ADVANCED MODEL TESTING TECHNIQUES FOR SHIP BEHAVIOUR IN SHALLOW AND CONFINED WATER

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Flanders Hydraulics Research (Antwerp, Belgium) belongs to the Mobility and Public Works Department of the Flemish Government, which is responsible for the access channels to the Flemish seaports. Therefore, one of the main research topics concerns the behaviour of ships in shallow and confined water. As model testing is considered to be the most reliable method to acquire knowledge on this topic, in particular data required for developing mathematical models for manoeuvring simulation, the Towing Tank for Manoeuvres in Shallow Water (co-operation Flanders Hydraulics Research – Ghent University) was built in 1992-1993. The towing tank (useful length 68 m, width 7 m, adjustable water depth < 0.5 m) is equipped with a planar motion carriage, a wave generator and auxiliary devices for ship-ship interaction tests. 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, or to study specific effects. In particular, attention will be paid to ship-bank and ship-ship interaction test setups, automatic operation, geometric accuracy, and free running model test technology.

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 *Fig. 1*). With a total maritime cargo traffic of 267 million tons (2008) [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. One of the main research topics of Flanders Hydraulics Research in Antwerp, the research laboratory for hydraulic, hydrological, and nautical studies of this Department, is therefore related to the investigation of the behaviour of ships in shallow and confined water.

As model testing still is considered to be the most reliable method to acquire knowledge on this topic, the *Towing Tank for Manoeuvres in Shallow Water (co-operation Flanders Hydraulics Research - Ghent University)* was built in 1992 - 1993 [2]. 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. However, during Spring 2009 the towing carriage has been adapted enabling free running manoeuvring tests.

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

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, or to study specific effects.

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 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 sea-keeping 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 *Fig. 2* and *Table 1*).

Table 1 - Main dimensions of the towing tank

Total length	87.5 m
Useful length	68.0 m
Width	7.0 m
Maximum water depth	0.5 m
Length of the ship models	3.5 - 4.5 m

Fig. 2 - General view of the towing tank

The draught 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, 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.

2.2. Motion mechanism

The main carriage is a rectangular frame, composed of two wheel girders, connected by two box girders (see *Fig. 6*). A lateral carriage is guided between the transversal girders and carries a slide in which a yawing table is incorporated (see *Fig. 4* and *Fig. 7*).

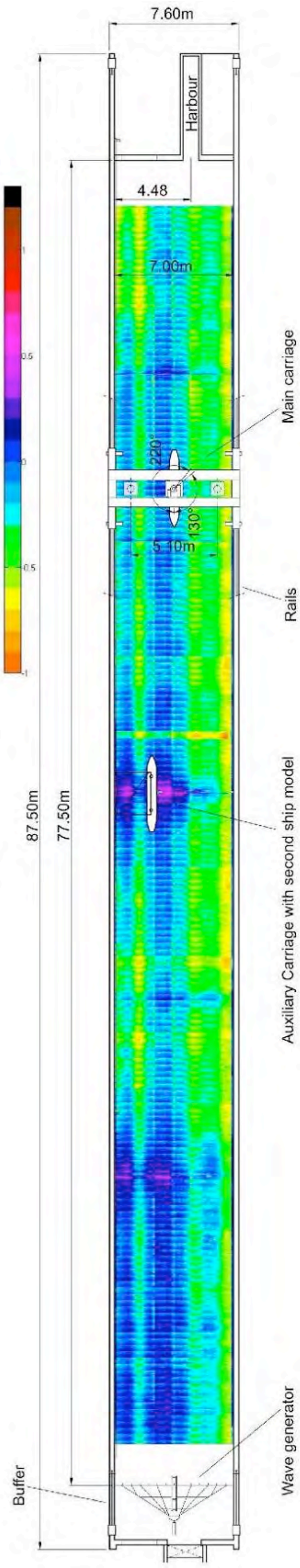


Fig. 3 - General layout with bottom profile

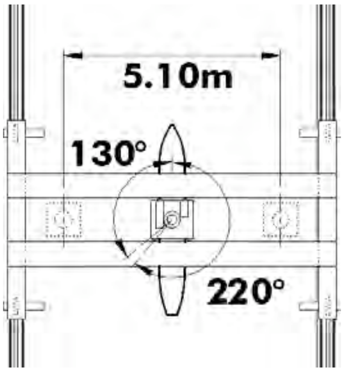


Fig. 4 - Top view of the towing carriage

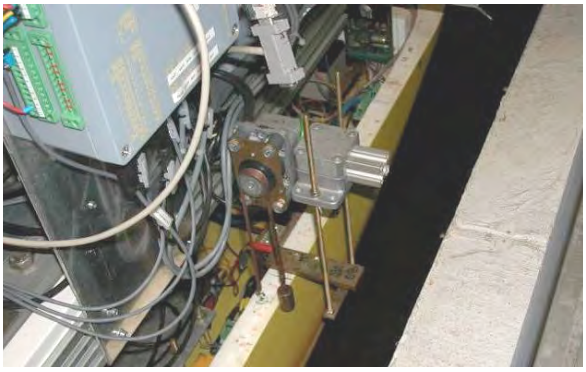


Fig. 5 - Mechanical safety device to protect the ship model from touching the bottom

This servo motor driven slide can be positioned manually in vertical sense 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. 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. 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, a mechanical safety device was installed (see *Fig. 5*).

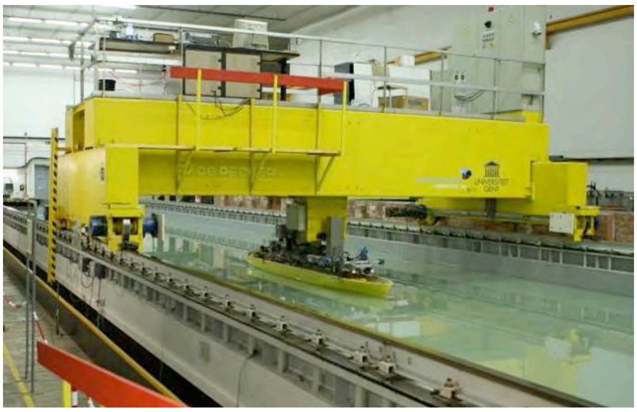


Fig. 6 - General layout

Fig. 7 - Top view of towing mechanism

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

Table 2 - Range of positions, velocities, and accelerations

		Main carriage	Lateral carriage	Yawing table
Position	Min	0.000 m	-2.550 m	-130.0 °
	Max	68.000 m	+2.550 m	+220.0 °
Velocity	Min	0.05 m/s	0.00 m/s	0.00 °/s
	Max	2.00 m/s	1.30 m/s	16.0 °/s
Acceleration	Max	0.40 m/s²	0.70 m/s²	8.0 °/s²
Power output		2 x 7.2 kW	4.3 kW	1.0 kW

2.3. Wave generator

The towing tank is equipped with a wave generator to study the vertical vessel motions induced by waves (see *Fig. 8*). Both regular and irregular waves can be generated. The piston of this wave generator is driven by an electro-hydraulic unit with kinematical characteristics given in *Table 3*.

Table 3 - Kinematical characteristics of the wave generator

Stroke	0.3 m
Velocity	0.6 m/s
Acceleration	4.4 m/s²

Fig. 8 - Captive sea-keeping tests

3. Interaction 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 maximum speed of 1.2 m/s (see *Fig. 9*). In this way, ship - ship interaction tests can be carried out with two meeting or overtaking ship models [3]. 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 an optical sensor.

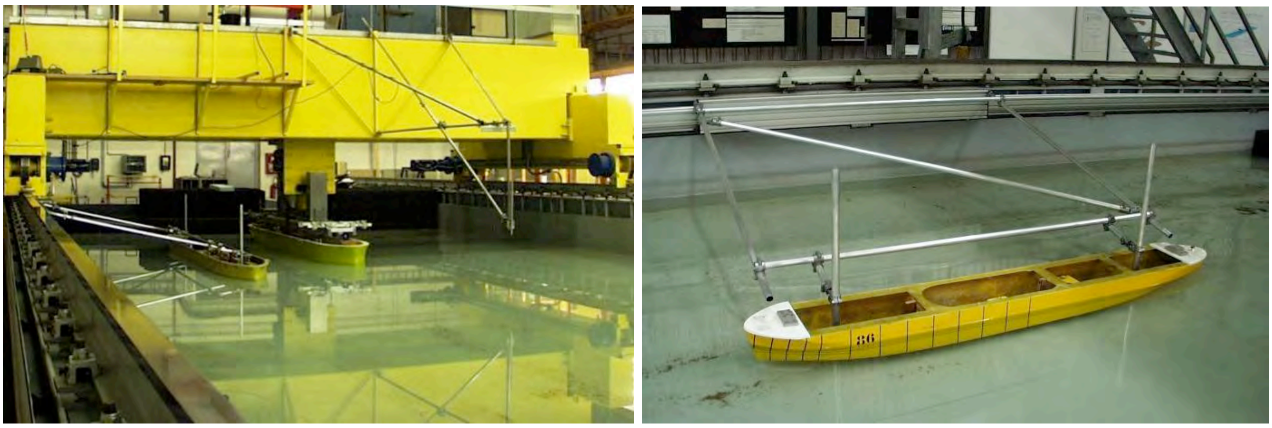


Fig. 9 - Auxiliary carriage for ship interaction tests

A second type of ship - ship interaction tests can be carried out by attaching an auxiliary beam to the towing carriage (see
Fig. 10) [4]. With this construction both ship models execute tests at the same speed. 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.

Fig. 10 - Second beam for the execution of ship - ship interaction
(left: lightering operation between VLCC and Aframax tankers [4]; right: ship - tug interaction)

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 *Fig. 11* and *Fig.*). The banks have to be built with a high accuracy, which can be controlled making use of the towing carriage for reference (see *Fig. 12*). The banks also need to be watertight, particularly at the joints between two bank elements.

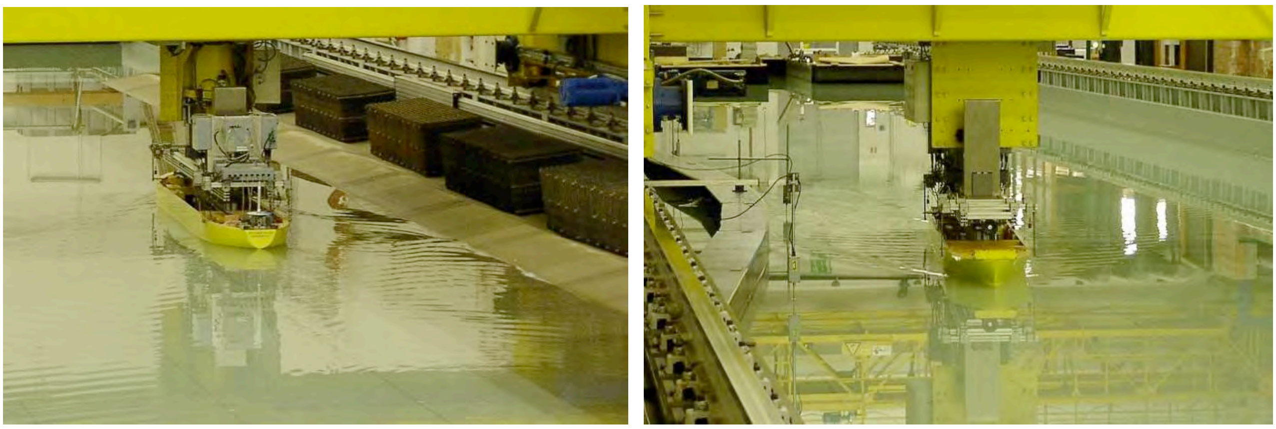


Fig. 11 - Bank effect model tests

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. They can either be used as a vertical element to construct quay wall or locks, or as a sloping bank. Another, more labour intensive way is often used to construct hydraulic scale models, and makes use of gravel and mortar (see *Fig. 12*). Both techniques have been applied for the construction of quay

walls, surface-piercing and submerged sloping banks [5], sinusoidal banks, variable canal sections [6], and harbour environments.
Presently, experiments are carried out to examine the use of coated prefabricated elements made of expanded polystyrene foam, applied to the tank bottom by a light vacuum pressure.

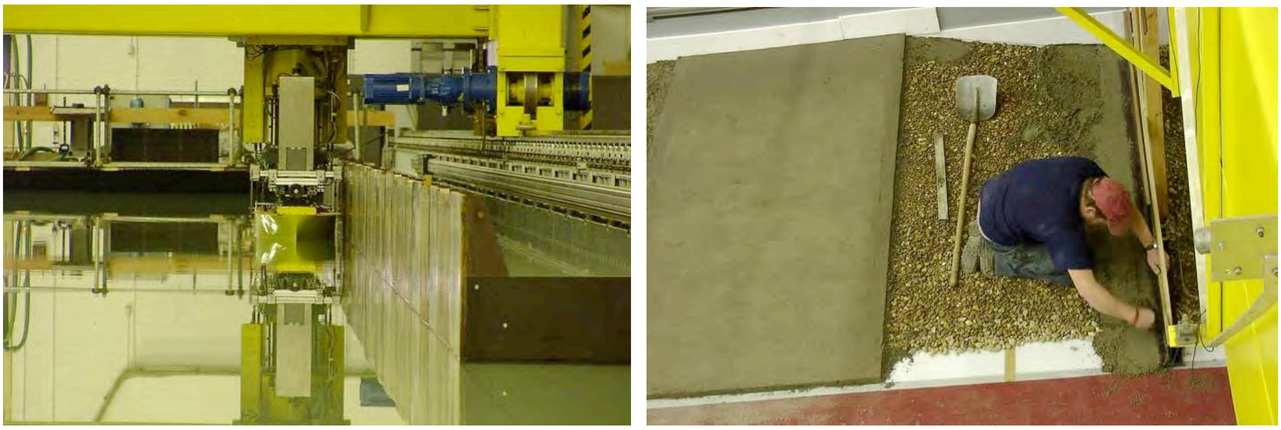


Fig. 12 – Model test close to the quay (Left)
Fig. 12 - Building banks with gravel and mortar, using the towing carriage as reference (Right)

4. Automatic operation

4.1. Test control and data acquisition

The three motion modes, the wave generator, the rudder(s), propulsion(s), the auxiliary devices for ship-ship interaction tests, and other external devices are controlled by a PC on the towing carriage and up to six DIOCs (Direct Input Output Control) (see *Fig. 13*). The DIOCs also assure the sampling and the control of the analogue and digital input signals. The DIOCS can be located on the carriage or ashore. The communication between the DIOCs and the PC can take place via a serial port or an Ethernet connection.

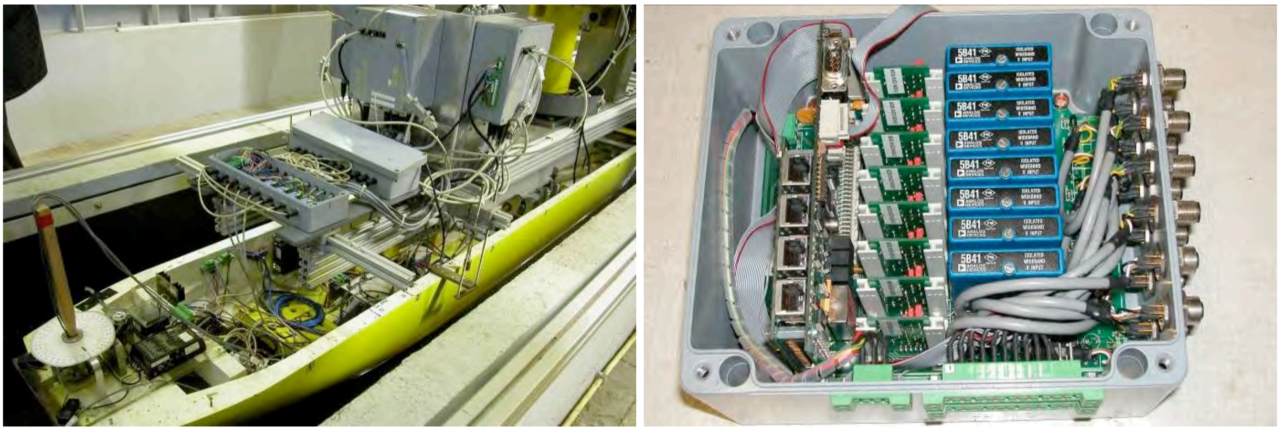
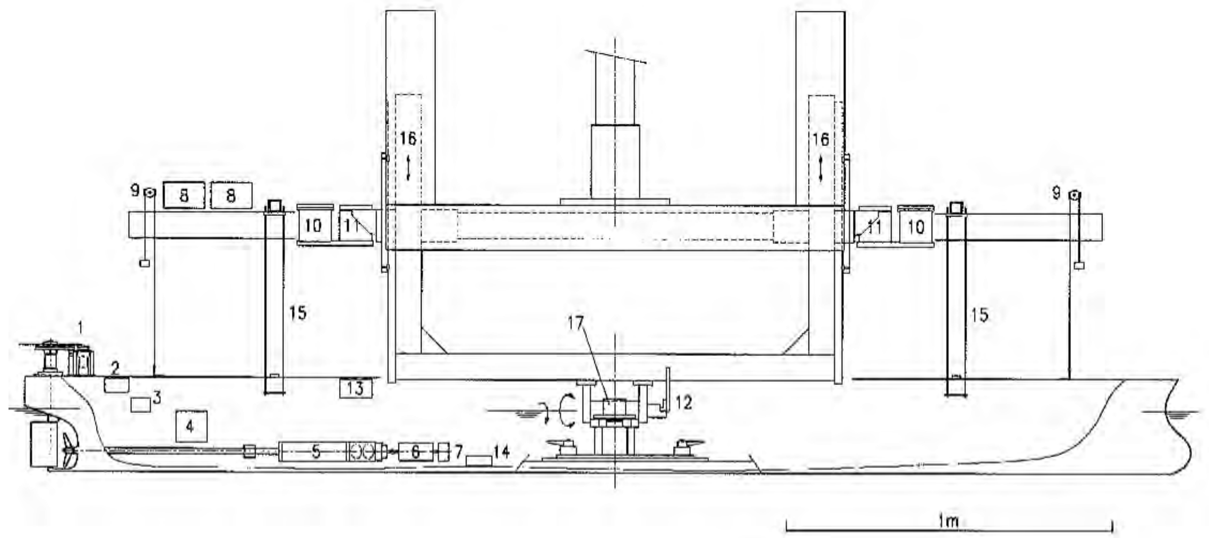


Fig. 13 - DIOCs for communication with the computer

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 and free 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, an average of 35 tests per 24 hours can be carried out in this way.

During captive manoeuvring tests, the ship model follows a predetermined trajectory, described in a *trajectory file* (see *4.3*), applied by the towing carriage. During this trajectory, the forces acting on the ship model (hull, propeller, and rudder), the propeller rate, the rudder angle, 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 *Fig. 14* for a typical setup). The PC can sample the 48 analogue and digital input signals and control the 24 analogue and 48 digital outputs of the 6 DIOCs and the positions of the longitudinal, lateral and yawing sub-mechanisms which are stored in a digital way (12 bit). A variable sample frequency up to 100 Hz can be selected.



1 rudder mechanism	7 propeller rate of turn meter	13 propeller control
2 rudder control system	8 amplifier	14 leakage alarm
3 leakage pump	9 sinkage measurement (4 positions)	15 limit vertical motion (4x)
4 battery	10 longitudinal dynamometer (2x)	16 vertical guidance
5 thrust & torque gauge	11 lateral dynamometer (2x)	17 pitch and roll mechanism
6 propeller motor	12 roll moment measurement	

Fig. 14 - Ship model instrumentation

During free running tests (see Chapter 6) there is no rigid connection between the ship model and the towing carriage. The rudder forces, the propulsion forces, the rudder 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.

4.2. Pre-processing

Software has been developed for the generation of *trajectory files* (see *4.3*) for several types of standard captive manoeuvring tests (see *Table 4*). Some tests can contain several conditions, e.g. several values for the propeller rate or rudder angle during one test run. The input data for the generation software is stored in manually edited *data files*, which contain some common characteristics, e.g. the used ship model and environment, and a number of trajectory lines supplying data typical for each trajectory, e.g. drift angle, propeller rate, rudder angle.

Table 4 - Types of standard captive manoeuvring tests (selection)

bollard pull test	propeller and rudder action at zero speed
stationary rectilinear test	constant forward or backward speed, propeller rate(s), rudder angle(s), drift angle
oscillation test	harmonic variation of longitudinal, lateral or yawing position, at zero speed
PMM sway / yaw test	constant forward speed, oscillatory sway / yaw
multimodal test	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)
interaction test	ship - ship interaction test with two passing or overtaking ship models
(ir)regular wave test	model test in regular or irregular (spectrum based) waves

For ship - ship interaction tests with the auxiliary carriage and wave tests additional programs are developed to generate an optimal *data file* based on an *input file*. The *input file* of the wave tests contains the information of the wave (regular or spectrum), the ship model, the environment, and the desired trajectory. Based on this information the optimisation program calculates the optimal start and stop position of the ship model and the optimal starting times for the towing carriage and the wave generator to maximise the number of useful encounter periods between the ship model and the wave train. The optimisation program for ship - ship interaction calculates the optimal trajectory for both ship models, so that the two ship models pass each other halfway the towing tank.

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 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 files with 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 captive manoeuvring tests

All information the towing carriage needs to execute a manoeuvring test is stored in the *trajectory file;* this is an ASCII-file which contains a sequence of reference values for the sub-mechanism positions and for the analogue and digital outputs as a function of time. 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 25 ms, are calculated and stored in the controller memory, with a maximum of 24000 points. This information is sent to the DIOCs before the test during the waiting time. This waiting time in shallow water is typically 2000 s; this time is needed to restrain the long wave and vortexes in the towing tank.

During the test the measurements are only sent to the PC to check the limits of the gauges, so that the test can be interrupted in case a range limit is exceeded. The measurements are saved at the DIOCs during the test and after finishing the test, all measurements are sent to the PC to be stored in a *documentation file*, an ASCII 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 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. An additional calibration of the hull forces is carried out when the ship's draught is changed. After a calibration the *input* and *output files* can be generated; these files contain the information on analogue and digital in/outputs (conversion of voltage to physical units or v.v., definitions, acceptable ranges, etc.).

4.5. Post-processing

In order to condense the data in a *documentation file*, which is in the order of magnitude of 1 MB, post-processing software has been developed. These programs apply corrections of measuring results, e.g. correction of sinkage due to imperfection of the rails according to information in a *correction file*, which is based on a rail calibration test (see *5.1.*). Furthermore, 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*, a *data point file* can be generated, containing the results of the tests which can be used for the derivation of mathematical models.

5. Accuracy

5.1. Rails

The rails on which the towing carriage moves are train rails of which the upper surface is milled and finished. This is also the case for the lateral surfaces of one of the rails, referred to as guide rail, so that excessive lateral deviations of the carriage can be avoided by means of lateral guiding wheels. 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.

The alignment of the rails is challenging because measuring devices with a resolution of the order of magnitude of the tolerances and a measuring range covering the whole tank length are not available. For this reason, a special measuring technique was developed to align the rails. First of all this technique was used for the installation of the towing carriage. The contractor of the towing tank would only install the towing carriage if the rails were aligned according to the required specifications in the request for quotation (see *Table 5*).

Table 5 - Requested accuracy of the rails

Straightness in the vertical plane (both rails)	Tolerance over the whole length	1 mm
	Local tolerance	0.1 mm / 1000 mm
Straightness in the horizontal plane (guide rail)		0.2 mm

Because the curvature of the earth is already noticeable along the whole length of the towing tank, the only way to level the rails is measuring the position of the rails to the water surface. For that reason, two gutters were mounted next to the rails to have the possibility to measure the distance between the rail and the water surface in the gutter with a clock gauge. To check the lateral deflection, two small wheels are fixed at both extremities of the rails. Between these two wheels an iron wire is tightened. Along the length of the rails, the iron wire will sag under its weight, so that an extra support has to be provided halfway the towing tank. The lateral distance between the rail and the iron wire can be measured with a clock gauge. To visualize the contact between the tip of the clock gauge and the iron wire a contact detector with two led diodes is used.

To start the measurement of the position of the rails, the gutters are filled with water. These gutters contain partitions to limit the influence of the disturbance of the water surface during the measurement. When the two gutters are connected with a tube, two communicating vessels are created with the same level; in this way, the difference in height between the two rails can be measured.

The rails can be measured in a manual and in an electronic way (see *Fig. 15*). When the rails are measured with the manual method, the height of the two rails and the lateral deflection of the guide rail are measured at every screw bolt. Taking account of the number of bolts (176 for each rail), this is a time-consuming method to measure thoroughly the rails. During this period the water level in the gutters may vary significantly due to evaporation; depending on the humidity level in the towing tank hall, the water level may change some hundredths of a millimetre per hour. For this reason, the level of a reference screw bolt at each rail is measured at the start and the end of the measuring campaign to correct for the evaporation.

When the rails are measured with the electronic method, the measurement instrument is connected to the wheelbase of the towing carriage. In this way, the measurement of the position of the rail can be executed as the towing carriage is moving during a test. With this method the distance between the wheel shaft and the water surface is registered continuously. The vibrating point of the measurement instrument has a stroke of 15 mm. When the vibration point touches the water surface the position of the rail is registered. During the measurement, the towing carriages moves at 0.5 m/s and the results are registered at 100 Hz. The resolution is 3 bits / 0.01 mm and the accuracy of the measurement is 0.05 mm. The electronic measurement is always verified with a manual random check.

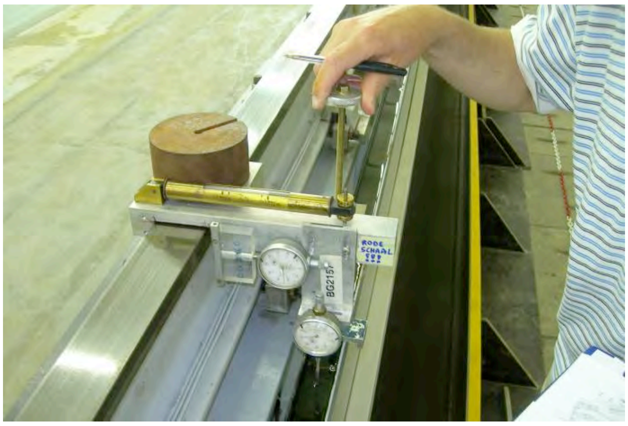



Fig. 15 - Alignment of the rails: manual method (left), electronic method (right)

The electronic method has been optimized during the last years and now it is possible to measure both rails at the same time.

The processing of the measurements results into a table presenting rail corrections at each screw bolt. To correct the rail position, a graduated arc on which the adjustment of the screw bolt is indicated in turn by 0.01 mm is used (see *Fig. 16*). When all the screw bolts are adjusted, the rails are measured a second time. The procedure of measuring and aligning the rails is repeated until the accuracy is within the specifications mentioned in *Table 5*.

The measurement of the rails is executed twice a year, namely 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.

Fig. 16 - Adjustment of the screw bolts with a graduated arc in turn by 0.01 mm

5.2. Bottom of the towing tank

The accuracy of the bottom level is very important for executing ship model tests in shallow water, as the hydrodynamic forces acting on the ship hull are very sensitive to small variations of the under keel clearance in the very shallow water range (< 20% of draft). For a ship model with a draft of 0.2 m, 1% of under keel clearance equals 2 mm, so that an accuracy in the order of magnitude of 1 mm is required.

Due to setting of the tank foundations after 15 years of activity, the accuracy of the bottom level did not meet the requirements any more, as the level difference between the highest and lowest point appeared to be about 8 mm. For that reason the bottom was flattened in May 2008 so that the extreme level difference is now less than 2 mm. In the area where most of the test are executed the accuracy is a fraction of 1 mm; only on the side of the towing tank and at the expansion joints the accuracy is ± 1 mm (see *Fig. 3*).

Because of the alignment of the rails with a high accuracy, it was obvious to use the latter as a reference to flatten the bottom of the towing tank. A construction with a milling machine was mounted on the towing carriage (see *Fig. 17*).

The upper layer of the concrete bottom of the towing tank consists of elastomer based self-levelling cement mortar. For this reason, it was important to select the appropriate milling procedure; for example, the right kind of diamond milling cutter had to be chosen in order to prevent untimely saturation. 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 is flattened in layers of 0.7 mm until the accuracy of ± 1 mm was reached.

Fig. 17 - Flattening the bottom of the towing tank

6. Free running model technology

Since 1993, the manoeuvring characteristics of ships in shallow and confined water have been investigated at Flanders Hydraulics Research. The results of these model tests are used to develop mathematical models for manoeuvring simulation. The developed mathematical models have to be validated. This can be done by comparing the predicted navigation behaviour of the mathematical model with the navigation of the real ship, but in reality there are no or insufficient full scale data available. Another way to validate the mathematical models is to use the same scale model to execute free running tests.

The ideal facility to perform such tests would be a tank of at least 80 m to 60 m, equipped with a tracking system, which is impossible to construct at the premises of Flanders Hydraulics Research. Nevertheless the validation of the mathematical models is important for the quality of the results of simulation studies, so as an alternative the towing tank has been extended with a tracking system for free running ships early 2009.

When using the towing tank in free running model test mode (see *Fig. 18*), the ship model is not mounted to the beam of the towing carriage, but it can manoeuvre freely and sails its own course determined by the autopilot which controls the propeller and rudder. In this case, the towing carriage follows the free running model as close as possible, and the relative position between the carriage and the model is measured.

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. The clamp system consists of two conical grippers which can clamp a cylinder mounted on the side of the ship model. The system is tuned to hold and release the ship model as smooth as possible to limit the effects on the ship model and the water surface at the beginning of the manoeuvre. The clamp system is controlled by air pressure by means of a noise and vibration free compressor mounted on the towing carriage. A metal protection frame at the front and the end of the beam ensures that the free running ship does not exceed the range of the towing carriage and it also prevents the ship model from touching the bottom of the towing tank. During the free running test the towing tank software application constantly calculates collision detection to protect the ship model. When there is a risk for collision the free running test will be interrupted. At the end of the free running test, when the towing carriage can safely stop, the ship model will be clamped "on the fly". When the ship model is in a dangerous position and there is no time for a safe deceleration, the towing carriage will slow down as soon as possible and will stop the ship model by means of the protection frame. After such an emergency stop the grippers will try to clamp the ship model; if this appears not to be safe, the test batch will be aborted. Otherwise the towing carriage takes the ship model to a safe position and continues the batch.

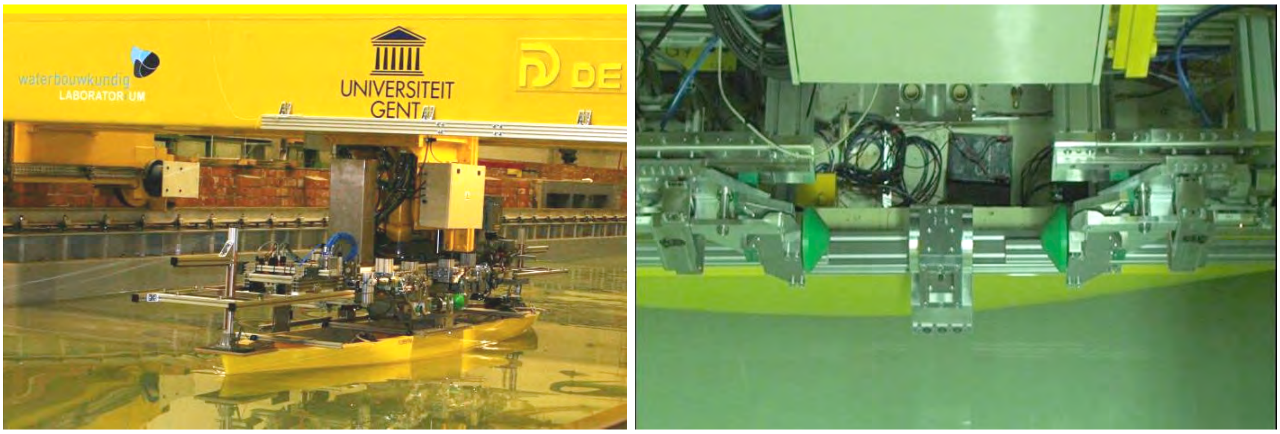


Fig. 18 - Free running model tests

At present the autopilot can execute crash stop, zigzag, acceleration, and stationary tests. It is also possible to execute free running tests in waves. The autopilot is still in development and will be extended with more options, such as course tracking.

7. Conclusions

Execution of captive manoeuvring and sea-keeping 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 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.

In order to assure the quality of the test results, procedures to check and enhance the quality of the infrastructure are in permanent development, as is illustrated by the efforts concerning the accuracy of the carriage rails and the tank bottom. But also the final result of captive manoeuvring tests, i.e. mathematical simulation models, needs to be validated; for this reason, the facility has been modified to allow the execution of free-running manoeuvring tests as well, taking optimal advantage of the existing automation.

8. References

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