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DEVELOPMENT AND APPLICATION OF A SHIP MANOEUVRING DIGITAL SIMULATOR FOR RESTRICTED WATERS

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Abstract: This paper reports on two case studies making use of a digital simulator to investigate the manoeuvring motions of ships in canals with shallow and restricted waters. The first case study corresponds to a manoeuvring analysis conducted for the Port of Rio Grande (RS - Brazil), whose aim was to assess the potential impact upon manoeuvres of the presence of a large offshore platform (the Petrobras P-53) which is to remain docked for several months at the Port to complete its construction. The second study made use of the simulator to evaluate the manoeuvring conditions along the approach route and manoeuvring basin of the Port of Ponta do Félix (PR – Brazil). The simulator includes a complete mathematical model of the ship dynamics in the horizontal plane when subjected to wind and current forces. It also comprises detailed models for the action of thrusters and propellers, both fixed and azimuth, employed to control manoeuvres and dynamically position ships, as well as rudders and tugboats. The models used by the simulator allow for the effects of shallow and restricted waters, including the increase in resistance and lateral forces, increase in additional mass and the appearance of lateral and vertical suction (squatting). The simulator is implemented via an interactive interface through which the user is able to apply control actions (rudder angle, main engine, thrusters and tugboats) in real time during manoeuvres, thereby reproducing to some extent the action of a pilot.

Keywords: Manoeuvring

1. INTRODUCTION

The pursuit of increased competitiveness throughout the chain of river and maritime transportation services has placed growing strains over the safety restrictions imposed upon the navigation along access waterways and on ship manoeuvres. Factors that are crucial for safety, such as the dimensions of channels and manoeuvring basins relative to ship size have been under close scrutiny. The Department of Naval Architecture and Ocean Engineering and the Department of Mechatronics Engineering of the University of São Paulo have been developing a computer simulation tool to evaluate the motions of vessels in situations of restricted depth and width. The simulator can be useful in dealing with complex problems that arise at the interface between the operability of the system and the safety of operations: dimensioning of areas and depths of passage, simulation of the (positive or negative) impact on safety of changes in navigation conditions, and analysis of the possibility of reduction of restriction to manoeuvres, amongst others.

Recently, the simulator was employed in two real-world studies. It was used to investigate the impact on the safety of manoeuvres at the Port of Rio Grande (Brazil) of the presence of a large oil platform which was docked at the harbour for completion of its construction. For the Terminal of Ponta do Félix (Brazil), the simulator was used to assess the manoeuvring conditions of a new, larger type of vessel.

All the main physical phenomena of interest to the realistic reproduction of ship manoeuvring motions are represented in the mathematical models that constitute the core of the simulator. From the step-by-step calculation of forces and moments acting upon the ship the simulator performs a numerical time integration to generate ship trajectories. These are animated in a bird's eye, two-dimensional graphical representation of the navigation area, allowing the operator (who plays the role of the ship's pilot) to conduct the manoeuvres by commanding power, steering, and tugboat parameters.

2. MATHEMATICAL MODELLING

This section will present the mathematical models included in the simulator and will provide the basic data for modelling of ships covered in the case studies that will be discussed throughout this work.

2.1 BASIC DATA OF THE VESSELS

The ship considered in the case study of the Port of Rio Grande was the Grimaldi Ro-Ro, Class Grande Francia. Henceforth this ship is referred to as vessel A. For the study of the Port of Antonina, the ship considered is the Star Class

H type open hatch (referred to as vessel B). Photos of the ships are shown in Figures 1 and 2.

Figure 1 - H Star Ship (Vessel B)

Figure 2 - Ro-Ro vessel (Vessel A)

The main data of the vessels are given in Table 1.

Table 1 Vessel's Data

Feature	Vessel A	Vessel B
Length (LOA)	214,0m	213,4m
Beam (B)	32,25m	31,00m
Draft (T)	8,23m	8,10m
Mass (m)	48561 ton	40672 ton
Mom. Inertia (Iz)*	1,24.10^{8}ton.m^2	1,05.10^8 ton.m^2
Wetted Area (S)	7222 m^2	7025 m^2
CG's Position	0m	0m
Block Coeff. (Cb)	0,83	0,80

2.2 WIND FORCES

The forces in the longitudinal direction (surge) and lateral (sway) and the yaw moment (yaw) due to the effect of wind on the emerged part of the vessel are modelled by the wind coefficients. Assuming that there is no spatial variation in speed and direction of wind incident on the vessel, the following relationships are assumed:

$$F_{1V} = \frac{1}{2}\rho_a C_{Vx}(\beta_V) A_F V^2 \quad F_{2V} = \frac{1}{2}\rho_a C_{Vy}(\beta_V) A_L V^2 \quad F_{6V} = \frac{1}{2}\rho_a C_{Vn}(\beta_V) L A_L V^2 \qquad (1)$$

where ρ is the density of air, F_{1V} and F_{2V} are forces in the longitudinal and transverse directions respectively, F_{6V} is the moment of yaw, C_{VX}, C_{Vy} and C_{VN} are dimensionless coefficients, A_f and A_L are the sailing frontal and lateral area (respectively) of the emerged part of the vessel and V is the wind speed. The angle of incidence with respect to the fixed axis OX is given by $\beta_{V,OXYZ}$ and the angle relative to the vessel is given by β_V ($\beta_{V,OXYZ}=\beta_V+\psi$), both defined in Figure 3. When the ship has her own speed, the angle of incidence β_V is corrected to consider the velocity of the hull.

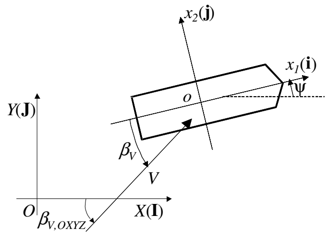

Figure 3 - Incident Wind Angles

The areas used for both vessels are given in Table 2. The dimensionless coefficients of forces and moment of wind on the hull and superstructure were calculated using the approach proposed by Isherwood (1973).

2.3 SHIP RESISTANCE

The resistance force is given by the expression:

$$F_X = \frac{1}{2}\rho S U^2 (C_f + C_r) \qquad (2)$$

where ρ is the density of water, U the speed in relation to the water, C_f is the resistance coefficient of friction and C_r the coefficient of shape and waves. The coefficient of friction is calculated by the ITTC approximation:

$$C_f \cong \frac{0{,}075}{(\log_{10}\mathrm{Re}-2)^2} \qquad (3)$$

The coefficient C_r is calculated according to the statistics proposed based on regressions by Holtrop; Mennen (1982) and Holtrop (1984).

2.4 ADDITIONAL FORCES

In addition to the resistance, the transversal force and yaw moment due to the flow of water acting on the hull are also considered. The speed of water in the hull is denoted by Vc (Figure 5); α is the direction in relation to the hull and α_{OXYZ} is the direction in relation to the fixed reference ($\alpha_{OXYZ}=\alpha+\psi$).

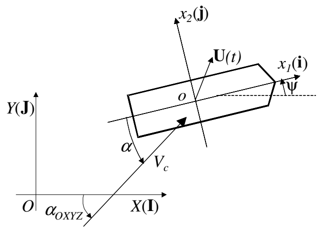

Figure 4 - Definitions to the Static Model of Current

The hydrodynamic forces are written as:

$$F_{1C} = \frac{1}{2}\rho V_{cr}^2 LT.C_x(\alpha); \quad F_{2C} = \frac{1}{2}\rho V_{cr}^2 LT.C_y(\alpha); \quad F_{6C} = \frac{1}{2}\rho V_{cr}^2 L^2 T.C_n(\alpha) \qquad (4)$$

where F_{1C} and F_{2C} are the forces in the longitudinal and transverse directions, respectively, F_{6C} is the yaw moment and C_x, C_y and C_n are the dimensionless coefficients of static current. These coefficients are calculated according to a heuristic short wing model presented in Leite et al. (1998),