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A methodology for evaluating the controllability of a ship navigating in a restricted channel

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A methodology is presented for evaluating the controllability of a ship navigating in a restricted channel by means of a hydrodynamic force analysis. This method is applied to assess the controllability of a container vessel in straight channel reaches and in bends in two practical cases. By comparing different initial conditions and bottom configurations the influence of different ship characteristics (main dimensions, draft, rudder and propeller characteristics), operational parameters (such as speed, propeller commands, and bank clearance), environmental parameters (such as current and tidal level), and channel characteristics (water depth, bank slope, bend radius) on this controllability can be evaluated. For estimating the components of the force analysis, use is made of results of captive model tests in shallow and restricted waters.

Keywords: *Controllability of a ship, bank effects, structural and operational measures*

Notations

A_{RT}: [m^2] – lateral rudder area,
C_{YR}: – non-dimensional lateral rudder force
C_{Th}: – thrust loading coefficient:

$$C_{Th} = \frac{T_P}{\frac{1}{8}\rho\pi D_P^2 u_A^2}$$

D_P: [m] –propeller diameter
Fr: – ship length related Froude number
Fr_h: – water depth related Froude number
h: H [m] – water depth at the ship
h_1: [m] – water depth outside waterway
h_{eff}: [m] – effective water depth
k_m: – propeller race contraction factor
L: [m] – ship length
L_{PP}: [m] – ship length between perpendiculars
m: [kg] – ship mass
n: [rpm] – propeller rate
$n_{\max}$: [rpm] – reference propeller rate
N_{ur}: – hydrodynamic coefficient
N_R: [Nm] – yawing moment generated by the rudder
N_C: [Nm] – moment generated by current
R: [m] – bend radius
T: [m] – draft

T_P: [N] – propeller thrust
u: [m/s] – longitudinal ship speed
u_A: [m/s] – advance speed at the propeller
u_R: [m/s] – average inflow velocity at the rudder
V_C: [m/s] – current velocity
V_T: [m/s] – reference speed in the propeller race

$$V_T = \sqrt{\left|\frac{8T_P}{\rho\pi D_p^2}\right|}$$

w: – wake fraction
x_G: [m] – longitudinal position of the centre of gravity
y_B: [m] – bank clearance
Y_R: [N] – lateral rudder force
z_m: [m] – mean sinkage
β_{ik}: – bank effect coefficients
ρ: [kg/m³] – water density

1. Introduction

Manoeuvring simulation, either controlled by an autopilot (fast time) or by a human operator (real time), is an approved tool for evaluating the feasibility and safety of ship manoeuvres and transits. In both control modes, the characteristics and quality of the controller may considerably affect the results and conclusions of the simulation study. On the other hand, regardless of the control system, it is impossible to keep the ship under control if the available control forces generated by the rudder are exceeded by the forces disturbing the ship (e.g. bank effects, current) or required to perform a given trajectory (e.g. bends). Due to inertia, a temporary unbalance (e.g. due to wind gusts, meetings, …) may be acceptable in particular cases, but a permanent exceeding of the control forces inevitably results into an uncontrollable ship.

In order to evaluate the inherent safety of a considered manoeuvre, a methodology can be used for comparing the available control forces with the forces that have to be counteracted. This hydrodynamic force analysis will only take yawing moments into consideration. This methodology can be applied to determine operational limits, to investigate the sensitivity of ship controllability with respect to parameter variations, and to compare existing situations to new conditions.

With respect to parameter variations, generally a large number of parameters affecting a manoeuvre can be identified. In the case of a ship taking a bend in a river with longitudinal current, following non-exhaustive distinction can be made:

- ship dependent characteristics such as draft, geometric dimensions (scale factor), and manoeuvring behaviour;
- environmental parameters such as water depth variations, current and tide;
- channel characteristics such as bank geometry, water depth and bend radius;
- operational parameters such as propeller rate, ship speed and bank clearance.