Concept and operation of a computer controlled towing tank for manoeuvres in shallow water

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Abstract

A description is given of the towing tank for manoeuvres in shallow water at Flanders Hydraulics, which was especially designed for investigation of ship behaviour in shallow and restricted waters. Special attention is paid to the fully automatized, computer-controlled operation and data processing.

1 Introduction

The presence of three important seaports in full expansion has aroused an increasing interest of the Belgian and Flemish authorities in the behaviour of ships in shallow and confined waters. As a matter of fact, an optimal use of existing and projected waterways and harbour areas is an absolute necessity, taking account of the growing international competition and restricted public funds. On the other hand, the safety of shipping traffic must be guaranteed under all circumstances, so that a scientifical approach is required.

As a result, Flanders Hydraulics, a research laboratory of the Ministry of the Flemish Community (Department of Environment and Infrastructure), is confronted increasingly more often with ship hydrodynamics and nautical problems, while ten years ago exclusively hydraulics were studied. In order to fulfil its function in the expansion of the Belgian harbours and their approach channels, an extension of activities was esteemed necessary. This new approach led to the installation of a ship manoeuvring simulator (1989).

As the study of ship behaviour in confined waters often requires model tests, experimental facilities for ship models were developed (1992-93) with the scientific support of the University of Ghent. The paper gives a brief description of this *Towing Tank for Manoeuvres in Shallow Water — co-operation Flanders Hydraulics - University of Ghent* which was accepted as a ITTC member organization in 1993.

2 Preliminary design considerations and requirements

It was considered that Flanders Hydraulics is primarily a *hydraulic* research station; ship hydrodynamics are not the major concern and are only studied in relation with the concept, adaptation and operation of navigation areas. This yields two restrictions for the concept of the ship model facilities:
- water depth may be limited to about twice the maximum draught;
- only low model speeds have to be realized.

Priority was given to following topics:
- ship manoeuvrability, with emphasis on determination of hydrodynamic coefficients occurring in the mathematical simulator model, with special attention for the influence of very restricted keel clearance and lateral restrictions (banks), the effect of muddy bottoms and manoeuvrability at low speed (ahead and astern);
- vertical ship motions caused by waves in shallow water.

As a result, the installation should allow the execution of captive manoeuvring and seakeeping tests in shallow water. The overall dimensions of the set-up were chosen as modest as possible, in order to reduce both the total cost and the loss of area for hydraulic scale models. Therefore, it was not possible to construct a wide manoeuvring and seakeeping basin; it was decided to install a towing tank, equipped with a planar motion mechanism (PMM) and a wave generator.

3 Concept

Main characteristics (Figure 1, Table 1)
Length, width The space available at Flanders Hydraulics allowed the construction of a 88 x 7 m^2 tank, with a useful length of 68 m. The latter is acceptable, as for manoeuvring tests ship models of about 4 m length are required, and one is mainly interested in low speed manoeuvres (<0.5 m/s).

Optimal parameter choice for captive manoeuvring tests was studied in [1],[2]. For stationary straight-line tests (resistance, propulsion, rudder action, oblique towing), a measuring length of about 5 ship lengths on the average appears to be acceptable, so that about three conditions can be performed per run. For harmonic oscillation tests, the usual frequency values allow the execution of 2 to 6 periods per run.

Depth Taking account of the draught of the ship models (0.15-0.20 m), variation of the water depth between 0.15 and 0.40 m must be possible, so that the height of the tank walls was chosen to be 0.50 m.

Generation of swaying and yawing motions A computer controlled sway carriage - yawing table combination was preferred instead of a mechanical PMM. This not only allows execution of harmonic oscillation tests, but also offers possibilities for handling several problems concerning ship behaviour in restricted water, such as the measurement of forces acting on ships navigating parallel to a bank or approaching a quay wall.

In order to realize a constant forward ship velocity component during harmonic yaw tests, it was decided to provide the main carriage with a variable speed control, instead of mounting a Δx-carriage.

Kinematic characteristics The maximal longitudinal velocity is sufficiently large compared with the economical speed of the ship models; at maximum speed, acceleration and deceleration zones both take 5 m. The velocities and accelerations of lateral carriage and yawing table allow harmonic oscillations with a track width of 5 m at the minimal (tank resonance) period of 12 s.

Table 1. Range of positions, velocities and accelerations.

	POSITION		VELOCITY		ACCELERATION	POWER
	MIN	MAX	MIN	MAX	MAX	(kW)
x_0	0.000 m	68.000 m	0.050 m/s	2.000 m/s	0.40 m/s²	4 x 7.2
y_0	-2.550 m	+2.550 m	0.000 m/s	1.300 m/s	0.70 m/s²	4.3
ψ	-130.0 °	+220.0 °	0.000 °/s	16.000 °/s	8.00 °/s²	1.0

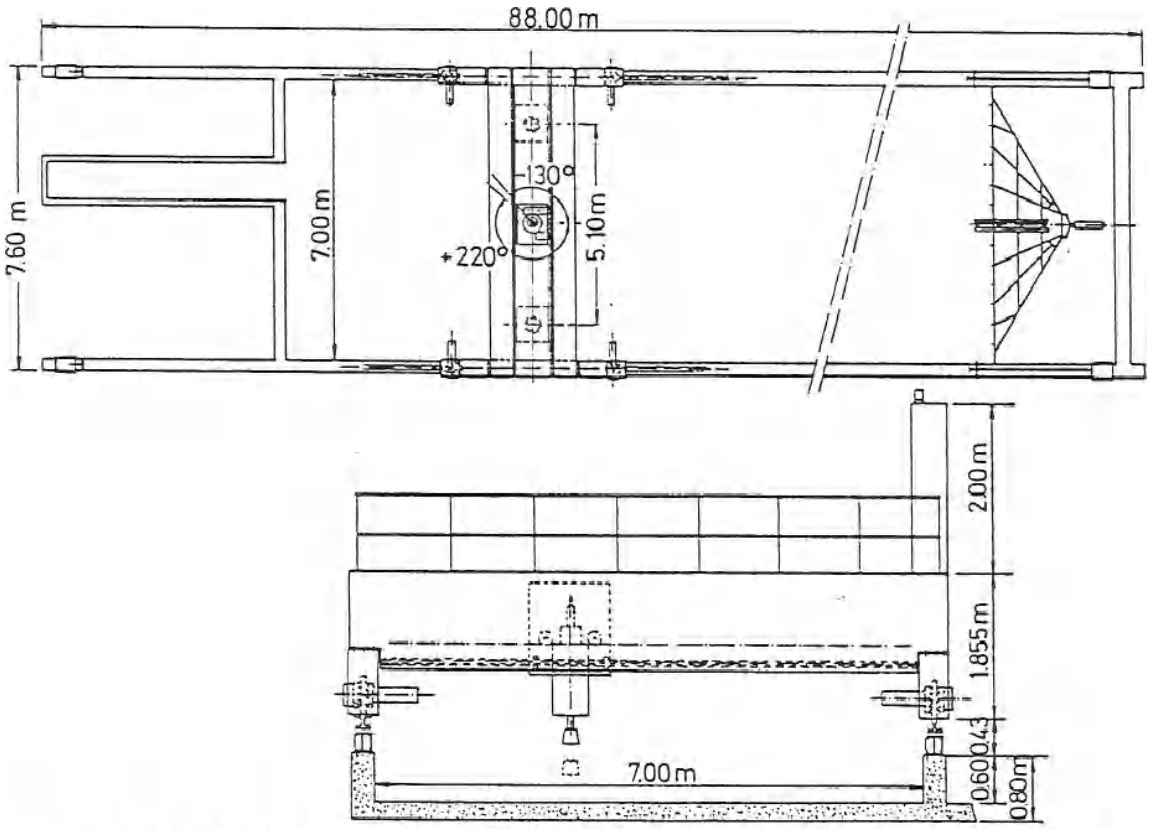

Figure 1: Towing tank for manoeuvres in shallow water: general layout

Accuracy It is clear that the results of captive model tests are influenced by imperfections of the experimental techniques, which cause divergences between prescribed and actual trajectories performed by the ship model. This influence was studied in [1],[2] in order to determine the accuracy requirements which should be met by the mechanism. A general theory was developed for determining the influence of trajectory divergences on the accuracy of the experimental value of hydrodynamic coefficients, which not only appears to be dependent on the accuracy of the experimental equipment, but also on experimental parameters, such as measuring length for stationary tests, frequency and number of cycles for harmonic tests.

Based on these theoretical developments, accuracy requirements for the sub-mechanisms were formulated (Table 2). The relative error due to control errors on the four main linear hydrodynamic derivatives (Y_v, Y_v, N_r, N_r) should be less than 1% if the test parameters are chosen properly.

Table 2. Acceptable divergences of prescribed trajectory.

		POSITION		VELOCITY	
		% amplitude	abs. min.	% amplitude	abs. min.
x_0			1.5 mm	0.25 %	0.5 mm/s
y_0:	amplitude = 350 mm amplitude > 350 mm	0.36 % 0.67 %	1.3 mm	3.3 % 3.0 %	1.7 mm/s
ψ:	amplitude = 15° amplitude > 15°	0.20 % 0.67 %	0.03°	3.0 % 3.0 %	0.08°/s

General layout

Tank The tank is composed of four sections of reinforced concrete, connected by joints. Foundations were not required due to the presence of underground reservoirs. The tank bottom was levelled with an accuracy of ± 1 mm, which is required for tests in shallow water. The rails are train rails of which the upper surface and, at one side, the lateral surfaces are milled and finished. The rails are aligned with high accuracy: the level difference of both rails and the lateral deflection of the guide rail are less than 0.5 mm.

Mechanism The main carriage can be considered as a rectangular frame, composed of two wheel girders, connected by means of two box girders (Figure 2). The lateral carriage, which carries the yawing table, is guided between the transversal girders (Figure 3-4). The four wheels are driven by brushless AC-servo-motors which are connected to the shaft by means of a gearing (Figure 5). The longitudinal position is determined separately by means of a measuring wheel. The lateral carriage is driven by means of a pinion-rack combination. The pinion is driven by a servomotor by way of a planet gear. A second pinion carries a brake. The vertical rotation tube is incorporated in a slide which can be positioned manually in vertical sense over 0.4 m, and is driven by a servomotor by way of a reducer with large ratio (1:320) and restricted backlash (Figure 4). The rotation angle is measured at the tube (Figure 6), to which a beam is connected by means of a flange. This beam is attached to the ship model by means of a mechanism which allows free heave and pitch, but creates a rigid connection in other modes.

Control (Figure 7)
The three motion modes, as well as three analog (AO) and four digital outputs (DO) for rudder, propulsion and auxiliary devices, are controlled by personal computer PC1. The software allows the operator to select among several options, e.g.:

- manual control of analog and digital outputs
- manoeuvring into or out of the "harbour"
- manual positioning
- detection of "home"-positions
- execution of captive manoeuvring tests.

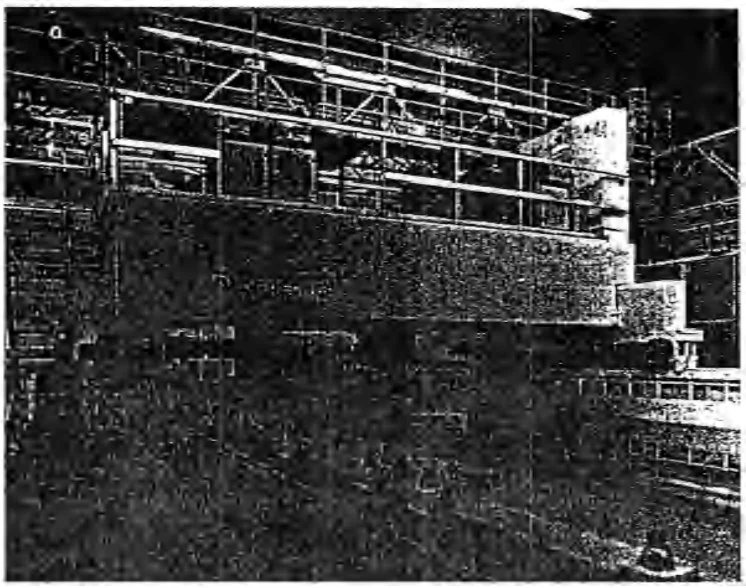

Figure 2: General view of carriage

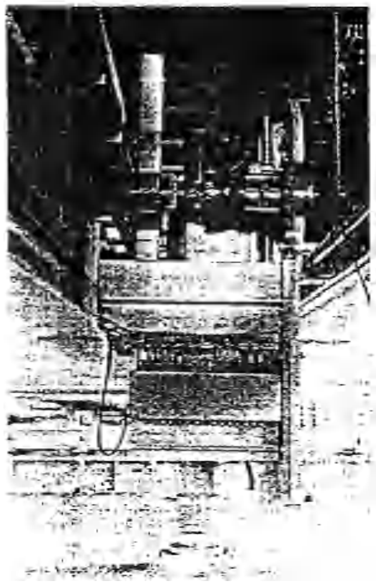

Figure 3: Sway carriage

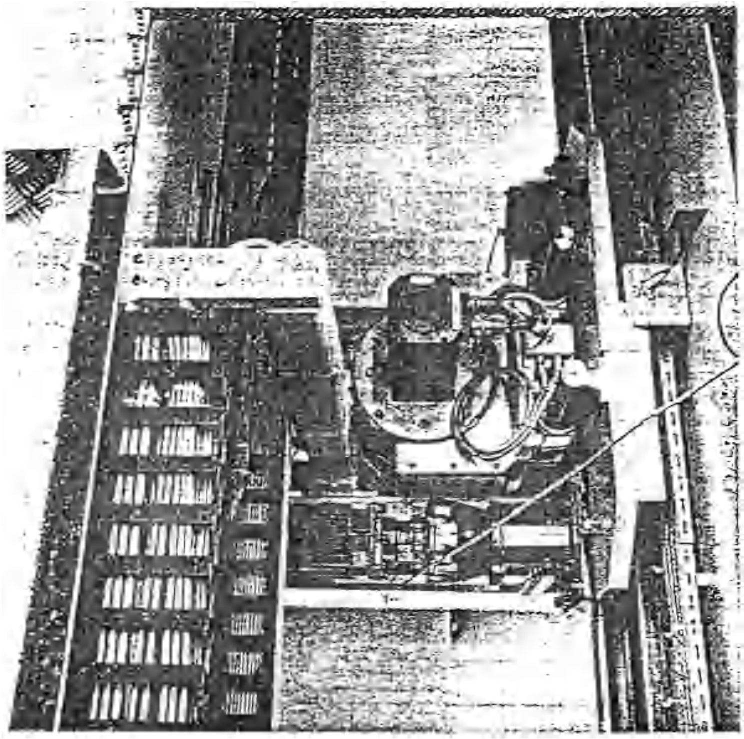

Figure 4: Sway carriage (from above): sway and yaw motion drives, vertical slide

All information required for execution of a captive test is stored in a *trajectory file*, which contains a sequence of reference values for the sub-mechanism positions and for the analog and digital outputs as a function of time. Based on this file, reference values for the velocity of the sub-mechanisms at each point of time are calculated and stored into the controller memory. The time increment is a multiple of 25 ms, the maximum number of points being 7000. During the test, the controller sends reference signals to the servo amplifiers which control the velocity of the respective motors M by means of a PI-control system. The motors are equipped with resolvers R with encoder simulation, so that their position is fed back to the controller, which adapts the velocity reference signals to the trajectory errors by means of digital PID-filters. With respect to the longitudinal motion mode, only one servomotor (master) is velocity controlled; in order to avoid slip of the wheels on the rails, the other motors (slaves) are torque controlled.

The test sequence can be determined by the operator, or described by means of a *batch file*, containing the names of trajectory files separated by waiting times. This option allows unmanned operation, so that experiments

Data-acquisition
A second PC, PC2, is able to sample successively 24 analog input signals (measurements AI0..21, x_0, y_0, ψ) which are stored in digital way (12 bit), with a variable sample frequency up to 40 Hz. During captive manoeuvring tests, following data are measured: lateral and longitudinal force components and sinkage at two towposts, propulsion forces (torque, thrust), rudder forces (longitudinal and lateral components, torque) and the actual values of the controlled variables (three motion modes, propeller rpm, rudder angle). After the test, the measured data are stored in a *documentation file*.

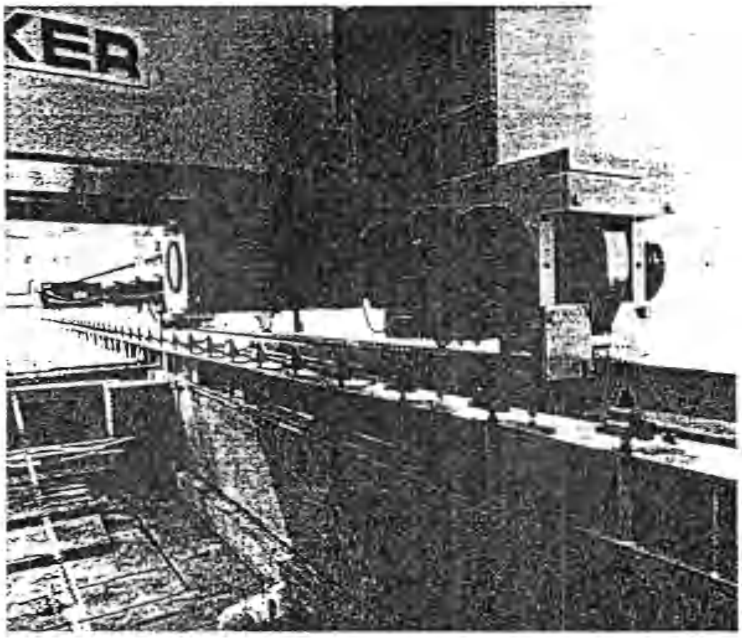

Figure 5: Guide rail, wheel with motor and gear reducer, measuring wheel with encoder

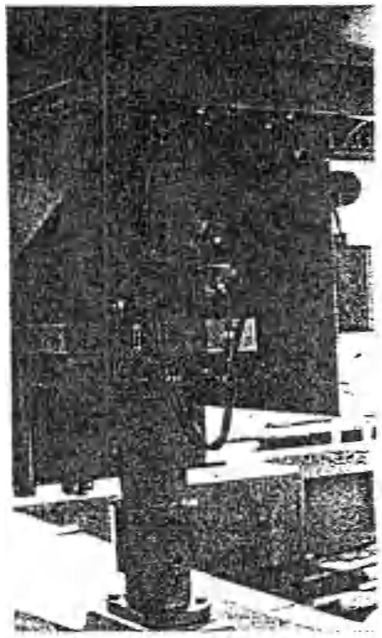

Figure 6: Vertical shaft with encoder

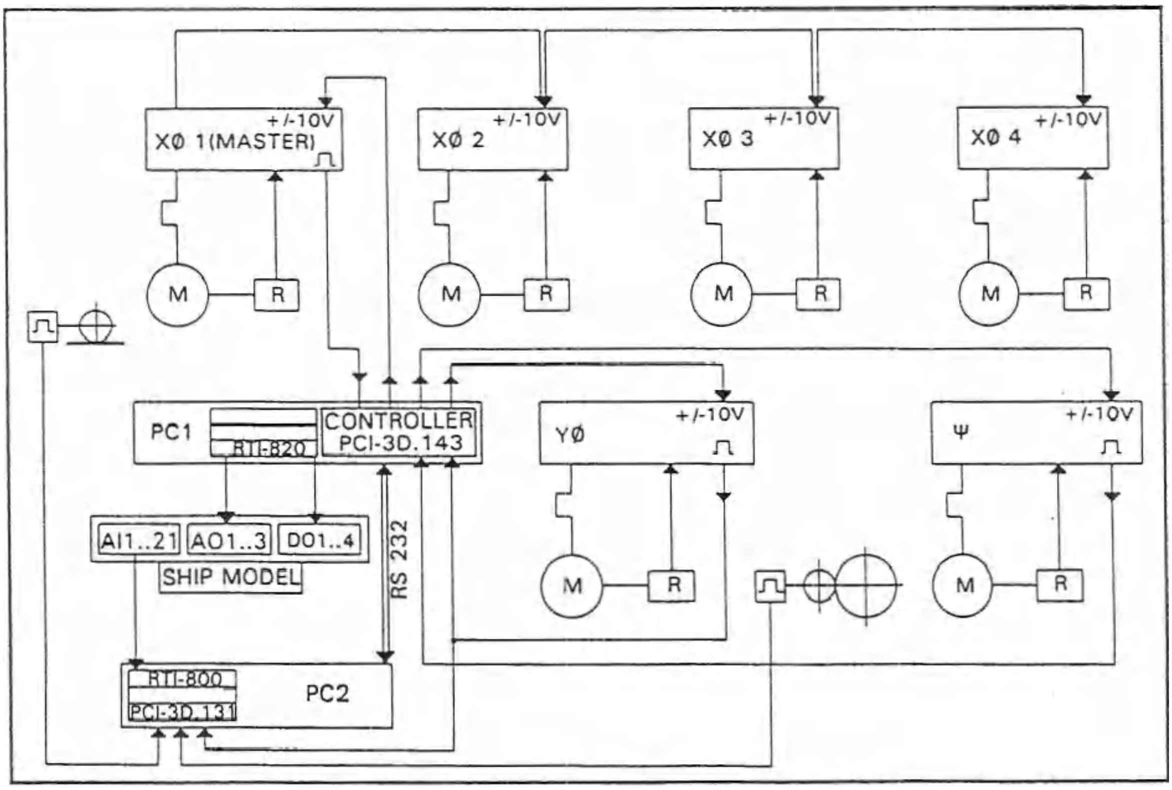

Figure 7: Control and data acquisition

Wave generator
The piston type wave maker is driven by an electrohydraulic unit with following kinematic characteristics: stroke 0.3 m, velocity 0.6 m/s, acceleration 4.4 m/s². The unit is controlled by a PC which is also able to sample up to 8 analog inputs (e.g. wave gauge) during wave generation. As software permits both manual (keyboard) and automatic (digital input) control of wave generation, the wave maker can be activated by PC1.

4 Data Processing

Introduction
Thanks to automation, about 50 runs can be executed daily. This implies that a large number of trajectory files has to be generated, and a huge amount of measuring data stored in documentation files (≈ 1 MB) has to be checked and processed. Furthermore, as most of the time the carriage is unmanned, precautions have to be made to ensure safety. For an optimal operation of the tank, software has been developed for generation and validation of trajectory files and processing of documentation files (Figure 8).

Preparation of trajectory files
Generation Programs have been developed for generation of several types of standard captive manoeuvring tests:
- bollard pull tests (propeller and rudder action at zero speed);
- stationary rectilinear tests (resistance, propulsion, rudder, drift);
- stationary combined yaw and sway tests (rotation about fixed point);
- oscillation tests in x_0, y_0 and ψ-mode (at zero speed);
- PMM sway and yaw tests (forward speed, oscillatory sway or yaw).

The first and second types can contain several conditions (e.g. several values for propeller rpm or rudder angle during the same run).

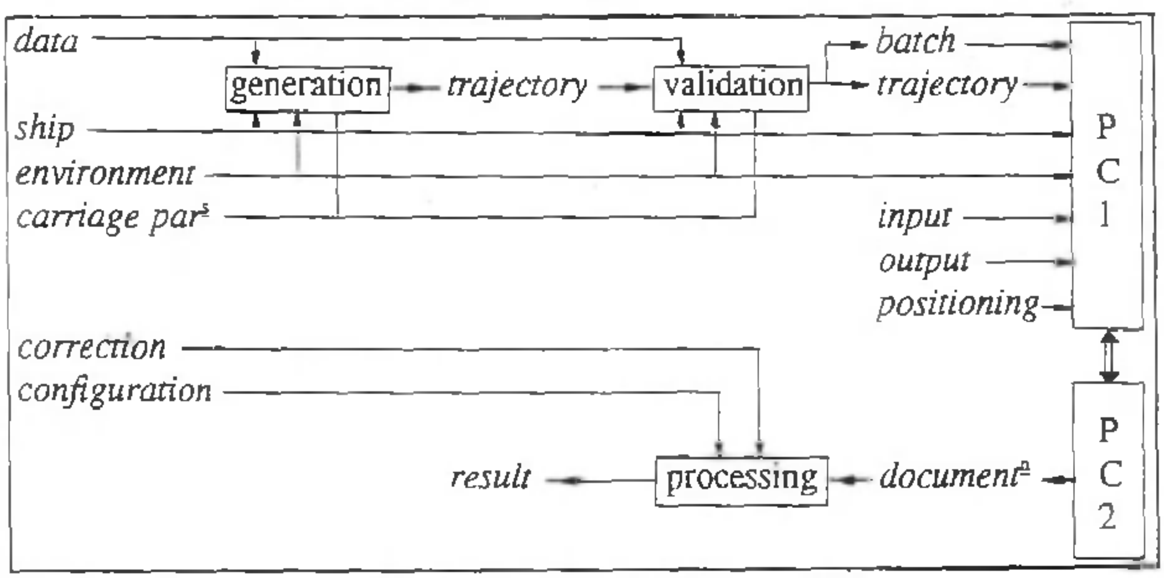

Figure 8: File management

Input data for generation programs are stored in manually edited *data files*, which contain some common characteristics and a number of trajectory lines supplying data typical for each trajectory.

Validation *Trajectory files* are not accepted by PC1 unless they contain a valid "signature", which is provided by a validation program. The latter checks whether the trajectory can be executed, taking account of:

- position, velocity and acceleration ranges for each sub-mechanism;
- possible contact between ship model and environment.

For this purpose, the program needs additional files: *carriage parameters file*, *ship file* and *environment file*. The validation program also generates a *batch file* allowing automatic operation. If desired, the trajectory can be plotted together with the tank and environment outlines (Figure 9).

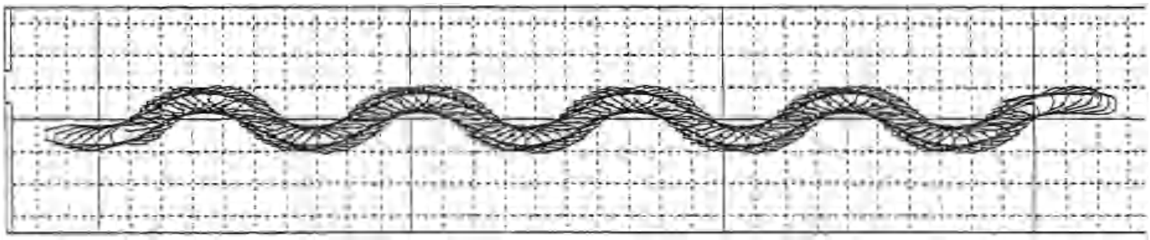

Figure 9: Example of output of visualisation program : PMM yawing test

Execution of captive manoeuvring tests

In addition to trajectory files and, eventually, batch files, the software on PC1 needs some more information in order to execute a test, e.g.:

- *positioning file*: positioning parameters (velocities, accelerations) for manual mode or motion to starting coordinates;
- *output file*: information on analog and digital outputs (conversion of physical units to voltage, definitions, ...)
- *input file*: information on analog inputs (conversion of voltage to physical units, definitions, acceptable range, ...)

as well as the above-mentioned ship and environment files.

The test is aborted automatically if the trajectory error exceeds one of the maximum values mentioned in the environment file, or if one of the analog input signals exceeds the acceptable range defined in the input file.

After execution of the test, PC2 generates a *documentation file* composed of the content of all above-mentioned files available at PC1 and a sequence of measuring data (time, positions, converted analog input signals).

Processing of documentation files

In order to condense the data in a documentation file, a set of processing programs was developed. Such a program executes following actions:

- correction of measuring results (e.g. correction of sinkage due to imperfections of the rails) according to information in a *correction file*;
- generation of a *result file* containing a summary of test parameters, and average values (for stationary tests) or amplitudes of 0th to 3rd harmonics (for oscillatory tests) for each input channel;
- plot of input channels, according to formats given in a *configuration file*.

5 Applications

Determination of manoeuvring coefficients

The first studies are meant to extend the present simulator fleet. Priorities are determined by the planning for the manoeuvring simulator, but the program in every way contains investigation of bulkcarriers with different geometry and container carriers with several rudder-propeller configurations.

As the main purpose of the simulator is the study of approach to and manoeuvring in harbours, the mathematical model should be reliable in a large range of ship and propeller speeds (ahead and astern), drift angles, rudder angles, rates of turn. Thanks to automation, a large number of parameter combinations can be studied in a reasonable time. Figure 10 shows an example of test results.

Due to the broad range of application, test results are not always compatible with existing mathematical models. Further research for optimal modelling is required.

Study of ship behaviour in confined waters (Figure 11)

Study of ship manoeuvring behaviour in particular harbour or waterway configuration require the construction of a scale model of the environment. Figure 12 shows forces and vertical motion measured on a bulkcarrier navigating into a lock. Due to automation, validation procedures and safety measurements, a large number of conditions (speed, drift, excentricity, propeller rpm) could be studied with a minimal risk of damage.

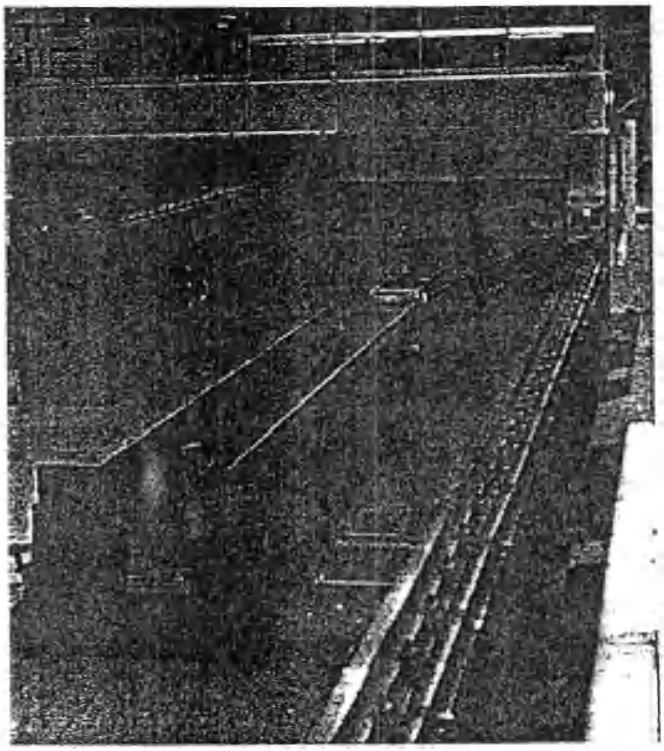

Figure 12: Captive model entering a lock

Future studies

At present, data are generated for a simulation study to evaluate the risk of grounding of panamax bulkcarriers in the sea canal Terneuzen-Ghent as a function of ship length. Due to the large blockage (27%), the restricted keelclearance (10% of draught) and bank irregularities, model tests have to be carried out for obtaining a reliable simulation of bank effects.

A comprehensive seakeeping test program is planned with deep-draughted ship models for determining criteria concerning the safety of shipping in the channels leading to the Belgian seaports, taking account of hydrological and meteorological conditions (project of Coastal Harbour Service).

It is the purpose to continue the investigation of nautical bottom in muddy areas. The presence of fluid mud on the bottom of navigation areas causes uncertainty concerning exact depth and allowable draught, and affects propulsion and manoeuvrability. A captive manoeuvring test program will be based on the results of extensive preliminary test series with self-propelled ship models above simulated mud layers, carried out at Flanders Hydraulics (1987-89) in the framework of a project of the Coastal Harbour Service on optimization of dredging works.

Acknowledgements

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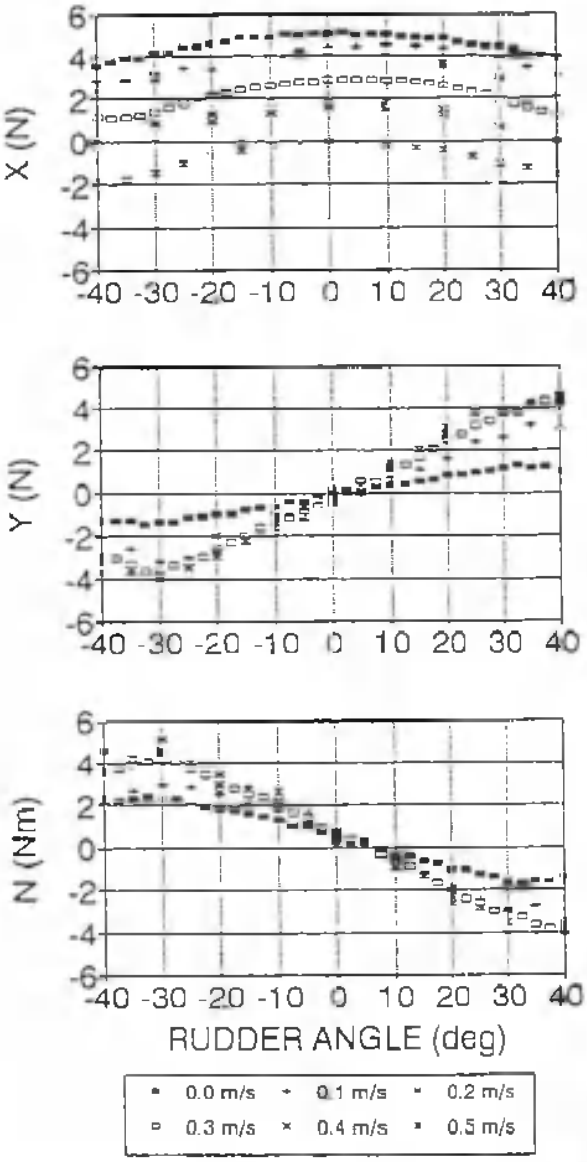

Figure 10: Scale model (1/70) of bulkcarrier (259x43x14.6 m³), h/T= 1.2: results of rudder angle tests

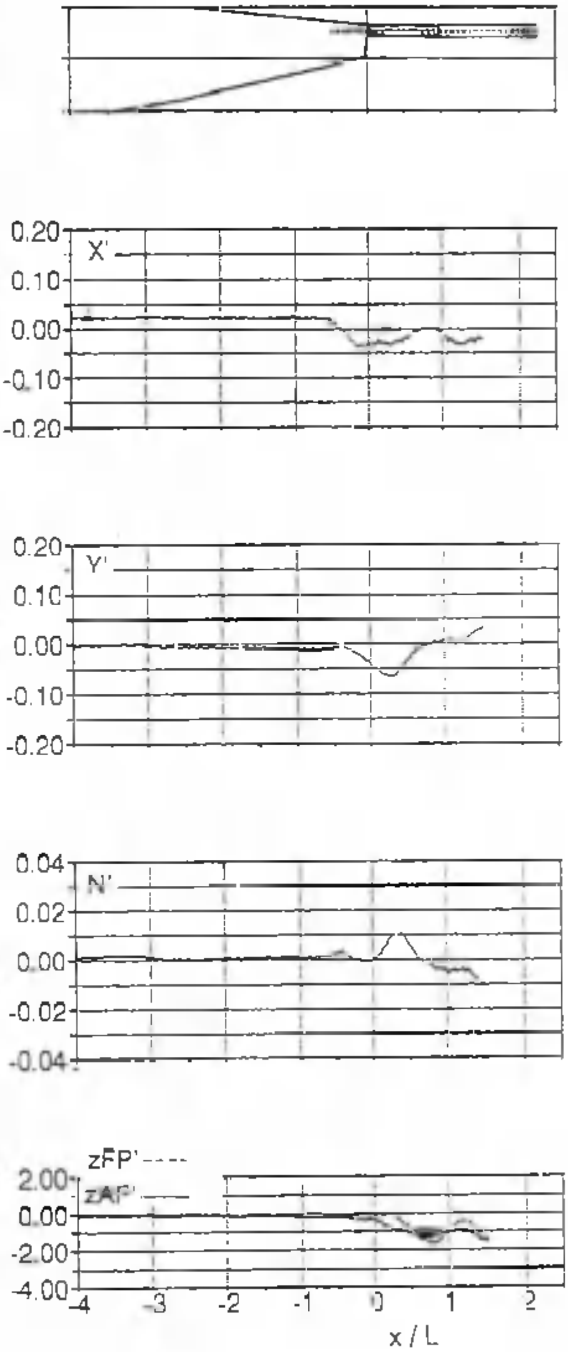

Figure 11: Bulkcarrier (260x43x17 m³) entering lock (h/T=1.2, W/B=1.23, Δy/B=0.087, drift 0, 1.6 knots, rpm 64%): undimensioned forces; sinkage (%T)

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