Experiment based mathematical modelling of ship-bank interaction

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A displacement vessel, as the name suggests, displaces an (enormous) amount of water. In open and unrestricted waters this water can travel relatively unrestricted underneath and along the ship's hull. In restricted and shallow sailing conditions this displaced water is squeezed under and/or along the hull. This tightness results in higher velocities of the water travelling along the hull which also generates a pressure drop around the same hull. This pressure drop acts as a combination of forces and moments on the vessel. These forces/moments are named bank effects if generated because of the presence of a bank.

The horizontal forces of the bank effects on a ship are sought for. These three forces are: the bank effects acting in the longitudinal direction and in the lateral direction at the forward and aft perpendicular. The knowledge of bank effects is acquired with an extensive literature study on one hand and with dedicated model tests carried out in different towing tanks on the other. The majority of the utilised model tests is carried out in the shallow water towing tank at Flanders Hydraulics Research in Antwerp, Belgium.

The data set on bank effects consists of more than 8,000 unique model test setups. Eleven different ship models, at a range of draft to water depth ratios, are tested. The captive towing tests are conducted at a range of different forward speeds and propeller actions. The data set contains model tests carried out along twenty five different bank geometries at different lateral positions of the ship from the bank. During the model tests forces, moments and motions are measured on the hull, propeller(s) and rudder(s). These measurements are the input for the analysis of bank effects and the creation of the mathematical model of the three previously mentioned forces in the horizontal plane.

The physical based mathematical model is constructed in such a way that (relative) easy implementation in a ship manoeuvring simulator is possible.

Overall the magnitude of the bank effects: the longitudinal force and both lateral forces (at the fore and aft perpendicular) increase with:

- A higher forward speed of the ship
- A more loaded propeller (higher propeller rate)
- A lower under keel clearance
- A more confined sailing area; steeper banks, smaller distance between port and starboard bank
- The closer the distance between ship and bank

The longitudinal force of the bank effects always acts on the ship as an augmented resistance. The lateral force at the aft perpendicular acts always as an attraction force directed towards the nearest bank. In deep water the lateral force at the forward perpendicular is also an attraction force towards the nearest bank while in very shallow water this force is always a repulsion force directed away from the nearest bank. In between there is a transition from repulsion to attraction which shifts with the forward speed of the ship and relative water depth.

In the mathematical model the thrust delivered by the propeller is transformed into a thrust velocity (the theoretic axial velocity behind the propeller). This velocity is combined with the forward speed of the vessel into an equivalent velocity. This, in turn, is used as input to calculate the Tuck number which takes into account the water depth and blockage (ratio of the cross section area of the ship and fairway). This Tuck number is proportional to the magnitude of longitudinal and lateral forces of the bank effects. For the lateral force at the forward perpendicular an extra function (dependent of the Froude number and relative water depth) is added to cope with the changing sign in the shallow water range.

The position and distance between a ship and random shaped bank is ambiguous. Therefore the weight factor is introduced. This factor is a value between zero and one which exponentially decreases further away from the ship (in both horizontal and vertical direction). The weight factor is integrated over the considered area (cross section at port/starboard, midship section) to achieve a weighted value for that area.

A dimensionless distance to the bank and equivalent blockage is introduced and calculated based upon weighted areas. As such the nuances of a random cross section are taken into account without exaggerating the bathymetry at a distance far away from the ship or without underestimating the bank shape very close to the ship. The lateral forces are inversely proportional to the dimensionless distance to the bank while the magnitude of the longitudinal force is proportional to the square of the equivalent blockage.

The influence width is the (horizontal) distance between a ship and bank where the bank effects are infinitesimally small and can be neglected. When the proximity between the ship and closest bank is greater than the influence width then the ship manoeuvres as sailing in unrestricted (but sometimes shallow) waters. Based upon dedicated model tests carried out in a towing tank it is found that this influence width is proportional to the water depth dependent Froude number.

Although the model tests are carried out with the utmost care and scaled according to Froude's law (common for model tests on ship hydrodynamics) there remains an issue with the boundary layer on ship and bank. This boundary layer is relatively thicker on model scale than at full scale when scaled according to this Froude's law. The lateral force at the aft perpendicular did no longer increase the closer it was towed to the bank when the ship model was towed very close to a (vertical) bank. The same is observed at very shallow water depths. This behaviour is ascribed to the influence of the boundary layer on the lateral force. When the gap between ship and cross section (keel – bottom or ship's side – bank) is narrower than the boundary layer influence thickness then the viscosity of the water comes into play and overrules the (mainly) non-viscous hydrodynamics generating the bank effects. This boundary layer influence thickness (a formulation is given) is about (relative) two to three times as thick on model scale than at full scale.