Experimental investigation of the efficiency of coupled- and uncoupled rudder work on twin-screw, twin-rudder ferry model ship in proximity of a pier in shallow water: Part 2

Wojciech A. Misiag, Research specialist, **Jacek Nowicki**, Director, & **Tomasz Jaworski**, Research Engineer, Foundation for Safety of Navigation and Environment Protection, Ilawa, Poland

Part 1 of this article was originally published in edition 33 of Port Technology International. It is available for download at www.porttechnology.org under journal archives.

The authors have designed a model ship experiment that would provide the data for forces and moments acting on a twin-screw, twin-rudder model ship of a ferry manoeuvring in shallow water while using propellers working with differential thrust and with synchronously or decoupled way of rudders operation. The data collected will answer the question: Which of the rudder operation methods results in larger total yaw moment and side force?

The research indicates that the rudders may be operated in any way, since the mode of their operation barely influences the total side force and the total yaw moment.

The research also indicates that in shallow water (H/d = 1,25) the vertical wall influences the side force and the yaw moment at least to the distance of one ship beam (B) between the wall and the ship's side. Part 1 of this article set out the test objectives and explained the experiment design including set-up and conditions.

Experimental results

During experiments longitudinal ($FX_{1,2}$) and lateral ($FY_{1,2}$) force components were measured on two dynamometers located at the bow and at the stern of the model ship. The force components were summed to provide a total force components (FX and FY). Using the lateral components ($FY_{1,2}$) the yawing moment Mz around the centre of gravity was computed.

The dimensional values of force components and yaw moment were non-dimensionalised using the model ship length Lpp and the half of the average total FX force for the case of zero rudders deflection angle and ahead-oriented propeller thrust (T0). Non-dimensional equivalent location of the side force (assuming that only the side force causes the yaw moment) X'_{FY} is given by the ratio of yaw moment and side force.

$$FX' = \frac{FX}{T0}, \quad FY' = \frac{FY}{T0}, \quad Mz' = \frac{Mz}{Lpp*T0}, \quad x'_{FY} = \frac{Mz'}{FY'}$$

TABLE 1: WATER DEPTH H/D = 3.0, DISTANCE SHIP SIDE – WALL Y/B = 1.0

No	Port	Starboard	FY'	FX'	Mz'	x'FY	Notes
1	DeadSAhead	DeadSAhead	-0,15	2,00	0,00	0,01	Ahead thrusts
2	SlowAhead	SlowAhead	-0,10	1,98	0,00	-0,03	
3	DeadSAhead	DeadSAstern	-0,30	0,06	0,15	-0,49	Differential thrust at Dead Slow settings
4	DeadSAstern	DeadSAhead	-0,19	0,06	-0,04	0,20	
5	SlowAhead	SlowAstern	-0,25	0,23	0,14	-0,57	Differential thrust at Slow settings
6	SlowAstern	SlowAhead	-0,10	0,13	-0,06	0,57	

TABLE 2: WATER DEPTH H/D = 1.25, DISTANCE SHIP SIDE – WALL Y/B = 1.0

No	Port	Starboard	FY'	FX'	Mz'	x'FY	Notes
1	DeadSAhead	DeadSAhead	-0,14	2,00	0,01	-0,07	Ahead thrusts
2	SlowAhead	SlowAhead	-0,05	2,00	-0,03	0,58	
3	DeadSAhead	DeadSAstern	-0,25	-0,82	0,05	-0,20	Differential thrust at Dead Slow settings
4	DeadSAstern	DeadSAhead	0,26	-0,06	-0,02	-0,08	
5	SlowAhead	SlowAstern	-0,24	0,33	0,11	-0,46	Differential thrust at Slow settings
6	SlowAstern	SlowAhead	-0,53	0,34	-0,09	0,17	

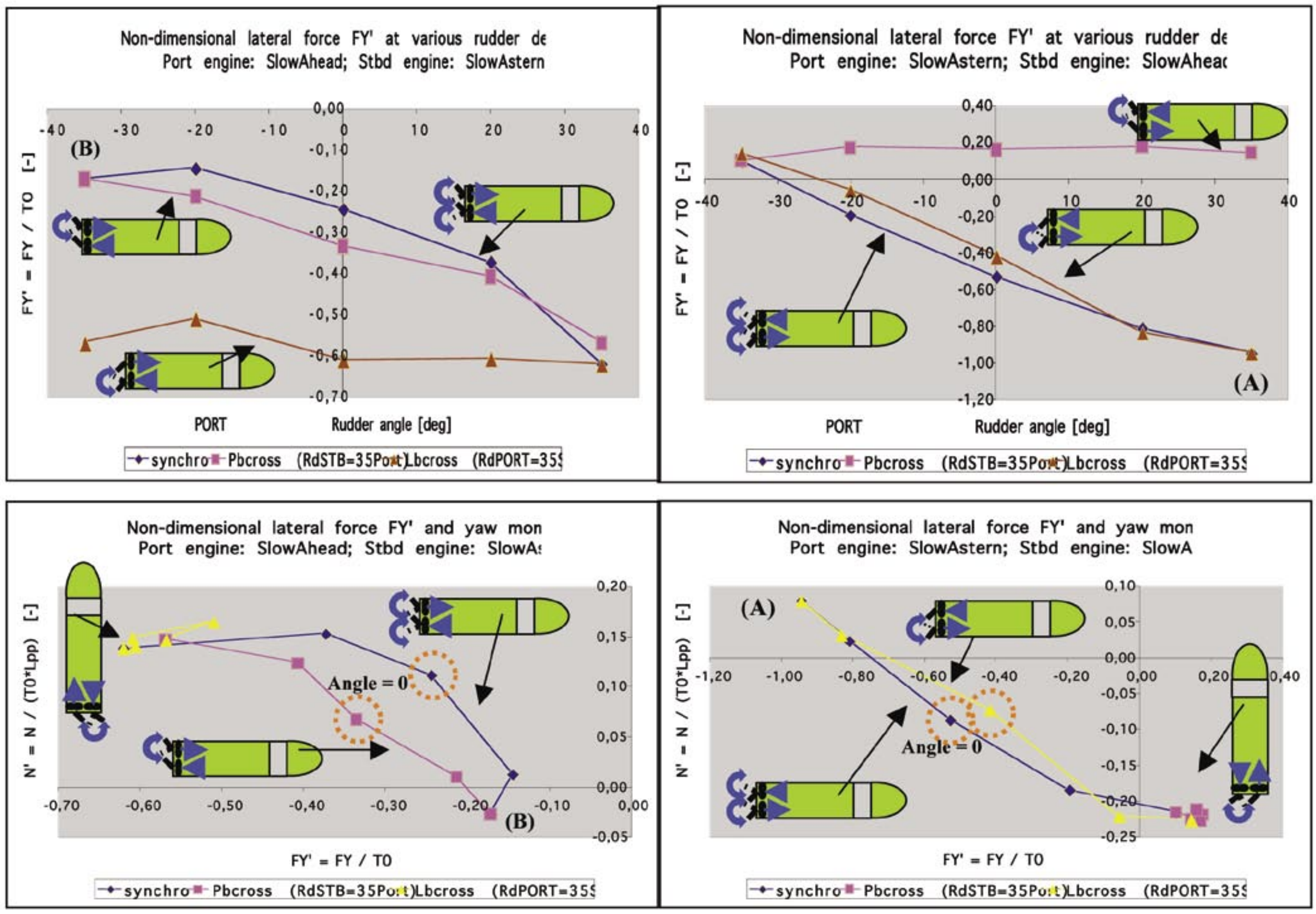

Figure 1. Side force and yaw moment in crabbing manoeuvre in shallow water.

Forces due to propellers' action alone

The total force and moment due to the propellers action alone (rudders set to zero deflection angle) show the amount of interaction between the ship and the flow boundaries (the bottom and the vertical wall). Tables 1 and 2 summarise the forces and moments for various combination of propeller settings.

The data show that the presence of the vertical wall induces side force oriented toward the wall for every mode of propeller operations. The shallow water increases the magnitude of the side force. More force is produced for higher propeller loads – as it was expected, since the propeller load causes the flow of the water around a model ship dead in water.

The propellers producing ahead thrust cause some side force and almost no yaw moment (No 1 and No 2 in 'deep' and shallow water tables). The presence of side force is interesting in this case, and the side force is in range of 10 per cent of the total surge force.

The more interesting thing is that more side force is induced when the Portside propeller (closer to the wall) is working astern at higher propeller load (cf. No 5 and No 6 in shallow water).

Forces due to the combined propellers' and rudders' action

Results are presented for engine settings on the level 'Slow'. In the ship model this setting gave relatively large forces, which were easier to measure. The settings on 'Dead Slow' were giving low values of side forces. During manoeuvres on the model ship the pilots often use 'Slow' or 'Half' settings.

The most interesting data are total side force FY and total yaw moment Mz. The measured results are shown in Figure 1. The propellers are set in differential mode (one ahead and the other astern). The results for three modes of the rudder deflection are presented: rudders move synchronously, rudder behind a propeller working astern remains deflected to the opposite side, and the rudder behind a propeller working ahead remains deflected to the opposite side.

The vertical plates in Figure 1 concern the same mode of propeller operations. The upper plates show the non-dimensional side force FY' as a function of the rudder(s) deflection angle. The lower plates show the relation between the side force FY' and the yaw moment Mz'. The points have been marked on force and moment plates corresponding to the same rudder deflections. On the plates with side force FY' the points corresponding to the zero rudder(s) deflection angle have also been marked, the point on the line of synchronous deflection of rudders gives also the reference to the capabilities of the propellers alone to generate the yaw moment and side force.

The obvious thing to note is the fact that deflection of the rudder placed behind the propeller working astern, while keeping the other rudder at constant angle (deflected to the opposite ship side) results in neither the change of the total side force nor the change of the total yaw moment. It may be concluded that such a rudder may be deflected at any angle, and it will contribute nothing to the ship manoeuvres – therefore other factors should decide about the angle of the rudder behind the propeller working astern.

The second thing to note are observations concerning the total side force (upper plates in Figure 1) for the case, when there is deflected the rudder placed behind propeller working ahead. One sees that the plots of side force remain quite close to each other. It is interesting that the difference between the forces decreases when the magnitude of the rudder deflection angle increases. This decreasing difference is important from the manoeuvring view point, since the pilot will use rather larger rudder deflection angles when he decides to use rudders at all to support the propellers working in differential mode.

The larger differences of forces at a zero rudder deflection angle (about 10 per cent of 'propeller thrust force') may be explained by the partial blockage of the flow ingested by the propeller working astern by the fully deflected other rudder.

We may state that from the view point of the side force there is no difference whether the rudders move in synchronous mode (coupled) or in uncoupled mode for propellers working in opposite directions.

The third thing of note is the observations of the total yaw moment (lower plates in Figure 1) also for the case, when there is deflected the rudder placed behind the propeller working ahead. The same comments may be repeated – there is rather no difference when the forces and moments for synchronous and uncoupled rudder operations are concerned.

This also supports the statement that from the manoeuvring view point it is unimportant whether the rudders are operated in synchronous or uncoupled modes.

What can also be seen from the plot of side forces and yaw moments is the fact that the hydrodynamic forces in the presence of the vertical wall are quite different – and most data would suggest that the distance of one ship beam from the quay (vertical wall) should be sufficient to soften the interference of the ship with the wall. It is also clear that the direction of the propeller thrust – and thus the propeller slipstreams produced by the twin-screw ship – has an effect on the side force and the yaw moment. It can be seen that it is possible to maintain the constant heading – one may find the zero yaw moment where the force-moment plots cross the ordinate axis on the lower plates. However, large rudder angles are required for this (to compensate the yaw moment from the propellers). However, there will be a suction force toward the vertical wall, so it will be impossible to keep the ship in position using just the rudders and propellers or to get out of the wall – to achieve this another forces will be needed, for example from the bow thrusters.

Discussion

The fact that there is no effect – side force and yaw moment – of the rudder deflection when the rudder is placed behind the propeller working astern is explained by the type of inflow to the rudder. The propeller working ahead pumps a large amount of water on the rudder, thus making the rudder behind it very effective. When the propeller works astern then the rudder is ineffective – therefore it does not matter what is done with it.

On twin-rudder twin-propeller ships we may see some interaction of flows when the rudder behind the astern working propeller is deflected. This may be explained by blockage of the flow, so keeping this rudder at a zero deflection angle would remove this small effect.

Significant asymmetry of forces when the action of propellers is reversed may be explained by shallow water and the proximity of vertical wall. This effect is quite difficult to predict and estimate – strong ship-wall interactions were not expected when the model ship was one beam from the wall and propellers were relatively low loaded.

Conclusions

Based on the preliminary research results – ship model tests performed in shallow water – it may be stated that during crabbing manoeuvres the mode of operation of rudders (coupled or uncoupled) has no practical effects on the total side force and the total yaw moment.

It also may be concluded that in shallow water (H/d = 1,25) the effect of vertical wall on side force and yaw moment is noticeable even in the distance of one ship beam between the ship's side and the ship's wall.

Further research

There is no mathematical model of ship manoeuvring that would describe the phenomena and forces observed during this research. It would be profitable for ship handling simulators, for ship control systems for harbour manoeuvring and for training of mariners to develop a model of rudder forces and for propeller working in four quadrants, especially in shallow water. The interactions between the propellers' slipstreams, the flow boundaries (bottom and wall) and the ship hull for ferry ships might be also modelled numerically and investigated using some CFD codes.

ABOUT THE AUTHORS

Tomasz Jaworski (M.Sc. in Electrical Engineering) is a Research engineer, involved in software development, measurement system development, experimental work, ship models design and maintenance.

Wojciech A. Misiag (Ph.D in Naval Architecture), is a Research specialist, working on ship hydrodynamics and ship manoeuvrability, lecturing at and managing ship training courses at Ship Handling Research and Training Centre in Ilawa, involved in ship design for manoeuvrability, simulation of ship manoeuvring and human factor analysis.

Jacek Nowicki (M.Sc in Naval Architecture), is Director of the Foundation, working on ship hydrodynamics and ship manoeuvrability, the designer of manned model training methodology, manned model training systems, designer of manned ship models and hydraulic models at Ship Handling Research and Training Centre in Ilawa, lecturing at and managing training courses at the Centre, involved in ship design for manoeuvrability, simulation of ship manoeuvring and human factor analysis, working on environmental studies and environment-friendly tourist systems designs.

ABOUT THE ORGANISATION

The **Foundation for Safety of Navigation and Environment Protection** is a non-profit company, focused on the promotion of the safety of navigation. The foundation designs and conducts ship handling training courses for pilots, ship masters and chief officers, using for this purpose manned ship models and hydraulic models of harbours and various waterways that are built on Silm Lake at the Ship Handling Research and Training Centre in Ilawa, Poland. The Foundation is also engaged in hydrodynamic research, human factor research, ship manoeuvring modelling and simulation, harbour safety assessment and ship design.

ENQUIRIES

Foundation for Safety of Navigation and Environment Protection

Ilawa Main Office
14-200 Ilawa Kamionka
Poland
Tel: +48 89 648 3353
Fax: +48 89 648 7490

Gdansk Office
Chrzanowskiego 36, 80-278 Gdansk
Poland
Tel/Fax: +48 58 341 5919
Email: office@ilawashiphandling.com.pl
Website: www.ilawashiphandling.com.pl