Free sailing model tests of evasive action manoeuvre of a river cargo motor barge in shallow waters.

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Abstract

The paper presents shallow water experiments of a self-propelled, free running model of an inland water motor barge. In accordance with the Rhine Manoeuvring Standards Rheinschiffsuntersuchungsordnung (RheinSchUO 1995, issue 2005), evasive action manoeuvring tests were realised. Model obtained from DST Duisburg Germany was a 5.00 meters long motor barge built to a scale of 1:20 and propelled with an 80 mm diameter ducted propeller. Tests were carried out in the auxiliary towing tank of the Ship Hydromechanics Division in Gdańsk. The experiment consisted of efficiency analysis of different rudder blades with variable rudder profiles and rudder blade areas. In total the evasive action test was repeated for three different rudder profiles, with three different chord lengths and at three different water depths each. For each particular case the total standard manoeuvre time and side rudder force was measured. These results were compared with the RheinSchUO standards. The model tests programme was realised within the EU CREATING project supported in the 6th Framework Programme.

Keywords: *shallow waters, free sailing, inland water motor barge*

INTRODUCTION

Inland waterways transportation in Western Europe has a steadily growing share in total cargo shipping. The similar tendency is expected also in Poland following the increasing road and railway congestion and assuming the infrastructure improvement on our main rivers. Resulting increased number of river ships on waterways raises a danger of collision. Therefore regulatory bodies put special emphasis on safety. With this respect the manoeuvring aspects are one of the key factors for a ship on the river, especially for ships with a long reaction time. Therefore ship designers try to reach the required safety level in an optimal manner.

Designers have a wide choice of various steering systems, with different impacts on the overall ship manoeuvring performance. However, the manoeuvring capabilities should be compatible with applicable manoeuvring standards. The knowledge regarding the compliance with requirements should be available as early in the design process as possible. The free running model testing provides the adequate measures for establishing the actual vessel performance with respect to the manoeuvring capabilities in a time and cost effective way (i.e. comparing with the PMM tests). Results of the model tests can be directly compared with appropriate standards providing the requested information at an early design stage.

In the EU project CREATING supported in the 6th Framework Programme a river cargo ship for Rhine was tested. Therefore the model was examined with the obligatory manoeuvring standards of the Rhine Manoeuvring Standards Rheinschiffsuntersuchungsordnung (RheinSchUO 1995, issue 2005), see Fig. 1 and references [1].

The purpose of tests was to make comparative analysis of different rudder blades efficiency by model simulation of the evasive action.

Ship and model data

The hull model No. M654 used for the tests was made of wood by DST Duisburg Germany to a scale of 1:20 and renovated by CTO S.A. It was propelled with an 80 mm diameter ducted propeller model No. P519 manufactured for the purpose of tests in CTO S.A. Before the tests the hull model was ballasted to the draft corresponding to 2.0m full scale.

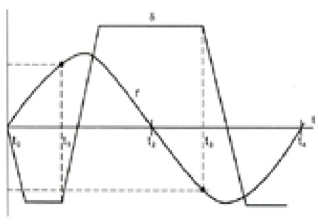

Figure 1 *Evasive action manoeuvre*

Table 1.1 *Ship and model data*

	Symbol	Unit	Ship	Model
Main data of the M654 ship hull (scale λ=20.0)				
Length between perpendiculars	L_{PP}	m	105.00	5.250
Length of waterline	L_{WL}	m	103.60	5.180
Breadth moulded	B	m	10.50	0.525
Draught: fore	T_F	m	2.00	0.100
Draught: aft	T_A	m	2.00	0.100
Displacement volume	V	m^3	1922.9	0.240
Wetted surface	S	m^2	1364.1	3.410
Block coefficient	CB	-	0.884	
P519 propeller model data				
Propeller diameter	D	m	1.600	0.080
Pitch at r/R=0.7	P	m	1.780	0.089
Pitch ratio at r/R=0.7	P/D	-	1.110	
Expanded blade area ratio	A_E/A_0	-	0.791	
Number of blades	z	-	4	
Direction of rotation		-	right	

In the tests three types of rudders were used – typical NACA

In the tests three types of rudders were used – typical NACA 0015, fishtail and the flat plate. Each of these rudders were made in three versions with different lateral area, so that the ratio of the rudder area to lateral area of ship wetted profilewas in the range of 1.6 – 2.4%.

Table 1.2 *Model rudder profiles*

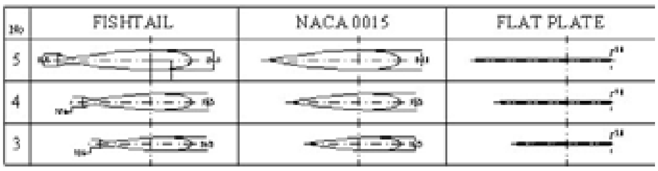

Table 1.3 *Rudder data*

	Rudder area		A_R/LT
	model scale	ship scale	
Rudder No.	mm^2	m^2	%
5	12443	4.98	2.40
4	10043	4.02	1.94

Test conditions

Conditions for evasive action tests for all versions of rudders were identical, corresponding to the Chapter 5 of RheinSchUO 1995 [1].

Table 3 *Tests conditions*

		Ship scale	Model scale
	Approach speed	13 km/h	0.8 m/s
1st test	Max. rudder angle	20°	20°
	Angular velocity	20 deg/min	1.49 deg/s
2nd test	Max. rudder angle	45°	45°
	Angular velocity	28 deg/min	2.09 deg/s

In total the evasive action test was repeated for nine rudders and at three different water depths – 1.3T, 1.6T, and 2.5T.

The number of model propeller revolutions was established at a deep-water condition to reach a speed of 0.8 m/s. During the tests the model speed was not measured but the approach speed was the same for all the test runs as the model was accelerated using the tank carriage with precisely controlled speed.

Because of a short time of manoeuvre the rudder angular velocity was established at .

Apparatus and facilities

Model was tested in a towing tank using free-running model test technique with the assistance of tank carriage equipped with measuring devices, radio controller and data processing computer. The tests were carried out in shallow water. During each run the rudder angle and angular velocity as well as rudder forces were, with the time step of 0.1 second, discrete recorded on a digital unit with associated computer data recording systems. The model was equipped in order to provide full autonomous operation during the tests. For this purpose the following subsystems were installed:

- propulsion subsystem consisting of a ducted propeller model, shafting and 500W AC motor,
- steering subsystem composed of the exchangeable rudder blade, rudder force dynamometer (2-component) and steering gear (stepping motor),
- manoeuvre control subsystem based on an own-developed controller governing the rudder deflection with respect to angular velocity signal obtained from the digital gyro,
- power supply for propulsion and steering system consisting of two batteries, DC/AC converter and electric motor inverter,
- power supply for data acquisition system (AC power pack),
- data acquisition system composed of signal amplifier, analogue-to-digital converter, radio transmitter, radio receiver and data processing computer (the last two items installed on the towing carriage)

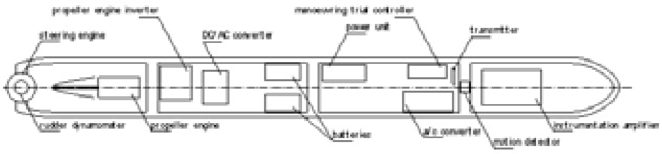

Figure 2. *Pictorial diagram of model outfit*

Performing the test

On a short length the model was accelerated to 0.8 m/s velocity with the help of towing carriage and the propeller revolutions set to the required level. During the acceleration the operator kept the model parallel to the towing tank axis by hand controlling its position using the laser beam projected to the model centre line. When the approach speed was reached and the resistance balanced with the propeller thrust, the model was released and the evasive manoeuvre started with first deflection (20˚ or 45˚).

During the complete manoeuvre the angular speed was measured and compared with limiting value (1.49˚ or 2.09˚ respectively) in the controller unit. The rudder was deflected to the opposite side each time the angular velocity reached the limiting value. Usually three or four turns were performed in the length of the towing tank.

Figure 5. *Model during the evasive manoeuvre test*

Results of experiments

The model test results; rudder angle, angular velocity and lateral rudder force, were computed to the full scale. For all tests six graphs were plotted, each for a different water depth. In all graphs the rudder angle, angular velocity and lateral rudder force were drawn. Example of the results for one rudder is presented below.

Table 4.1 *Results for NACA 0015 N5 for 20° rudder deflection*

Rudder angle d [deg]	Angular velocity r [deg/min]	Elapsed time t [s]	Side rudder force Y_R [kN]	Elapsed time t [s]	Side rudder force Y_R [kN]	Elapsed time t [s]	Side rudder force Y_R [kN]
		h=1.3T		h=1.6T		h=2.5T	
δ_0=0°	r_0= 0	0.0	0.0	0.0	0.0	0.0	0.0
δ_1=20° PS	r_1= 20	53.4	12.2	16.6	14.0	21.1	16.4
δ_2=20° SB	r_2= 0	74.1	-28.2	42.8	-19.8	43.1	-24.5
δ_3=20° SB	r_3= -20	101.1	-19.2	62.4	-19.5	62.7	-21.4
δ_4=20° PS	r_4= 0	132,6	20,0	85,8	25,2	80,1	23,8

Table 4.2 *Results for NACA 0015 N5 for 45° rudder deflection*

Rudder angle d [deg]	Angular velocity r [deg/min]	Elapsed time t [s]	Side rudder force Y_R [kN]	Elapsed time t [s]	Side rudder force Y_R [kN]	Elapsed time t [s]	Side rudder force Y_R [kN]
		h=1.3T		h=1.6T		h=2.5T	
δ_4'=0°	r_4'= 0	0.0	0.0	0.0	0.0	0.0	0.0
δ_5=45° PS	r_5 = 0	26.4	45.2	13.9	54.6	12.1	65.8
δ_6=45° SB	r_6= 0	49.4	-64.3	39.0	-66.2	35.9	-71.1
δ_7=45° SB	r_7= 0	63.5	-51.4	54.3	-54.3	46.2	-57.6
δ_8=45° PS	r_8= 0	87.0	59.4	78.6	70.2	66.5	75.8

results obtained could be directly compared with manoeuvring standards providing instant information regarding the compliance with requirements. As far as the time required for tests performance and elaboration of the results is concerned, the proposed method was advantageous comparing to the captive methods (PMM). Usual source of inaccuracies caused by the environmental conditions were omitted due to performance the tests in the strictly controlled conditions of a towing tank (precisely controlled approach speed, constant water depth and calm wind conditions). The method can be successfully applied both in the case of comparative model tests and in order to determine the actual manoeuvring performance of the vessel with a given steering arrangement.

References

[1] Rheinschiffsuntersuchungsordnung 1995 (RheinSchUO 1995), Zentralkommission für die Rheinschifffahrt, Ausgabe 2005.

[2] Reichel M. (2006), "Free running evasive manoeuvre model tests – river cargo ship DST M1409" Technical Report of Ship Hydromechanics Division, Ship Design and Research Centre S.A. N0 RH-2006/T-031.