The Manoeuvring Committee

Final Report and Recommendations to the 22nd ITTC

1. GENERAL

1.1 Membership and meetings

The following members of the 21st ITTC left the Manoeuvring Committee : Prof Kijima, Dr Renilson, Dr Aage, and Prof Wu. The members of the present Committee wish to express their appreciation for their effort during their term. The Committee appointed by the 21st ITTC consisted of the following members :

Dr. Rod Barr (Secretary)
Hydronautics Res. Inc.

Dr. Giovanni Capurro
CETENA

Dr. Stéphane Cordier (Chairman)
Bassin d'essais des carènes

Dr. Masayoshi Hirano
Akishima Laboratory

Dr. J. Buus Pederson
Danish Maritime Institute

Prof. Key Pyo Rhee
Seoul National University

Prof. Marc Vantorre
Flanders Hydraulic, University of Ghent

Dr. Ing. Zou Zaojian
Wuhan Transportation University

The Committee meetings were as follows :

January 20th and 21st 1997
CETENA, Genoa, Italy

September 8th and 9th 1997
DMI, Lyngby Denmark

April 16th and 17th 1998
Akishima Lab., Yokohama, Japan

September 16th, 17th, and 18th 1998
Bassin d'essais des carènes, France

January 25th, 26th, and 27th 1999
Flanders Hydraulics, Antwerpen, Belgium

1.3 Tasks assigned by the Advisory Council

The advisory council defined the following tasks to be performed by the Committee:

1. Review the state-of-the-art, comment on the potential impact of new developments on the ITTC, and identify the need for research and development into manoeuvrability. Monitor and follow the development of new experimental techniques and extrapolation methods.
2. Review the ITTC recommended procedures, benchmark data, and test cases for validation and uncertainty analyses and update as required. Pass the information to the Quality Systems Group for publication in 1999.
3. Identify the requirements for new procedures, benchmark data, validation, uncertainty analyses and stimulate the necessary research for their preparation.
4. Prepare an up-to-date bibliography of relevant technical papers and reports.
5. Strongly promote comparative model tests and force predictions including experimental, semi-empirical, computational methods, and comparisons with the results of sea trials for modern ship types in deep water. Specific interest is in the full-load condition, waterjet propulsion, and the effect of aft-body varia-

tions.

6. Develop a reliable method of predicting manoeuvring in shallow and restricted water, including squat.
7. Continue to promote research into manoeuvrability standards, including the IMO interim standards, in order to provide advice to organisations who set standards, such as the IMO, and pilot organisations.

The committee has attempted to perform these tasks with the exception of the 6th task concerning the development of a « reliable method for predicting manoeuvring in shallow water.. » which was felt to go beyond the commonly accepted ITTC scope of work.

2. SPECIAL GROUPS

2.1 RR74

In relation to the IMO Interim Standards for Ship Manoeuvrability (IMO Resolution A.751(18)), the panel of RR74 Manoeuvrability WG was established by Japan Shipbuilding Research Association in 1995. The primary task of this panel is to develop a database of full scale manoeuvring trials mainly for newly-built ships with modern hull forms, and to review the Standards on the basis of the database developed. Trial results of more than 200 ships have been collected and manoeuvrability analyses are being carried out with respect to adequacy of the criteria of the Standards. Some results obtained through RR74 activity are described by Haraguchi et al (1998). Besides the primary task, basic studies for ship manoeuvring prediction are also being made by focusing research targets to the IMO Manoeuvrability Standard.

2.2 SNAME panel H10

SNAME Panel H10 (Ship Controllability) has been active since 1996 in a number of SNAME sponsored research projects and co-operative projects with U. S. pilots. A study of the prediction of slow speed manoeuvring was initiated in1997. A survey of current methods used to address the unique problems ofvery low speed manoeuvring including criteria for measuring accuracy was made. In October 1998 a workshop was held at the U. S. Merchant Marine Academy. The workshop, which was attended by more than 20 designers, hydrodynamicists, pilots and ship operators, explored all facets of this problem and refined the plan of action for the project, which should be completed by the end of 1999. A project to obtain full scale manoeuvring data in the Houston Ship Canal was initiated because of the channel's pending widening and deepening and the ability this offered to conduct trials in a before and after situation. This is a co-operative project with other groups concerned with the safety and operation of the waterway. The panel will help develop a data acquisition plan using DGPS, with special attention to vertical motions (squat), which can provide the data most useful in advancing understanding of ship behaviour in highly restricted waters. Work on analysis of a large body of ship trials data has continued. It is intended to add these data to the existing SNAME/Coast Guard Ship Manoeuvring Data Base. Track data for several hundred ship have been analysed, but suitable ship characteristic data, which are required by the data base, have been found for few of these ships. Co-operative projects with pilots have included an on-ship evaluation of various portable DGPS Navigation Units, preparation of recommendations for a more detailed pilot card and preparation of a Hydrodynamics Handbook for use by pilots. The first two of these projects have been completed while the last is ongoing. The panel supported a workshop on best practices for master-pilot communications. This workshop which was sponsored by the American Pilots Association, the Maritime Administration and the U. S. Coast Guard resulted in a best practices document that is now being used by industry as a standard. Proceedings of the panel sponsored workshop on squat and the final report on modular manoeuvring models will be published in 1999

2.3 MARIN Co-operative Research, Ships

The 3 years program (1994-95-96) to develop a manoeuvring prediction code for single screw vessels was completed and the MPP code is now in use among the various CRS member organisations.

At the 1996 Annual General Meeting (AGM), the Working Group received a new task for the extension of the MPP code to twin-screw vessels. A one year project (1997) was accepted as a pilot study. The aim of the study was to investigate the possibilities and limits of an extension to twin-screw vessels of the manoeuvring prediction program (MPP) developed for single-screw ships. A modified version of the MPP (MPP 97-1), covering both single and twin screw ships (with one or two rudders) was developed, but still based on hydrodynamic coefficients of single screw hulls.

A new validation process started in July 1997 and the Working Group discussed the results at meeting in October 1997. More than 30 ships were used, and the comparison between calculations and measurements (model or full-scale) were not always satisfactory: especially turning circle parameters showed a large scatter and some systematic deviations. It was thus decided by the Group that it would be desirable to modify the MPP97-1 program in order to achieve an accuracy similar to that of single-screw ships.

The proposal for a two years project (1998-99) was accepted by the AGM (1997) with the main objective to develop a reliable prediction tool for manoeuvring performances of twin-screw vessels.

3. HYDRODYNAMIC FORCES

A great deal of effort has been devoted to developing theoretical, semi-empirical as well as experimental methods for estimating the hydrodynamic forces acting on manoeuvring ships and for predicting ship manoeuvrability more accurately at the initial design stage. In particular, the effect of hull form and hull/rudder/propeller interaction have received more attention.

At the same time, more and more efforts have been devoted to applying advanced numerical techniques to calculate the hydrodynamic forces, and great progress has been achieved in this respect. Although these methods are still not wholly reliable, their use as a design tool will become widely accepted and used in the near future.

3.1 Hull Forces in Deep Water

Numerical Methods: RANS Solvers. Remarkable achievements have been made during the last few years in the prediction of the hydrodynamic forces acting on a manoeuvring ship by using 3D viscous flow methods.

After several years of code development several calculations have been performed by different groups of researchers in order to test and to assess the validity of codes solving the RANS equations. Test cases include constant drift and steady turning motions of a Series 60 hull, the *ESSO OSAKA*, and the SR221 tankers: Alessandrini & Delhommeau (1998), Cura Hochbaum (1998), Tahara et al (1998), Berth et al (1998), Ohmori et al (1996), Makino & Kodama (1997), Sowdon (1996). Generally, the results presented show good agreement with available experimental data. These methods are particularly interesting since they can be used for a wide range of different geometries. However, a point which needs improvement is the dependence of the results to the grid size and topology.

Sato et al (1998) proposed a numerical simulation method for solving the manoeuvring motion of blunt ships by coupling the equations of motion with the Reynolds Averaged Navier Stokes (RANS) equations or RANSE.

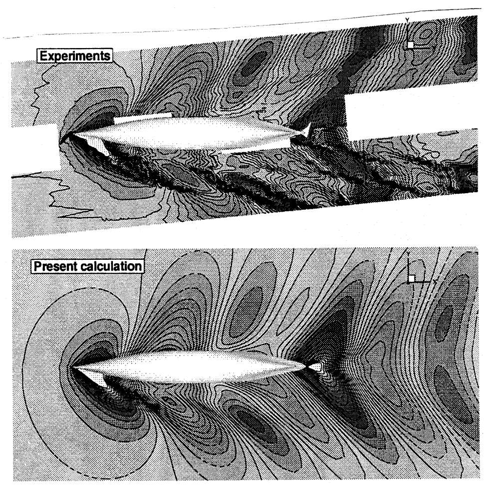

Figure 3.1 : Free-surface calculated around a Series 60 at 10° drift angle (Alessandrini and Delhommeau, 1998)

Numerical Methods: Potential flow solvers. The use of potential flow based numerical methods has continued with several recent developments. One of the principal difficulties in modelling manoeuvring forces using potential flow methods is to include the lift generating vortices in the computation: their position along the hull, as well as their intensity, constant or varying. Although this problem can usually be solved for lifting surface type bodies such as keels, rudders, etc., these simulations on ships, and particularly on full form ships, require some prior knowledge of the vortex field. As a consequence, and given the complexity of the wake in steady turning motion, calculations are sometimes limited to steady oblique towing. Ando et al (1997) and Nakatake et al (1998) developed a surface panel method and presented numerical results for three VLCC models with different after-body shapes were compared with experiments.

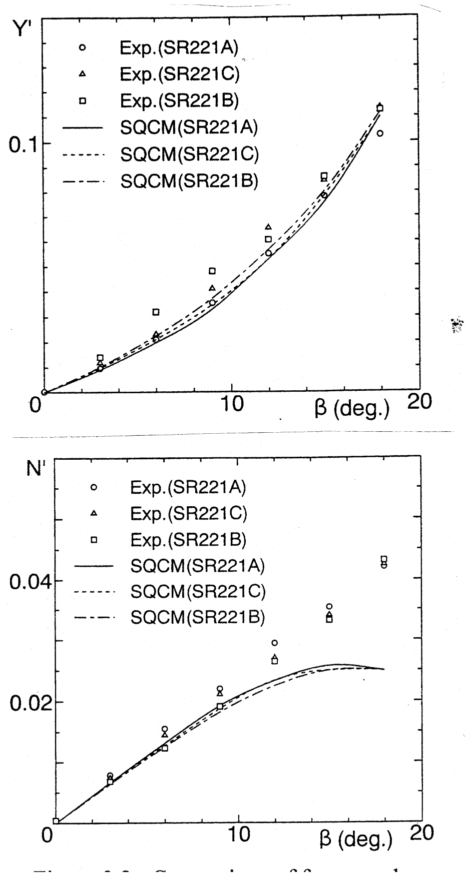

Figure 3.2 : Comparison of forces and moments in oblique towing (Nakatake et al, 1998)

By solving a 3D lifting potential flow problem, Landrini & Campana (1996), and Zou (1996), calculated the hydrodynamic forces on a surface piercing plate in steady drift and turning motion, in which the free surface conditions were linearised with respect to the double model flow and the wake was modelled by a system of trailing vortices shedding from the trailing edge and keel edge.

Combining a 3D Rankine Panel method with the unsteady linear lifting surface theory, Zou & Soeding (1995) simulated the forced sway and yaw oscillating motion of a surface-piercing plate and calculated the linear hydrodynamic derivatives.

Pinziy et al (1995) developed a panel method using the wave resistance Green's function for solving the Neumann-Kelvin problem for a surface-piercing body moving at forward speed with lifting effects. Results were presented for a simple shape wing at yaw angles and for a Wigley hull in symmetric motion.

Kijima et al (1995a) and Furukawa & Kijima (1996) proposed a prediction method for the cross flow drag acting on a ship hull based on the vortex shedding model with damping of the free vortices. It was shown that the longitudinal distribution of cross flow drag along the ship length can be predicted with good accuracy.

Kijima et al (1995b, 1996a, and 1996b) propose a prediction method to estimate the lateral force and yaw moment acting on a ship hull in oblique and turning motion. They improved the method by assuming the separation line position based on the results of captive model tests and investigated the influence of afterbody shape based on SR221 ships A, B, C.

Several publications present developments using slender body theory: Kose et al (1996, 1997), and Xiong & Kose (1996), Wellicome et al (1995), Liu et al (1996), Clarke & Horn (1997b). Yumuro (1997) calculated manoeuvring hydrodynamic forces on a ship hull with heel angle by using Bollay's lifting surface theory. Beukelman (1997) proposed a theoretical method to determine the lift forces on hull and rudder as well as the manoeuvring derivatives making use of the rate of change of fluid momentum. Based on slender body theory Tanaka (1996, 1998) proposed a practical method for predicting hydrodynamic forces acting on a ship moving with large drift angles. The flow was modelled by two dimensional cross flow at each cross section, whereas both bound vortices and free vortices are distributed to represent the two dimensional separated flow. Kim & Rhee (1996) applied parameter identification techniques to estimation of the manoeuvring coefficients of a slender body. Karasuno & Maekawa (1996, 1997) presented a component type mathematical model of hydrodynamic forces in steering motion. They estimated the ideal flow force, viscous and induced drag by applying a simplified vortex theory.

Experimental Methods. Ishida & Fujiwara (1995) conducted a large amplitude forced sway motion test to investigate the effect of hull forms on the non-linear sway force and moment. Takano et al (1995) conducted oblique towing test to investigate the effect of bow and stern shape on ship hydrodynamic forces. Nonaka et al (1996) measured stern flow fields and hydrodynamic forces acting on three VLCC models in oblique towing motion. Kijima et al (1997) carried out measurements of hydrodynamic lateral force and yaw moment acting on a ship hull to clarify the effect of roll motion on the hydrodynamic forces. Nakatake et al (1995) measured wake distributions of three ship models in oblique towing. Sadakane (1996) measured the lateral drag coefficient on models moving laterally from rest. Longo & Stern (1997) performed extensive force, flow field and wave measurements in the vicinity of a series 60 model in oblique tow for CFD validation purposes.

Semi-Empirical Methods. Clarke & Horn (1997a) developed new empirical expressions for the hydrodynamic velocity derivatives. Alternative predictor variables were suggested. Sutulo & Kim (1997) developed a regression model for estimation of hydrodynamic forces acting on the hull of a submersible in arbitrary three dimensional manoeuvring motion. Biancardi (1997) proposed a method for calculating the hydrodynamic coefficients of surface ships by applying adjusted formula obtained previously for submerged bodies. The calculated sway force and yaw moment were compared with the model scale measurements.

Kodan et al (1996) performed model tests of recent ships to obtain their hydrodynamic coefficients, and developed a new prediction procedure of ship manoeuvrability based on these data.

3.2 Hull Forces in Restricted Water

Theoretical/Numerical Methods. By using a finite volume method Ohmori (1998) calculated the viscous flow around a *ESSO OSAKA* tanker model in steady drift motion and turning motion in shallow water. The calculated hydrodynamic forces were compared with experimental data, and qualitatively good agreement was obtained. Assuming that a ship hull can be replaced by a rectangular flat wing, Yumuro (1995) proposed a simplified method for calculating the manoeuvring hydrodynamic forces and the shedding angles of the trailing vortices in shallow water.

Yasukawa (1997, 1998) applied unsteady slender body theory to predict the hydrodynamic coefficients of the ship hull and rudder. The hydrodynamic memory effect of wake vortices generated by a slender ship advancing with sinusoidal steering in shallow water was investigated theoretically. Nakao et al (1995) calculated the hydrodynamic forces acting on a manoeuvring ship in confined water using slender body theory. Xiong & Wu (1996) applied a 3D Rankine source method to calculate forces and wave patterns of ship hulls moving in restricted water. The effect of free surface and canal bank effects on the forces was emphasised. Yumuro (1996) proposed a simplified method for calculating forces on a ship on an off-centreline course in a narrow water channel.

Experimental and Semi-Empirical Methods. Vantorre & Eloot (1996) described unsteady hydrodynamic phenomena which were observed during systematic captive model test series carried out in shallow water. Ishibashi et al (1996) conducted captive model tests covering a wide range of yaw and sway motion in shallow water to identify characteristics of hull, propeller and rudder as well as interaction forces. Clarke (1997) pointed out an error found in a simple shallow water correction of hydrodynamic derivatives published previously and suggested new equations for hulls with rectangular sections. Gronarz (1995) proposed a formulation of an exponential equation built up of a constant term and a term describing the dependency of the manoeuvring hydrodynamic coefficients from the water depth.

Laforce et al (1996) presented experimental results of systematic captive model tests on three ship models of different lengths in open shallow water and in restricted water including a cross section of the canal and a scale model of the geometry of the bends. The influence of the ship's length, water depth and canal banks on hydrodynamic forces were discussed.

3.3 Manoeuvring devices

Conventional rudders: Chau (1998) computed the turbulence flow around ship rudders in uniform inflow by solving the RANSE, using the standard k-C turbulence model with wall function.

Gong et al (1995) conducted a series of model tests to investigate the effect of rudder area on the manoeuvrability of a ship with large B/T. Rudder open water characteristics were determined by open water tests, and HPMM tests were carried out for the ship with rudders of different areas. Ding et al (1997) conducted ship model tests for measuring rudder lateral force in both still water and following seas. Oda et al (1996) measured the open water normal force and chordwise force of the mariner rudder.

Jordan (1989) investigated the loads on the rudder and especially the rudder stock during emergency manoeuvres.

Non-conventional rudders: Zhu & Tang (1995) and Zhu & Wang (1996) conducted experiments on low aspect ratio circulation-controlled rudders in a circulating water channel which demonstrated lift augmentation capability.

Tachi & Endo (1996) conducted rudder open water tests with a Schilling rudder. Hamamoto & Enomoto (1997) investigated analytically and experimentally the forces on a Vec Twin Rudder system as well as the interaction between the two rudders. They proposed a model of Vec Twin Rudder performance for the MMG model.

Other manoeuvring devices. Hirayama et al (1996a, 1996b) and Hirayama & Niihara (1996) performed model experiments and numerical simulations to investigate the effectiveness of an active vertical fin on improvement of the transverse stability and manoeuvrability of high speed displacement mono-hull ships.

Knowles et al (1996) performed a numerical study of the unsteady hydrodynamics of an UAV thruster, using a vortex-lattice, lifting-surface model modified to handle unsteady operating conditions during dynamic positioning and manoeuvring.

Endo et al (1997) conducted model tests and proposed hydrodynamic mathematical models for side-thrusters.

Jukola & Castleman (1995) tested tractor and stern drive tugs and concluded that vessels equipped with Z-drives are capable of other means of producing arresting and steering forces with reduced risk of placing the escorting tug in a potentially dangerous situation.

The increasing use of podded propulsion is notable and is causing large changes in the manoeuvrability of these ships, essentially cruise ships. However, little published data is available on the manoeuvring characteristics of pods.

3.4 Hull/Propeller/Rudder Interaction

Theoretical/Numerical Methods. A number of models of the hull/propeller/rudder forces and interactions have been developed, some of which include viscous effects.

Suzuki et al (1996) computed the flow field around a rudder behind a propeller by a viscous flow code and compared the results with mean flow measurements. Hinatsu et al (1995) calculated the viscous flow field around a tanker and its rudder. The propeller effect was considered using equivalent body force distribution.

Kulczyk & Tabaczek (1995) applied an advanced computational method to calculate forces and moments on a rudder located in a propeller slipstream. Molland & Turnock (1996, 1998) developed a theoretical method to predict the hull/propeller/rudder interaction forces. Wang et al (1994) studied the propulsive performance of the propeller/rudder system. A vortex lattice method was applied to describe the performance of the rudder behind the propeller.

Yasukawa et al (1996) proposed a method to calculate hydrodynamic forces on a ship moving with constant rudder angle. Tamashima et al (1995) developed a theoretical method for predicting the performance of a propeller/rudder behind a ship. The propeller and the rudder were modelled separately, and the mutual interaction was taken into account by an iterative procedure.

Li & Dyne (1995) presented a linear method to calculate the steady forces on the propeller/rudder combination working in a uniform flow.

Experimental and Semi-Empirical Methods. In order to develop a rational model for ship manoeuvring, a series of rotating arm and linear towing test were conducted to isolate forces on the hull, propeller and rudder, and to study the interactions between them (Lewandowski & Klosinski, 1992, Klosinski & Lewandowski, 1993). A systematic set of model tests with fourteen different ship models and various rudder-propeller configurations was performed by Sedat & Fuller (1995). The testing was made to create data which could be used for a modular simulation model

Nakatake et al (1996a, 1996b, 1997) conducted tests and calculations using the SQCM method to clarify the hull/propeller/rudder interaction mechanisms and found good agreement between their numerical techniques and the experimental data.

Molland & Turnock (1995) conducted experimental investigations to study the influence of changes in the relative position of the rudder and propeller and concluded that significant changes in both manoeuvring and propulsive performance could occur when the relative position of the rudder and propeller was altered. Based on wind tunnel tests, Molland & Turnock (1998) also demonstrated the importance of the flow straightening influence of upstream hull form on the performance of the propeller/rudder combination which can be used for the development of prediction methods which would include the effects of the drift angle and the upstream hull geometry.

3.5 External influences

Proximity effects: Based on slender body theory, Kijima (1997) predicted hydrodynamic interaction forces between two ships and between a ship and a pier. Manoeuvring motion in the proximity of the pier was studied. Using potential flow around a slender body with a rigid free surface, Varyani et al (1997) calculated the hydrodynamic interactive forces between three ships in a restricted waterway. The effects of water depth and separation distance between ships were investigated.

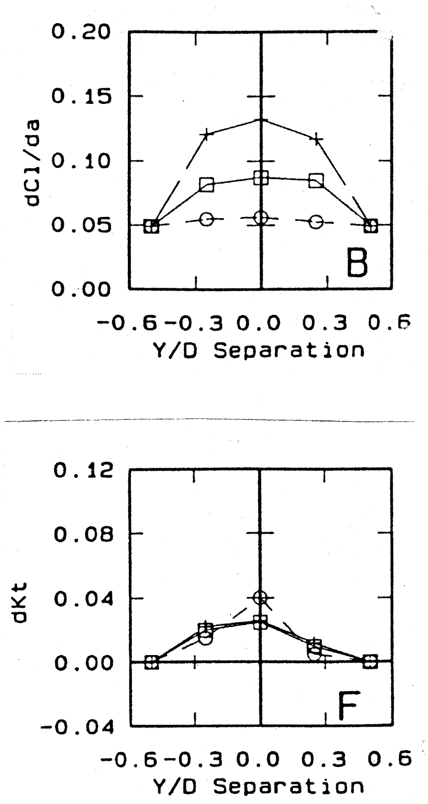

Figure 3.3 : Effect of rudder lateral separation on rudder lift slope (dcl/da) and propeller thrust coefficient (dKt) (Molland & Turnock, 1995)

Wind. Blendermann (1995, 1996) proposed an empirical method to estimate the wind loading of ships in uniform and non-uniform flow based on wind-tunnel tests. Blendermann (1997) also investigated the effect of beam wind on overtaking manoeuvres using wind-tunnel test data and numerical simulation. Shigehiro et al (1997) conducted model tests in a wind tunnel and in a circular tank, and studied the course stability of towed fish preserves in the presence of wind. Fukuchi et al (1997) proposed a method to improve the course-keeping ability of a small vessel scudding under strong wind by spreading canvas around the flying bridge. Model experiments were carried out in a wind/water facility to measure wind loads. Simulations were conducted using the experimental data. Yamano & Saito (1997) developed a practical estimation method for wind forces.

Wave. Feng et al (1996) predicted the non-linear motion responses of a submerged slender body running near the free-surface due to wave exciting forces.

3.6 Non-Conventional Ships

Zhang & Andrews (1998) investigated the manoeuvrability of a trimaran ship. The hydrodynamic forces due to the presence of the side hulls have been analysed using a combination of theoretical and empirical methods. The interaction effects between the hulls were neglected.

Brizzolara et al (1998) presented a semi-empirical method for the study of dynamic course stability of waterjet propelled monohulls. PMM tests were carried out to measure the hydrodynamic lateral force and yaw moment for small drift angles and yaw rates with and without fins, whereas the influence of the waterjet steering forces and waterjet inlets were theoretically evaluated. Lewandowski (1997) developed a method to evaluate the coupled roll/yaw/sway dynamic stability of planing crafts and presented expressions for the linear stability derivatives.

Sahin et al (1997) used a low-order singularity panel method to predict the hydrodynamic characteristics of underwater vehicles. Chiu et al (1997) investigated the lateral stability of an AUV using captive model test and empirical data. Caccia et al (1997) performed tests to identify hydrodynamic derivatives on a ROV.

Hiroshima et al (1997) and Kataoka et al (1997) developed and applied a 6 DOF performance prediction simulation method for yachts, in which the forces and moments were derived from the CFD computation. Suzuki & Yoshihara (1995) computed the hydrodynamic forces acting on sailing yachts by means of a surface panel method. Tahara (1995, 1996) developed a numerical method for calculating boundary layer and wake flows around a sailing yacht with yaw angle. The RANS equations were solved with the Baldwin-Lomax turbulence model.

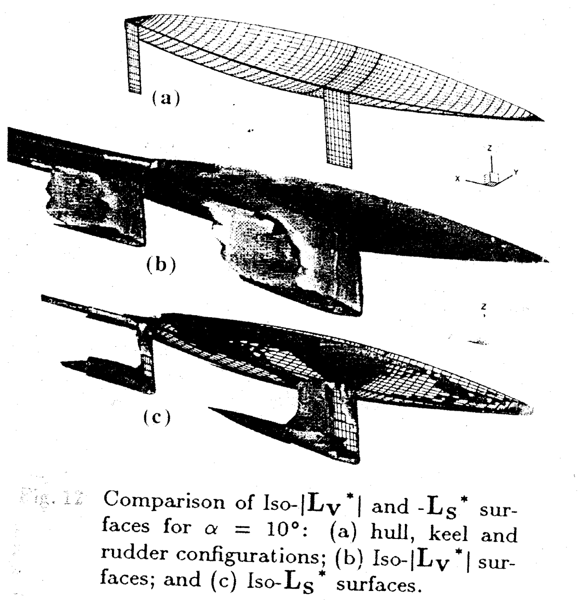

Figure 3.4 : Calculated flow around a IACC yacht in oblique flow (Tahara, 1996)

4. SIMULATION OF DYNAMICS

The work performed in the area of ship manoeuvring simulation covers the development and applications of mathematical models used in manoeuvring simulations. This activity has been stimulated by the need to meet IMO manoeuvring standards at design stage and to predict manoeuvres in restricted waters (harbours, waterways....). Specific issues related to the application of the IMO standards are in section 6.4

4.1 Modelling of Ship Dynamics.

Mathematical models of ship dynamics have been improved through use of more refined techniques, comparisons between manoeuvring models, and parametric studies. It is now possible to incorporate very sophisticated simulation models in desktop simulators.

Mathematical Model Structure. It is now accepted practice to divide mathematical manoeuvring models into « whole ship models » and « modular models ». In « whole ship models », equations of motion are composed of terms representing the total hydrodynamic forces acting on the hull/propeller/rudder combination, and the hydrodynamic force coefficients required in these equations of motion are determined from tests of a model or from theoretical predictions for a ship in which the propeller and rudder are installed and the propeller is operating at the appropriate loading condition(s). In modular models, forces acting on the hull, propeller and rudder and the forces due to interaction of these components or « modules » of the ship are each represented by different terms in the equations, and forces of force coefficients are measured or predicted separately for the hull, propeller and rudder. In modular models, interactions between hull, propeller and rudder are sometimes measured in model tests, but are more typically determined from empirical relationships incorporating parameters that depend on the geometry and position of the rudder and propeller relative to the hull. « modular ship models » should not be confused with « modular computer programs or codes » in which various physical and computational functions are incorporated in separate software modules or subroutines to facilitate modification and de-bugging of the software.

Finally, the increase in computer power now enables the resolution of the equations of motions with forces calculated at each time step by an unsteady CFD code (Sato et al, 1998). An example of this approach is given by McDonald and Whitfield (1997) for a change of depth manoeuvre of a self-propelled submarine (figure 4.1). This approach has the advantage of being truly unsteady as opposed to the usual quasi steady models.

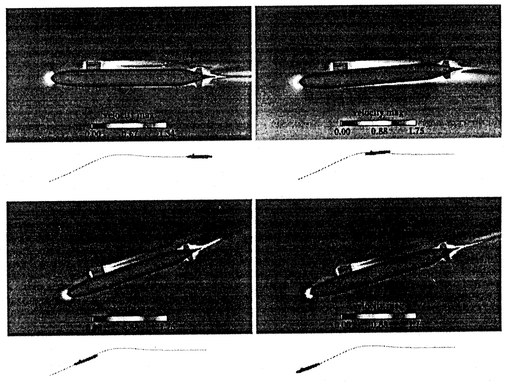

Figure 4.1 : Change of depth manoeuvre

McDonald and Whitfield (1997)

Lee et al (1997) compared the MMG mathematical manoeuvring model with a typical whole ship model such as the Abkowitz mathematical model (Strom-Tejsen and Chislett, 1966). Results of simulation with a product carrier using PMM model test data are given. The purpose of introducing a modular simulation model compared with a "whole ship" model is the ability to split the mathematical model into relevant physical phenomenon, typically a separation of hull forces and rudder-propeller-hull interaction forces, but also other mathematical models can be included such as the behaviour of the engine, either a slow or medium speed diesel engine or a turbine. Furthermore, research can be made with individual modules.

Several authors presents work concentrated on models for the hull-rudder-propeller interaction. Chislett (1996) describes how hull forces related to yaw rate, and rudder-propeller forces can be non-dimensionalized in all four quadrants. Molland et al (1996) describe an enhanced rudder propeller model. Based on simulation studies it is indicated that the enhanced rudder propeller model should lead to improvements of rudder propeller interaction effects in a manoeuvring simulator. Lee et al (1996) and Kobayashi et al (1994) studied mathematical models for a twin screw and twin rudder ships.

Perdon (1998) suggests a model for control forces due to a hydrojet based on experimental data.

Alternative ways of defining the equations of motions have been investigated by Bailey et al (1995, 1997, 1998a). Their work combines the knowledge of impulse response functions from linear sea-keeping theory with traditional manoeuvring equations of motion, creating a unified general theory of ship motions. An interesting finding has been made that the traditional manoeuvring derivative Y_r was found experimentally to be approximated by

$$Y_r = -B_{26} - \bar{U}A_{22}$$

in contradiction to the traditional theory found in numerous textbooks that

$$Y_r = -B_{26} - \bar{U}A_{11}$$

where B_{26} is the frequency dependent sway-yaw damping and A_{11}, A_{22} the frequency dependent surge and sway added mass coefficients.

Pawlowski (1996) proposed a link between formal hydrodynamic models and CFD hydrodynamic models. A general mathematical model for ship manoeuvring simulation is proposed and a discussion of various mathematical manoeuvring simulation model approaches is given.

Degrees-of-Freedom (DOF). The need in some cases to include more than 3 DOF in the equations of motion has been accepted; in particular roll motion for surface ships. The influence of GM and thereby the roll motion on ship manoeuvrability was investigated among others by Kijima et al (1997) and Kijima & Furukawa (1998). Measurements of hydrodynamic forces as a function of speed and GM were made and numerical simulations including roll motion were performed. Figure 4.2 shows the significant effect of varying these parameters on the simulated 1st overshoot angle in 10-10 and 20-20 zig-zag manoeuvres. The effect of including roll in the equations of motion can be seen to increase with ship speed.

A similar conclusion was obtained for a modern over-panamax container carrier by Oltmann (1996) who showed that yaw instability increases with increasing approach speed. These results confirm earlier conclusions about the effect of roll motion on the manoeuvrability of ships with low transverse stability (low GM).

Sutulo & Kim (1997) present a unrestricted mathematical model of submersible dynamics based on regression of parameters for the 6 DOF forces and moments.

Prediction of Dynamics. Simulation of standard manoeuvres has become more relevant since the IMO Res. 751 was adopted.

A method for predicting ship manoeuvring which paid special attention to stern shape was developed by Kang & Kim (1995) using slender body theory, low-aspect-ratio theory, and cross-flow theory. For the cases considered the simulation results show good agreement with measured manoeuvres. Hooft & Quadvlieg (1996) also use cross-flow drag and slender body theory for prediction of forces used in a simulation model. Comparisons between simulated manoeuvres and full scale measurements show acceptable agreement.

When sea trials are performed in a “semi-loaded” condition means of extrapolating the data to full load condition are required. Kijima et al (1995) developed such a method where turning ability is predicted satisfactorily but the prediction of overshoot angles in zig-zag manoeuvres is less satisfactory.

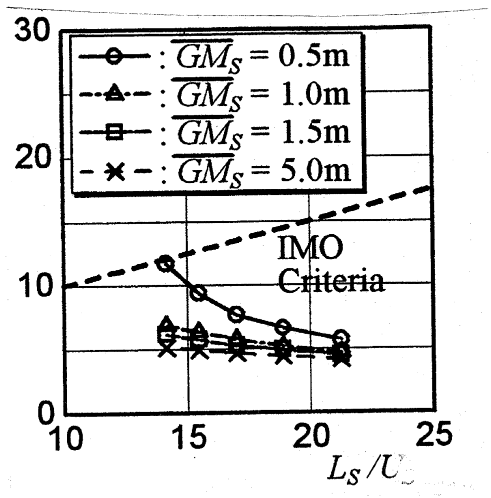

Figure 4.2.a: 10-10 zig-zag manoeuvre

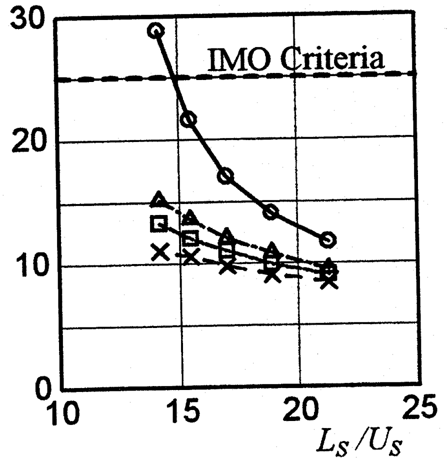

Figure 4.2.b: 20-20 zig-zag manoeuvre

Figure 4.2: Influence of approach speed and GM on first overshoot angles (Kijima & Furukawa, 1998)

Kristensen (1998) describes the design and service experience with the manoeuvrability of three designs of double ended ferries with low L/B and high B/T ratios. The manoeuvrability was significantly improved through model tests resulting in slight changes in hull form or the addition of skegs or bulbs/fins

Yoshimura et al (1997) developed a method for predicting the effect of a flapped rudder. The method is validated against free running model tests. It is concluded that for course keeping smaller flap angles are better for stable ships and larger flap angles better for unstable ships.

Sohn et al (1996) made model tests with varying rudder sizes for a full-formed ship. One conclusion is that the course stability does not necessarily improve with increasing rudder size. Another paper by Gong et al (1995) investigates the influence of rudder area on the manoeuvrability of a ship with large beam-to-draught ratio by use of PMM tests and simulations. It is concluded that the rudder size improves the manoeuvrability of the tested ship except for straight course keeping.

The manoeuvring of a twin screw tanker with rudder failure modes was investigated by Trägärd (1998). It is concluded that the tanker complies with the IMO criteria even with only one rudder working. The behaviour of the engine during the last part of a turning circle manoeuvre or during the stopping manoeuvre has influence on the result of the manoeuvre. Also, for harbour manoeuvring a realistic modelling of the engine is essential.

Benvenuto et al (1996) suggests a mathematical model for simulating the behaviour of a diesel engine. The emergency stopping manoeuvre was investigated by Schmidli (1996) and he suggests that changes in the engine system could improve the stopping distance for some ship types.

Simulation of submersible manoeuvres has had some attention in this period. Li (1997) calculated a manoeuvring index and frequency characteristics for a submersible.

Sensitivity Analysis. Sensitivity analysis provides a basis for determining the importance and the required accuracy of the individual terms in the mathematical model. This is done through analysis of simulations performed with systematic variations of each term. Such studies have been stimulated by the need for more accurate manoeuvring predictions at the design stage.

Vassalos et al (1995) performed a sensitivity analysis based on a naval ship manoeuvring model. He identified Y_v, Y_r, N_v, N_r as the most important coefficients for the steady turning motion.

Ishiguro et al (1996) studied the sensitivity of simulated IMO manoeuvres to values of the coefficients in the MMG model using three different ship types. The coefficients Y_r, Y_β, N_r, N_β as well as the flow straightening factor γ and the wake fraction ratio ε were identified as the most important as shown in figure 4.3.

The knowledge from the SR221 research project with three tankers with the same main particulars but different stern frame sections were used to suggest a correction as function of aft body shape (U to V shaped) to the proposed mathematical model. Significant improvements in prediction were obtained, especially for directionally unstable ships (Ishiguro et al, 1996, Kose et al, 1996).

The sensitivity of selected manoeuvring output variables (advance, transfer, overshoot angles etc.) to various hull form parameters (stern shape, LCB, L/B) was investigated by Kang et al (1995). Simulations were made based on measured hull derivatives determined from systematic PMM and free running tests on 19 slow speed, full form hulls with stern bulbs and with horn type rudders. The stern shape parameter,

$$\sigma_a = \frac{C_{wa}}{1 - C_{pa}}$$

where C_{wa} is the water plane area coefficient of the aft body and C_{pa} is the aft body prismatic coefficient, was found to have a large influence on the overshoot angles in the 10-10 zig-zag manoeuvre but limited influence on the tactical diameter. However, the σ_a parameter was not included in the suggested regression equations.

Lee & Shin (1998) also used 19 PMM test results to suggest another set of regression equations to estimate the hydrodynamic hull coefficients as well as the ε and γ parameters for the MMG model. The regression included the parameters L, B, T, C_B and a stern bulb area parameter. The sensitivities of the 1st and 2nd overshoot angles in the 10-10 zig-zag manoeuvre to various parameters in the MMG model are shown in Figure 4.4.

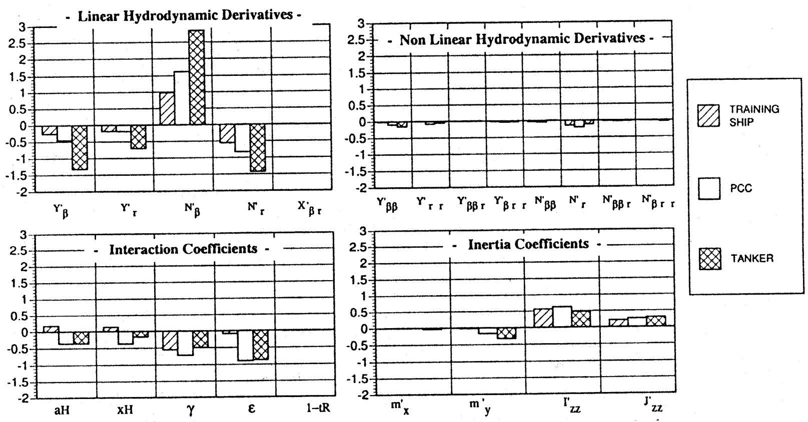

Figure 4.3: Sensitivity of MMG model parameters on 1st overshoots in the 10-10 zig-zag manoeuvre for three different types of ships (Ishiguro et al 1996).

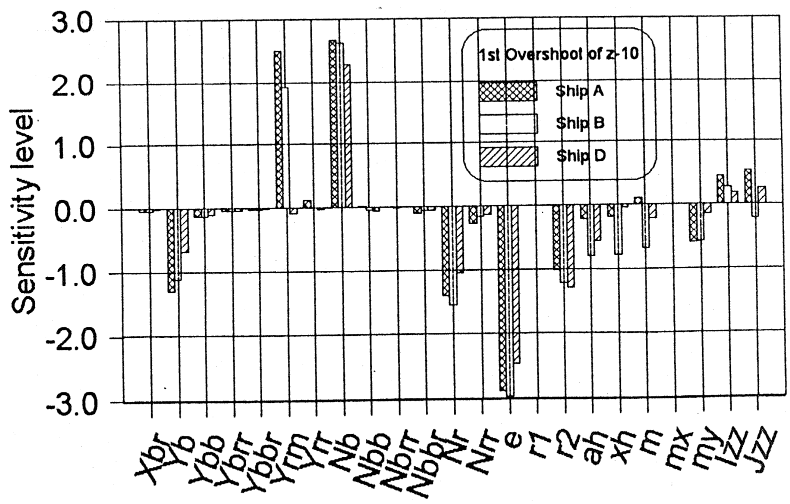

Figure 4.4: Sensitivity of MMG parameters on 1st overshoots in the 10-10 zig-zag manoeuvre for three different ship models (Lee & Shen, 1998)

The sensitivity study shows that ε and N_β have a particularly large influence on the overshoot angles in the 10-10 zig-zag manoeuvre. Simulation results based on estimated hydrodynamic parameters show good agreement with simulated results based on measured hydrodynamic parameters.

Generally, the sensitivity of simulated manoeuvres to each mathematical parameter will depend on the following items:

- the mathematical model itself.
- the hydrodynamic of the ship
- the manoeuvre that is investigated, i.e. turning circle, zig-zag or other manoeuvres.

The work performed in the period covers primarily the items 2 and 3. Most of the sensitivity studies use the MMG mathematical model. These sensitivity studies identify the parameters which are most important, and where to put the emphasis of research. Improvements in regression equations have been suggested by many authors to estimate the most important parameters.

Modelling of Fast Ship Dynamics. Due to increased interest in fast transportation at sea, the manoeuvrability of fast ships is particularly important and research in this area is increasing. However, research efforts concentrate on individual projects and not on general tools which is due to the wide diversity of fast ship designs and the limited experience in the area.

Hirayama et al (1996a) (1996b) investigated the effect of anti-rolling active vertical fins on the manoeuvrability for displacement-type super high speed ship. Kobayashi et al (1995) studied the manoeuvrability of a high speed boat. The manoeuvrability of an air cushion vehicle was investigated by Huang et al (1996). Plante et al (1998) investigated the maneuverability of a planing craft. It is found that added masses depend on the forward speed of the planing craft.

Enhancement Features. Simulation of the standard manoeuvres via the Internet is described by Hasegawa & Sasaki (1997). The model is based on the well known MMG model and the users can via the Internet simulate standard manoeuvres on their own computer by downloading the Java source code. Ship simulators of today include many features for modelling realistic harbour manoeuvres.

The use of desktop simulators for harbour design studies has become widely used. Kose et al (1995a), Galor (1997), Yang (1996) all present mathematical models suited for harbour design studies.

4.2 Modelling of External Influences

Tugs and Towlines. An important aspect in harbour manoeuvring is the use of tug assistance as the number or size of tugs can be the influencing factor for a successful harbour manoeuvre. Also, ocean towing of large ships has received attention.

Harbour manoeuvres including tugs has been addressed by Laible & Gray (1997) and Rooij (1996) who discusses the simulation of tugs. The use of varying modelling details of tugs in ship simulators is described in Jakobsen et al (1996).

The combined motion of a tug towing a large tanker were investigated by Jiang (1997) and Jiang et al (1998). The modelling included the non-linear restoring forces of the elastic towline. Numerical simulations shows that the dynamic behaviour of the system is qualitatively different from results obtained with simpler models. It is also shown that it is of great importance to include the tug dynamics in the mathematical modelling of a tug-tanker tow system. Also Milgram (1995) investigated tow line tension in open ocean towing

Position and length of tow wire for a tug towing a barge in shallow water was studied by Kijima & Furukawa (1995) by use of simulations. Varyani (1997) describes a method for simulating of a tow including three ships.

Shigehiro et al (1996 & 1997) investigated the influence of the course stability on a high speed towed fish preserve. Kreibel & Zieleski (1990) investigated the effect of different viscous damping models for single point mooring simulations.

Restricted Water Influences. The influence of restricted water covers both shallow water manoeuvring and manoeuvres in channels or in the vicinity of banks.

Different formulations of lateral force and yawing moment were compared with model experiment results for shallow water manoeuvring for all drift angles by Vantorre & Eloot (1996). It was found that a tabular formulation of the lateral force and the yawing moment was needed to cover the whole range of drift angles. Propeller action seems to have significant influence on lateral force and yawing moment, especially at large drift angles.

A study of the influence of the length of bulk carriers in a canal was undertaken by Laforce & Vantorre (1996), Laforce et al (1996). Captive model tests with three different ship sizes were undertaken, multi harmonic tests were performed, and fast time simulations were made to evaluate the influence of ship length for the risk in the canal. Unsteady phenomena in restricted water were observed during model testing.

Shallow water harbour manoeuvring was also investigated by Ishibashi et al (1996). Kobayshi (1995) developed a method for simulating shallow water manoeuvres based on deep water hydrodynamic derivatives which produces results with enough accuracy for practical purposes.

The determination of hydrodynamic forces acting on a ship during berthing was investigated by Chen et al (1996) using a RANS code in 2D suited for unsteady time domain simulations.

Environmental Influences. There has been little published research on the influence of wind, current and waves.

Spyrou (1995) investigated the yaw stability of ships in steady wind. It is concluded that dynamic instability can occur in following or head winds whereas for other relative wind directions the ship will be course stable. Larjo (1994) defined wind limits on large cruise ships. Wind tunnel experiments were performed to determine the wind loads for use in the simulation model.

The phenomena leading to broaching of ships in following waves were investigated by Spyrou (1996 & 1997). Both steady state and transient analysis is carried out. Yang and Fang (1998) addressed ship manoeuvring in a non-uniform current. More generally, the influence of shear current on the ship hull seems to have had little attention in the past.

5. SCALE EFFECTS AND VALIDATION

Publications on the topics of this chapter have been very scarce during the period of 22nd ITTC. The state of the art is reviewed and summarised based mainly on committee reports of previous ITTC proceedings.

5.1 Scale Effects

In spite of a great deal of efforts to reveal scale effects, the ship-model correlation is still one of the key issues related to model testing techniques in ship manoeuvrability.

Model tests are generally classified into two categories. One is free-running model tests, where the same tests as in full scale are typically performed. Manoeuvring characteristics of a full scale ship can be predicted directly from model tests or through simulations using coefficients obtained by system identification techniques. The other is captive model tests where hydrodynamic forces in manoeuvring motion are measured. Full scale predictions are made with the use of a mathematical model in which results of model tests are used as input data.

The most important scale effect in manoeuvring tests is caused by the inability to achieve Reynolds Number similarity. As a result, scale effects in the area of ship manoeuvrability are essentially caused by the lack of similarity for velocity field in stern region especially over the rudder.

Other possible factors affecting the fidelity of model tests (accuracy of model geometry, surface tension, cavitation number, roughness, engine controller...) are generally less important or can be accounted for if deemed important.

Prediction from Free-running Model Tests. There are two principal aspects of Reynolds Number related scale effects in free-running model tests: decreased velocity field in stern region due to thicker boundary layer and increased flow velocity over the rudder due to higher propeller loading at the model self-propulsion point. As a result of these scale effects, rudder effectiveness of a model may generally be over-estimated compared with that of a real ship. Accordingly, free running models tend to be more stable (or less unstable) with respect to course-keeping ability. This effect is typically less significant for fine ships because of their inherent stable course keeping ability.

One typical example which illustrates the above-mentioned effect is given in figure 5.1, where steady turning performances obtained by free-running model tests for 100 KDWT crude oil carrier are presented together with full scale trial results (Okamoto et al, 1972). It is seen in Fig. 5.1 that small-sized models (both L = 2 & 6 m) show stable course keeping ability while large-sized model (L = 14.5 m) has unstable characteristics similar to that at full scale.

On the other hand, an opposite result has been reported for a ULCC with the use of three models of L = 4, 10 & 30 m (Sato et al, 1973). In this free-running model tests, the larger-sized model was less unstable than the smaller model (figure 5.2). However, full scale trial results indicated that the ship was more unstable than the smallest model.

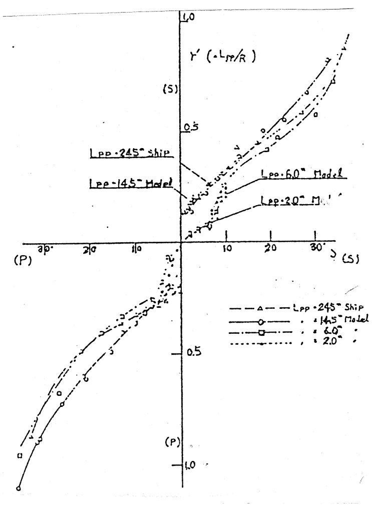

Figure 5.1 : Spiral test results for 100 KDWT tanker model

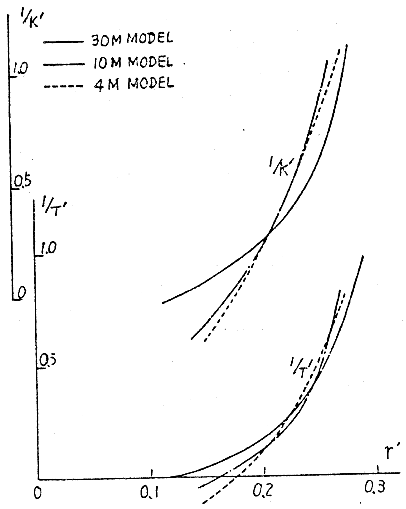

Figure 5.2 : Scale effects on K' and T' indices (ULCC model)

Attempts to apply additional towing force to a self-propelled model have been made in order to compensate the over-estimated rudder effectiveness mentioned above. Oltmann et al (1986) used this technique on a 20/20 zig-zag manoeuvre with a model of the *ESSO OSAKA*. It was found that a propeller loading between model and ship self-propulsion points gives the best agreement with full scale results.

The contradictory results on scale effects on slow, full form ships raise questions about our understanding of scale effects even for large models. For finer hull forms such inconsistencies have not been reported and free-running model tests continue to be widely used to predict the manoeuvring behaviour of ships.

Prediction from Captive Model Tests. Hydrodynamic forces measured in captive model tests are used as input data to a mathematical model of ship manoeuvring motion, where scale effects can be applied to each hydrodynamic coefficient. In this respect, full scale predictions from captive model tests are widely understood to be more scientifically based for most manoeuvres than free-running model tests.

While scale effects on the ahead resistance are taken into account in the conventional manner, the lateral forces and yaw moments obtained by captive model tests are generally not corrected. Results obtained in a co-operative effort with geosim models of the *ESSO OSAKA* (L = 2.5 - 7.256 m) shown in figure 5.3 (17th ITTC proceedings) indicate that no significant scale effects exist on the linear coefficients. Although scale effects are expected in non-linear coefficients which are mainly dependent on cross flow drag, non-linear coefficients derived from the same model tests do not reveal clear scale effects. This may be due to the fact that non-linear coefficients depend on the range of drift angles and yaw rates used in these sets of experiments as well as the regression techniques used to identify the coefficients.

Given the importance of scale effects on hull/propeller/rudder interactions, scale effect corrections should be applied. These can readily be introduced in modular models (e.g. MMG) through scaling of interaction parameters such as propeller and rudder wake factors and the flow straightening coefficients. Scale effects on the first two parameters are very significant, while the flow straightening coefficient may not be affected (Yumuro & Yamamoto, 1992).

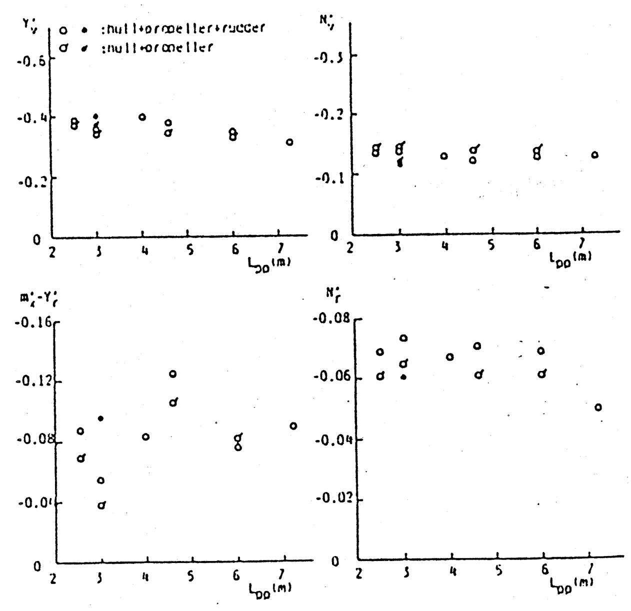

Figure 5.3 : Comparison of hydrodynamic linear derivatives for different model sizes (*ESSO OSAKA*)

5.2 Validation

Validation of the predicted manoeuvres is performed by comparison with full scale trial results. Hence, the quality of the validation will largely depend on the reliability and quality of full scale trials. It should be noted that adequate validation requires more than a “good agreement” on limited manoeuvres for limited ship type.

However, both prediction methods and full scale trial results are subject to different types of errors and uncertainty. It is therefore essential that in both cases the uncertainty in the results should be known in order to validate the method.

The method needed for validation depends on the method used to predict the manoeuvres ; typically free-running model tests and simulation models (Berlekom, 1992). In the first case, validation is rather simple and can be performed in a straight forward manner. In the case of simulation models, validation of the prediction method requires the validation of the different stages (we identified 5 stages) which comprise the construction of a ship manoeuvre simulation software.

Free-running model tests. The validation of free-running model tests is performed by comparison of model scale manoeuvres with full scale test data for a given set of conditions and ship state parameters (rpm, rudder angles, etc..).. The validity of test results depends on the accuracy of the measured model manoeuvres and on scale effects which are difficult to account for in these tests. The accuracy of the model manoeuvres can be assessed through an analysis of the experimental errors (uncertainty analysis) which arise in the course of following a specific test procedure for these experiments.

Validation of Simulation Models. The validity of a simulation model depends on a number of factors as outlined in figure 5.4

The validation of force data as determined by captive model tests, and computational methods relies on the availability of reference benchmark data. Chapter 8 discusses and attempts to establish a benchmark data base for this purpose using the *ESSO OSAKA* hull form. There is a need for benchmark data for other hull types. The CFD community has been using the Series 60 although little manoeuvring data is known for this form.

The accuracy of measured forces depend on the uncertainty in the measurement and on the use of an appropriate test procedures. The document written by this Committee and incorporated in the ITTC QM presents such a test procedure and a method for assessing the uncertainty of forces measured and, to some extent, the uncertainty in the coefficients derived from PMM tests. However, adherence to the test procedure alone does not guarantee the accuracy of the results, since the parameters of the test (e.g. model size, amplitude and frequency of oscillations...) are crucial. For this purpose recommended guidelines are included in Chapter 7.

Uncertainties arise in the identification of coefficients from force data measurements such as oblique towing or PMM tests. Hence, an uncertainty analysis of these derived quantities should be made.

Validation procedure for predicting trials manoeuvres using simulations.

1 - Forces

Source :
Force measurement (steady or harmonic), Numerical computations
Validation requirement :
Benchmark data

2 - Coefficients

Source :
Empirical formulas
Force data regression
System identification from free-running tests
Validation requirement :
Documentation of method used
Benchmark data

3 - Math Model Structure

Source :
Adapted to the type of manoeuvre (DOF....)
Validation requirement :
To be determined

4 - Simulation Software

Validation requirement :
Test cases (debug)

5 - Simulated Manoeuvres

Type of manoeuvres:,
Std. manoeuvres (i.e. IMO),
Controlled ship operations (i.e. harbour)
Validation requirement :
Trials data
Mariner's input

Figure 5.4: Validation procedure for predicting trials manoeuvres.

Empirical formulae are widely used at the design stage to provide estimates of the coefficients based on principal characteristics of the ship. The most commonly used parameters in the regression equations for describing the ship are the L, B, T, C_B, LCB, and σ_a which to some extent describes the shape of the aft body. It is the opinion of the committee that more parameters describing the ship are needed to increase the accuracy of the most important parameters. This, however, requires a large data base of reliable model test and/or computational data. The results shown in Chapter 8 imply that the compilation of such a data base would require prior verification of the sources of data (tests or calculations).

Two applications of simulations can be identified:

- simulations performed in the course of the design of a ship to verify the performance for standard manoeuvres.
- simulations of controlled ship operations (e.g. simulators)

The validation of a mathematical model should reflect the simulation requirements of the application considered: ship geometry, manoeuvring devices, expected ship motions (roll), restricted waterway, etc..

Research in ship manoeuvrability has shown that with 20 to 30 coefficients and parameters in a mathematical model the standard manoeuvres of a ship may be predicted with sufficient accuracy.

Each model in a ship simulator has a specific purpose, sometimes a very simple model working in the first quadrant is perfectly suitable, at other times detailed modelling of all four quadrants at slow speed and large drift angles is necessary. Environmental interaction from wind current, waves, shallow water, banks, ship-ship interaction etc. can be of utmost importance. It is therefore obvious that the validation of a simulation model is closely connected with the purpose for which each model is going to be used.

In the case of controlled ship operations, quantitative validation is not practical. Therefore the acceptance of such models is based on the qualitative assessments of professional mariners. The committee recommends that a set of standard manoeuvres covering the parameters (and subsequent ranges) which will be used in a specific simulation should be performed and documented before a simulation is started.

Full Scale Benchmark Data. There are very few full scale trials carried out at a scientific level with which validation can successfully be made. The *ESSO OSAKA* trial is one of such scarce and valuable full scale trials, where extensive manoeuvring tests had been carried out both in deep and shallow water conditions. Taking the opportunity of *ESSO OSAKA* trial, extensive model tests have been made at many places from both aspects of hydrodynamic forces and manoeuvring motions. A benchmark study is made for *ESSO OSAKA* by the Manoeuvring Committee as described in Chapter 8, where efforts are made to provide a means to validate hydrodynamic forces. Another set of extensive full scale trials data obtained on a Mariner hull was used as a basis for validation in the 14th ITTC proceedings (Eda, 1975).

Full scale trials are always carried out for a newly-built ship before delivery according to the contract and a large number of full scale trial results have been collected and accumulated in ship yards. Unfortunately few of them have been reported and fewer have been used for validation purposes and in the past the quality of these results has sometimes been poor due to lack of accurate tracking, environmental conditions, motivation...

A practical way to validate predictions is through comparisons with trials data for a large number of ship types and manoeuvres. Hirano (1981) has compared full scale trial results for seven merchant ships, covering a wide range of ship types from 10 KDWT traditional cargo boat to 400 KDWT ULCC with block coefficients of C_B = 0.52 - 0.83, and for three types of manoeuvring motions covering a wide range of rudder angle. A suitable level of validation was confirmed through these comparisons.

A methodology to evaluate validity of the prediction method on a scientific basis was discussed in 20th ITTC Proceedings. In order to assess the degree of "agreement" in quantity in a sophisticated manner, a concept of error bands had been proposed, Dand (1992).

Accuracy of Full Scale Measurements. Since 1994, the NAVSTAR GPS (Global Positioning System), consisting of a constellation of 24 satellites, is in operation giving world-wide coverage 24 hours a day. The absolute positional accuracy of GPS in the autonomous mode can be as low as 100m. In order to improve accuracy, DGPS (Differential Global Positioning System) has been developed, which is now used widely as a means to get accurate (1 - 5 m) and continuous position information in a reliable and cost-effective manner. Applications of DGPS for monitoring full scale trials in general and standard manoeuvres in particular are described by Cortellini & Lauro (1995), Stenson (1995), Yum et al (1996) and Youn et al (1997).

In addition, an advanced technique of KGPS (Kinematic Global Positioning System) has recently been developed to further improve the measurements accuracy. Full scale measurements with the use of KGPS and RTKGPS (Real Time KGPS) have been made by Hirata et al (1997) for standard manoeuvres of a small-sized cargo ship (L = 70 m). The measurement accuracy obtained was 2 cm in the horizontal direction and 5cm in the vertical direction. Similar full scale measurements by both KGPS and RTKGPS have been made by Takase et al (1997) and Suzuki et al (1998).

In general, the use of DGPS is recommended in order to keep a position accuracy better than 10 m as required by Norske Standard NS2780 (1985), or 3% of the turning diameter as suggested by the 20th ITTC Manoeuvring Committee.

6. SHIP OPERATION AND SAFETY

Because safety during navigation depends on interaction between ships, the environment, and the operators, studies have been conducted to promote marine safety through improvements in shiphandling simulators and application of modern control algorithms. Also, inherent ship manoeuvrability has become an important design factor since the adoption of "Interim Standard for Ship Manoeuvrability" by the IMO.

6.1 Ship-handling Simulators

Ship-handling simulators have been widely used in the design of ports and fairways, and for training and demonstrating competence of many maritime skills and objectives, and to evaluate the performance of newly developed controller.

The primary emphasis and publications in simulator development are concerned with the fidelity of the simulator environment, including the display. Improvements in the underlying manoeuvring models are reported in section 4.

Some of the recent publications in the use of ship simulators to assess ship safety and operations are discussed in this section.

Gong, et al (1996) developed a simulation system for the assessment of harbour capabilities from the view point of safety of ship navigation in congested harbour area. Pourzanjani (1996) examined the effectiveness of electronic chart system on collision avoidance behaviour in coastal water navigation. Endo, et al (1996) used a ship handling simulator to evaluate the control performance of the joy stick controller for berthing based on decoupling control theory. Takahashi, et al (1996) verified the effectiveness of the navigation support systems, leading lights and the Ramark Beacon, when entering port of the Techno Super Liner, and the results of simulator experiments were compared with the records of the experimental ship HISHO. Kose, et al (1995) designed a prototype Integrated Navigation System(INS) taking into consideration the human decision making process, and Ishioka, et al (1996) used real time ship handling simulator to evaluate the supporting system in INS for collision avoidance.

6.2 Control

Autopilot. The first application of control theory to the ship is an autopilot for course keeping. Nowadays, autopilots have been used widely in ship steering, and several kinds of control theories are adopted to enhance the robustness or to increase the effectiveness of the controller.

Jiang (1997) studied the influence of tow-hook location, towline length, and control parameters of a PID autopilot on the non-linear dynamic behaviour of the tow when a tug-tanker tow is operating in calm water by use of locally linearised stability analysis, time-domain simulation and Poincare map. Nakatani et al (1996) proposed a simple and safe automatic PID gain tuning methods using relay control for typical marine PID controller, and they applied this method to an autopilot system, a yaw control system through bow thruster and a diesel engine governor system.

Neural networks was applied to the autopilot for tanker conning by Logan (1995). He envisaged the intelligent autopilot that will learn ship manoeuvring dynamics through experience, allowing the neuro-controller to apply rudder and engine speed control in the same manner as humans. Sutton, et al (1996) used artificial neural networks in the design of fuzzy autopilots and later Sutton & Marsden (1997) used a genetic algorithm to optimise a fuzzy rule based autopilot, and showed that such approaches can produce effective designs.

Adaptive controllers which can compensate the disturbance such as wind and wave during manoeuvring motion were designed. Zhang et al (1996 & 1997) designed a robust autopilot system for course regulation or directional stability control in assumed wave disturbances and in a random sea by applying a control strategy of variable structure control. Wang et al (1996) applied the fuzzy control method for the adaptive control of heading and position under uniform wind. An adaptive autopilot for submarine via gain scheduling was designed by Dumlu et al (1995) based on the stochastic controller and observer techniques which possesses robustness against possible changes in the external environment. Ogawara et al (1995) showed that the Learning Feed-Forward Control System has good controllability to compensate for the wind disturbance.

A robust digital servo control method incorporating the concept of the annihilator polynomial was applied to auto-pilot control system in course change to the specified direction by Han et al (1995) and confirmed the effectiveness of the proposed control method by model tests. and Zuev et al (1996) applied impulsive course-keeping autopilot to unstable ship.

Collision Avoidance. For safe and effective navigational assistance, collision avoidance systems have been developed in two ways. One is to reason the degree of collision risk, and the other is to determine the collision avoidance manoeuvre. Imazu (1996) assumed that the collision avoidance was consisted of an information processing ability and the avoiding action ability, and developed decision model for collision avoidance action considering the actions on a second and subsequent stages based on a forecast of the encounter condition. An algorithm is proposed for the real-time detection of encounter situation compatible with the real behaviour of ship's officers by Zec (1996). Hilgert et al (1996) created a common risk level from the actions requested by relevant steering and sailing rules of the International Regulation for Preventing Collisions at Sea (COLREGS). The moment at which a collision avoidance manoeuvre should be executed in a dangerous two-ship encounter in order to obtain a certain passing distance was calculated by Kwik (1996) based on the ships' equations of motion in conjunction with the kinematics of ship encounters. Lisowski et al (1996) determined ship's optimum safe trajectory in a collision situation of passing many moving targets by using a multistage decision-making process.

6.3 IMO Standards

Since IMO has adopted Resolution A.751 (18) "Interim Standards for Ship Manoeuvrability", several studies have compared the performance of existing ship populations to the Standards. Based on these comparisons, certain changes in the criteria have been proposed.

In order to review the IMO standards, extensive efforts to compile full scale manoeuvring databases were made by Capurro & Sodomaco (1996), and Kang et al (1996). Raestad (1996) found that the criteria generally are based upon sound principles and that most ships behaving “normally” will be in compliance with the standards. Kijima, et al (1997) pointed out through use of numerical simulation the importance of GM, which is not considered in the interim standards.

Oltmann (1998) presented an overview of the activities concerning the definition of various proposed manoeuvring standards during the last fifty years, with special attention to the IMO. A constant limiting value of 17° for the 1st overshoot angle in a 10° zig-zag regardless of speed is proposed.

Following the adoption of the IMO interim standards, a special effort was made by the Ship Research Institute of Japan to collect full scale trial data for newly-built ships (Haraguchi et al, 1998). The database consists of trial results of 226 ships in total, most of which have been built during the last decade. The database covers a wide range of ship types, in which about two third of the ships are full hull form ships such as oil tankers and bulk carriers with modern hull forms (pram stern with semi-balanced rudder). Full scale tests have been carried out for 73 ships in service condition, of which 23 dry cargo vessels and bulk carriers. According to the IMO Manoeuvrability Standards, data for three types of manoeuvring motions, namely turning motion with 35deg. rudder, 10/10 and 20/20 zig-zag manoeuvre and full astern stopping motion, have been collected and stored.

As shown in figures 6.1 and 6.2, there exist a considerable number of ships which do not comply with the criteria for the second overshoot angle in 10/10 zig-zag manoeuvre and the first overshoot angle in 20/20 zig-zag manoeuvre. Moreover it is pointed out that about a half of the ships which do not comply with the above-mentioned criteria do comply with the criteria for the first overshoot angle in 10/10 zig-zag manoeuvre.

Based on these results, Japan has formally submitted a proposal for revision of the interim standards (IMO MSC 70/20/6 dated 28/7/98). This proposal indicates that the criteria for the 2nd overshoot angles in a 10/10 and the 1st overshoot angle in a 20/20 zig-zag manoeuvres are not appropriate because "...the present criteria may regard ships with good manoeuvring performance as having poor manoeuvring performance."

Furthermore, this document indicates that "...the criteria on stopping ability should be improved based on results of research work considering physical parameters e.g. displacement, horsepower of a ship and so on...".

Norrbin (1998) discussed the procedures and experiences of the crash-stop test against a review of trial and scale model results, track reach estimates, and presented a guideline formula for the track reach not to be exceeded.

6.4 Squat.

Definition of squat**.** Tuck defines squat as follows: "Squat is not a change of draft (...). It is an overall lowering of the ship together with the water in the neighbourhood of the ship. Hence it is almost unseen in the open sea, where it is nevertheless present. However, squat is mainly of concern in restricted water (...)". For this reason, papers handling the sinkage due to forward speed in deep, unrestricted water are not discussed in this report.

Need for reliable squat data. The organisation of meetings on squat (SNAME Workshop, Washington DC, 1995; Nautical Institute Seminar, Hull, 1995) and the attention paid to this subject by international maritime associations (PIANC/IAPH, 1997) reveal a renewed interest in this topic. A need is recognised for more reliable information about a ship's sinkage, which is an essential element in determining an appropriate under-keel clearance for safe transit through channels with restricted depth Overestimation of squat may lead to excessive dredging expenses or non-optimal use of navigation areas while underestimation of squat can lead to unsafe situations.

Squat predictions. Reviews of practical, empirical methods allowing an estimation of squat based on a limited number of parameters characterising ship geometry, waterway configuration and ship speed are published by PIANC/IAPH (1997), Dand (1999), Vantorre (1999a), Millward (1996). Substantial deviations can be observed between the results of such formulae.

A new simple prediction method based on numerical calculations using slender body theory and model test data was published by Kijima & Higashi (1999). Ankudinov et al (1996) and Ankudinov & Jakobsen (1999) developed a semi-empirical engineering and simulation tool to estimate squat for conventional ship types with a minimum of input variables and computational efforts.

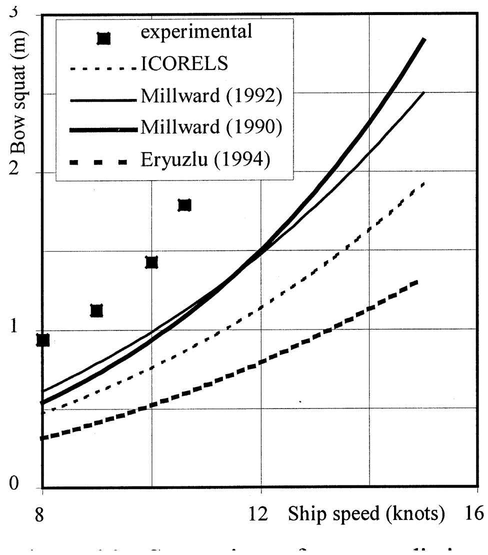

Figure 6.3 : Comparison of squat predictions (PIANC/IAPH, 1997)

Full scale measurements. Use of GPS techniques for real-time measurements of a ship's squat leads to more reliable results with a standard deviation of less than 0.1 m. Queensland Transport (1996) reports squat effects on a large passenger ship transiting an entrance channel using DGPS and RTKGPS positioning software. Comparison with empirical squat formulae shows a good correlation with the formula of Millward (1996), while the values extracted from the ship's squat estimation table were considerably in excess. A GPS survey of deep-draft vessels in the Chesapeake Bay channels, including squat measurements, was described by Hewlett (1999). The use of GPS for compensating hydrographic surveys for the squat of the survey vessel was discussed by Huff (1999).

Special conditions. Effects of channel confinement and asymmetry on squat are described by Norrbin (1999). Vantorre (1999b) discusses the influence of fluid mud covering the bottom of a navigation area on a ship's squat.

Special craft. Bertram & Grollius (1994) present a 3D potential flow panel method for computing resistance, sinkage and trim of SWATH ships in shallow water. Results are good, except near critical depth Froude numbers. The wavemaking resistance and squat of a fast catamaran moving uniformly in a straight rectangular shallow water channel was theoretically investigated by Jian et al (1995) using the technique of matched asymptotic expansions.

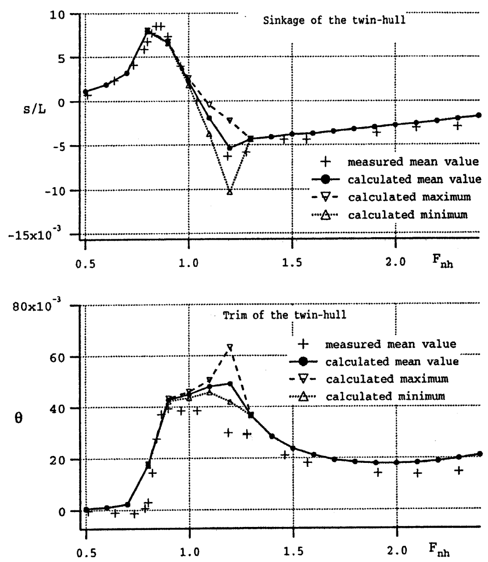

Figure 6.4. Measured and calculated sinkage and trim of twin-hull moving in shallow water channel with H/T = 2.27 (Jiang et al, 1995)

7. MODEL TEST TECHNIQUES

Considering experimental research with ship models in the area of manoeuvrability, a distinction is made between free-running and captive model techniques. Progress in both techniques has been reviewed and a comprehensive survey of current practice in captive model tests was organised and analysed with respect to the choice of experimental parameters for captive model tests. The present Committee has also formulated an adapted version of procedures of captive model testing on behalf of the ITTC Quality Manual.

7.1 Review of free-running model tests

Test techniques. The requirements to be met by an outdoor test location for conducting standard manoeuvres with radio-controlled large models are discussed by Rossignol (1995). A detailed description of the NSWCCD facilities (Lake Needwood) is given; outdoors and indoor test results are compared.

An application of a GPS technique to free-running model tests has been attempted by Ueno et al (1997), and compared with the existing UPS (Ultrasonic Positioning System). Sufficient accuracy and reliability for position measurement was obtained.

Analysis techniques. The use of neural networks for the identification of a 4 DOF model based on free-running tests (zigzag manoeuvres, harmonic rudder angle variations, steady turn) is discussed by Caux & Jean (1996). They concluded that a classical linear neural network model generally provides good predictions, although results are less reliable if rudder variations are applied in the resonance frequency range for roll.

7.2 Review of captive model tests

Test techniques. Several efforts were made to optimise captive manoeuvring test programs by using novel techniques.

A very compact apparatus for circular motion tests (CMT), to be used autonomously or combined with a towing carriage, is described by Karasuno et al (1996). The application of this apparatus to several types of tests with the intent to reduce test duration is discussed.

Reduction of the time required for a captive test program may be achieved by combining several test parameters in one run; e.g. combined oscillatory tests can replace separate yaw and drift tests (Rhee et al, 1998). Results of alternative tests in shallow water ($h/T<1.2$) are compared with stationary tests by Eloot & Vantorre (1998). Although in some cases good agreement was obtained, discrepancies may occur due to non-stationary effects and incomplete flow development around hull or rudder.

A technique using a rotating arm (RA) facility for determining equilibrium conditions (speed, drift angle, rudder angle) as an alternative to free running tests was described by Perdon (1998).

Agdrup et al (1998) investigated the applicability of a wind tunnel PMM to ship manoeuvrability assessment; except for Y_r', a qualitative agreement with tank results was obtained.

Test program and analysis. The literature reflects a tendency towards an optimised standard captive test program and analysis technique developed for a particular simulation model. The PMM test program presented by Blok et al (1998) contains 97 runs, comprising both bare and appended hull tests, while Sutulo & Kim (1998) claim that a specially optimised experimental program of only 20 combined sway/yaw tests is sufficient for use with their mathematical manoeuvring model.

Existing guidelines for selecting suitable parameters (amplitude, frequency) for harmonic captive manoeuvring tests are reviewed by Vantorre & Eloot (1997). A relation between non-stationary phenomena and interference with the model's swept path during PMM tests is discussed, and a alternative non-stationary sway test is proposed. A method for optimising PMM test conditions, yielding most reliable results, is suggested by Rhee et al (1998), based on sensitivity analysis. Several estimators applied to determine manoeuvring coefficients from PMM tests are compared; the non-recursive least square estimator appears to be preferable to the recursive and genetic algorithm estimators.

7.3 Current practice in captive model tests

Captive model test techniques have been used for the last 30 years. During this period, each institution has developed its own methods, mainly based on semi-empirical considerations. The ITTC identified a need for guidelines in order to ensure the quality of test results. The 21st ITTC Manoeuvring Committee formulated a "Recommended standard PMM test procedure" which has been extended in three ways:

- to cover rotating arm tests (RA),
- to provide quantitative guidelines,
- to suggest an analysis procedure for the uncertainty.

The quantitative data are based on two sources: literature on captive testing published during the last decades, and the results of a questionnaire distributed among all ITTC member organisations in 1997. A positive response was received from 37 institutions, providing a solid base for an overview of actual practice.

Questionnaire. Taking account of an increasing need for guidelines and even standard test procedures, the Committee considered a thorough insight in present methodologies for selecting the experimental parameters for captive model tests - being the result of years of experience of many institutions - as a requirement. For this reason, a questionnaire was circulated among 110 ITTC Member Organisations in order to obtain an overview of the actual practice of captive model testing. A positive answer was received from 37 institutions, covering a total of 61 facilities. This report summarises the response to the questionnaire. A more detailed overview will be published.

The questionnaire consisted of three parts:

1. Experimental facilities: main specifications and physical limitations.
2. Experimental program: actual practice.
3. Data acquisition and processing.

Test types. Taking account of the mechanism involved and the motion imposed to the ship model, a distinction can be made between different types of tests:

(a) Stationary straight line tests in a towing tank
- (a1) straight towing;
- (a2) straight towing with rudder deflection;
- (a3) oblique towing;
- (a4) oblique towing with rudder deflection;

(b) Harmonic tests, requiring a towing tank equipped with a PMM:
- (b1) pure sway;
- (b2) pure yaw;
- (b3) pure yaw with rudder deflection;
- (b4) pure yaw with drift;

(c) Stationary circular tests, by means of a rotating arm or a x-y-carriage:
- (c1) pure yaw;
- (c2) yaw with drift;
- (c3) yaw with rudder deflection;
- (c4) yaw with drift and rudder deflection.

Tests a1, a3, b1, b2, b4, c1, c2 are carried out for determining hull forces; a2, a4, b3, c3, c4 yield rudder induced forces, and are therefore non-applicable in case the model is not fitted with rudder and propeller (bare hull testing).

The questionnaire covered the following numbers of facilities for each category:

(a) Stationary straight line tests ..... 53 facilities
(b) Harmonic tests.......................... 34 facilities
(c) Stationary circular tests .... 14 facilities

Experimental facilities. Figure 7.1 presents differential and cumulative distributions of the data on ship model length L. When an average value was given, the limiting values of model length were assumed to be 33 % lower and higher than the mean value. The following conclusions can be drawn for test types (a) and (b):

- comparable lengths are used for (a) and (b);
- the median value for L appears to be 4.5 m;
- the distribution reaches a peak at a L ≈ 3 m;
- 95% of all tests are carried out with L> 2 m.

On the average, circular tests (c) are performed with smaller models. The median length is only 3 m, the peak in the distribution is reached at 2.2 m, and the 95% limit is 1.5 m.

Figure 7.2 shows that most tests of types (a) or (b) are carried out in a tank with a length of 35 times the ship model length, which is also approximately the median value. Most circular tests (c) are carried out in a tank the largest dimension of which is about 20 times the model length.

According to figure 7.3, a median value for model length to tank width ratio (L/W) is 0.47 for stationary straight-line tests (a), and somewhat smaller (0.42) for harmonic tests (b). This difference can be explained by the fact that PMM mechanisms are mounted in tanks with a width, which is larger than the average towing tank. As most circular tests are executed in circular or wide tanks, the median value of L/W for test type (c) is much smaller (0.09).

Experimental program: test type (a). Table 7.1 gives an overview of the number of ship speeds, propeller loadings, drift angles and rudder angles applied during captive model tests. A larger number of model speeds is used for resistance-propulsion tests (a1), as the self-propulsion point has to be determined by this kind of tests. For other types of tests (a2, a3, a4), the median value appears to be 1 or 2.

The majority of the tests are carried out at the (model or ship) self-propulsion point. Straight towing tests without rudder action (a1) and rudder force tests (a2) are often carried out at other propeller loadings as well.

The number of drift angles applied in tests a3-a4 is on the average smaller for oblique towing tests with rudder action. The highest frequency is observed at 12 angles for type (a3), and 5 angles for type (a4). A similar distribution is obtained for the number of rudder angles at which tests a2/a4 are carried out. The way drift and rudder angles are selected is displayed in figures 7.4(a3) and 7.5(a2), respectively.

Besides parameters related to the ship model kinematics and control, the questionnaire requested for details concerning some parameters related to experimental and analysis techniques: waiting time between runs, acceleration phase, settling phase, steady phase, deceleration phase. An overview is given in Table 7.2.

Experimental program: test type (b). An overview of the number of parameters determining the ship model kinematics and control is shown in Table 7.1. Most harmonic tests are carried out at only one speed-rpm combination.

The number of sway or yaw velocity amplitudes applied during tests of types (b1) and (b2), respectively, varies between 1 and 20, 4 being a median value. There is only a slight difference between the distributions for (b1) and (b2), which is remarkable, as in general sway tests are only performed for determining the sway acceleration derivatives, while yaw tests also provide data on yaw rate dependent forces and moments. Median ranges for nondimensional sway and yaw velocities are [0.1 ; 0.35] and [0.16 ; 0.58], respectively.

The number of amplitudes applied in a harmonic sway (b1) and yaw (b2) test program may vary between 1 and 10, 3 being a median value. The median number of frequencies selected for such types of tests is 2.

The ratio of lateral amplitude y_A to tank width W is in some cases restricted by the technical limitation of the driving mechanism, but even if the lateral motion extends over the full width, y_A/W is selected to be not larger than a certain value in order to avoid wall effects. As shown in figure 7.6, the sway amplitude typically takes less than 10% of the tank width.

An important issue concerns the selection of the PMM frequency ω, which can be expressed non-dimensionally in various ways:

$$\omega_1' = \frac{\omega L}{u} \qquad (7.1)$$

$$\omega_2' = \omega\sqrt{\frac{L}{g}} = \omega_1' F_n \qquad (7.2)$$

$$\omega_3' = \frac{\omega u}{g} = \omega_1' F_n^2 \qquad (7.3)$$

Figure 7.7 and table 7.3 present an overview of actual practice in selecting ω'_1, ω'_2, ω'_3. For this purpose, a Froude number range between 0.05 and 0.3 was assumed if no indication could be found on this topic in the completed questionnaires. Table 7.3 also mentions recommended values according to empirical rules of thumb formulated by several authors (see ITTC Quality Manual: Manoeuvring - Captive Model Test Procedure, discussed in paragraph 7.4).

Interaction of yawing with drift and rudder action is typically verified at four drift angles and three rudder deviations, but are only seldom combined. No tendency can be observed concerning the selection of the rudder angle range (see figure 7.5(b3)); drift angles for combination with yawing are selected in the range $|\beta| < 30$ deg, [0 deg;16 deg] being a median range (see figure 7.4(b4)).

Common practice concerning execution parameters, such as the number of cycles considered for analysis is given in Table 7.4, which also gives an indication about the number of cycles skipped in order to obtain a steady state. Waiting times between tests of types (a) or (b) are comparable.

Experimental program: test type (c). An overview of the number of ship speeds, propeller loadings, drift angles and rudder angles applied during rotating arm or circular motion tests is given in Table 7.1.

Non-dimensional yaw rates r' vary from 0.07 to 1; a median range appears to be [0.2 ; 0.75]. The number of yaw rates varies between 2 and 16, 4 being a median value.

The maximum drift angle applied during tests of type (c2) varies between 10 and 20 deg. About 50% of the respondents apply an asymmetric range.

Data acquisition and processing. The member organisations were requested to answer, which of a list of data were always, sometimes or never measured during captive manoeuvring tests. The replies, reflected in figure 7.8, can be summarised as follows:

- longitudinal and lateral hull force components and yawing moment are (of course) always measured;
- a majority always measures the position and/or speed components of the driving mechanism, as well as parameters characterising the control of the ship model steering and propulsion equipment (rudder angle, propeller rpm), and thrust and torque acting on the propeller(s);
- following data are always or sometimes measured by a majority of the respondents: rolling moment,

forces and moments on rudder(s) and, to some lower extend, sinkage and trim.

Sampling rates vary between 4 and 250 Hz, 20 Hz being a median value.

7.4 Captive model test procedures and analysis techniques

Captive model test techniques have been used for the last 30 years. During this period, each institution has developed its own methods, mainly based on semi-empirical considerations.

The ITTC identified a need for guidelines in order to ensure the quality of test results. The 21st ITTC Manoeuvring Committee (1996) formulated a "Recommended standard PMM test procedure". On behalf of the ITTC Quality Group, the present Committee proposed an updated version of this procedure, entitled “Manoeuvring - Captive Model Test Procedure”, which can be considered as an extension of the latter in three ways.

In the first place, the considered techniques are not restricted to PMM testing, but other captive methods are also discussed. Procedures for rotating arm tests, however, are still in development.

Secondly, an attempt is made to provide quantitative data, unlike the former procedure, which intentionally was given a qualitative character. The quantitative data are based on two sources: literature on captive testing published during the last decades, and the results of the questionnaire discussed in section 7.3.

Finally, basic ideas for an uncertainty analysis are formulated. It is clear that in comparison with other tests, such as resistance tests, such an analysis is far more complex in the case of captive manoeuvring tests, for several reasons:

- The number of possible causes of uncertainty is very large, and substantially depends on the concept and the characteristics of the experimental facility.
- Several data have to be measured simultaneously during captive manoeuvring tests.
- According to the kinematics imposed to the ship model, a large number of test types can be distinguished.
- A rather important number of parameters has to be selected for determining a captive model test.
- Several techniques may be applied to analyse the measured data.
- The structure of the mathematical manoeuvring model is also of importance for assessing the uncertainty of test results.

For these reasons, it is not possible to formulate a universal uncertainty analysis procedure that can be applied for any captive model test. Instead, some examples are given, indicating the importance of the selection of test parameters.

For further details reference is made to the ITTC Quality Manual.

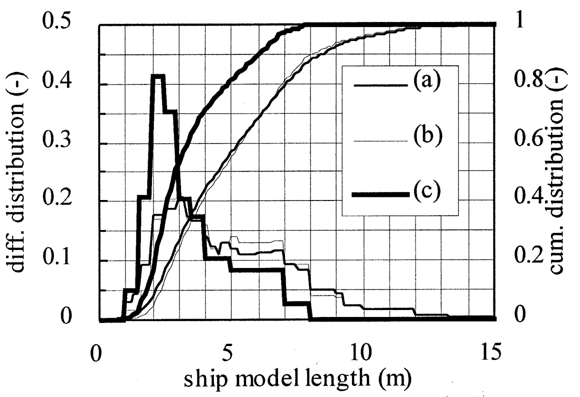

Figure 7.1. Differential and cumulative distribution of the length of ship models used for several types of captive model tests.

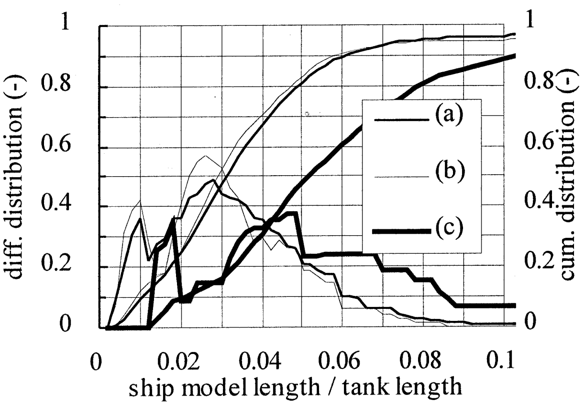

Figure 7.2. Differential and cumulative distribution of the ratio of ship model length to tank length for several types of captive model tests.

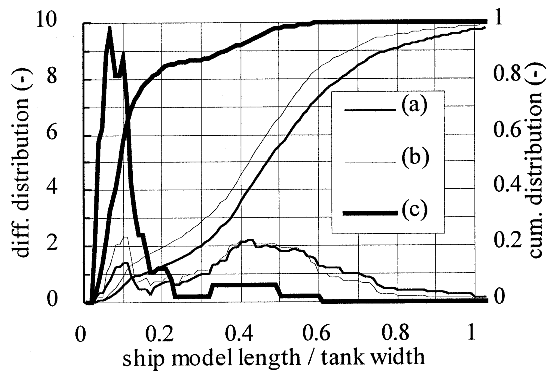

Figure 7.3 : Differential and cumulative distribution of the ratio of ship model length to tank width for several types of captive model tests.

Table 7.1. Test types (a), (b), (c): number of test parameters.

	# forward speeds					#propeller loadings				
	cum. distr. (%)				Max	cum. distr. (%)				max
	0	50	80	100	Freq	0	50	80	100	freq
a1	1	3	9	15	1	1	2	5	20	1
a2	1	2	4	6	1	1	1	5	10	1
a3	1	2	3	9	1	1	1	5	10	1
a4	1	1	3	5	1	1	1	8	10	1
B	1	1	3	10	1	1	1	1	10	1
C	1	1	2	4	1	1	1	3	8	1

	# drift angles					# rudder angles				
	cum. distr. (%)				Max	cum. distr. (%)				max
	0	50	80	100	Freq	0	50	80	100	freq
a2	-	-	-	-	-	2	10	15	17	9
a3	3	11	15	23	12	-	-	-	-	-
a4	3	8	14	20	5	2	8	14	20	10
b1	-	-	-	-	-	1	1	1	10	1
b3	-	-	-	-	-	2	3	4	6	3
b4	2	4	6	10	4	1	1	4	10	1
c2	3	7	12	24	6	-	-	-	-	-
c3	-	-	-	-	-	2	6	17	24	6

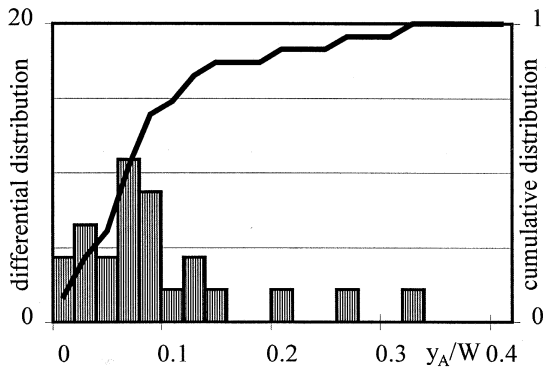

Figure 7.6. Harmonic sway tests (b1): distribution of sway amplitude to tank width ratio.

Table 7.2. Stationary straight line tests (a): experimental parameters

	Cumul. distr. (%)				max
	0	50	80	100	freq.
Acceleration (L)	0.07	1.7	5.5	33.3	0.8
Settling (L)	0.1	2.2	5.5	13.3	1.5
Steady (L)	0.3	8.7	17.2	80.0	3.5
Deceleration (L)	0.07	1.7	5.3	20.0	0.7
Waiting time (min)	15	15	20	20	15

Table 7.3. Harmonic tests (b): frequency selection

	max. Freq.	P=50%	P=80%	empiri-cal
ω_1'	0.5 - 1.5	5.0	14	1 - 4
ω_2'	0.1 - 0.2	0.5	0.9	0.15-0.2
ω_3'	0.02- 0.04	0.08	0.22	<< 0.25

Table 7.4. Harmonic tests (b) execution parameters.

	P = 50%	P = 80%	max.freq.
Transient Steady	1 cycle 2 cycles	3 cycles 4 cycles	1 cycle 2 cycles
Waiting time	15 min	25 min	15 min

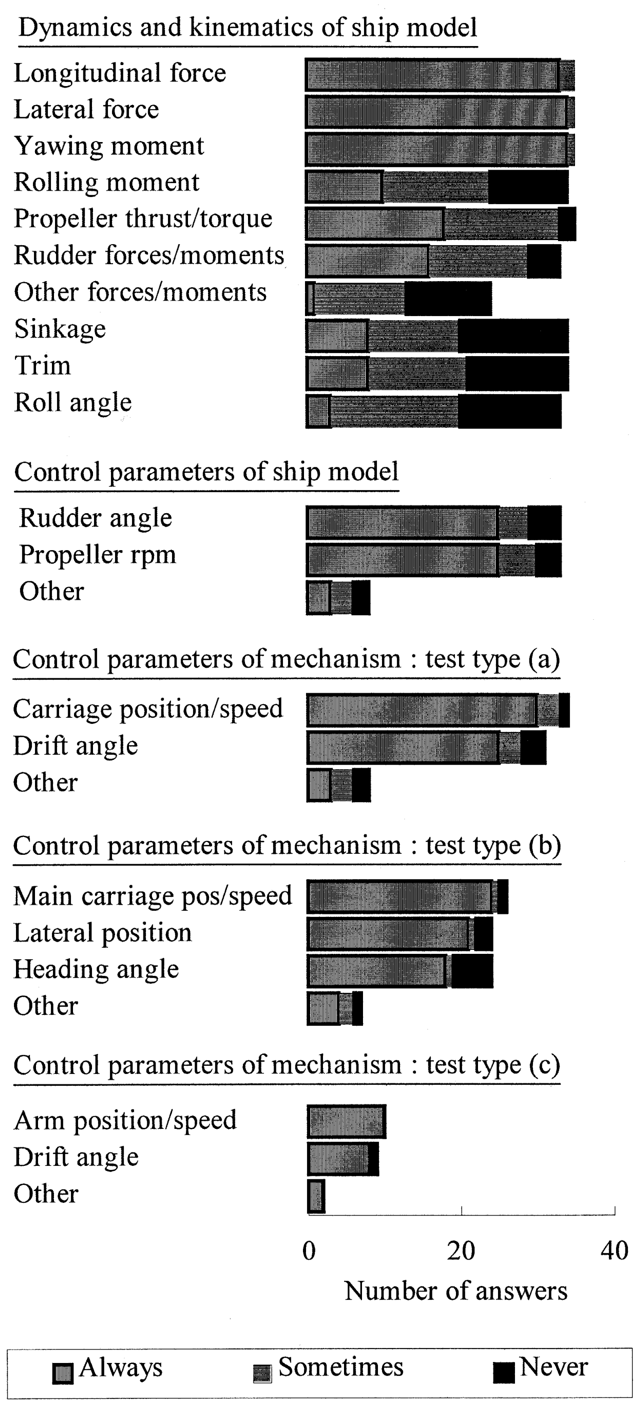

Figure 7.8. Data-acquisition: data measured during captive manoeuvring tests.

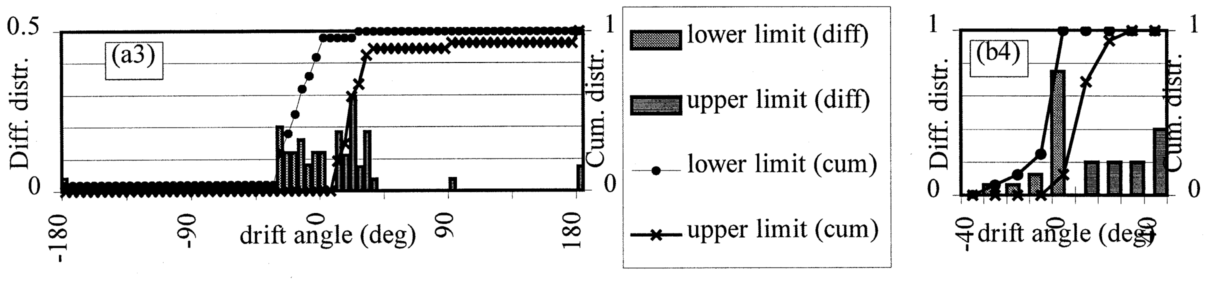

Figure 7.4. Distributions of limits of drift angle range applied for tests (a3) and (b4).

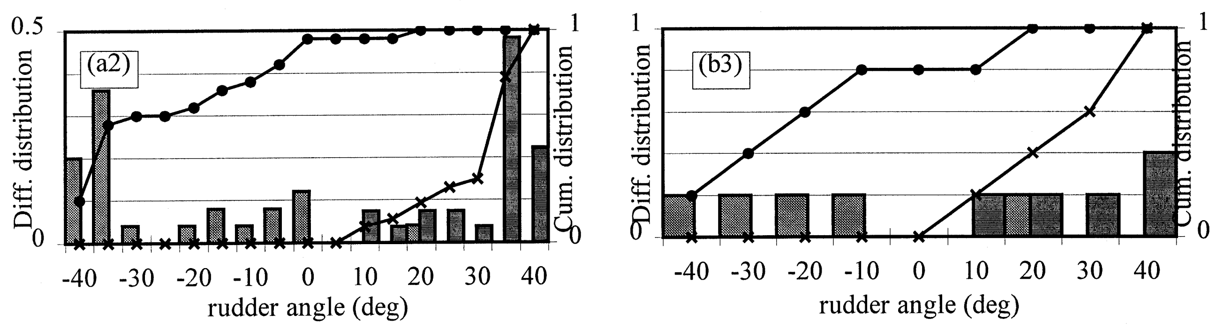

Figure 7.5. Distributions of limits of rudder angle range applied for tests (a2) and (b3) (legends: see figure 7.4).

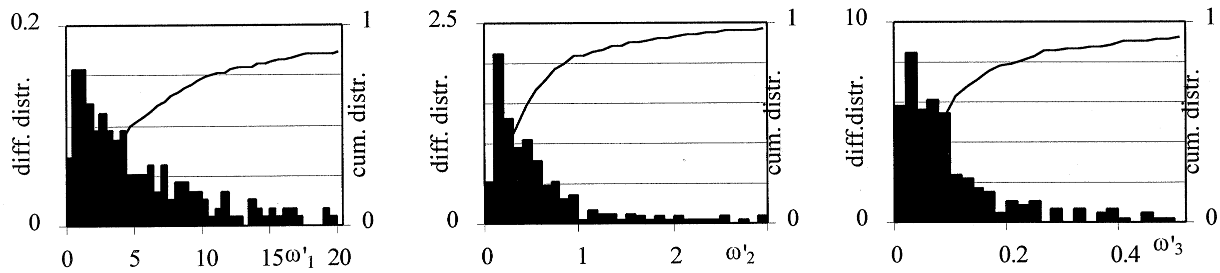

Figure 7.7. Distributions of non-dimensional PMM frequencies for tests (b).

8. *ESSO OSAKA* Benchmark Study

One of the tasks assigned to the committee and which was considered essential by this committee was to develop a quantitative basis for assessing the ability and limitations of current captive model test techniques and numerical computation methods for predicting important hydrodynamic forces acting on a ship (bare hull or appended hull) under typical manoeuvring conditions (drift angle, yaw rate or rudder angle). Of particular interest are the variations existing in measured or predicted force, the influence of experimental factors such as model scale ratio, and the capabilities of numerical methods.

The *ESSO OSAKA* was selected as a benchmark ship for assessing current state of the art in prediction of manoeuvring forces and motions for the following reasons:

- Data are available from a very extensive and very carefully conducted set of ship trials in deep and finite (shallow) water depths;
- Many model tests at various model scale ratios, and many manoeuvring simulation studies, have been conducted for the *ESSO OSAKA*;
- The *ESSO OSAKA* was extensively studied in Japan and reported by JAMP **(**1985).
- An extensive comparison of available results for the *ESSO OSAKA* was presented by Barr (1993).

Other ships considered, but not selected because of their more limited database, included the Mariner which was previously considered in detail by the 15th ITTC Manoeuvring Committee, and a ship from the MARAD series of more modern, shallow draft, full form hulls, described by Roseman (1987). It is recognised that there is an essential need for a similar set of data comparable to the *ESSO OSAKA* set but for other hull forms.

8.1 ITTC Member Survey

To determine the expected level of support and co-operation in using the *ESSO OSAKA* as a benchmark ship, a survey was prepared and sent to all ITTC member organisations. This survey is summarised in Table 8.1.

Table 8.1: Questionnaire on *ESSO OSAKA* Manoeuvring Studies

1. Have you previously conducted *ESSO OSAKA* model tests? Can raw data or other data be provided?
2. Have you done manoeuvring simulations? Can results or simulation model be provided?
3. Have you made numerical computations for the *ESSO OSAKA* ? Can results be provided, and are methods described in the open literature?
4. Would you be willing to conduct new model tests using an existing, new or borrowed model? Would you be willing to build a new *ESSO OSAKA* model?
5. Do you currently have a model of the *ESSO OSAKA* ? What is scale ratio, would you loan to others?
6. Would you conduct numerical computations?
7. Indicate where responses apply to deep water, shallow water or deep and shallow water.

49 organisations responded to this survey. More than 30 organisations indicated a willingness to carry out numerical calculations of hydrodynamic forces, while very few indicated a willingness to undertake new model tests. Table 2 summarises responses to the survey. Not all respondents answered all questions.

Table 8.2 Summary Responses

Question/Response	Yes	No
Conducted previous tests	19	30
ESSO OSAKA model now available	11	37
Willing to build new model	10	29
Willing to conduct new tests	28	20
Deep water only	20	
Deep and shallow water	8	

Conducted previous simulations	19	30
Conducted numerical predictions	39	10
Willing to make new numerical manoeuvring predictions	22	23

As prediction of forces was of greatest interest to the Committee, all organisations agreeing to calculate forces were requested to do so for the following set of typical operating conditions:

Water Depth	Drift Angle β (°)	Turning Rate r' (rad/s)
Deep	20	0
Deep	0	0.5
Deep	0	0.75
Deep	8	0.5
H/T=1.2	8	0
H/T=1.2	0	0.5
H/T=1.2	8	0.5

Electronic data files defining the hull and rudder lines and propeller characteristics were prepared from the drawings and sent to each organisation.

The present investigation was restricted to hull damping. Propeller and rudder forces, which are of equal or greater interest, were not considered due to the lack of consistency in, or absence, of data.

Forces and moments are non-dimensionalized as follows:

$$Y' = Y/ (½\ \rho\ U^2L^2)$$

$$N' = N/ (½\rho U^2L^3)$$

where:

Y	sway force
N	yaw moment
ρ	water mass density
U	ship forward speed in m/s
L	ship length (LPP) in m.

Forces are plotted as a function of drift angle, β (in degrees), and non-dimensional yaw rate, r':

$$\beta = \sin^{-1} (v/U)$$

$$r' = r.L/U$$

where:

v	sway velocity in m/s
r	yaw rate in rad/s

8.2 *ESSO OSAKA* Hull Force Data Sources

Sources of available *ESSO OSAKA* force data and coefficients are presented in Table 8.3. Included are only those sources used in the present comparisons. Data sources which could not be easily used due to the data format (plots only..) were not included.

Table 8.3 Sources of *ESSO OSAKA* Force Data

References	Source Data	Format
JAMP(1985)	Model test	Coefficients
Miller (1980)	Model test	Coefficients
Ankudinov (1979)	Empirical	Coefficients
Abkowitz (1981), (1984)	Systems ID (SI)	Coefficients
Gronarz (1988)	Model test	Coefficients
Dand (1983)	Model test	Coefficients
Eda (1983)	Model test	Coefficients
Ogawa (1977) K.U.	Model test	Coefficients
Shiraka (1997)	Model test	Coefficients
Bogdonov (1987)	Model test	Coefficients
Bigot (1997)	Tests/CFD	Force tables
Lech (1998)	Model test	Coefficients
Copenchov (1998)	Model test	Coefficients
Varyani (1995)	Empirical	Coefficients
Ohmori (1998)	CFD	Coefficients
Zou (1998)	Theory	Coefficients
Hirano (1985)	Model test	Coefficients

Data presented by Bigot (1997) is noteworthy for the extensive CFD and model test results.

8.3 Deep Water Force Data

Non-dimensional force data obtained from the sources listed in Table 8-3 were compared, and statistical variation of these forces determined. Figures 8.1 through 8.4 present comparisons of sway and yaw forces as a function of drift angle, for r' = 0 and 0.75, for both bare hull and hull with rudder. Comparisons for other yaw rates are similar. The present comparisons are more comprehensive than those of Barr (1993), as they include many new theoretical and experimental results obtained in response to the Committee's request to member organisations. Tables 8.4 and 8.5 present standard deviations of forces divided by the mean value. The largest values typically result from small mean values.

When considering the results in figures 8.1 to 8.4 and the tables 8.4 and 8.5, it is evident that extremely large variations exist in measured hydrodynamic forces which are fundamental in the prediction of manoeuvres (Chapter 4).

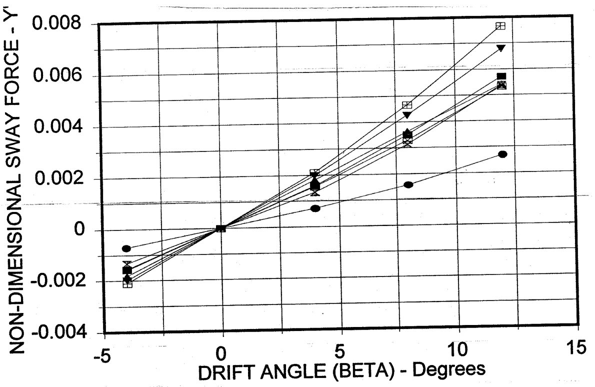

Figure 8.1: Comparison of bare hull sway forces as a function of drift angle (r'=0)

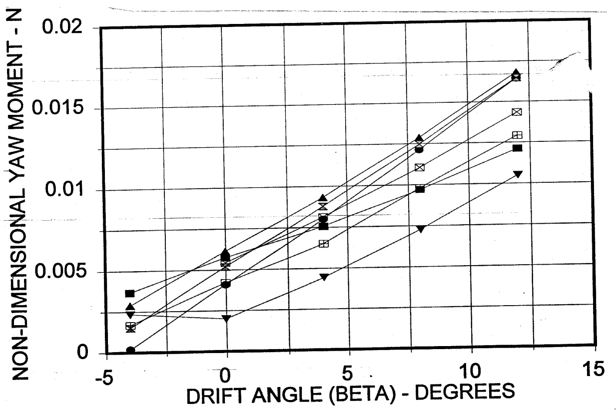

Figure 8.2: Comparison of bare hull yaw moments as a function of drift angle (r'=0.75)

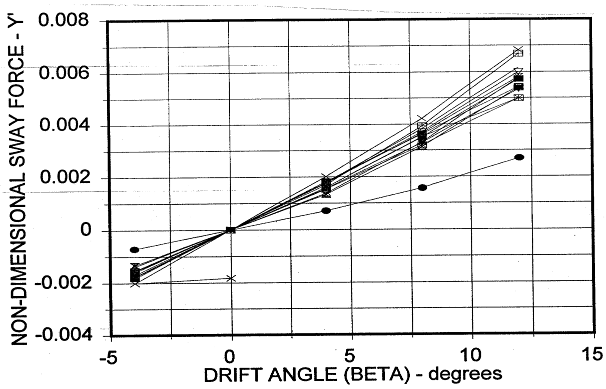

Figure 8.3: Comparison of hull and rudder sway forces as a function of drift angle (r'=0)

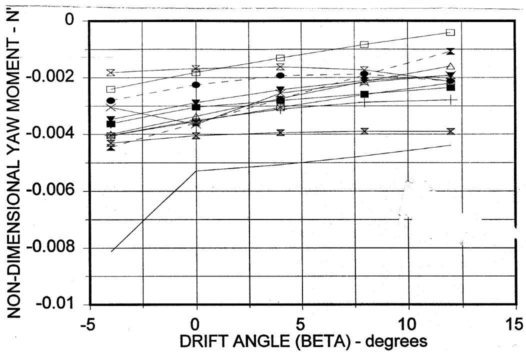

Figure 8.4: Comparison of hull and rudder yaw moments as a function of drift angle (r'=0.75)

Table 8.4: Statistics of forces and moments for bare hull

		Sway Force		Yaw Moment	
Drift Angle	r'	Mean $.10^3$	Std./ Mean	Mean $.10^3$	Std./ Mean
0	0.30	1.61	0.36	-1.24	0.154
	0.50	2.83	0.35	-2.20	0.13
	0.75	4.74	0.33	-3.54	0.13
8	0.30	6.05	0.20	-0.04	2.77
	0.50	8.06	0.20	-1.21	0.18
	0.75	11.3	0.19	-2.99	0.13

Table 8.5: Statistics of forces and moments for hull with rudder and propeller

		Sway Force		Yaw Moment	
Drift Angle	r’	Mean .10^3	Std./ Mean	Mean .10^3	Std./ Mean
0	0.30	2.14	0.54	-1.17	0.24
	0.50	3.64	0.52	-2.02	0.25
	0.75	5.58	0.52	-3.16	0.28
8	0.30	5.85	0.13	-0.07	4.06
	0.50	7.87	0.20	-1.06	0.46
	0.75	10.83	0.24	-2.46	0.37

Figures 8.5 through 8.8 present standard deviations of forces and moments. On these graphs the mean value of the force and moment corresponding to a typical for a large rudder angle turn (r’=1, β = 8°) is plotted to provide a absolute reference of forces.

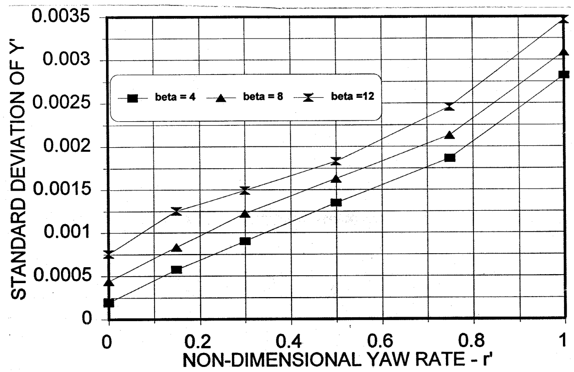

Figure 8.5: Std. deviation of sway forces on a bare hull as a function of yaw rate

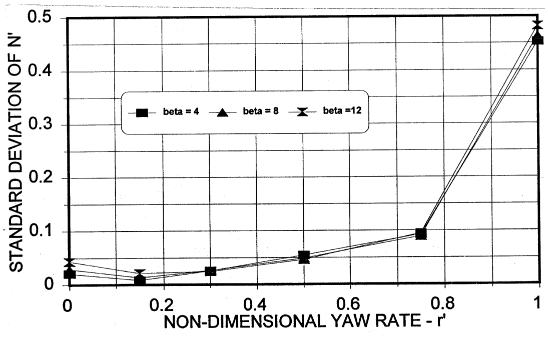

Figure 8.6: Std. deviation of yaw moments on a bare hull as a function of yaw rate

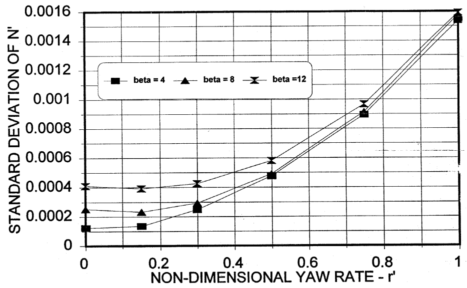

Figure 8.7: Std. deviation of sway forces on hull and rudder as a function of yaw rate

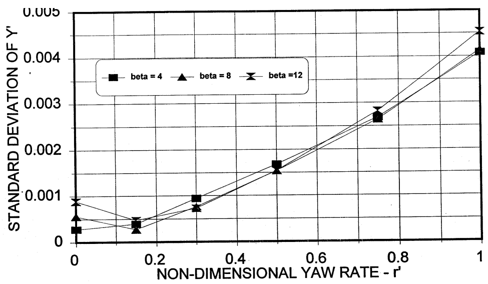

Figure 8.8: Std. deviation of yaw moments on hull and rudder as a function of yaw rate

These figures show that the standard deviation is relatively constant for r'<0.2, but that above this value, it increases monotonically. The standard deviation is much less sensitive to drift angle. It should be noticed that the computed standard deviations are of the same order of magnitude as the forces or moments acting on the ship when manoeuvring (value at r'=1.0, β=8°).

<u>Scale and speed effects:</u> One issue on which it was hoped to shed some new light was that of scale effects. Previous studies, Barr (1993), have found evidence, but no clear confirmation, of scale effects. Figure 8.9 shows a very large amount of scatter and indicates no correlation of sway force at 12° drift angle with model length (correlation factor of 0.37). There was also no correlation of yaw moment at 12° drift angle with model length. Identical conclusions were drawn from sway forces or yaw moments for r’ = 0.75 with or without drift. The effect of Reynolds number could not be investigated as test speeds were often not published.

Figure 8.10, from Bigot (1997) shows ro-

tating arm and oblique towing test data at varying speeds which show no significant effect of speed in the speed range tested. There is little difference in yawing moments at significant yaw rates or in sway forces for any drift angles or yaw rates. However, large differences do exist between hull yaw moments due to pure drift at a ship speed of 5 knots. These results indicate that important scale effects may exist at these low model Reynolds number for yaw moment due to pure drift.

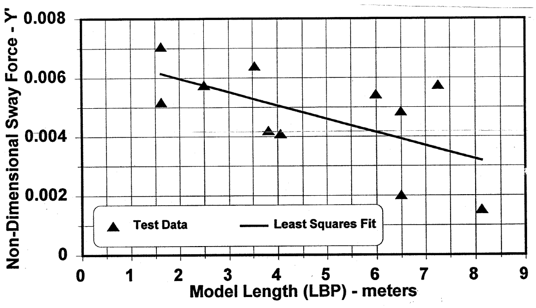

Figure 8.9: Sway force as a function of model length (β=12°)

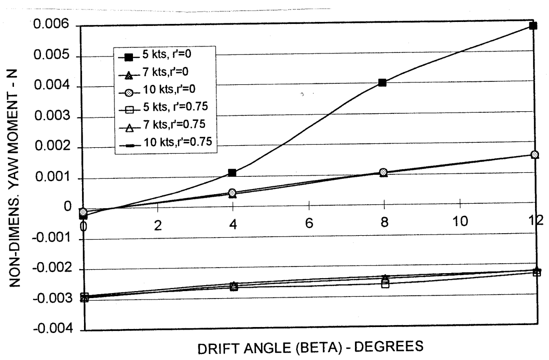

Figure 8.10: Yawing moment as a function of drift angle for different scaled ship speeds (r' = 0 and 0.75)

Force Data from Systems Identification. Abkowitz (1981 and 1984) investigated system identification (SI) procedures for estimating forces and moments from *ESSO OSAKA* trials in deep and shallow water. In the 1984 report he discusses the use of different numbers of state variables for the identification of deep water force coefficients and concludes that little is gained by using four measured parameters (u, v, ψ and r) rather than three parameters (u, v, ψ) plus a value of r calculated from ψ. Table 8.6, which compares identified values of linear coefficients for various input parameters, indicates large differences in yaw moment coefficients.

Figure 8.11 compares yaw moments calculated using these three sets of parameters for a range of yaw rates for two drift angles (0° and 12°). Also shown on the figure are the extreme values of all model test data for appended models. These results indicate that the differences in yaw moments obtained from trials data using different SI methods are as large as the scatter of test data from all model tests. It is therefore concluded that values of the identified coefficients have to be validated by simulating manoeuvres *other* than those used in the identification. Furthermore, the choice of suitable identification parameters has to be validated for other manoeuvres and other ships.

Table 8.6: Linear coefficients for different identification parameters, Abkowitz (1984)

Parameters	4	3	3+
Coefficient	u, v, r, ψ	u, v, ψ	u, v, ψ, ψ
Yv'	-0.0261	-0.0255	-0.0257
Nv'	-0.0141	-0.0061	-0.0145
Yr'	0.0037	0.0034	0.0036
Nr'	-0.0048	-0.0025	-0.0066

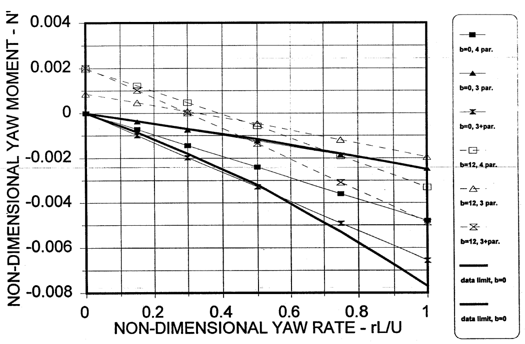

Figure 8.11: Yaw moments obtained through SI method using different sets of parameters

8.4 Shallow Water Force Data

Force data and coefficients for operation in water of finite depth (water depth-draft ratios of 2 to 1.2) were available from many sources. This comparison was limited only to linear damping coefficients. This is appropriate for the slower responses experienced in shallow water.

Figures 8.12 and 8.13 compare the variation of two linear damping coefficients with water depth (ratio of coefficient at finite water depth to that in deep water) Table 8.7 presents statistics (mean values and standard deviations or STD.) of each coefficient and the ratio Nv'/Yv' (measure of static yaw or weathervane stability). There are increasingly large variations in the force ratios derived from this data as water depth is reduced.

Table 8.7: Statistics of shallow water force coefficients from 16 sources

H/T=1.50

Coefficient	Mean	Std.	Std./Mean
Yv'/Yv'_∞	2.270	1.652	0.73
Nv'/Nv'_∞	2.233	0.896	0.40
Yr'/Yr'_∞	0.914	0.874	0.96
Nr'/Nr'_∞	1.324	0.456	0.34
Nv'/Yv'	1.239	0.776	0.63

H/T=1.20

Coefficient	Mean	Std.	Std./Mean
Yv'/Yv'_∞	5.238	2.818	0.54
Nv'/Nv'_∞	3.798	2.203	0.58
Yr'/Yr'_∞	1.847	0.587	0.32
Nr'/Nr'_∞	1.745	0.693	0.40
Nv'/Yv'	0.769	0.344	0.45

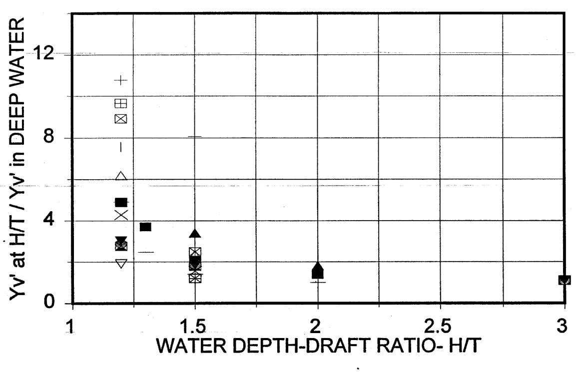

Figure 8.12: Effect of water depth on sway damping coefficient Yv'

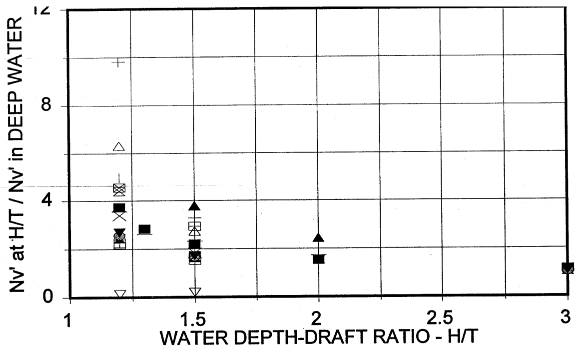

Figure 8.13: Effect of water depth on yaw damping coefficient Nr'

9. TECHNICAL CONCLUSIONS

1. CFD has been shown to be useful in predicting forces associated with manoeuvring and its use is becoming more widespread.
2. Work should be pursued on CFD approaches to reduce the required amount of experiments
3. It has been demonstrated that when roll angle exceeds a specific value, this motion and its coupling with other modes of motion has to be modelled in the simulation.
4. Sensitivity analysis performed with mathematical models for conventional ship types has proven useful in identifying the most important terms in simulation models and determining their necessary level of accuracy.
5. Systematic investigations of the influence of local hull geometry on forces are needed to generate more accurate simulation methods.
6. Work needs to continue to develop more accurate simulation methods.
7. Some scale effects can be taken into account in simulations using modular models by applying corrections to hull resistance, and effective wakes at propeller and rudder. Other scale effects on hull forces may exist but are not currently taken into account.
8. Validation of the hydrodynamic coefficients used in simulation models requires benchmark data at model scale.
9. Validation of simulations, and of free-running model test results, require benchmark data at full scale.
10. Research is required to quantify scale ef-

fects on hydrodynamic forces acting on a manoeuvring vessel, particularly the lateral forces and yawing moments.

11. Clarification is required on the scale effects present in free-running models.

12. There is evidence that manoeuvres predicted using free-running model tests on full form ships can be subject to significant scale effects which are not yet well understood.

13. Research is needed to improve the accuracy of practical prediction methods, including numerical methods, for squat.

14. Research has to be conducted to assess the relevance of existing IMO criteria, particularly overshoot angles, to practical ship manoeuvring performance. The development of criteria which best quantify ship manoeuvring performance should be pursued.

15. Comparison of trials data for a large number of newer ships with the IMO standards indicated that a large majority of these ships met all IMO performance criteria. The criteria most frequently not met are the overshoot angles in zig-zag manoeuvres and the reach in a crash stop.

16. Differential Global Positioning System measurements of squat provide a new source of data for validation of squat predictions.

17. New methods have been proposed and applied to reduce the number of tests required to obtain a complete set of hydrodynamic coefficients. The general applicability of these methods has to be demonstrated.

18. Current practice for captive model tests, and in particular PMM tests, shows a wide spread in the relative size of model and facility.

19. The choice of parameters used in PMM tests, particularly the frequency of oscillation, often does not follow published guidelines.

20. Based on proposed guidelines for captive model tests and described uncertainty analysis, the number of sources of uncertainty in captive model tests is significantly greater than typically considered (i.e. in resistance tests).

21. The accuracy of test results, in particular for PMM tests, depends to a great extent on the physical mechanism, the choice of test parameters, and the method of the analysis.

22. Based on the comprehensive collection of existing and new results, surprisingly large differences exist in published hull forces and moments for the *ESSO OSAKA* for both deep water and shallow water.

23. The available data for the *ESSO OSAKA* in its current form is not suitable for use as benchmark .

10. RECOMMENDATIONS TO THE CONFERENCE

1. Adopt the procedure on captive model tests (ITTC Procedure 4.9-03-04-03)

2. Standardised precision limits should be provided with both predictions and full scale results. “Good agreement” should be defined based on these precision limits.

3. A systematic validation procedure, such as the one outlined in figure 5.4 for simulation models, should be applied and presented with the results of simulations.

11. RECOMMENDATIONS FOR FUTURE WORK

1. Model test procedures should be developed for free-running model tests.

2. The committee strongly recommends that the Esso Osaka benchmark data effort be continued in the following five areas:

- Reduce the scatter in existing data either by eliminating suspect data sets, or by stimulating new, benchmark quality experiments.
- Compare propeller and rudder forces and propeller-hull-rudder interactions.
- Carry out a systematic series of simulations using one reference mathematical model (e.g. MMG with fixed propeller and rudder forces and interactions) using available sets of hull damping coefficients (linear and non-linear).
- Compare the results of these systematic simulations with available track data and particularly the full scale trials data.
- Promote the disclosure of benchmark data through the organisation of a workshop

3. Work should be pursued to define the critical roll angle values above which 4 DOF are needed in the simulation.

4. Work should be pursued on the modelling of a ship manoeuvring in a non-uniform or shear current.

5. Trials data for all ship types at fully load-

ed condition should be collected to support evaluation of the IMO standards.

6. The lack of benchmark data for all manoeuvring problems needs to be addressed by conducting suitable (free-running and captive) benchmark quality tests at model and full scale.

REFERENCES

Abkowitz, M., 1981, “System Identification in Ship Maneuvering Trials : Analysis of the *ESSO OSAKA* Trials Data, MIT Dept. of Ocean Engineering Report 81-9.

Agdrup, K., Jensen, A.G., Aage, C., 1998, "Wind Tunnel Assessment of Ship Manoeuvrability using PMM Technique", MAN’98, Val de Reuil, France, pp. 1-9F.

Alessandrini, B., Delhommeau, G., 1998, “Viscous Free Surface Flow Past a Ship in Drift and Rotating Motion”, 22nd Symposium on Naval Hydrodynamics, Washington, D.C., USA.

Ando, J., Yamamoto,T., Maita, S., Nakatake, K., 1997, “An Estimation of Hydrodynamic Forces Acting on a Ship in Oblique Towing by a Simple Surface Panel Method (SQCM)”, (in Japanese), TWCNA, No. 94, pp. 13-20.

Ankudinov, V., and Miller, E., 1979, “Predicted Maneuvering Characteristics of the Tanker Esso Osaka in Deep and Shallow Water,” Hydronautics Report 778-1.

Ankudinov, V., Daggett, L., et al, 1996, “Squat Predictions for Manoeuvring Applications”, MARSIM'96, Copenhagen, Denmark, Vol.1, pp. 467-495.

Ankudinov, V.K., Jakobsen, B.K., 1999, "Squat Predictions at an Early Stage of Design", Workshop on Ship Squat in Restricted Waters, SNAME Technical and Research Bulletin.

Bailey, P. A., Price, W.G., Temarel, P., 1995, “The Dynamic Stability and Manoeuvring of a Ship in a Sea-way”, PRADS’95, Seoul, Korea, pp. 1.479-1.493.

Bailey, P. A., Price, W.G., Temarel, P., 1997, “A Unified Mathematical Model Describing the Manoeuvring of a Ship Travelling in a Seaway” Trans. RINA, W6.

Bailey, P. A., Hudson, D.A., Price, W.G., Temarel, P., 1998a, « Theoretical and Experimental Techniques for Predicting Seakeeping and Manoeuvring Ship Characteristics », International Conference on Ship Motions & Manoeuvrability, London, England, RINA.

Bailey, P. A., Hudson, D.A., Price, W.G., Temarel, P., 1998b, «The Measurement and Predicition of Fluid Action Experienced by a Manoeuvering vessel », MAN’98, Val de Reuil, France, pp. 117-123.

Barr, R. A., 1993, “A Review and Comparison of Ship Maneuvering Simulation Methods,” Transactions of the SNAME, Vol. 101. pp. 609-671.

Benvenuto, G., Carrera, G. et al, 1996, “A Dynamic Diesel Engine Model for Ship Manoeuvrability Prediction Studies”, MARIND’96, P.A. Bogdanov, Procs. Vol. III, pp. 393-404.

Berlekom, W., B., 1992, “Experimental Manoeuvring Facilities”, Hydrodynamics: Computations, Model Tests and Realty, Proceedings of MARIN Workshops, Wageningen, The Netherlands, pp. 533-537.

Bertram, V., Grollius, W., 1994, “Shallow water effects for SWATH ships.”, Ship Technology Res, Vol. 41 n° 2, pp. 55-57

Beukelman, W., 1997, “Fluid Momentum in Ship Hydrodynamics”, Ship en Werf de Zee, Vol. 7, No.3, pp. 30-36

Bigot, E., 1997, « Etude Expérimentale et numérique des efforts hydrodynamiques sur le tanker Esso Osaka », Study E1009 Report no.1 and 2, Bassin d’essais des carènes

Berth, F., Bigot, E., Laurens, J-M., 1998, « Numerical Simulation on the Esso Osaka », MAN’98, Val de Reuil, France, pp. 109-116.

Biancardi, C.G., 1997, “An Alterative Methodology for Calculating Ship Manoeuvring Coefficients at the Design Stage”, International Shipbuilding Progress, Vol. 44, No. 440, pp. 273-297.

Blendermann, W., 1995, “Estimation of Wind Loads on Ships in Wind with a Strong Gradient”, Copenhagen, Denmark, Vol. 1, PtA, pp. 271-277.

Blendermann, W., 1996, “Wind Loads of Ships – Collected Data from Wind Tunnel Tests in Uniform Flow”, Institut fuer Schiffbau der Universitaet Hamburg, Report No. 574.

Blendermann, W., 1997, “Overtaking Manoeuvres of Ships in Beam Wind”, Ship Technology Research, Vol. 44, pp. 193-197.

Blok, J.J., Quadvlieg, F.H.H.A., Toxopeus, S.L., 1998, "Computerised PMM approach for *ESSO OSAKA*", MAN’98, Val de Reuil, France, pp. 101-107.

Bogdonov, P., et al, 1987, “Esso Osaka Tanker Manoeuvrability Investigation in Deep and Shallow Water,” Intl. Shipbuilding Progress Vol. 34, No. 340.

Brizzolara, S., Grossi, L., Chislett, S., 1998, “Course Keeping Aspects in the Design of Fast Deep V Monohulls”, International Conference on Ship Motions & Manoeuvrability, London, England, RINA, Paper No.6

Caccia, M., Indiveri,G., Tiano,A., Veruggio, G., 1997, “Experimental Comparison of Identification Methods for an Open Frame ROV”, MCMC’97, Brijuni, Croatia, pp. 16.

Capurro, G., Sodomaco, P., 1996, “Applications of the Manoeuvring Prediction Program SIMSUP to Meet the New IMO Strandard », MARSIM’96, Copenhagen, Denmark, pp. 563-576.

Caux, C., Jean, P., 1996, "Neural Networks Applied on Identification of Ship Motions", MARSIM'96, Copenhagen, Denmark, pp. 577-590.

Chau, S. W., 1998, “Computation of Rudder Forces and Moment in Uniform Flow”, Ship Technology Research, Vol. 45.

Chen, M., Chen, H.C., Davis,D.A., 1996, “Numerical Simulation of Transient Flows Induced by a Berthing Ship”, ISOPE 96, Los Angeles, USA, Vol. IV, pp. 533 - 542.

Chislett, M.S., 1996, “A Generalized Math Model for Manoeuring”, MARSIM 96, Copenhagen, Denmark, pp. 593-606.

Chiu, F. C., Guo, J., Huang, C. C., Wang, J. P., 1997, “On the Linear Hydrodynamic Forces and the Manoeuvrability of an Unmanned Untethered Submersible with Streamlined Body (2nd Report: Lateral Motion)”, JSNAJ, Vol. 182, pp. 151-159.

Clarke, D., 1997, “The Shallow Water Effect on Linear Derivatives” Proceedings of MCMC’97, Brijuni, Croatia, pp. 87-92.

Clarke, D., Horn, J.R., 1997a, “Estimation of Hydrodynamic Derivatives”, 11th Ship Control System Symposium, Southampton, UK, Vol. 2, pp. 275-290.

Clarke, D., Horn, J.P., 1997b, “The Effects of Trailing vortices and Stern Design on Ship Manoeuvring”, IMDC’97, Newcastle upon Tyne, UK. Vol.1, pp. 595-608.

Copchenov, V., 1998, Communication to the ITTC Manoeuvring Committee, Krylov Shipbuilding Research Institute.

Cortellini, L., Lauro, G., 1995, “Assessment of Ship Performance Using A DGPS System”, International Seminar on Differential GPS Applications to Ship Sea Trials, Genova, Italy.

Cura Hochbaum, A., 1998, “Computation of the Turbulent Flow Around a Ship Model in Steady Turn and in Steady Oblique Motion”, 22nd Symposium on Naval Hydrodynamics, Washington, D.C., USA

Dand, I., W., 1992, “Measurement Errors and Manoeuvring Prediction”, Workshop on Prediction of Ship Manoeuvrability, Fukuoka, TWSNA, pp. 1-16.

Dand, I.W., 1999, "Prediction of squat at sub-, trans- and supercritical speeds for displacement ships in shallow water", Workshop on Ship Squat in Restricted Waters. SNAME Technical and Research Bulletin.

Dand, I., and Hood, D., 1983, "Manoeuvring Experiments Using Two Geosims of the Esso Osaka," NMI Report R 163.

Ding, Y., Min, M., 1997, "Experimental Study on Rudder Effect Decreasing of a Ship in Following Seas', (in Chinese), Shipbuilding of China, No. 138, pp. 23-27.

Dumlu, D., Istefanopulos, Y., 1995,"Design of an Adaptive Controller for Submersibles via Multi-modal Gain Scheduling.", Ocean Eng., Vol. 22, No. 6, pp. 953-975.

Eda, H., 1975, "The Mariner Model Cooperative Test Program – Correlations and Applications," Appendix V, Report of the Manoeuvrability Committee, Fourteenth ITTC, Vol. 2, pp. 414-427.

Eda, H., 1983, "Studies on Vessel Maneuvering Characteristics - Shallow Water Effects," Davidson Laboratory Report SIT-DL-79-9-2012.

Eloot, K., Vantorre, M., 1998, "Alternative Captive Manoeuvring Tests: Possibilities and Limitations", MAN'98, Val de Reuil, France, pp. 89-98.

Endo, M., Kobayachi, H., Murayama, Y., 1996, "Ability of Berthing Assisted by Joy Stick controller.", MARSIM '96,. Copenhagen, Denmark, Vol. 1, pp. 349-355.

Endo, M., Yokoi, K., Tachi, K., Kobayashi, H., Takeda, M., 1997, "Estimated Manoeuvrability of T.S. Wakashio – maru – II – Side Thruster Model Tests –" (in Japanese) JJIN, Vol. 96, pp. 185-193.

Feng, X., Miao, Q., Jiang, Q., 1996, "Prediction of Non-linear Motion Responses of a Submerged Slender body Running near Free Surface due to Wave Exciting Forces", (in Chinese), Shipbuilding of China, No. 134, pp. 29-35.

Fukuchi, A, Fukutani, T., Hori, A., Tanaka, S., 1997, "Effects of a Canvas on the Course Keeping Ability of a Small Vessel Scudding under Strong Wind", (in Japanese), JJIN, Vol. 97, pp. 183-190.

Furukawa, Y., Kijima, K., 1996, "Study on Prediction Method for Hydrodynamic Forces Acting on a Ship Hull in Sway Motion (Continued)", (in Japanese), JSNAJ, Vol. 180, pp. 235-240.

Galor, W., 1997, "The Navigation Tests of Designing the Entrance Into the Port of Leba", 2nd International Conference on Marine Technology, ODRA' 97, Szczecin, Poland.

Gong, I.., Kim, Y., Lee, C.-, Kim, J., Lee, H., 1996, "Development of harbor capability assessment simulation system by the application of fuzzy algorithm", MARSIM '96; Copenhagen, Denmark, pp. 9-13.

Gong, I.Y., Kang, C.G., Kim, Y.G., You, Y.B., Huh, D., Kim, Y.H., 1995, "The Influence of rudder Area on the Manoeuvrability of a Ship with Large Beam to Draft Ratio", PRADS'95, pp. 1.700-1.711.

Gronarz, A., 1995, "A Numerical Simulation of the Ship's Motion in Manoeuvres with Special Consideration of the Dependency of the Water Depth", (in German), Ph.D. Thesis, Gerhard Mercator Universität, Duisburg.

Gronarz, A., 1988, "Manoeuvring Behavior of a Full Ship in Water of Limited Depth," VBD (Duisburg, Germany) Report 1225.

Hamamoto, M., Enomoto, T., 1997, "Manoeuvring Performance of a Ship with Vec Twin Rudder System", JSNAJ, Vol. 181, pp. 197-204.

Hasegawa, K., Sasaki, Y., 1997, "Java-based simulation tool for ship manoeuvring", MCMC 97, Brijuni,Croatia.

Hewlett, C., 1999, "Methods for Measuring Squat in the Field", Workshop on Ship Squat in Restricted Waters. SNAME Technical and Research Bulletin.

Hilgert, H., Baldauf, M., 1996, “A common risk model for the assessment of encounter situations on board ships”, Maritime Collision and Prevention, The Hill Taylor Dickinson Seminar on Maritime Collision, Vol.2, p. 136.

Hinatsu, M., Hino, T., et al 1995, “Numerical Simulation of Flow around a Ship Hull with Rudder in Self Propulsion Condition”, (in Japanese), TWSNA, No. 90, pp. 1-10

Hirano, M., 1981, “A Practical Calculation Method of Ship Maneuvering Motion at Initial Design Stage”, Naval Architecture and Ocean Engineering (published by the Society of Naval Architects of Japan), Vol. 19, pp. 68-80.

Hirano, M., et al, 1985, “An Experimental Study on Maneuvering Hydrodynamic Forces in Shallow Water,” Transactions of WJSNA, Vol. 60.

Hirata, N., Kose, K., Takase, S., Nakamura, Y., Terada, K., Ito, R., 1997, “Applications of a Kinematic GPS to Ship Maneuvering Trials” (in Japanese), TWSNA, No. 94, pp. 111-119.

Hirayama, T., Niihara, Y., 1996, “Improvement of Transverse Stability and Manoeuvrability of Displacement Type High Speed Mono-Hull Ship by an Active Vertical Fin”, High Speed Marine Craft, No. 20, pp. 1-21.

Hirayama, T., Niihara, Y., Saito, Y., 1996a “Introduction of Anti-Rolling Active Vertical Fin and its Application to Manoeuvrability for Displacement-Type Super High Speed Ship (2nd report)” (in Japanese), JSNAJ, Vol. 180, pp. 251-262.

Hirayama, T., Niihara, Y., Nishimura, K., 1996b, “Introduction of Anti-Rolling Active Vertical Fin and its Application to Manoeuvrability for Displacement Type Super High Speed Ship”, (in Japanese), JSNAJ, Vol. 178, pp. 329 - 339.

Hiroshima, F., Miyata, H., Akimoto, H., 1997, “Design Method for Sailing Boats by CFD Performance Simulation”, (in Japanese), JSNAJ, Vol.181, pp.15-23

Hooft, J.P. & Quadvlieg, F.H.H.A., 1996. “Non-Linear Hydrodynamic Hull Forces Derived from Segmented Model Tests”, MARSIM ’96, Copenhagen, Denmark, Vol. 1. pp. 399-409.

Huff, L.C., 1999**,** "On-the-fly GPS for Vertical Control of Hydrographic Surveys", Workshop on Ship Squat in Restricted Waters. SNAME Technical and Research Bulletin.

Imazu, H., 1995, “The effect of ship's speed on collision avoidance”, FAST '95, Lubeck Travemunde, Germany. Procs, Ed by C.F.L. Kruppa. Publ by Schiffbautechnische Gesellschaft, Germany. Vol. 1, pp. 393-405.

Ishibashi, A., Kobayshi, H., Ugajin, T., 1996, “A Study on Ship Manoeuvrability Characteristics in Shallow Water On the Harbor Manoeuvring at Low Speed Range”, (in Japanese), JJIN, Vol.95, pp. 371-380.

Ishida, S., Fujiwara, T., 1995, “Measurement of Hydrodynamic Sway Force Acting on Twodimensional Models of Small Ship”, (in Japanese), JSNAJ, Vol.178, pp. 147-159.

Ishiguro, T., Tanaka, S., Yoshimura, Y., 1996, “A Study On the Accuracy of the Recent Prediction Technique of Ship’s Manoeuvrability at Early Design Stage”, MARSIM’96, Copenhagen Denmark, pp. 547-561.

Ishioka. Y., Nakamura, S., et al, 1996, “A Sutudy on a Supporting of Decision-making for Collision Avoidance in INS.”, MARSIM '96, Copenhagen, Denmark, Vol. 1, pp. 49-58.

Jakobsen, B.K., Miller, E.R., Wulder, J. H., Hensen, H., 1996, “The Simulation of Tug Operations in a Multiple Simulator Environment”, MARSIM’96, Copenhagen, Denmark, pp. 29-36.

JAMP report, 1985, “Prediction of Manoeuvrability of a Ship,” Bulletin No. 668 of JSNAME.

Jian, T., Sharma, S.D., Chen, X-N., 1995, “On the Wavemaking Resistance and Squat of

Catamaran Moving at High Speed in a Shallow Water Channel.", FAST '95, Lubeck-Travemunde, Germany. Procs. Ed by C.F.L. pp. 1313-1325.

Jiang, T., 1997, "Autonomous Oscillations and Bifurcations of a Tug-Tanker Tow.", Ship Technology Res, Vol. 44, No.1, pp. 4-13.

Jiang, T., Henn, R., Sharma, S.,D., 1998, "Dynamic Behaviour of a Tow System under an Autopilot on the Tug", MAN'98, Val de Reuil, France, pp. 183-193.

Jordan, K., 1989, Rudder Loads at Emergency Manoeuvres (Evaluation Procedure and Results)", Versuchsanstalt fuer Wasserbau und Schiffbau, Final Report, Part 1.

Jukola, H., Castleman, G.E., 1995, "Z-Drive Escort Tug Operating Modes", Marine Technology, Vol. 32, No. 3, pp. 193-196.

Kang, C-G., Kim, J-H., 1996, "Assessment of Ship Manoeuvrability Based on IMO Resolution No.A.751(18)", MARSIM'96, Copenhagen, Denmark, pp. 293-302.

Kang, C.G., Kim, Y.G., 1995, "A Prediction Method of Manoeuvrability Including the Effects of Side Profile at the Initial Design Stage", PRADS, pp. 1.629-1.637.

Kang, C.,G, Gong, I.,Y., Kim, S., Y., 1998, "The Manoeuvrability of Full Form Ships with Low Speed", MAN'98, Val de Reuil, France, pp. 165-171.

Karasuno, K., Maekawa, K., 1996, "A Componenttype Mathematical Model of Hydrodynamic Forces in Steering Motion Derived by Simplified Vortex Model", (in Japanese), JSNAJ, Vol. 179, pp. 139-151.

Karasuno, K., Maekawa, K., 1997, "A Componenttype Mathematical Model of Hydrodynamic Forces in Steering Motion Derived by Simplified Vortex Model (2) – Applied 3D Cross Flow Model ", (in Japanese), JSNAJ, Vol. 182, pp. 141-150.

Karasuno, K., Yasunaga, T., Maekawa, K., Takano, K., Januma, S., 1996, "Measurement and Analyzed Results of Hydrodynamic Forces Acting on a Ship in Oblique and Turning Motion by Means of a Very Compact Apparatus for Circular Motion Test, 1st Report"

Kataoka, H., Miyata,H., Kanai, A., 1997, "Design Method for Sailing Boats by CFD Performance Simulation (2nd Report)", (in Japanese), JSNAJ, Vol. 182, pp. 113-20.

Kijima, K., Furukawa, Y., 1995, "On a Study for Towing Method in Narrow Water"(in Japanese), TWSNA, Vol. 89, pp. 167-172.

Kijima, K., Nakira, Y. et al, 1995, "On a study for influence of loading condition on a prediction of ship manoeuvrability" (in Japanese), TWSNA, No. 89, pp. 155-166.

Kijima, K., Furukawa, Y., Tsukamoto, K., 1995a, "Study on Prediction Method for Hydrodynamic Force Acting on a Ship Hull in Swaying Motion", (in Japanese), JSNAJ, Vol. 178, pp. 273-280.

Kijima, K., Yukawa, K., Maekawa, K., 1995b, "An Estimation of Hydrodynamic Forces Acting on a Ship Hull in Oblique Motion", (in Japanese), TWSNA, No. 90, pp. 115-125.

Kijima, K., Yukawa, K., Maekawa, K., 1996a, "An Estimation of Hydrodynamic Forces Acting on a Ship Hull in Oblique Motion (continued)", (in Japanese), TWSNA, No. 91, pp. 95-106.

Kijima, K., Yukawa, K., Maekawa, K., 1996b, "An Estimation of Hydrodynamic Forces Acting on a Ship Hull in Turning Motion", (in Japanese), TWSNA, No. 92, pp. 105-116.

Kijima, K., 1997, "Prediction Method for Ships Manoeuvring Motion in the Proximity of a Pier", Ship Technology Research, Vol.44, No.1, pp. 22-31.

Kijima, K., Furukawa, Y., Eshiwa, M., Yamamoto, K., 1997, "Influence of Roll Motion on Ship Manoeuvrability", (in Japanese), TWSNA, No. 93, pp. 35-46.

Kijima, K., Furukawa, Y., 1998, “Effect on roll motion on manoeuvrability of ship”, MAN’98, Val de Reuil, France, pp. 157-163

Kim, C.K., Rhee, K.P., 1996, “Estimation of Manoeuvring Coefficients of a Submerged Body Using Parameter Identification Techniques”, Journal of the Hydrospace Technology, Vol. 2, No. 2, pp. 24-35.

Klosinski, W.E., Lewandowski, E.M., 1993, “Systematic Series Model Tests”, Technical Report SITDL9392689, Davidson Laboratory, Stevens Institute of technology, USA.

Knowles, J., Grosenbaugh, M., Keenan, D., 1996, “Numerical Simulation of an AUV Thruster during Manoeuvring”, ISOPE’96, Los Angles, USA. Vol. 2, pp. 247-250.

Kobayashi, E., 1995, “The development of practical simulation system to evaluate ship manoeuvrability in shallow water”, PRADS 95, pp. 1712-1723

Kobayashi, H., Arai,, Y. et al, 1995 “A study on the manoeuvrability of a high-speed boat” (in Japanese), JKSNA, No. 223, pp. 81-89.

Kobayashi, H., Ishibashi, A., et al, 1994, “A study on a mathematical model for the manoeuvring motions of a twin propeller and twin rudder ship” (in Japanese), JJIN, Vol. 91, pp. 263-270.

Kodan, N., Yamasaki, K., et al, 1996, Prediction Procedure of Ship Manoeuvrability in Consideration with Hull Forms”, NKK Technical Review, No. 75, pp. 37-40.

Kose, K., Kobayashi, H., et al, 1995b, “A study on a supproting procedure for collision avoidance in INS.”, JSNAJ, Vol. 177, pp. 409-418.

Kose, K., Mislag, W.A., Hashizume, Y., Nogami, S., Ishioka, Y., 1995a, “A Practical Approach To The Mathematical Model of Ship Maneuvering In Harbours”, Ship Maneuvering Symposium - Ilawa’ 95, Poland.

Kose, K., Mislag, W.A., Xiong, X.M., 1996, “Systematic Approach for Ship Manoeuvrability Prediction”, MARSIM’96, Copenhagen, Denmark, pp. 535-545.

Kose, K., Xiong, X.M., Mislag, W.A., 1997, “A New Prediction Approach for Ship Manoeuvring Hydrodynamics”, TWSNA, No. 93, pp. 47-61.

Kreibel, D., Zieleski, J., 1990, “Evaluation of Viscous Damping Models for Single-Point Mooring Simulations » US Naval Academy Report, July 1990.

Kristensen, H. O., 1998, “The Manoeuvrability of Double-Ended Ferries Design, Considerations, Construction and Service Experience” International Conference on Ship Motions and Manoeuvrability, London.

Kulczyk, J., Tabaczek, T., 1995, “Calculation of Influence of Propeller Slipstream on Marine Rudder Performance”, Ship Manoeuvring Symposium, Ilawa, Poland, Vol. 1, pp. 164-168 .

Kwik, K.H., 1996, “Mathematical calculation of collision avoidance.”, Maritime Collision and Prevention, The Hill Taylor Dickinson Seminar on Maritime Collision; Dalian, China. Procs. Publ by Chiavari Publishing, UK, ISBN 09520592 4x. Vol. 2, pp. 99-115.

Laforce, E., Claeyssens, P., Vantorre, M., 1996, “Influence of the Ship’s Length on the Manoeuvrability in a Canal”, Proceedings of 11th International Harbor Congress, Antwerpen, Belgium, pp .523-534.

Laforce, E., Vantorre, M., 1996, “Experimental determination and modelling of restricted water effects on bulk carriers”, MARSIM 96, Copenhagen, Denmark, pp. 451-464.

Laible, D.H., Gray, D.L., 1997, “Escort tug computer simulation - standards and advances”, Tug & Salvage Convention, Seattle, Washington, USA 1996, Thomas Reed Publications, pp. 201-208.

Landrini, M., Campana, E.F., 1996, “Steady Waves and Forces About a Yawing Flat Plate”, JSR, Vol. 40, No. 3, pp. 179-192.

Lech, R., 1998, Communication to the ITTC Manoeuvring Committee - “Model Test of Esso Osaka,” Centrum Techniki Okretowek, Gdansk, Poland.

Lee, H.Y., Shin, S.S., 1998, ”The prediction of ship’s manoeuvring performance in initial design stage”, Practical Design of Ships and Mobile Units, The Netherlands.

Lee, S.K., Kim, Y.S., Lee, S.J., 1996, “Research on the Prediction of Maneuvring Motion for a Twin-Screw Twin-Rudder Ship” (in Japanese), JSNAK, Vol. 33, No. 4, pp. 60-65.

Lewandowski, E.M., 1997, “Transverse Lee, H.Y., Yum, D.J., Shin, S.S., Lee, T.I., 1997, “Prediction of Manoeuvrability using PMM Model Tests - Comparative Study of Mathematical Models” (in Korean), JSNAK, Vol. 34, No. 2, pp. 48-55.

Dynamic Stability of Planing Craft”, Marine Technology, Vol. 34, No. 2, pp. 109-118.

Lewandowski, E.M., Klosinski, W.E., 1992, “Rotating Arm and Linear Towing Tank Tests on a Mariner Model”, Technical Report SITDL9292679, Davidson Laboratory, Stevens Institute of Technology, USA.

Li, D.Q., Dyne G., 1995, “Study of Propeller Rudder Interaction based on a Linear Method”, International Shipbuilding Progress, Vol. 42, No. 431, pp. 235-257.

Li, T., 1997, “Calculation of manoeuvring index and frequency characteristics for submersible” (in Chinese) Shipbuilding of China, No. 136, pp. 15-24.

Lisowski, J., Mohamed-Seghir, M., 1996, “Ship's optimum safe trajectory in a collison situation of passing many moving targets in fuzzy environment.”, Polish Maritime Res, Vol. 3, No. 4, pp. 29-32.

Liu, Z.Y., Zhang, X.D., Wu, X.H, 1996, “Calculation of Manoeuvring Hydrodynamic Force including the Effect of Viscosity”, MARSIM’96, Copenhagen, Denmark, pp. 419-424.

Logan, K.P., 1995, “Neural network-based autopilot for tanker conning.”, Sea Technology, Vol. 36, No. 4, pp. 51-54.

Longo, J, and Stern, F. , 1997, « Yaw effects on Model-Scale Ship Flow », Twenty-First Symposium on Naval Hydrodynamics, Trondheim, Norway, pp. 312-327.

Makino, M., Kodama, Y., 1997, “Computation of Flows around Full Hull Forms in Oblique Towing or Steady Turning Using NICE Code”, (in Japanese), JSNAJ, Vol. 181, pp. 67-73.

McDonald, H. and Whitfield, D. 1997, « Self-propelled Manoeuvring Underwater Vehicles », 21st Symposium on Naval Hydrodynamics, Trodheim, Norway, pp. 478-489.

Milgram, J., 1995, “Extreme Tensions in Open Ocean Towing”, Journal of Ship Research, SNAME, Vol. 39, No. 4, pp. 328-346.

Miller, E., and Ankudinov, V., 1980, “Model Test and Simulation Study Based on the Full Scale “Esso Osaka”Maneuvering Trial,“ Hydronautics Report 8007-1.

Millward, A., 1996, “A review of the prediction of squat in shallow water.”, JJIN, Vol. 49, No. 1, pp. 77-89.

Molland, A.F., Turnock, S.R., 1995, “Some Effects of Rudder-Propeller-Hull Arrangements on Manoeuvring and Propulsion”, PRADS’95, Seoul, Korea, pp. 1.333-1.345.

Molland, A.F., Turnock, S.R., Wilson, P.A., 1996, “Performance of an enhanced rudder force prediction model in a ship manoeuvring simulator”, MARSIM 96, Copenhagen, Denmark, pp. 425-434.

Molland, A.F., Turnock, S.R., 1996, “A Compact Computation Method for Predicting Forces on a Rudder in a Propeller Slipstream”, RINA, Spring Meeting, London, Paper No. 2.

Molland, A.F., Turnock, S.R., 1998, “The Effect of the hull on the Manoeuvring Performance of Rudders”, International Conference on Ship Motion & Manoeuvrability, London, RINA, Paper No. 8.

Nakao, I., Iseki, T., Ohtsu, K., 1995, “The Effect of Heading Angle on Ship Manoeuvring in Confined Water”, (in Japanese), JJIN, Vol. 93, pp. 171-178.

Nakatake, K., Yoshitake, A., Shimomichi,Y., Yamamoto, T., 1995, ”Measurement of Wake Distributions Behind Ships with Yaw Angle”, (in Japanese), TWSNA, No. 90, pp 11-20.

Nakatake, K., Ando,J., Ohmori, T., Kataoka, K., 1996a, “A Method to Calculate Interaction Forces during Rudder Angle Tests”, (in Japanese), TWSNA, No. 91, pp. 71-80.

Nakatake, K., Oda, K., Yoshitake,A., Fujita, K., Nakajima, A., 1996b, “Experimental Study on Interaction Forces during Rudder Angle Test”, (in Japanese), TWSNA, No. 92, pp.95-103.

Nakatake, K., Ando, J., Yoshitake, A., Hashimoto, K., 1997, “Hull Propeller Rudder Interactions during Rudder Angle Test”, International Conference, NAV & HSMV’97, SorrentoHotel Cocumella, pp. 361-368.

Nakatake, K., Ando, J., Maita, S., Yamamoto, T., 1998, “Prediction of Forces Acting on Ship with Different Afterbody Shapes in Oblique Towing”, MAN’98, Val de Reuil, France, pp. 173-180.

Nakatani, T., Ohtsu, K., et al, 1996, “A study on automatic turning of ship's PID regulators.”, JSNAJ, Vol. 179, pp. 231-238.

Nonaka, K, Nimura, T., Haraguchi, Ueno, M., 1996, “Measurements of Stern Flow Field of a Ship in Oblique Towing Motion”, MARSIM’96, Copenhagen, Denmark, pp. 389-398.

Norrbin, N. H., 1998, “ On the stopping of ships, including the proposal for a new standards for the crash-stop-astern capabilities”, Proc. International Conference on Ship Motions & Manoeuvrability, London, pp.

Norrbin, N.H., 1999**,** "The effects of flow confinement and asymmetry on a ship in a fairway passage", Workshop on Ship Squat in Restricted Waters. SNAME Technical and Research Bulletin**.**

Norrbin, N.H., 1996, “Further notes on the dynamic stability parameter and the prediction of manoeuvring characteristics”, MARSIM’96, Copenhagen, Denmark, A.A. Balkema, Rotterdam, Netherlands, pp. 527-531.

Oda, K., Yamashita, S., Ichinose, T., Nakatake, K., 1996, “On Normal Force and Drag of Mariner Rudder”, (in Japanese), TWSNA, No. 91, pp. 15-23.

Ogawa, A., et al, 1977, “Report on MMG, I, Mathematical Models of Manoeuvring Motions,” Bulletin No. 575, SNAJ.

Ogawara, Y., Iwamoto, S. Yoshimura, G., 1995, “Basic study on the compensation control system of the wind disturbance influence to the ship manoeuvring motion with the learning feed-forward control”, JSNAJ, Vol. 178, pp. 321-329.

Ohmori, T., 1998, “A Study on Hydrodynamic Characteristics of a Manoeuvring Ship in Shallow Water by a FiniteVolume Method”, MAN’98, Val de Reuil, France, pp. 15-20.

Ohmori.T., Fujino, M., Tatsumi, K., Kawamura, T., Miyata, H., 1996, “A Study on Flow Field Around Full Ship Forms in Manoeuvring Motion (3rd Report: Flow Field Around Ship’s Hull in Steady Turning Condition)”, (in Japanese), JSNAJ, Vol. 179, pp. 125-138.

Okamoto, H., Tamai, H., Oniki, H., 1972, “Correlation Studies on Manoeuvrability of Full Ships” (in Japanese), JSNAJ, Vol. 131, pp. 189-202.

Oltmann, P. , 1998, « Reflections on the Assessement of the Manoeuvring Behavior of Ships », International Conference on Ship Motions & Manoeuvrability, London, England, RINA, Paper No. 10.

Oltmann, P. , 1996, “On the influence of speed on the manoeuvring behaviour of a container carrier”, MARSIM’96, Copenhagen, Denmark, pp. 527-531.

Oltmann, P., Wolff, K., Muller, E., Baumgarten, B., 1986, “On the Correlation between Model and Full-Scale Ship for Manoeuvring Tests in Deep and Shallow Waters” (in German), Jahrbuch STG, Vol. 80, pp. 217-245.

Pawlowski, J.S., 1996, “Hydrodynamic modelling for ship manoeuvring simulation”, MARSIM’96, Copenhagen, Denmark, A.A. Balkema, Rotterdam, Netherlands, pp. 625-634.

Plante, M., Toxopeus,S. , Blok, J., Keuning, A. 1998, « Hydrodynamic manoeuvering aspects of planing craft », MAN’98, Val de Reuil, France, pp. 147-155.

Perdon, P., 1998, "Rotating arm manoeuvring test and simulation for waterjet propelled vessels", MAN’98,Val de Reuil, France, pp.41-46.

PIANC/IAPH, 1997, "Approach Channels - A Guide for Design", PTC II-30:Final report of joint Working Group PIANC-IAPH II, in cooperation with IMPA and IALA, Supplement to PIANC Bulletin No. 95.

Pinziy,B., Ba, M., Guilbaud, M., 1995, “Hydrodynamic Force Computations on Yawed and Surfacepiercing Bodies”, ISOPE’95, The Hague, The Netherlands, Vol. 3, pp. 308-313.

Pourzanjani, M., “A Study of collision avoidance vehaviour, using a PC based simulator.”, Maritime Collision and Prevention, The Hill Taylor Dickinson Seminar on Maritime Collision, Dalian, China. Procs. Publ by Chiavari Publishing, UK, pp .50-60.

Queensland Transport, 1996, “Queensland Transport Transport Technology Kivision - Document No R-007 Squat measurements in the Port of Cairns”, BOOK ; Queensland Transport Place: Queensland, Australia Format: REPORT

Raestad, A., E., 1996, “A Classification Society’s Experience with IMO Resolution No.A.751(18)”, MARSIM’96, Copenhagen, Denmark, pp. 309-318.

Rhee, K.-P., Lee, S.Y., Sung, Y.J., 1998, "Estimation of manoeuvring coefficients from PMM test by genetic algorithm", MAN’98, Val de Reuil, France, pp.77-87.

Roseman, D., 1987, <u>The MARAD Systematic Series of Full-Form Ship Models</u>, The SNAME, New York.

Rossignol, G., 1995, "Outdoor radio-controlled maneuvering experiments", 24th ATTC, Session 9, pp. 323-330.

Rooij, h. van, 1996, “OPA ’90 - response or prevention ? The European perspective”, Tug & Salvage Convention, Seattle, Washington, USA, Thomas Reed Publications, pp. 209-212.

Sadakane, H., 1996, “A Study on Lateral Drag Coefficient for Ship Moving Laterally from Rest”, (in Japanese), JJIN, Vol. 95, pp 193-200.

Sahin, I., Crane, J.W., Watson, K.P., 1997, “Application of a Panel Method to Hydrodynamics of Underwater Vehicles”, Ocean Engineering, Vol. 24, No. 6, pp. 501-512.

Sato, S., Nakamura, I., Takagi, M., Jono, T., Yamada, K., Hikino, M., Takai, T., Yao, H., 1973, “On a Study of Ship-Controllability of a Wide-Beam Tanker” (in Japanese), JSNAJ, Vol. 134, pp. 205-222.

Sato, T., Izumi, K., Miyata, H., 1998, “Numerical Simulation of Maneuvering Motion”, 22nd Symposium on Naval Hydrodynamics, Washington, D.C., USA.

Shiraka, A., 1997, Communication to ITTC Manoeuvring Committee, “Collection of the Manoeuvring Model Test Data on the Esso Osaka, NKK Corporation.

Schmidli, C., 1996, “Reducing the stopping distance of deep sea vessels”, Institute für Schiffbau der Universität Hamburg, Report No. 562.

Sedat, R., Fuller, N., 1995, "U.S. Coast Guard Modular Model Manoeuvring Tests", 24th ATTC, Session 9, pp. 309-315.

Shigehiro, R., Ueda, K., Arii, T., 1996, "Course Stability of the High-Speed-Towed Fish Preserve" (in Japanese), JKSNA, No. 227, pp. 79-87.

Shigehiro, R., Ueda, K., Arii, T., Nakayama, H.,1997, "Course Stability of the High-Speed-Towed Fish Preserve with Wind Effect" (in Japanese), JKSNA, No. 228, pp 167-174.

Sohn, K.H., Lee, G.W., Kim, H.S., Kim, Y.S., Ha, M.K., 1996, "A study on the Effect of Rudder Area with Reference to Changes in Span Distance on Course Stability of a Ship" (in Korean), Transactions of the SNAK, Vol. 33, **No**

Sowdon, A., 1996, "CFD Computations of Hydrodynamic Forces Acting on Full Hull Forms in Oblique Tow", Ship Research Institute Japan Papers, Vol. 33, No. 1, pp. 1-34.

Spyrou, K., 1995, "Yaw stability of ships in steady wind", Ship Technology Research, Vol. 42, No. 1, pp. 21-30.

Spyrou, K., 1996, "Dynamic Instability in Quartering Seas: The behavior of a Ship During Broaching", Journal of Ship Research, SNAME, Vol. 40, No. 1, pp. 46-59.

Spyrou, K., 1997, "Dynamic Instability in Quartering Seas- part III: non-linear effects on periodic motion", Journal of Ship Research, SNAME, Vol. 41, No. 3, pp. 210-225.

Stenson, R., J., 1995, "Use of the Global Positioning System for the Conduct of US Navy Performance and Special Trials", International Seminar on Differential GPS Applications to Ship Sea Trials, Genova, Italy.

Sutton, R., Marsden, G.D., 1997, "A fuzzy autopilot optimized using a genetic algorithm.", JJIN, Vol. 50, No. 1, pp. 120-132.

Sutton, R., Taylor, S.D.H. Roberts, G.N., 1996, "Neuro-fuzzy techniques applied to a ship autopilot design.", JJIN, Vol. 49, No. 3, pp. 410-431.

Sutulo, S., Kim, S.Y., 1998, "Systematic approach to PMM/rotating arm experiment planning, parameter estimation, and uncertainty analysis", MAN'98, Val de Reuil, France, pp. 57-67.

Sutulo, S., Kim, Y.-G., 1997, "Structure of Mathematical Model for Description of Hydrodynamic Forces and Moments Acting Upon the Hull of a Submersible in Arbitrary 3D Manoeuvring Motion", Proceeding of the Annual Spring Meeting, SNAK, Chinhae 1997.

Suzuki, H., Ichihawa, M., et al, 1996, "Computation of a Flow Field around a Rudder behind a Propeller", (in Japanese), JKSNA, No. 225, pp. 15-24.

Suzuki, K., Yoshihara, A., 1995, "Computation of Hydrodynamic Forces Acting on Sailing Yacht by Means of Surface Panel Method", (in Japanese), JSNAJ, Vol. 178, pp. 113-124.

Suzuki, O., Nakamura, T., Namie, H., Yasuda, A., 1998, "Real Time Anchor Watch by GPS" (in Japanese), JJIN, Vol. 98, pp. 25-32.

Tachi, K., Endo, M., 1996, "Estimated Manoeuvrability of T.S. Wakashiomaru Wind Tunnel Test and Rudder Open Test", (in Japanese), JJIN, Vol. 94, pp. 17-26.

Tahara, Y., 1995, "Computation of Boundarylayer and Wake Flows around IACC Sailing Yacht For a Canoe Body Case ", JKSNA, No. 224, pp. 1-11

Tahara, Y., Longo, J., Stern, F., Himeno, Y., 1998, "Comparison of CFD and EFD for the Series 60 Cb=0.6 in Steady Yaw Motion", 22nd Symposium on Naval Hydrodynamics, Washington, D.C., USA

Tahara,Y., 1996, "A Multi-Domain Method for Calculating Boundary layer and Wake

Flows around IACC Sailing Yacht", JKSNA, No. 226, pp. 63-76.

Takahashi, H., Hagiwara, H., et al, 1996, "Study on support systems of entering a port for techno super liner.", JJIN, Vol. 95, pp. 71-79.

Takano, K., Thamby, A., Karasuno, K., Maekawa, V., Jyanuma, S., 1995, "Fundamental Study by Experiment on Ship Hydrodynamic Forces in Oblique Motion Affected by Bow and Stem Shape", (in Japanese), JKSNA, No. 224, pp. 59-67.

Takase, S., Kose, K., Hirata, N., Furumoto, M., Minh, L-M., Yamada, T., 1997, "Accuracy and Application for Measurement of Ship Motion by Kinematic GPS" (in Japanese), JJIN, Vol. 97, pp. 15-22.

Tamashima, M., Yang, J.M., Matsui, S., Yamazaki, R., 1995, "The Performance of PropellerRudder System with Rudder Angle", Proceedings of PRADS'95, Seoul, Korea, Vol. 1, pp. 1.321-1.332

Tanaka, S., 1996, "On Hydrodynamic Forces Acting on a Ship at Large Drift Angles", (in Japanese), TWSNA, No. 91, pp. 81-94.

Tanaka, S., 1998, "On Hydrodynamic Forces Acting on a Ship Moving with Large Drift Angles, MAN'98, Val de Reuil, France, pp. 31-38.

Trägårdh, P., 1998, "Manoeuvring of a twin screw tanker including engine and rudder failure modes", Symposium on forces acting on a manoeuvring vessel, Val de Reuil, France.

Ueno, M., Nimura, T., Fujiwara, T., Nonaka, K., 1997, "Evaluation of RTK-OTF Positioning System for Free Running Manoeuvrability Test of a Model Ship" (in Japanese), JKSNA, No. 228, pp. 113-121.

Vantorre, M. ,Eloot, K., 1996, "Hydrodynamic phenomena affecting manoeuvres at low speed in shallow navigation areas", 11th International Harbour Congres, Antwerpen, Belgium, pp 535-546.

Vantorre, M., 1999a, "A review of practical methods for prediction of squat", Workshop on Ship Squat in Restricted Waters. SNAME Technical and Research Bulletin.

Vantorre, M., 1999b, "Influence of fluid mud layers on squat effects", Workshop on Ship Squat in Restricted Waters. SNAME Technical and Research Bulletin.

Vantorre, M., Eloot, K., 1997, "Requirements for standard harmonic captive manoeuvring tests", MCMC'97, Brijuni, Croatia, pp. 93-98.

Varyani, K. S., Incecik,A., Hannah, S., 1995, "Manoeuvring Simulations of British Bombadier, Mariner and Frigate Forms," Report NAOE-95-19, and "Shallow Water Manoeuvring Simulation of ESSO OSAKA and BRITISH BOMBADIER," Report NAOE-95-3, University of Glasgow.

Varyani, K.S., Hamoudi, B., McGregor, R., 1997, "Interactive Forces between Three Ships in a Restricted Waterway", Proceedings of MCMC'97, Brijuni, Croatia, pp. 127-133.

Vassalos, D., Park, S.H., Lee, B.S., 1995, "Developing a manoeuvring design capability for naval vessels", PRADS'95, pp. 1616-1628.

Wang, D., Zhu, S., Jia, X., 1996, "Design and research on an intelligent collision avoidance system.", Maritime Collision and Prevention, The Hill Taylor Dickinson Seminar on Maritime Collision; Dalian, China. Procs. Publ by Chiavari Publishing, Vol. 2, pp.182-191.

Wang, G. Jiang, S., Yang, C., 1994, "On Propusive Performance of Propeller and Rudder System", Selected Papers of the Chinese Society of Naval Architects and Marine Engineers, Vol. 9, pp. 13-31.

Wellicome, J.F., Wilson, P.A., Cheng, X., 1995, "Prediction of Sway Force and Yaw Moment on Slender Ships", International Shipbuilding Progress, Vol. 42, No. 431, pp. 259-276.

Xiong, X.M., Kose, K., 1996, “A Study on Numerical Methods for the Manoeuvring Hydrodynamics Based on the Slender Body Theory”, TWSNA, No. 91, pp. 61-70.

Xiong, X.M., Wu, X.H., 1996, “A Study on Manoeuvring Hydrodynamic Forces Acting on 3D ShipHulls with Free Surface Effect in Restricted Water”, International Shipbuilding Progress, Vol. 43, No. 433, pp. 48-69.

Yamano, T, Saito, Y, 1997, “An Estimation Method of Wind Forces Acting on Ships” (in Japanese), JKSNA, No. 228, pp. 91-100.

Yang, Y., 1996, “Study on ship manoeuvring mathematical model in ship handling simulator”, MARSIM’96, Copenhagen, Denmark, pp. 607-614.

Yang, Y., Fang, X., 1998, “Simulation model of ship manoeuvring motion in uneven current and it’s application”, Shipbuilding of China, No. 1 (Serial No. 140),(In Chinese).

Yasukawa, H., Yoshimura, Y., Nakatake, K., 1996, “Hydrodynamic Forces on a Ship Moving with Constant Rudder Angle”, MARSIM’96, Copenhagen, Denmark, pp. 435-447.

Yasukawa, H. 1997, “Manoeuvring Response of a Slender Ship with Sinusoidal Steering in Shallow Water”, (in Japanese), TWSNA, No. 94, pp. 89-99.

Yasukawa, H. 1998, “Computation of Effective Rudder Forces of a Ship in Shallow Water”, MAN’98, Val de Reuil, France, pp. 125-133.

Yoshimura, Y., Sasaki, H., Takekawa,, M., 1997 “Prediction of Ship Manoeuvrability with a Flapped Rudder” (in Japanese), JSNAJ, Vol. 181, pp. 191-196.

Youn, Y-P., Kim, Y-S., 1997, “The Measurement and Analysis of Manoeuvrability at Sea Trial” (in Korean), Annual Spring Meeting, SNAK, pp. 257-260.

Yum, D-J., Le, T-I., Lee, H-Y., Lee, H-W., 1996, “New Manoeuvring Sea Trials system Using DGPS”, MARSIM’96, Copenhagen, Denmark, pp. 333-340.

Yumuro, A., Yamamoto, K., 1992, “An Experimental Study on Scale Effect on Direction of Flow Behind Ship Hulls Moving Obliquely” (in Japanese), JKSNA, No. 217, pp. 137-143.

Yumuro, A., 1995, “Manoeuvring Hydrodynamic Forces Calculated Using Circulation Retention Characteristics”, (in Japanese), JKSNA, No. 224, pp. 69-76.

Yumuro, A., 1996, “An Approximate Calculation Method for Manoeuvring Hydrodynamic Forces on Ship Hulls in a Narrow Water Channel”, (in Japanese), JKSNA, No. 225, pp. 133-139.

Yumuro, A., 1997, “An Approximatie Calculation Method for Manoeuvring Hydrodynamic Forces on a Ship Hull with Heel Angle”, (in Japanese), JKSNA, No. 228, pp. 137-142.

Zec, D., 1996, “An algorithm for a real-time detection of encounter situations”, JJIN, Vol. 49, No. 1, p. 121.

Zhang, J.W., Andrews, D., 1998, “Manoeuvrability Performance of a Trimaran Ship”, International Conference on High Speed Craft Motions & Manoeuvrability, London, RINA, Paper No. 9.

Zhang, R., Sun, Z., Xu, H., 1996, “On the application of a novel control scheme to ship steering”, Intl Shipbuilding Progress, Vol. 43, No. 434, pp.167-185.

Zhang, R., Sun, Z., Xu, H., 1997, “Robust autopilot design for ship steering in waves”, Intl Shipbuilding Progress, Vol. 44, No. 437, pp. 59-75.

Zhu, S.L., Tang, Z.G., 1995, “An Experimental Study of Circulation Controlled Rudder with Grooves at After-body”, (in Chinese), Ship Engineering, No. 1, pp. 8-11.

Zhu, S.L., Wang,X.F., 1996, “Experimental Investigation of a High-Lift Rudder – Circulation Control Rudder”, International

Shipbuilding Progress, Vol. 43, No. 436, pp. 347-357.

Zou, Z.J., 1996, “Hydrodynamic Forces on a Surfacepiercing Plate in Steady Manoeuvring Motion”, Proceedings of 21st Symposium on Naval Hydrodynamics, Trondheimn Norway, pp. 986-995.

Zou, Z.J., Soeding, H., 1995, “A 3D Numerical Method for Hydrodynamic Forces on a Plate in Manoeuvring Motion”, Ship Maneuvering Symposium, Ilawa, Poland, pp. 21-38.

Zou, Zao-Jian, 1998, Communication to the ITTC Manoeuvring Committee - “New Calculation Results of ESSO OSAKA,” Wuhan University

Zuev, V.A., Lukomsky, J.A., Miroshnikov, A.N., 1996, “Impulsive course-keeping autopilot for unstable ships.”, MARIND'96, Varna, Bulgaria.

Abbreviation of Journal, Transaction and Conference

- JJIN: Journal of Japan Institution of Navigation
- JKSNA: Journal of Kansai Society of Naval Architects
- JSNAJ: Journal of the Society of Naval Architects of Japan
- TWSNA: Transaction of the West-Japan Society of Naval Architects
- JSR : Journal of Ship Research edited by SNAME
- MARSIM’96: Marine Simulation and Ship Manoeuvrability Symposium, Ed. S. Chislett, A.A. Balkema, Rotterdam, Netherlands.
- MAN’98 : Symposium and Workshop on Forces Acting on a Manoeuvring Vessel. Ed. S. Cordier, Bassin d’essais des carènes, Val de Reuil, France.
- RINA : Royal Institute of Naval Architects

The Manoeuvring Committee

Committee Chair: Dr. Stéphane Cordier
(Bassin d'essais des carènes)
Session Chair: Prof. Robert F. Beck (Univ. of Michigan)

I Discussions

Contribution to the Discussion of the Report of the 22nd ITTC Manoeuvring Committee

by Dr. Yum and Dr. Lee, HHI.

Congratulate the Manoeuvring Committee for the well organized and comprehensive report. When manoeuvring sea trials are carried out under the influence of apparently strong environmental effects such as wave, wind and current, the corrections of the results are necessary in order to get the results of calm sea condition.

For turning circle tests, IMO's Resolution A751 "Interim Standards for Ship Manoeuvrability" recommended a correction method for wind and current. Except the fact that the tests should be carried out up to at least 540 degrees, the method is very simple, straightforward and, most of all, has been known to give reasonable results. Fig 1 shows the turning test results before and after the correction of environmental effects for large bulk carrier.

But the situation for Zig-Zag tests is quite different. There is no well known correction method for Zig-Zag test even though the environmental conditions can give large discrepancies in the test results. Table 1 shows 10o/10o Zig-Zag sea trial results for medium size product carrier. Depending on the directions of wind and current, both the 1st and 2nd overshoot angles can be quite different. Big differences are also noticed depending on the initial directions of rudder execution.

Considering not only the facts that IMO's criteria is quantitative one and will be a mandatory requirements in a near future but that the sea trial results are the source of validation for the theoretical and experimental study, a well confirmed correction method for Zig-Zag manoeuvr hope to be made by ITTC community.

Fig. 1 Turning Test Results for Bulk Carrier

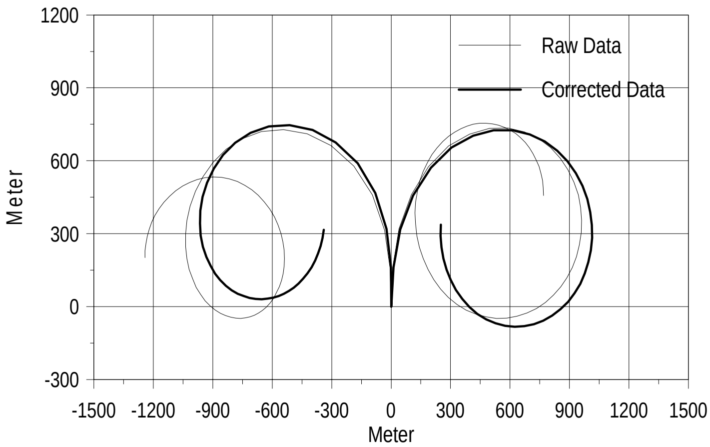

Table 1 10o/10o Zig-Zag Test Results of Product Carrier

Initial heading of the vessel (deg)	10	110	270	IMO Criteria
Currents	10 deg. , 1～2 knots			
Wind direction (deg)	310	290	300	
Wind speed (m/s)	10 ～ 15			
1st overshoot angle (deg)*	9.2 / 23.1	6.1 / 17.1	19.9 / 4.3	16.2
2nd overshoot angle (deg)*	39.6 / 20.6	37.5 / 22.9	9.3 / 21.2	31.2

* Overshoot angles with initial rudder execution to starboard/port sides

Contribution to the Discussion of the Report of the 22nd ITTC Manoeuvring Committee

by Dr. Mehmet, SVA, Potsdam

Congratulation to the manoeuvring committee for their well done job. When I remember, my old professor had divided manoeuvring of ships in two items :

Dynamic yaw stability and steering ability

1. Can you make some remarks to the first item from your experience, because I missed it in your report.
2. In connection with IMO standard I do miss some comments to the ability of ships to go on a straight course.
3. Did you find any information in the materials of Ship Research Institute of Japan to this matter? What is the connection of the fulfilling the standard and the dynamic yaw stability.
4. In my opinion, it is necessary to deal with this problem in future.

Contribution to the Discussion of the Report of the 22nd ITTC Manoeuvring Committee

by Prof. Kijima, Kyushu University.
(not available)

II Committee Replies

Reply of ITTC Manoeuvring Committee to Dr. Yum and Dr. Lee

The manoeuvring committee thanks Dr. Yum and Dr. Lee for their discussion note which the committee finds very relevant.
The committee is in total agreement with your comment. It is a problem that a quantitavie criteria like the overshoot angles in the 10-10 zig-zag is difficult to measure. It is well known that the 10-10 zig-zag manoeuvre is the most difficult one to predict compared with the other IMO manoeuvres. The reason is that very small rudder forces are controlling the kull forces, which is a very sensitive balance.

The committee does not see any clear and straight forward solution to this problem. As can be seen from your table 1, the wind varied from 10 to 15 m/s which corresponds to a factor of two considering the wind forces which makes even more difficult.

Until such a method is developed the committee can only suggest to build a simulation model of the ship. Use the simulation model to repeat the executed trials including the environmental conditions and obtain some sort of correlation between trials and simulations. Then simulate the required manoeuvres without wind and current to get the result.

Since the manoeuvring trials are coming back into the manoeuvring committee for the 23rd ITTC this matter is certainly something that the next committee will have to look into.

Reply of ITTC Manoeuvring Committee to Dr. Mehmel

The committee thanks Dr. M. Mehmel for his written discussion.

Regarding the first discussion, general features of the course keeping ability (« dynamic yaw stability » in this discussion) are not described in our report because of the nature of ITTC technical committee report. Comments for the course keeping ability are made in the part needed only, for instance the discussion on scale effects on the course keeping ability in the free running model test and so on.

With respect to the course keeping ability in IMO Manoeuvring Interim Standard, we have three criteria with the use of each three indices, name by the first overshoot angle in 10°/10° zig-zag manoeuvre (abbreviated as « Z »), the second overshoot angle in 20°/20° Z. Among them, it is generally understood that the course keeping ability may well be represented by the first index of the first overshoot angle in 10°/10° Z.

Regarding the third point, as described in chapter 2, the panel of RR74 is organised by Japan Shipbuilding Research Association in order to review and evaluate the IMO Manoeuvring Interim Standard. A database of manoeuvring full scale trials has been developed at Ship Research Institute of Japan through RR74 activities. Based on the extensive study with use of the database, Japanese Government has submitted a proposal to discuss matters relating to the standard (focusing on the adequacy of criteria for the course keeping ability) to MSC of IMO in May in 1999. We hope that the work to review and evaluate the Standard will start at DE of IMO from next year.

Finally we agree the Dr. M. Mehmel's view of the necessity to deal with the problem relating to the criteria for the course keeping ability in the future work.

Reply of ITTC Manoeuvring Committee to Prof. Kijima

The committee thanks Prof. Kijima for his comment on stern shape parameter.
IMO Standards for Ship Manoeuvring Performance let the shipyards to prepare the design tools which can predict ship manoeuvring performance at design stage.

The modular type models of manoeuvring motions proposed by Mathematical Modeling Group in Japan are now widely used in the design offices of shipyards. One reason this was done was to simplicity in predicting the hydrodynamic coefficients using empirical formulae without experiments.

But the widely used empirical formula for the hydrodynamic coefficients can not follow the variation of stern shapes which seem to give much effects on the manoeuvring performance for full ships such as tankers.

As was noted in the report, Kang et al a manoeuvrability research group in Korea also found by experiments that the stern shape parameter using waterplane area coefficient of the aft body and the aft body prismatic coefficient shown in the report gives large influence on the overshoot angles in the 10-10 zig-zag manoeuvre.

So, the inclusion of the stern shape parameter in the regression equation seems to be necessary as was commented by Prof. Kijima.