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THE TOWING TANK FOR MANOEUVRES IN SHALLOW WATER

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SUMMARY

The Towing Tank for Manoeuvres in Shallow Water at Flanders Hydraulics Research (FHR) is operated together with the Maritime Technology Division of Ghent University. The possibilities of the tank are continuously updated. This article therefore provides an overview of the capabilities for future reference among the scientific community. The paper also discusses a number of specific challenges characterizing experimental ship model research in shallow and confined water. Although the project of the second towing tank is still under approval, a sneak preview of its characteristics is given as well.

NOMENCLATURE

Fr_h	Froude number (-)
g	acceleration due to gravity (m/s²)
h	water depth (m)
m	blockage factor (-)
T	ship's draft (m)
V	ship's speed (m/s)

1 INTRODUCTION

Most ships are designed and optimised for operation at full ocean, to navigate from port to port at an economic speed and to transport as much cargo as possible. However, almost every ship has to enter a harbour from time to time for loading and unloading her cargo. This harbour can in general only be reached by channels with restrictions in both depth and width, so speed has to be slowed down, bends have to be taken, and external effects, such as wind and current, will become increasingly important. The ship's controllability will be disturbed during transit of these access channels because of hydrodynamic interaction forces caused by the reduction of the distance between the vessel on one hand, and the bottom, the banks of the waterway, and other shipping traffic on the other hand.

The Mobility and Public Works Department of the Flemish Government (Belgium) is responsible for the access channels to the ports of Antwerp, Ghent, Ostend, and Zeebrugge (see Figure 1). With a total maritime cargo traffic of 274 million tons (2015) [1], a considerable part of the European import and export is handled by these ports. Ensuring the accessibility of these ports, as well as the optimal use of the dense inland waterways network, is of crucial importance for maintaining the economic prosperity. Flanders Hydraulics Research in Antwerp is a laboratory of the Mobility department, which investigates the impact of human activity and nature on water systems and the consequences for navigation. The latter focusses on the investigation of the behaviour of ships in shallow and confined water.

Especially in confined waters model testing is still considered to be the most reliable method to acquire knowledge on ship hydrodynamics. The Towing Tank for Manoeuvres in Shallow Water (co-operation Flanders Hydraulics Research - Ghent University) was built in 1992 - 1993. The towing tank is equipped with a planar motion carriage, a wave generator, and auxiliary devices for ship - ship interaction. Most experimental results are used to develop mathematical models for manoeuvring simulations, so that the equipment was designed for captive model testing. Since 2009 free running manoeuvring tests can be carried out as well.

A short overview of the infrastructure will be given, followed by a more detailed description of specific features that have been introduced to improve the quality and the efficiency of the testing facility and an overview of some challenges when dealing with tests in shallow water.

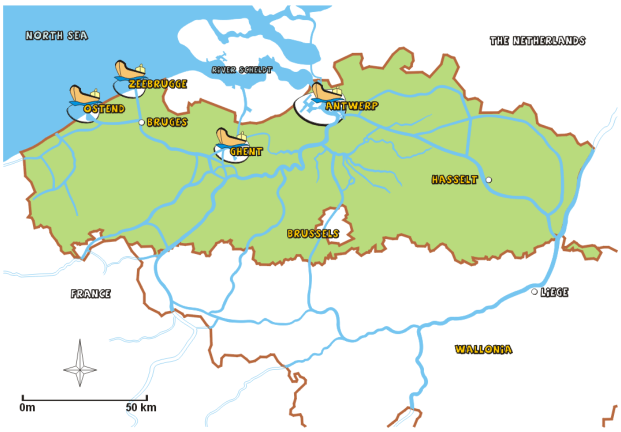

Figure 1. The four seaports of Flanders (Belgium): Antwerp, Ghent, Ostend, and Zeebrugge.

2 MAIN INFRASTRUCTURE

2.1 TOWING TANK

The Towing Tank for Manoeuvres in Shallow Water (co-operation Flanders Hydraulics Research - Ghent University) has a total length of 87.5 m, of which 68.0 m is useful for experiments, and a width of 7.0 m. These dimensions are rather modest, but sufficient for the execution of manoeuvring and seakeeping tests with ship models with a length over all between 3.5 m and 4.5 m at low or moderate speed (typically < 1.2 m/s on model scale) (see Figure 2 and Table 1). This length range is valid for sea-going vessels and self-propelled inland barges, but can be exceeded considerably for push convoys.

Table 1. Main dimensions of the towing tank

Total length	[m]	87.5
Useful length	[m]	68.0
Width	[m]	7.0
Maximum water depth	[m]	0.50
Length of the ship models	[m]	3.5 – 4.5

Figure 2. General view of the towing tank.

The draft of the ship models used at the towing tank typically varies between 0.10 m and 0.20 m. In practice, the range of under keel clearances may vary between (less than) 10% to 150% of draft in harbours and their access channels, so a variation of the water depth between 0.10 and 0.50 m is required in the towing tank. For that reason the water depth of the towing tank is limited to 0.50 m. While such a range allows to determine experimentally ship behaviour in water depths that are usually considered as very deep for waterways authorities, the vicinity of the bottom may still have an important effect on the ship's hydrodynamics.

2.2 MOTION MECHANISM & INSTRUMENTATION

2.2 (a) Towing carriage

The main carriage is a rectangular frame, composed of two wheel girders, connected by two box girders (see Figure 3). A lateral carriage is guided between the transversal girders and carries a slide in which a yawing table is incorporated (see Figure 4 and Figure 5).

This servo motor driven slide can be positioned manually in vertical direction over 0.4 m to take account of water level variations. Two of the four wheels are driven by brushless AC-servo-motors which are connected to the shaft by means of a gearing. The longitudinal position is determined independently using a measuring wheel. The lateral carriage is driven by means of a pinion - rack combination. The pinion of this combination is driven by a servo motor and a second pinion carries a brake. The rotation angle is measured at the tube, to which a beam is connected by means of a flange.

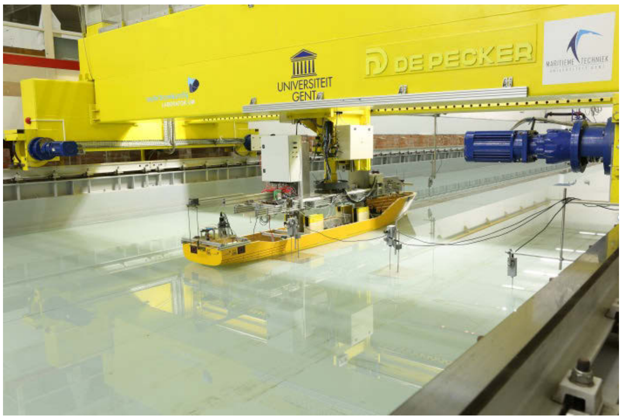

Figure 3. General layout.

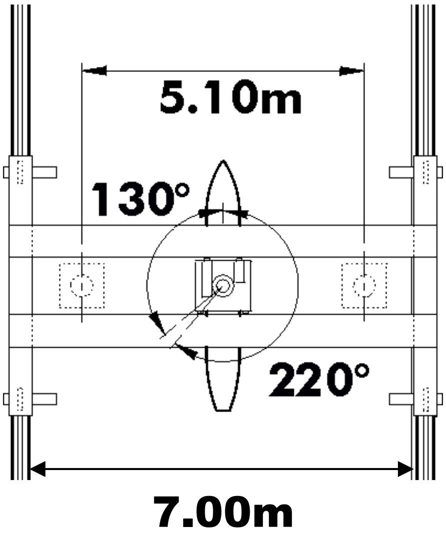

Figure 4. Top view of the towing carriage.

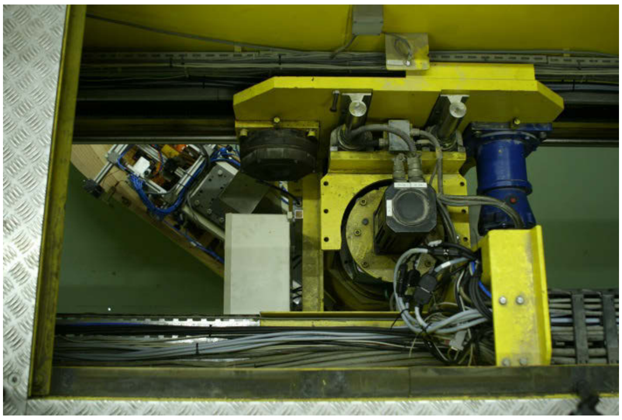

Figure 5. Top view of towing mechanism.

The main kinematic characteristics of the three horizontal motion modes are summarised in Table 2.

Table 2. Range of positions, velocities, and accelerations

	Main carriage	Lateral carriage	Yawing table
Minimal position	0.000 m	-2.550 m	-130.0°
Maximal position	68.000 m	+2.550 m	+220.0°
Maximal velocity	2.01 m/s	1.30 m/s	16.0°/s
Maximal acceleration	0.40 m/s²	0.70 m/s²	8.0 °/s²
Power Output	2 x 7.2 kW	4.3 kW	1.0 kW

2.2 (b) Captive mode

The ship model is attached to this beam by means of a mechanism which provides a rigid connection in the horizontal plane, but allows free heave and pitch; roll can be restrained or free, but will be controllable from 2016 (6.1). See Figure 6 for a typical setup.

2.2 (c) Free running mode

During free running tests there is no rigid connection between the ship model and the towing carriage. The steering forces, the propulsion forces, the steering angle(s), propeller rate(s), and the relative position between the carriage and the model, measured by lasers in six degrees of freedom, are sampled, see Figure 7. An autopilot controls the ship model and the towing carriage follows the free running model as close as possible. As the acceleration and deceleration of the ship model by own propulsion would occupy a significant fraction of the towing tank, the ship model is launched to the desired initial speed by the towing carriage in a captive way. Once this speed is reached, the ship model is released. At the end of the free running test, when the towing carriage can safely stop, the ship model will be clamped "on the fly".

2.2 (d) Instrumentation

The towing tank is equipped with:

- 4 x 2 dynamometers for longitudinal and lateral forces (20, 50, 100, 200 N) (only captive);
- dynamometers for roll moment (only captive);
- measurement of propeller rpm;
- 3 propeller thrust and torque dynamometers (30 N, 0.5 Nm);
- measurement of vertical motion (due to squat or wave action) at different positions;
- measurement of rudder angle;
- 5 rudder force and moment dynamometers (50 N, 2 Nm);
- custom instrumentation such as Z-drives, lateral thrusters, etc. with steering capabilities and force measurements;
- wave height measurement devices;
- visuals system to assess water and wave actions.

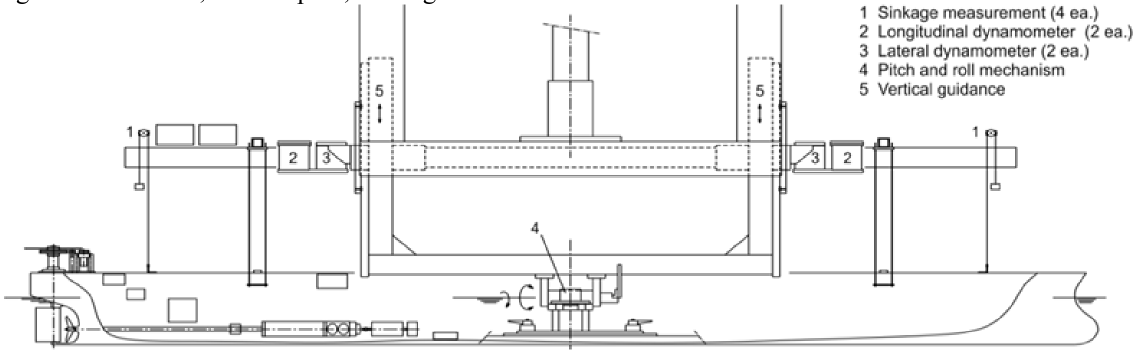

Figure 6. Ship model installation used during captive model tests

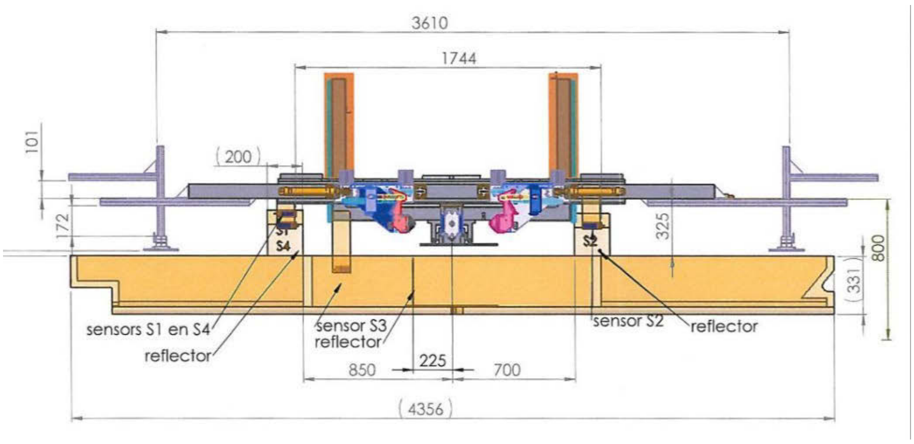

Figure 7. Ship model installation used during free running model tests

2.3 WAVE GENERATOR

The towing tank is equipped with a wave generator to study the vertical vessel motions and horizontal forces and moments induced by waves (see Figure 7). Both regular and irregular long-crested waves can be generated. The piston of this wave generator is driven by an electro-hydraulic unit with kinematical characteristics given in Table 3.

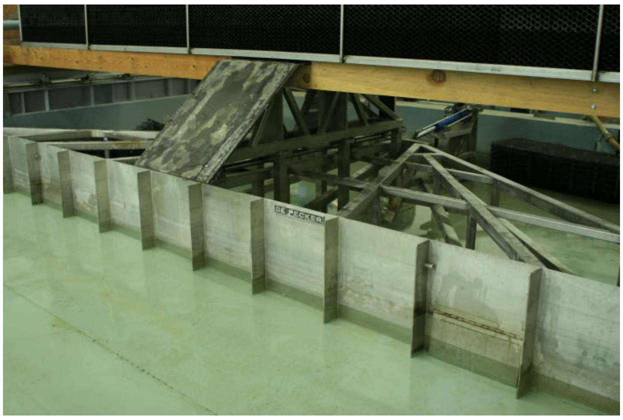

Figure 7. Wave maker.

Table 3. Kinematical characteristics of the wave generator (maximal values)

Stroke	Velocity	Acceleration
0.3 m	0.6 m/s	4.4 m/s

2.4 TEST PREPARATION

2.4 (a) Ship loading

An instrumented ship model has a certain loading distribution (position of centre of gravity, moments of inertia), which can be determined with a physical pendulum, see Figure 8. In order to meet the desired loading condition during tests, an optimization algorithm computes the distribution of ballast weights (0.25 to 10 kg) to be put in the ship model.

Figure 8. Determination of the moments of inertia (principle of the physical pendulum).

2.4 (b) Ship calibration

Ballasting and calibration of the ship model is performed in a smaller section at the end of the tank, which is referred to as the harbour, and offers an easy and dry access for the staff to work on the ship model. Figure 9 shows an example of the calibration of the lateral force. Calibrated weights are used to derive the relationship between the physical units and the voltages measured in the strain gauges.

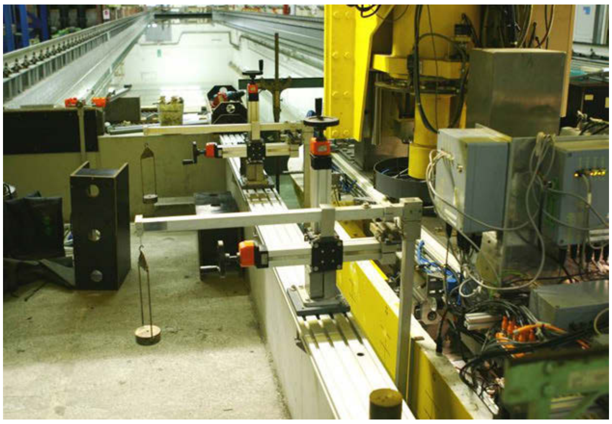

Figure 9. Ship calibration in the harbour of the tank.

3 SPECIFIC TEST SETUP

3.1 SHIP-SHIP INTERACTION TESTS

The tank is equipped with an auxiliary carriage allowing a second (“target”) ship model to perform a straight trajectory parallel to the tank walls, according to a prescribed speed history, with a stationary speed between 0.1 and 1.2 m/s (see Figure 10). In this way, ship - ship interaction tests can be carried out with two meeting or overtaking ship models. The auxiliary carriage is connected to a belt driven by an electric motor which is speed controlled. The passing time of both ship models is detected by a proximity sensor. No measurements are performed on the target ship model.

In addition to that forces and moments can be measured on ship models moored alongside a quay or the tank wall [2].

Figure 10. Auxiliary carriage for ship interaction tests.

Figure 11. Second beam for the execution of ship - ship interaction (top: lightering operation between VLCC and Aframax tankers [3]; bottom: ship - tug interaction)

A third type of ship - ship interaction tests can be carried out by attaching an auxiliary beam to the towing carriage (see Figure 11) [3]. With this construction both ship models have the same speed during the test. The second ship can be positioned manually or automatically in the longitudinal direction. The lateral position is set manually and is fixed during a batch of manoeuvring tests.

3.2 BANK EFFECTS

The effect of eccentric navigation of a ship with respect to the centreline of the waterway can be examined by applying an eccentric trajectory in the towing tank. However, the execution of ship – bank interaction tests requires the construction of banks in the towing tank (see Figure 12). The banks have to be built with a high accuracy, which can be controlled making use of the towing carriage for reference. The banks also need to be watertight, particularly at the joints between two bank elements.

Several techniques can be used to build banks into the towing tank. An easy way is to use prefabricated quay elements, made of water-resistant plywood board, constructed with a fixed slope. Alternatively, heavier elements in concrete can be constructed, for instance to counteract the buoyancy. The elements can either be used as a vertical element to construct quay wall or locks, or as a sloping bank. A second, more labour intensive way is often used to construct hydraulic scale models, and makes use of gravel and mortar. This technique is most suitable for banks with a nonlinearly varying slope or width, but for programs of long duration the material tends to dissolve in the water.

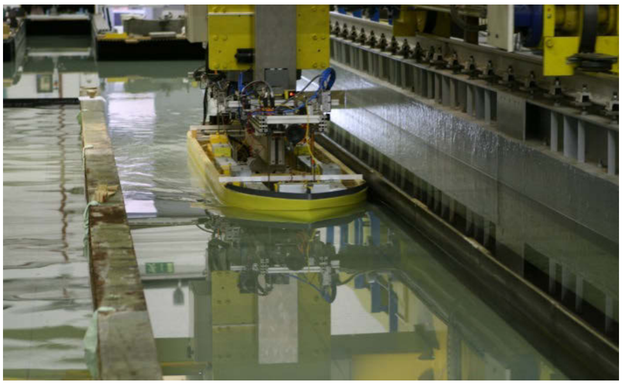

Figure 12. Ship model sailed in an extremely narrow canal

All these techniques have already been applied for the construction of quay walls, surface piercing and submerged sloping banks, sinusoidal banks, variable canal sections, and harbour environments.

3.3 FLOW DETECTION

Registration of the flow occurring around the ship hull, both during calm water and during seakeeping tests, is becoming more important for validation with numerical tools, such as CFD. For common manoeuvring purposes only the undulations of the air water interface are measured with wave gauges (see Figure 3). In more specific research projects the flow can be dyed for visualisation purposes or fluorescent light can be used to track the ship’s waterline during seakeeping tests [4]. Some examples are shown in Figure 13.

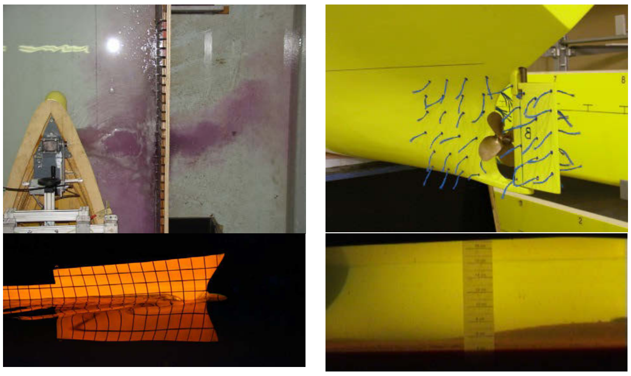

Figure 13. Clockwise from top left: bow thruster jet through semi permeable wall, propeller flow measurement, waterline tracking, rise of water mud interface.

4 AUTOMATIC OPERATION

4.1 TEST CONTROL AND DATA ACQUISITION

The three motion modes, the wave generator, the steering device(s), propeller(s), the auxiliary devices for ship-ship interaction tests, and other external devices are controlled by a PC on the towing carriage and presently up to six PIOCs (Programmable Input Output Control). The PIOCs also assure the sampling and the control of the analogue and digital input signals. The PIOCS can be located on the carriage, in the ship model or ashore. The communication between the PIOCs and the PC occurs over a LAN connection. A directional wireless bridge connects the carriage with the shore. Timing and synchronisation is assured by an implementation of the IEEE 1588 (PTP) timing protocol.

The towing tank application software allows the operator to control the carriage mechanisms and the analogue and digital outputs manually, to manoeuvre into or out of the harbour, to "home" (calibrate the position), to adapt the settings of the software application, and, of course, to execute captive or free running manoeuvring tests. The control system allows unmanned operation, so that experiments can be executed in batch in a fully automatic way during day and night, seven days a week. In spite of the long waiting time between the runs that is required for shallow water tests, see 5.1, an average of 35 tests per 24 hours can be carried out in this way. Safety measures are put in place to safeguard the people around the towing tank from being hit by the carriage.

During captive manoeuvring tests, the ship model follows a predetermined trajectory in the horizontal plane, described in a trajectory file (see 4.3), applied by the towing carriage. During each run, the forces acting on the ship model (hull, propeller(s), and steering device(s)), the propulsion rate(s), the steering angle(s), and the sinkage at four points are measured; depending on the type of test, other signals are sampled as well, e.g. forces on and motions of target vessels, wave gauges mounted at a fixed location in the tank or attached to the towing carriage (see Figure 3 for a typical setup). Each PIOC can sample up to 24 analogue and 20 digital input signals and control up to 4 analogue and 20 digital outputs. The PC controls the positions of the longitudinal, lateral and yawing sub-mechanisms which are stored in a digital way (16 bit). A variable sample frequency up to 200 Hz can be selected.

4.2 PRE-PROCESSING

Software has been developed for the generation of trajectory files in XML format for several types of standard captive and free running manoeuvring tests (see Table 4). The trajectory file contains a sequence of reference values for the sub-mechanism positions and for the analogue and digital outputs as a function of time. In the case of free running tests an additional file is needed which contains the commands for the autopilot. Most captive tests can contain several conditions, e.g. several values for the propeller rate(s) or steering angle(s) during one test run. A graphical user interface allows to input both the common characteristics for all trajectories, e.g. the used ship model and environment, and a number of trajectory rows supplying data typical for each trajectory, e.g. drift angle, propeller rate, rudder angle.

For the specific test type in (ir)regular waves the trajectories are optimized, which means that the optimal start and stop position of the ship model and the optimal starting times for the towing carriage and the wave generator maximise the number of useful encounter periods between the ship model and the wave train. However, it is also possible to use the wave maker to generate regular waves for most test types without this optimization algorithm.

Table 4. Types of standard manoeuvring tests (selection)

Type	Description
	CAPTIVE
bollard pull	propeller and rudder action at zero speed
stationary rectilinear	constant forward or backward speed, propeller and rudder action, drift angle, regular wave climate
oscillation	harmonic variation of longitudinal, lateral or yawing position, at zero speed
PMM sway	constant forward speed, oscillatory sway, propeller action, regular wave climate
PMM yaw	constant forward speed, oscillatory yaw, propeller and rudder action, drift angle, regular wave climate
multimodal	harmonic test to vary at the same time the longitudinal and/or lateral and/or yawing velocity, propeller rate(s) and/or rudder angle(s), regular wave climate
interaction	ship - ship interaction test with two passing or overtaking ship models
(ir)regular waves	model test in regular or irregular (spectrum based) waves with trajectory optimization
	FREE RUNNING
acceleration	determination of the model self-propulsion point
constant	no autopilot control after release
crash stop	perform a stop given a certain propeller reversal law
track keeping	the autopilot tries to keep the ship model on a prescribed track given external disturbances (banks, regular waves,…)
zigzag	the autopilot performs a zigzag test, based on heading or yaw rate

Before the tests can be carried out by the PC of the towing carriage, the trajectory files have to contain a valid signature provided by a validation program. The validation software checks whether the captive trajectory can be executed, taking account of the position, velocity, and acceleration ranges for each sub-mechanism. It also checks for possible contacts between the ship model and the environment. To validate the model tests the validation program needs additional information such as the carriage parameters, the ship characteristics and the environment geometry. When the tests are validated, the validation software generates a batch file, allowing execution of the test series by automatic operation.

4.3 EXECUTION OF MANOEUVRING TESTS

All information the towing carriage needs to execute a manoeuvring test is stored in the trajectory file. After the trajectory file is read, the ship model is moved to the start position of the trajectory and the waiting time is started. Based on the trajectory file, reference values of the position of the sub-mechanisms at each point of time, the time increment being a multiple of 5 ms, are calculated and stored in the controller memory, with a maximum of 50,000 points. This information is sent to the PIOCs before the test during the waiting time. The waiting in between two tests can be dynamically controlled by monitoring different analogue input signals, such as water levels and forces acting on the waiting ship. The waiting time has a maximum value, after which the test is started disregarding the state of any input signal. A typical waiting time is 2000 s, see also 5.1.

During the test the measurements are only sent to the PC to check the limits of the gauges, an alarm occurs in case a range limit is exceeded. Depending on the settings, alarms can cause either a simple log message or interrupt the test or even the entire batch. The highest alarm level triggers an emergency stop. Alarm warnings can also include an e-mail message or text message which is sent to the operator.

The measurements are saved at the PIOCs during the test and after finishing the test, all measurements are sent to the PC to be stored in a documentation file, an XML text file with all information of the executed manoeuvring test. The documentation file contains the input, output, positioning, ship, and environment files followed by the measurements.

Because of full computer control a series of tests can be carried out consecutively. In a batch file, the trajectory files that have to be executed are listed, separated by the required maximal waiting times. As these batch runs may take several days, the measurement instrumentation is checked by a calibration test which is carried out at the beginning and at the end of the batch file, and after every 60 tests during the batch. The results of these runs are compared and should be equal, otherwise a problem would have occurred with one of the gauges. In this case, corrective actions are required and a calibration check has to be carried out. A full calibration is executed when a new ship is attached to the towing carriage (see also 2.4 (b)). An additional calibration of the hull forces is carried out when the ship's draft is changed. After a calibration the user needs to update the information on analogue and digital in/outputs (conversion of voltage to physical units or vice versa, definitions, acceptable ranges, etc.) in the towing tank program.

4.4 POST-PROCESSING

In order to condense the data in a documentation file, which is in the order of magnitude of 10 MB, post processing software has been developed, which applies corrections of measuring results, e.g. correction of sinkage due to imperfection of the rails according to information based on a rail calibration test (see 5.3 (b)). A running average, based on an interval defined by the user, can be applied to all test results and is stored in a separate XML-file.

Additionally, for captive tests a result file is generated containing a summary of test parameters, and average values (for stationary tests) or amplitudes of 0^{th} to 3^{rd} harmonics (for oscillation tests) for each input channel. Based on this result file or on the running average, a data point file can be generated, containing the results of the tests which can be used for the derivation of mathematical models.

5 SHALLOW WATER CHALLENGES

5.1 EXECUTION TIME

Slow speed, large drift angles and a propeller working in four quadrants are common conditions in harbour manoeuvres. The towing tank was built dedicated for shallow and restricted water tests in harbour conditions. In this way a significant amount of different parameters could be varied. A typical program to derive a mathematical manoeuvring model for one ship at one loading condition and one water depth comprises 300 captive tests with an average execution time of 5 min. The duration of a test program is however heavily affected by the waiting time in between two tests. This waiting time is needed for the water in the towing tank to return to rest. In shallow water this process takes longer, not only due to the decreased wave speed, but also to the natural induction of vortices throughout the tank, especially after a test at large drift angles. At present a standard waiting time is used of 2000 s in between tests. Alternatively the waiting time can be regulated dynamically by continuously monitoring the water motions and forces acting on the ship hull in between two tests. Once an acceptable level is obtained the next test in line can be initiated.

5.2 SPEED AND SINKAGE

The critical speed in shallow water is given by the speed of shallow water waves:

$$V_{crit1} = \sqrt{gh} \rightarrow Fr_{h,crit1} = 1 \quad (1)$$

h being the water depth. A displacement ship cannot exceed this critical speed which puts an upper limit on the speeds that can be attained in confined water. In a confined environment, such as a towing tank, the critical Froude depth number is given by the more general expression [5]:

$$Fr_{h,crit1} = \left(2sin\left(\frac{arcsin(1-m)}{3}\right)\right)^{3/2} \le 1 \qquad (2)$$

In this equation m represents the blockage, which is the ratio between the ship's cross section and the cross section of the fairway. The resulting critical speed range is significantly smaller compared to the speed range expressed by equation (1), and will continue decreasing if obstacles, such as banks, are placed in the towing tank, or in case interaction with other ship models takes place. Figure 14 shows for a selection of ship model cross sections in the towing tank the supercritical full scale speed as a function of the water depth and scale factor. This means that the selection of the scale factor also needs to take into account the desired speed range.

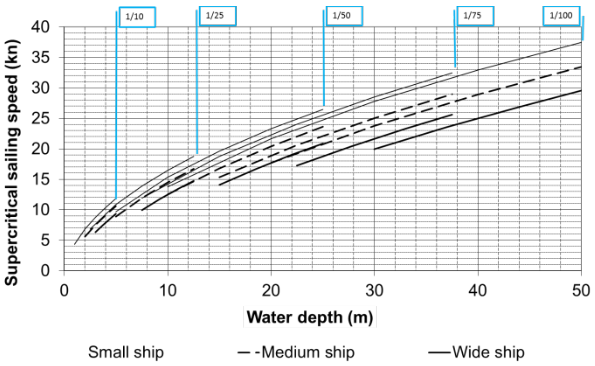

Figure 14. Supercritical sailing speed in function of full scale water depth, without obstacles in the towing tank.

Depending on the speed and the water depth, the ship will squat. To prevent the ship model hitting the bottom, the ship model is equipped with safety contacts (Figure 15). An alarm occurs once a safety contact is touched, which is also registered as the measured forces and motions cannot be considered as reliable in this case.

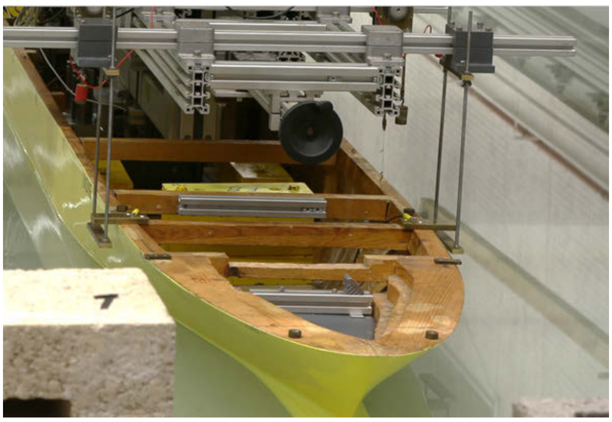

Figure 15. Mechanical safety device to protect the ship model from touching the bottom.

To protect the ship model from touching the bottom of the towing tank or built-in banks, which can cause damage to the hull, rudder, propeller, and/or force gauges, mechanical safety devices were installed fore and aft at both port and starboard sides (see Figure 15).

5.3 ACCURACY

5.3 (a) Requirements

In shallow water the forces acting on a vessel are approximately inversely proportional with the under keel clearance written as $\frac{h}{h-T}$. Moreover, scale models of conventional ships used in the towing tank typically have a draft of 0.2 m, which are tested at under keel clearances up till 10% of the ship's draft. This means that a deviation in either ship's draft or tank bottom of 1 mm causes an uncertainty of 0.5% on the under keel clearance. The position of the rails on which the towing carriage moves is also extremely important, because deviations in both the vertical and the horizontal plane can introduce undesired dynamic effects on the measurements.

5.3 (b) Rails

Train rails of which the upper surface is milled and finished are used to guide the carriage. By means of lateral guiding wheels on one of the rails excessive lateral deviations of the carriage can be avoided. The rails are adjustable in vertical and lateral direction by screw bolts with an in-between distance of approximately 0.5 m, and have to be aligned with high accuracy. The level difference of both rails and the lateral deflection of the guiding rail are less than 0.2 mm; the height difference over the entire length of the rails is less than 1 mm (see Table 5).

Table 5. Rail accuracy

Vertical		Horizontal
Global	Local	
1 mm	0.1 mm/1 m	0.2 mm

Twice a year the position of the rails is checked. This is done at the beginning of the summer and the winter, when the largest temperature deviations occur which lead to extension or shrinkage of the rails. Moreover, during every batch of model tests a rail calibration test is executed, during which the towing carriage moves at 0.03 m/s and the position of the rails is checked indirectly by measuring the sinkage of the ship model. When the results of this test exceed the accuracy limits, a thorough electronic measurement of the rails is executed to re-align the rails between the requested tolerances. The processing of the measurements results into a table presenting rail corrections at each screw bolt, more or less located every m along the towing tank. Several iterations of measurement and adaptation may be needed to obtain the desired accuracy.

5.3 (c) Tank bottom

With respect to the tested under keel clearances, a maximal deviation of the tank bottom level of 1 mm is considered acceptable. After 15 years of operation the bottom was flattened in May 2008 to meet the desired accuracy. The first layers were milled using the towing carriage in manual mode, but when the largest differences had disappeared, the towing carriage was programmed to flatten the bottom automatically. The bottom was flattened in layers of 0.7 mm until the accuracy of ± 1 mm was reached. Stiffness and water tightness of the bottom (and any built in obstacle) is important to correctly measure the ship's responses and manoeuvring forces.

5.4 SHALLOW WATER WAVES

The tests with regular waves in the towing tank are optimized to maximize the useful output. Several criteria have to be met:

- A useful sea state is obtained once the wave train generated by the wave maker has reached the ship model over its full length with an amplitude which is acceptably close to the desired value. The time to reach this point can be computed given the position of the ship, the position of the wave maker, the group and phase velocities of the waves and the start time of the wave generation;
- A wave that reaches the ship model is reflected and sent back to the wave maker where it interferes with the produced wave system. The resulting wave system is different and when it reaches the ship another sea state is obtained. This process is known as diffraction and should be avoided. The time to reach this point is given by the position of the ship, the position of the wave maker, the phase velocity and the start time of the wave generation;
- A wave that has passed the ship model travels further towards the end of the tank where the wave is reflected. If the reflected wave reaches the ship model it interferes with the present wave system. This process is known as reflection and should be avoided as well. The time to reach this point is given by the position of the ship, the position of the wave maker, the wave speed, the position of the tank wall and the start time of the wave generation;
- The ship should be sailing at a stationary speed, thus without acceleration, deceleration or waiting phases.

In addition to the above, interaction between the ship, the wave and the side walls occurs as well. In shallow water this is rather inevitable due to the small ship speeds compared to the wave speed, especially at oblique wave angles and/or drift angles of the ship.

Moreover waves in shallow water are significantly affected by the water depth. Wave braking occurs at smaller wave amplitudes and the wave profile is mostly of higher order with narrow, large crests and wider, shallow troughs which has to be coped with higher order theories.

6 FUTURE DEVELOPMENTS

6.1 ACTUAL TOWING TANK

In 2016 the towing tank will be upgraded by adding forced roll motion as a fourth captive degree of freedom. This will allow to measure forced roll motions, even in combination with yaw and sway motions and to investigate and model the effect of roll on the manoeuvring behaviour of a ship. In 2016-2017, the motor drives of the carriage power will be replaced and the electrical systems refurbished.

Steps are taken towards further automation. In the future the water depth variation should also be included in the batch, which will lead to longer net operational times. Cameras will be added to increase the distant monitoring level, which allows to solve certain alarm issues without necessarily having to be present.

6.2 A SECOND TOWING TANK

The size of the sea-going ships have been increasing since the first towing tank was built in 1992. As a result present scale factors are increasing, which puts a limit on the accuracies that can be achieved. Moreover the mentioned shallow water challenges, such as wave reflection, critical speed,… put a severe limit on the possibilities of the current towing tank.

In 2009 a project was initiated to build a second towing tank. The dimensions of this towing tank are given in Table 6.

Table 6. Main dimensions of the second towing tank

Total length	[m]	174.0
Useful length	[m]	140.0
Width	[m]	20.0
Maximum water depth	[m]	1.0
Length of the ship models	[m]	3.5 – 8.0

FHR has not sufficient space to build a tank of this size at its present location, for this reason a second site has been designed and will be built in Ostend, near the Belgian coast. The tank will also aim at manoeuvring and seakeeping tests in shallow water. It will be equipped with a 4 DOF captive carriage, with possibilities to mount a 6 DOF hexapod and to operate in free running mode.

At present political approval is still needed to release the necessary funds.

7 CONCLUSIONS

Execution of captive manoeuvring and seakeeping tests with ship models in shallow and confined water is time-consuming, not only because of the large number of varying parameters, but also because additional shallow water challenges, such as long waiting times between two test runs have to be taken into account. Experience at Flanders Hydraulics Research in Antwerp has shown that optimisation of a ship model experimental facility can be obtained through intensive automation of the test operations. However, an efficient use of an automatic system also requires the development of reliable pre- and post-processing software to organise the data flow, and the availability of auxiliary infrastructure to investigate interaction effects with the channel environment and other shipping traffic that is integrated into the automated system.

Despite the already high level of automation, further modernization steps are planned, including the construction of a state of the art second, larger towing tank.

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