033013	-0.00368	0.001354	0	0
-2	0	0.01492245	-0.06185	-0.01756	0	0
-4	0	0.014022211	-0.12807	-0.03594	0	0

Figure 4 – Simulated forces with the KVLCC2, 20% ukc, V_S, 5.6 knots full scale, propeller rate 0.81 rps (case 2.1.1)



2.4 Case 2.1.2

This test case can be computed similarly to test case 2.1.1. The COMPUTE commands can be found in Figure 5 and the results in Table 6 and Figure 6.

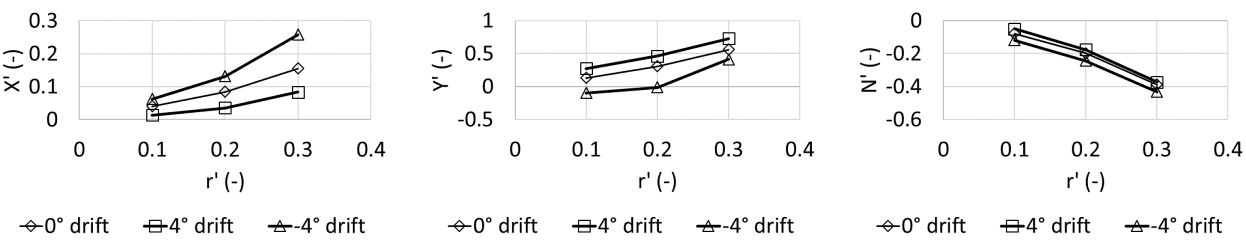
Figure 5 – COMPUTE commands for case 2.1.2

```
<row>0;2.88088888888889;0;0.00565661210571362;0.81;0;0;0</row>
<row>100;2.88088888888889;0;0.0113132242114272;0.81;0;0;0</row>
<row>200;2.88088888888889;0;0.0169698363171409;0.81;0;0;0</row>
<row>300;2.87387118834852;-
0.20096065013752;0.00565661210571362;0.81;0;0;0</row>
<row>400;2.87387118834852;-0.20096065013752;0.0113132242114272;0.81;0;0;0</row>
<row>500;2.87387118834852;-0.20096065013752;0.0169698363171409;0.81;0;0;0</row>
<row>600;2.87387118834852;0.20096065013752;0.00565661210571362;0.81;0;0;0</row>
<row>700;2.87387118834852;0.20096065013752;0.0113132242114272;0.81;0;0;0</row>
<row>800;2.87387118834852;0.20096065013752;0.0169698363171409;0.81;0;0;0</row>
```

Table 6 – Results of case 2.1.2

β (°)	r'(-)	X' (-)	Y' (-)	N' (-)	γ (°)	χ (°)
0	0.1	0.040425195	0.1293	-0.07847	17.44059	90
0	0.2	0.084261032	0.307949	-0.19762	32.14191	90
0	0.3	0.154780696	0.559655	-0.38855	43.30381	90
4	0.1	0.01392787	0.272203	-0.05016	17.48059	102.519
4	0.2	0.035744831	0.463043	-0.17611	32.20489	96.33508
4	0.3	0.083569142	0.725848	-0.37341	43.37356	94.23297
-4	0.1	0.062571618	-0.09787	-0.11926	17.48059	77.48105
-4	0.2	0.131600013	-0.01364	-0.2431	32.20489	83.66492
-4	0.3	0.257327314	0.414046	-0.43181	43.37356	85.76703

Figure 6 – Simulated forces with the KVLCC2, 20% ukc, V_S, 5.6 knots full scale, propeller rate 0.81 rps (case 2.1.2)



3 Test Case 2.2

3.1 Overview

The description of case 2.2 corresponds to the SIMMAN 2014 data and is as such based on test results from FHR and MARIN. Again the packages are in supplementary order.

Table 7 – Description of the free running model test cases[(2)] for the KVLCC2 in shallow water

Package	Manoeuvre	Starting speed V_0
Case 2.2.1	Self propulsion information	Fn = 0.064 (equivalent to 7 knots full scale)
Case 2.2.2	20°/5° zig-zag test, starting to portside	Fn = 0.064 (equivalent to 7 knots full scale)
Case 2.2.3	35° turning circle test, starting to portside	Fn = 0.064 (equivalent to 7 knots full scale)

Important here are the required inertial values:

- GM is 5.64 m, for KM = 24.285 m this corresponds KG = 18.645 m or $\boldsymbol{z_G}$ **= +2.155 m**. Presently in the simulator: ZG = 0m.
- The yaw and pitch radius of gyration are equal to 0.25L_{PP} m, or given a ship mass of 3.13E+08 kg, the moments are **2.00E+12 kgm²**. Presently in the simulator: I_{YY} = 1.99E+12 kgm² and I_{ZZ} = 1.82E+12 kgm².
- The roll radius of gyration is equal to 0.38B m, or given a ship mass of 3.13E+08 kg, the moment is **1.52E+11** kgm². The actual value in the simulator is 1.02E+11 kgm².

The values in the sbw-file have been adapted to the values in bold.

3.2 Self-propulsion information

3.2.1 COURSECONTROL autopilot

The self-propulsion information was already obtained by means of a computation test, but here a PID controller is needed. This was implemented in the simulator as a new autopilot type COURSECONTROL. This autopilot requires the information shown in Figure 7.

In the code the following expression is evaluated to steer the rudder angle.

$$-\max\delta \le \delta = K_P\psi_e + K_D r + K_I\int_0^t \psi_e\,dt \le \max\delta \quad (6)$$

In the present case the I action is neglected, and $K_P = 3$, K_D = 26 s (on full scale).

[2] http://simman2019.kr/contents/test_case_2.1.php

Figure 7 – Required information for autopilot type COURSECONTROL

*<!-- De volgende 3 opties zijn enkel van belang bij koerscontrole: min_roerhoek <= roerhoek = P*dPsi + I*som(dPsi*dt) + D*r -->*

<coeff name="COURSECONTROL_P" unit="-" type="real" value="3" comment="proportionele roeractie t.g.v. een afwijking t.o.v. de gewenste koers"></coeff>

<coeff name="COURSECONTROL_I" unit="1/s" type="real" value="0" comment="roeractie t.g.v. een cumulatieve afwijking t.o.v. de gewenste koers"></coeff>

<coeff name="COURSECONTROL_D" unit="s" type="real" value="26" comment="roeractie t.g.v. een afwijkende giersnelheid"></coeff>

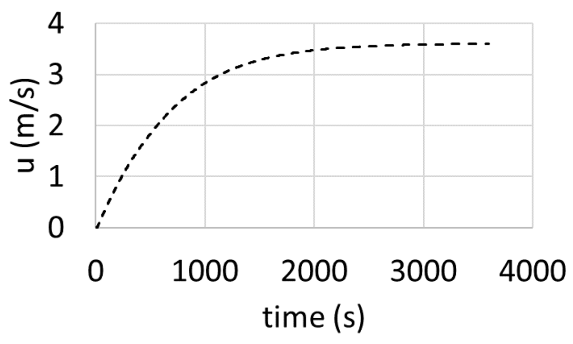
3.2.2 Simulation results

With the given PD controller an offset remains, which disappears with minor I action of 0.01 /s on full scale. The attained speed with the controller is 3.62 m/s (7.04 knots) for 0.81 rps and the offset rudder angle in steady state is 1.9°, which corresponds to the neutral rudder angle for the drag.

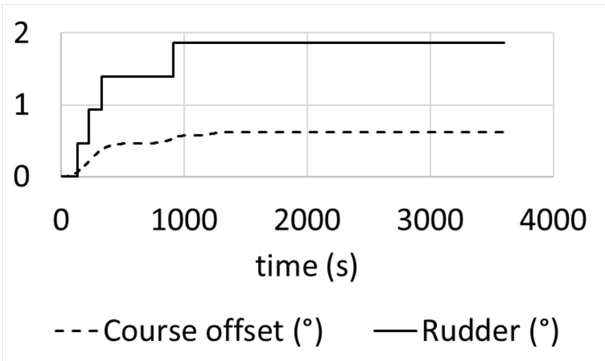
At 0.80 rps the speed is 3.58 m/s (6.96 knots) and at 0.805 rps (48.3 rpm) a speed of 7 knots is attained. The self-propulsion point for this case is somewhat lower compared to the 48.6 rpm for the captive case, but still larger than the 46.2 rpm from SIMMAN 2014.

In all cases, the steady state rudder angle is 1.9° and the course offset is 0.6°, see Figure 8. For the following manoeuvres, the initial conditions are u = 3.6 m/s, δ = 1.9° and n = 0.805 rps. The starting conditions in the vertical dimensions are: dz = 0.2507 m; θ = -0.0412°, ϕ = -0.0099°.

Figure 8 – Course control with the KVLCC2, 20% ukc, propeller rate 0.805 rps



a. Velocity

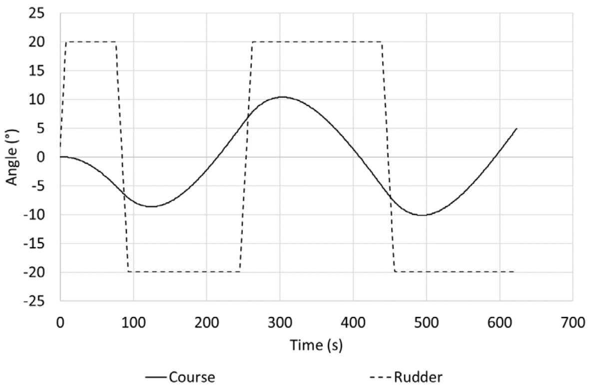


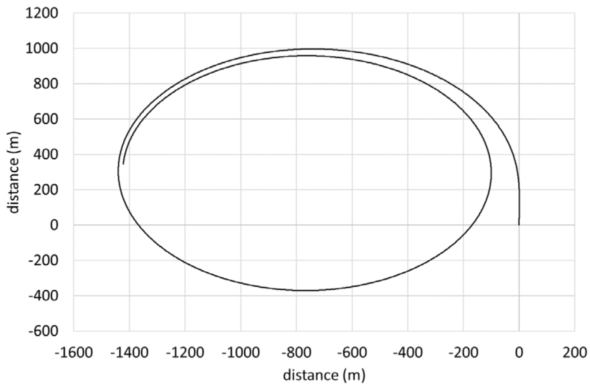
b. Course offset and rudder angle

3.3 20/5 zigzag test and 35° turning circle

Based on the starting values derived in 3.2.2, a 20/5 zigzag test and a 35° turning circle have been carried out. The trajectories are shown in Figure 9. Mind that the results will have to be delivered at model scale (1/75).

Figure 9 – 20/5 zigzag test and 35° turning circle trajectory, KVLCC2, 20% under keel clearance, starting values as in 3.2.2





4 KCS in shallow water

4.1 Overview of test cases

Table 8 gives an overview of the different test cases which are elaborated in the next paragraphs.

Table 8 – Description of the test cases[3] for the KCS in shallow water

Case	Test case	Hull	Water depth to draught	Corresponding full scale Speed [knots]	Froude number	Propeller RPM	Rudder angle protocol	Validation Variables	Range of kinematic conditions	Facility
4.1	Case 4.1.1	KCS	Wd/T=1.2	8.75	0.095	Self propulsion for 8.75 knots	0	X, Y, K, N	r'=0.0; β=0, 2, 4, 6, 8, 10	Kriso
	Case 4.1.2	KCS	Wd/T=1.2	8.75	0.095		0	X, Y, K, N	r'=0.0; β=0, 2, 4, 6, 8, 10	Kriso
4.2	Case 4.2.1	KCS	Wd/T=1.2	8.75	0.095	Self propulsion for 8.75 knots	20°/5° PS 35° PS	time traces of rudder, rate of turn, drift angle, speed loss; bird-eye views of x, y and heading; and derived characteristics RPM, T, Q and neutral rudder angle for CFD's	-	Marin
	Case 4.2.2	KCS	Wd/T=1.2	8.75	0.095				-	Marin

4.2 Test Case 4.1

4.2.1 Description

The background data of this case are the tests carried out at KRISO with the appended KCS at a scale factor of 1/31.6, corresponding to L_{PP} equal to 7.2785 m. The setup of the tests is the same as similar tests executed at FHR (captive with free to heave and pitch).

The captive model tests have been carried out at two different speeds:

- Fr = 0.09476 (8.75 knots full scale – cases 4.1.1 and 4.1.2 package 1), with turning propeller rate corresponding to the self-propulsion point at model scale
- Fr = 0.06317 (5.83 knots full scale – cases 4.1.2 packages 2 and 3), with the same turning rate as the previous speed.

The packages are shown in supplementary order in Table 9.

A 6 DOF simulation model is available for the KCS at 20% ukc, and the forces can be computed on model scale.

[3] http://simman2019.kr/contents/cases.php

Table 9 – Description of the captive model test cases[4] for the KCS in shallow water

Package	Drift angle (β=-atan(v/u)	Non-dimensional rate of turn r'	Requested quantities
Case 4.1.1	15°	0	X', Y', N'
	10°	0	X', Y', N'
	6°	0	X', Y', N'
	4°	0	X', Y', N'
	2°	0	X', Y', N'
	0°	0	X', Y', N'
	-2°	0	X', Y', N'
	-4°	0	X', Y', N'
Case 4.1.2, package 1	0°	0.3	X', Y', N'
	0°	0.35	X', Y', N'
	0°	0.4	X', Y', N'
Case 4.1.2, package 2	4°	0.3	X', Y', N'
	4°	0.35	X', Y', N'
	4°	0.4	X', Y', N'
Case 4.1.2, package 3	8°	0.3	X', Y', N'
	8°	0.35	X', Y', N'
	8°	0.4	X', Y', N'

4.2.2 Determination of the self-propulsion point

First the self-propulsion point has to be computed. The latest (2018) mathematical model of the KCS is used, without any tuning, in fresh water and without ITTC correction for the frictional resistance. A speed of 8.75 knots or 4.501 m/s is needed at full scale. A propeller rate of 0.73 rps or 43.8 rpm is found with forced simulation. An acceleration trial gives a final speed of 4.49 m/s (8.73 knots) with **0.73 rps** and 4.56 m/s (8.86 knots) with 0.74 rps. This corresponds to the results of the captive model tests (ca. 320 rpm or 0.735 rps).

In SIMMAN 2014 the self-propulsion point was 0.76 rps. During the free running tests of 2018 a model speed of 0.62 m/s corresponded to a propeller rate of 329 rpm or in full scale also 0.76 rps (mind that this was obtained by PID controller).

Considering the inertia, required for free running conditions, the following values are needed:

- GM is set to 0.60 meter (full scale).
- Radius of gyration for yaw and pitch are $0.24L_{PP}$.
- Radius of gyration for roll is $0.4B$.

The following changes are performed:

- The actual value of GM in the simulator is 2.565 m and has been changed to 0.6 m. $\boldsymbol{z_G}$ changes as well to **-3.54 m.**
- Given a ship mass of 5.177E+07kg, the moments of inertia (yaw, pitch) should be **1.580E+11 kgm²** (Presently in simulator: I_{YY} = 1.65E+11 kgm² and I_{ZZ} = 1.71E+11 kgm²).

[4] http://simman2019.kr/contents/test_case_4.1.php

- Given the ship mass, the roll moment of inertia is **8.59E+09 kgm²**
  (Presently in simulator: 5.63E+09 kgm²).

4.2.3 Case 4.1.1

This test case can be computed similarly to test case 2.1.1, but now with the KCS. The compute commands can be found in Figure 10 and the results in Table 10 and Figure 11.

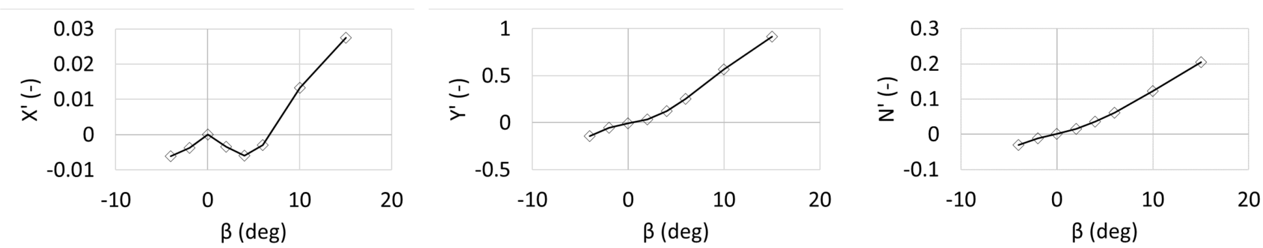
Figure 10 – COMPUTE commands for case 4.1.1

<row>1;4.34800778194843;-1.16504517385732;0;0.73;0;0;0</row>
<row>101;4.43300267710079;-0.781657977525724;0;0.73;0;0;0</row>
<row>201;4.47672980956746;-0.470523263125646;0;0.73;0;0;0</row>
<row>301;4.49042373179457;-0.314001015839875;0;0.73;0;0;0</row>
<row>401;4.49864676440124;-0.157096206684452;0;0.73;0;0;0</row>
<row>501;4.50138888888889;0;0;0.73;0;0;0</row>
<row>601;4.49864676440124;0.157096206684452;0;0.73;0;0;0</row>
<row>701;4.49042373179457;0.314001015839875;0;0.73;0;0;0</row>
<row>800;4.49042373179457;0.314001015839875;0;0.73;0;0;0</row>

Table 10 – Results of case 4.1.1

β (°)	X' (-)	Y' (-)	N' (-)
15	0.0279	0.910742439	0.202912
10	0.013562	0.569043241	0.123011
6	-0.00277	0.255128642	0.062306
4	-0.00586	0.125105944	0.035767
2	-0.00343	0.035924779	0.015164
0	6.47E-05	-0.00741343	0.002101
-2	-0.0036	-0.05132406	-0.01079
-4	-0.00602	-0.14402196	-0.03039

Figure 11 – Simulated forces with the KCS, 20% ukc, V_S, 8.75 knots full scale, propeller rate 0.73 rps (case 4.1.1)



4.2.4 Case 4.1.2

This test case can be computed similarly to test case 4.1.1. The compute commands can be found in Figure 12 and the results in Table 11 and Figure 13.

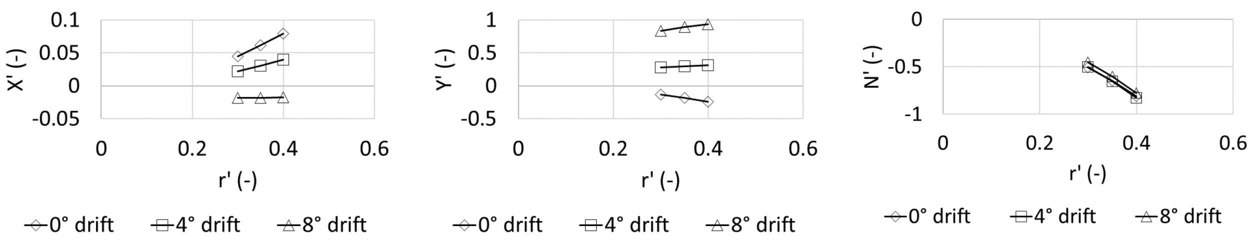
Figure 12 – COMPUTE commands for case 4.1.2

```
<row>0;4.50138888888889;0;0.0368909485155236;0.73;0;0;0</row>
<row>100;4.50138888888889;0;0.0430394399347776;0.73;0;0;0</row>
<row>200;4.50138888888889;0;0.0491879313540315;0.73;0;0;0</row>
<row>300;2.99190518358427;-0.209214391125311;0.0245799119823432;0.73;0;0;0</row>
<row>400;2.99190518358427;-0.209214391125311;0.0286765639794004;0.73;0;0;0</row>
<row>500;2.99190518358427;-0.209214391125311;0.0327732159764576;0.73;0;0;0</row>
<row>600;2.97002299474826;-0.417409510767217;0.0245799119823432;0.73;0;0;0</row>
<row>700;2.97002299474826;-0.417409510767217;0.0286765639794004;0.73;0;0;0</row>
<row>800;2.97002299474826;-0.417409510767217;0.0327732159764576;0.73;0;0;0</row>
```

Table 11 – Results of case 4.1.2

β (°)	r'(-)	X' (-)	Y' (-)	N' (-)	γ (°)	χ (°)
0	0.3	0.044370548	-0.13162	-0.50948578	43.30381	90
0	0.35	0.06134307	-0.17993	-0.64779817	47.71483	90
0	0.4	0.07893168	-0.23952	-0.80721916	51.48811	90
4	0.3	0.022481004	0.280804	-0.50142326	43.37356	94.23297
4	0.35	0.030321091	0.298053	-0.65099134	47.78438	93.63001
4	0.4	0.039649244	0.314309	-0.824851	51.55618	93.17725
8	0.3	-0.01819143	0.834416	-0.45232964	43.58356	98.40001
8	0.35	-0.01824779	0.891821	-0.6039319	47.99361	97.21368
8	0.4	-0.01719416	0.938744	-0.77616816	51.76082	96.31978

Figure 13 – Simulated forces with the KCS, 20% ukc, V_S, 8.75 (0° drift) or 5.83 knots full scale, propeller rate 0.73 rps (case 4.1.2)



4.3 Test Case 4.2

4.3.1 Overview

Table 12 gives an overview of the different free running trials. These correspond to a new benchmark set carried out by MARIN and correspond to a model scale approach speed of 0.6203 m/s at model scale.

Table 12 – Description of the free running model test cases[5] for the KCS in shallow water

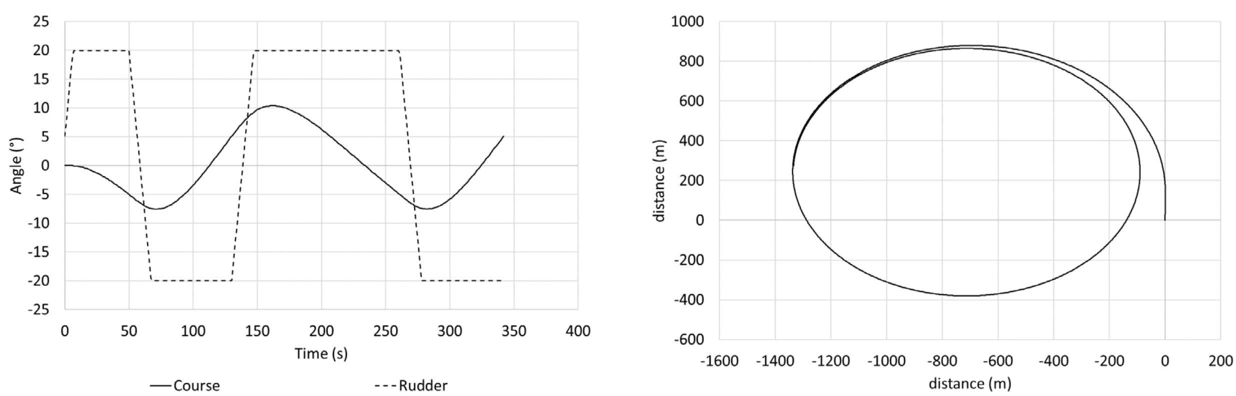
Package	Manoeuvre	Starting speed V_0
Case 4.2.1	Self propulsion information	Fn = 0.0948 (equivalent to 8.75 knots full scale)
Case 4.2.2	20°/5° zig-zag test, starting to portside	Fn = 0.0948 (equivalent to 8.75 knots full scale)
Case 4.2.3	35° turning circle test, starting to portside	Fn = 0.0948 (equivalent to 8.75 knots full scale)

4.3.2 Self-propulsion information

The self-propulsion information has to be retrieved by performing a course keeping test, in the same fashion as described in section 3.2.1. For the present case the I action is neglected, and $K_P = 1$, K_D = 18.5 s (on full scale). In a first run the propeller rate is set at 0.73 rps, which corresponds to the captive self-propulsion point. After 1 h the speed is 4.5 m/s with a rudder angle of 5.1° and an offset angle of 4.9°. No drift or yaw is occurring. These conditions will be used as initial conditions for the zigzag and turning circle tests: u = 4.5 m/s, δ = 5.1° and n = 0.73 rps. The starting conditions in the vertical dimensions are: dz = 0.321 m; θ = -0.0244°, ϕ = 0°.

4.3.3 20/5 zigzag test and 35° turning circle

Figure 14 – 20/5 zigzag test and 35° turning circle trajectory, KCS, 20% under keel clearance, starting values as in 4.3.2



[5] http://simman2019.kr/contents/test_case_4.2.php

Figure 14 shows the trajectories of the zigzag and turning circle test carried out with the KCS at the initial conditions mentioned in section 4.3.2.

The zigzag test mentioned in case 4.2.2 is also available as experimental result. Compliancy is achieved with the starting speed with corresponding model self-propulsion point and constant propeller rate. The rudder rate is also compliant. GM was set at a full scale value of 0.62 m, which is also compliant, taking into account the uncertainty and the ukc was 20%. The applied air inertia radii were also pretty compliant, with respective values of 0.241 L_{pp} and 0.400 B.

The difference is the autopilot routine (to obtain the self-propulsion information). Here an adaptive PID controller has been used, where P, I and D were adapted based on the ship's velocity. Submissions are required in model scale values (1/37.89), so these measured trajectories should be scaled up. Another difference is that during the free running tests, the first rudder execute was already carried out when releasing the ship model.

To retrieve the vertical sinkage, the roll velocity and the pitch velocity, a 1 Hz low pass filter was applied on the measured data, before computing the derivatives.

Figure 15 – Ship control during 20/5 zigzag test, KCS, 20% under keel clearance, comparison between simulations and EFD

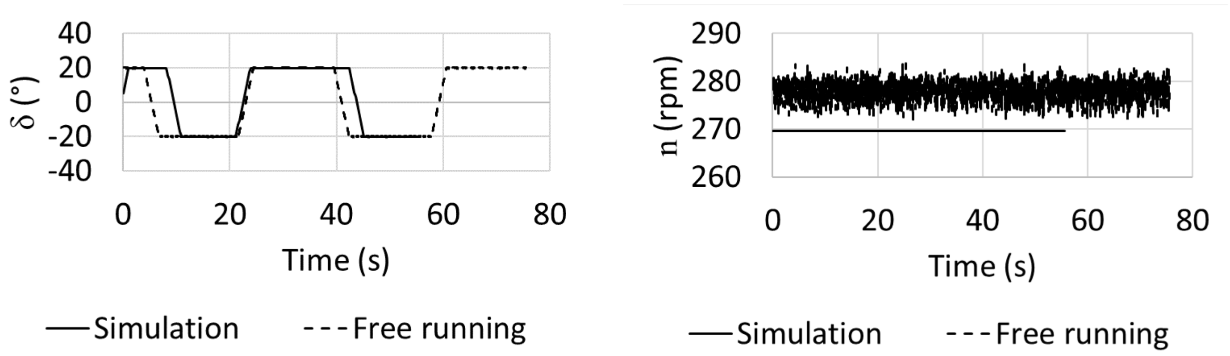


Figure 16 – Ship positions during 20/5 zigzag test, KCS, 20% under keel clearance, comparison between simulations and EFD

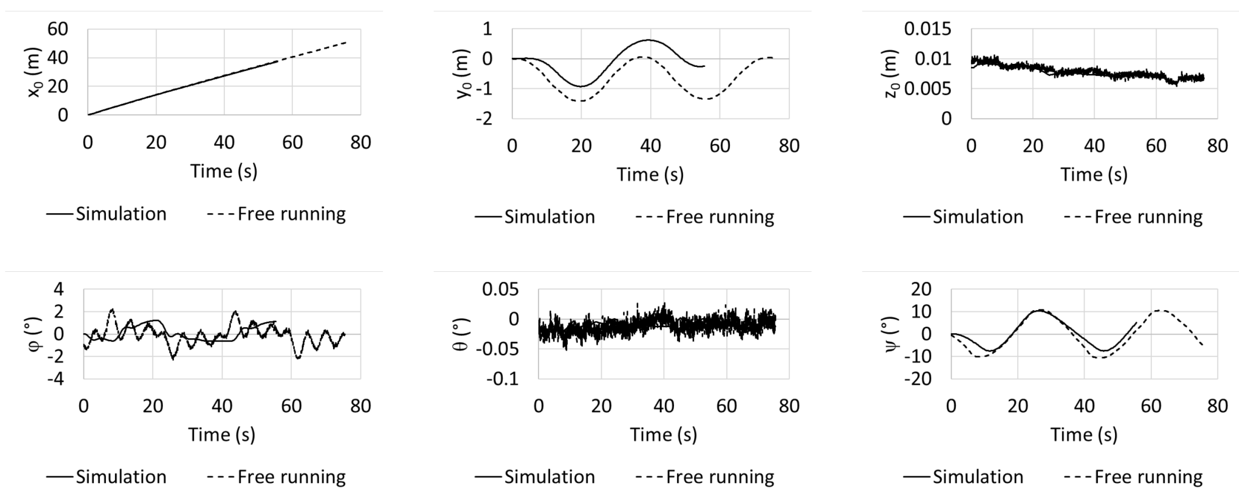
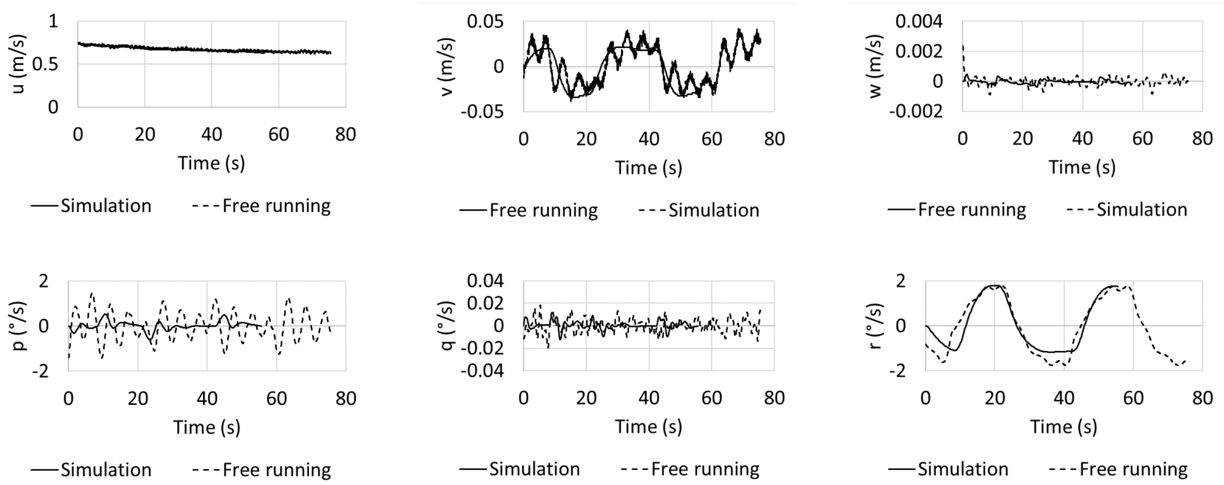


Figure 17 – Ship velocities during 20/5 zigzag test, KCS, 20% under keel clearance, comparison between simulations and EFD



A comparison between the simulation results and one of the free running tests is shown in Figure 15Figure 16 to Figure 17. In both cases the results are shown in a model scale of 37.89. One can observe the influence of starting at zero rudder angle or not, but also the fact that the roll and sway velocity do not show a steady behaviour during the free running test. The periodicity of the zigzag manoeuvre seems well captured by the 2018 manoeuvring model of the KCS.

5 Test Case 3.3: KCS in waves

5.1 Description

The KCS in waves is the novel test case, however, limited to deep water. The supplementary cases are shown in Table 13. The original free running tests are carried out at scale 75.24 in Hiroshima University.

Table 13 – Description of the free running model test cases[6] for the KCS in waves

Package	Manoeuvre	Starting speed V_0
Case 3.3.1	35° turning circle test, starting to starboard side	0.86 m/s (equivalent to 14.5 knots full scale)
Case 3.3.2	35° turning circle test in waves, starting to starboard side	0.86 m/s (equivalent to 14.5 knots full scale)

The model scale wave conditions are as follows:

- Regular waves
- Wave height 48 mm on model scale, (3.61 m on full scale)
- Wave length to ship length ratio = 1.0, meaning that the wave frequency is 4.49 rad/s on model scale (0.518 rad/s on full scale). Consequently, the wave period is 1.4 s on model scale (12.14 s on full scale)
- Wave direction: head waves with the ship approaching t=0
- The rudder execute (t=0) is when a wave bottom is passing midship.

The roll decay tests are available upon request. In the present report only the calm water run will be discussed (case 3.3.1).

5.2 Case 3.3.1

For the calm water run, which should be carried out in deep water, the maximally available under keel clearance of 100% is selected (which is not yet a deep water condition). The values in the sbw file have been adapted to meet the free running criteria:

- The actual value of GM in the simulator is 2.565 m, which was changed to 0.6 m ($\boldsymbol{ZG}$ changes as well to **-3.54 m**).
- The yaw and pitch radius of gyration should correspond to $0.25L_{PP}$, or given a ship mass of 5.177E+07kg, the moments of inertia should be equal to **1.712E+11 kgm²** (Presently in the simulator the following values were used: I_{YY}= 1.65E+11 kgm² and I_{ZZ} =1.71E+11 kgm²).
- The roll radius of gyration should be equal to 0.49B, or given the ship mass, the roll moment of inertia is **1.29E+10 kgm²**, contrary to the present value in the simulator: 5.63E+09 kgm².

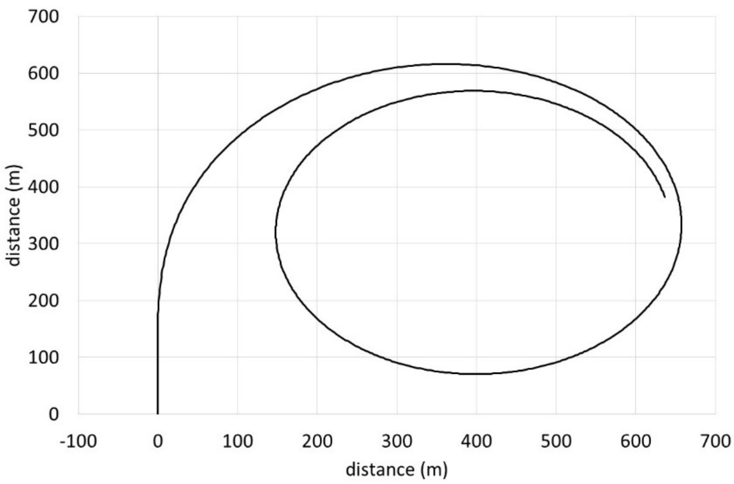
6 http://simman2019.kr/contents/test_case_3.3.php

The approach speed of the manoeuvre is 14.5 knots or 7.4594 m/s. The autopilot conditions were not provided, but the same setup as for the shallow water trials has been used. A speed of 4.64 m/s is obtained at a propeller rate of 0.73 rps.

An issue with the KCS is that larger propeller rates are difficult to achieve due to the engine model, it was therefore decided to multiply the A coefficient of the engine model with 10. A speed of 7.46 m/s is then obtained at a propeller rate of 1.175 rps or 70.5 rpm, which will be used as propeller rate for the turning circle.

The other starting parameters needed for a straight approach are $\delta = 5.1°$, u = 7.4648 m/s, ϕ = 0°, dz = 0.5358 m and θ = -0.0691 °. The resulting trajectory is shown in Figure 18. Mind that most probably the present trajectory will be an overestimation, because the ship's resistance is too large at 100% to achieve the required 24 knots or 12.347 rps, mentioned in the SIMMAN case 3.2, so a consolidated[7] mathematical model is recommended to simulate the deep water behaviour of the KCS.

Figure 18 – -35° turning circle trajectory, KCS, 100% under keel clearance



[7] A consolidated manoeuvring model expresses the different regression tables as a function of the under keel clearance and allows the extrapolation to the deep water condition.

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