SHIP MANOEUVRE ANALYSIS AND SIMULATION TO OBTAIN SCOURING RELATED PROPELLER VARIABLES

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Keywords: AIS data, ship trajectory monitoring, ship simulator, scouring action, propeller generated erosion.

Abstract. The evolution of shipping industry in terms of bigger and more powerful ships, is causing several issues in existing ports and marinas designed, initially, to host smaller vessels with smaller propulsion systems and lower drafts, such as harbour basin erosion near quay walls, deposited zones in low frequented areas and reduction of operational areas. Previous studies concluded that main problems come from regular vessels such as ferries, which dock and undock frequently in the same quays performing the same manoeuvres. This contribution deals with a method to reproduce real ship manoeuvres in a full mission ship simulator obtained through Automatic Identification System (AIS) data analysis. A faithful reproduction permits to extract propeller and propulsion variables, which, in turn, allow the study of the scouring action using literature formulae. Results obtained show that AIS data can be used to obtain manoeuvring patterns, allowing the study of the scouring action for every particular case depending on vessel type, manoeuvre or met-ocean conditions.

1 INTRODUCTION

The evolution of shipping industry in terms of bigger and more powerful ships, is causing several issues in existing ports and marinas designed, initially, to host smaller vessels with smaller propulsion systems and lower drafts, such as harbour basin erosion near quay walls, deposited zones in low frequented areas and reduction of operational areas. The erosion of port sediment in which quays and other structures are settled is leading to structural problems caused by scouring action and navigational problems due to sediment transport and relocation. Previous studies concluded that main problems come from regular vessels (excepting tugboats and pilot vessels) such as ferries, which dock and undock frequently in the same quays performing the same manoeuvres. Moreover, ferry ships require a particular quay to allow their ramping systems to be used during port operations, which is parallel to the propeller plane, so it is perpendicularly affected by main propellers generated thrust during docking and undocking manoeuvres.

This problem has been approached in engineering by several authors over the last decades, mainly through laboratory studies considering mostly one single propeller ([1]–[5]), with more recent research using twin propeller generated streams ([6]). They consider different combinations of the main propellers characteristics such as rotational velocity, pitch, blade projected area, etc., to obtain the size and location of the generated scour depending on the propeller behaviour. However, the real value of these variables, in particular rotational velocity and pitch, are mostly unknown by harbour authorities and researchers. The study of the manoeuvre, obtained through AIS data analysis ([7]–[9]), and its reproduction by means of a full mission bridge simulator can be used to obtain the evolution of parameters directly related with the scouring action.

This contribution deals with a method to reproduce real ship manoeuvres in a full mission ship simulator starting from AIS data analysis from a concrete study case. A faithful reproduction permits to extract variables such as rotational velocity, engine power and propeller pitch, which, in turn, allow the study of the scouring action using literature formulae. Once the engine and propeller behaviour variables are obtained and related to the geographical position of the ship during the maneuver, the points of maximum forcing can be located, giving the port authorities a clue about the most probably affected area so that they can arrange prevention and protection actions.

2 SCOURING VARIABLES

Equations proposed by the guidelines of PIANC [1] use as independent variables i) the efflux velocity: V_0; ii) ship propeller features: propeller diameter, D_p, power, P; and iii) seabed and manoeuvre characteristics such as the sediment size, D_{50}, the clearance distance, c, and sediment density. The first variable introducing uncertainty is the efflux velocity. Many authors have tried to validate a coefficient, A, for the equation obtained using the momentum and mass conservation conditions:

$$V_0 = AnD_p\sqrt{C_T} \tag{1}$$

with *n,* the speed rotation in *rps*, and C_T the thrust coefficient of the propellers.

According to the axial momentum theory, *A = 1.59*, but Hamill and Johnston [10] propose *A = 1.03*, whereas Hashmi [11] increase it up to *A = 1.1*. Stewart in his PhD thesis developed a more complex equation to obtain the coefficient *A* through the characteristics of the propellers:

$$A = D_p^{-0.0686} p^{1.519} \beta^{-0.323} \tag{2}$$

where p is the pitch to diameter ratio and β is the blade expanded area ratio.

However, using the axial momentum theory as the basis, efflux velocity can be computed using other variables, when one of the previous variables is difficult to obtain –usually the thrust coefficient. Eq. (3) is proposed by the Spanish guidelines [12] for non-ducted propellers and also by the international guidelines published by PIANC [1]. The main differences are the percentage of maximum installed power, P_p, each of them recommends: $f_p = 0.4$ and 0.15 respectively; and the coefficient C_1, for which they recommend 1.17 and 1.48 respectively

$$V_0 = C_1 \left(\frac{f_p P_p}{\rho_w D_p^2} \right)^{1/3} \tag{3}$$

All the previous equations have been proposed for single propellers after experimental campaigns in laboratories. Mujal-Colilles et al. [13], compared the laboratory experiments of twin propellers with the equations present in literature and concluded that both Eq. (1) and Eq. (3) overestimated by a factor of two the experimental results, yielding Eq. (1) closer results.

The second variable needed to estimate the seabed erosion is the velocity at the seabed. Blockland an Smedes [14] proposed the following expression using in-situ measurements

$$V_b = 2.8 V_0 \frac{D_p}{X_w + \left(c + \frac{D_p}{2} \right)} \tag{4}$$

where X_w is the distance from the propellers to the vertical wall of the quay. Again, the uncertainty is introduced by the several definitions of the efflux velocity.

Finally, according to the conclusions found in Mujal-Colilles et al. [15], the maximum scouring depth in confined situations, ε_{max}^c, is located close to a vertical wall and can be computed using the equation proposed by Hamill et al. [5] for confined situations:

$$\begin{gathered} \varepsilon_{max}^c = \varepsilon_{max}^u + \left[\varepsilon_{max}^u + \left(c + \frac{D_p}{2} \right) \right] \left[1.18 \left(\frac{X_w}{X_m^u} \right)^{-0.2} \right] \\ X_m^u = c F_0^{0.94} \\ \varepsilon_{max}^u = 45.04 \cdot 10^{-3} \Gamma^{-6.98} \left(ln(t) \right)^{\Gamma} \\ \Gamma = 4.1135 \left(\frac{c}{D_{50}} \right)^{0.724} \left(\frac{D_p}{D_{50}} \right)^{-0.522} F_0^{-0.682} \end{gathered} \tag{5}$$

introducing more uncertainties since the densimetric Froude number, F_0, includes at the same time the efflux velocity and the sediment diameter.

3 METHODOLOGY

AIS data is used as a reference to simulate the docking and undocking manoeuvre at a particular harbour basin. Location of the harbour basin is kept confidential due to the requirements of the harbour authorities. Lat-Long data, Speed Over Ground (SOG) and Heading (HDG) are the main AIS variables guiding the simulation at the navigation simulator. A previous analysis of the docking and undocking maneuver during spring season indicates that the manoeuvre of the study vessel is similar every day. In particular, the study vessel is a Ro-Pax ferry with a daily docking frequency and a draft to depth ratio of up to 0.6.

A Transas NTPro 5000-v-5.35 simulator is used to reproduce the manoeuvre aiming to obtain the speed rotation, the pitch of the propellers during the manoeuvre and the power exerted by the propulsion system. Due to the lack of the particular ship, the simulation is performed using a similar vessel in terms of dimensions and propulsion systems. A comparison between them is shown in Table 1.

Table 1. Comparison between study and simulator vessel.

Variable	**Study Vessel**	**Simulator Vessel**
Vessel dimensions		
Gross Tonnage (GT)	25993	21104
Maximum beam (m)	27	25.5
Depth (m)	9.6	16.62
Freeboard (m)	3.2	-
Maximum draft (m)	6.4	6.5
Maximum length (m)	198.99	182.6
Length between perpendiculars (m)	177	166.29
Propeller characteristics		
Number of main engines	2	2
Indicated power (kW)	12775	11520
Number of propellers	2	2
Number of blades per propeller	4	4
Propeller diameter (m)	5.1	5.0
Propeller type	CPP	CPP
Delivered power (kW)	11640	10714
Propeller centroid depth (m)	3.8	4
Maximum engine R.P.M.	500	510
Maximum propeller R.P.M.	137	130
Rotational direction	Inward	Inward

The main differences between the study and the simulator vessel observed in Table 1 are the depth, considered in the simulator as the sum of the maximum draught and the freeboard, but not an important variable in the equations presented so far, and the engine losses with a 2% difference between the study and the simulator vessel. Differences between the propeller centroid, the indicated power and the maximum engine *rpm* are not significant in terms of the results and the simulation of the maneuvers.

4 RESULTS

A comparison between AIS Lat-Long data and simulation results of the same variable is shown in **Figure 1**, where no big differences can be found either in arrival or departure maneuver. In fact, according to the Lat-Long position of the ship in the simulator, both maneuvers are reproduced almost equal to the real AIS data. **Figure 1** also confirms the few differences existing between one and another arrival/departure maneuver from different days. It is important to bear in mind that **Figure 1** plots the transmitting point of the vessel AIS data, which is located near by the bridge.

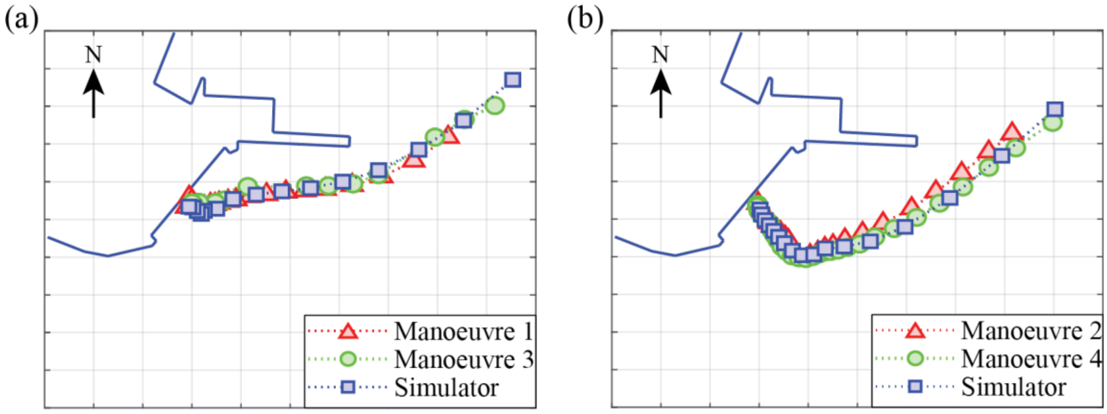

Figure 1. Comparison between AIS Lat-Long data and simulator Lat-Long results. (a) Arrival maneuver. (b) Departure maneuver.

The most harmful instants of each maneuver, according to the conclusions of Llull et al. [16], are plotted in **Figure 2**. During the arrival maneuver, when the ship is already parallel to the dock and the captain starts the stopping orders, the wash generated by the propellers is directed towards the wall being, therefore, a harmful potential action. This is marked using a circle with number one in **Figure 2**a. Likewise, the departure maneuver, **Figure 2**b, the wash is directed towards the Ro-Ro dock, at the beginning of the maneuver, number 2 in **Figure 2**b, and when the vessel is turning to exit the harbor basin, number 3 in **Figure 2**b.

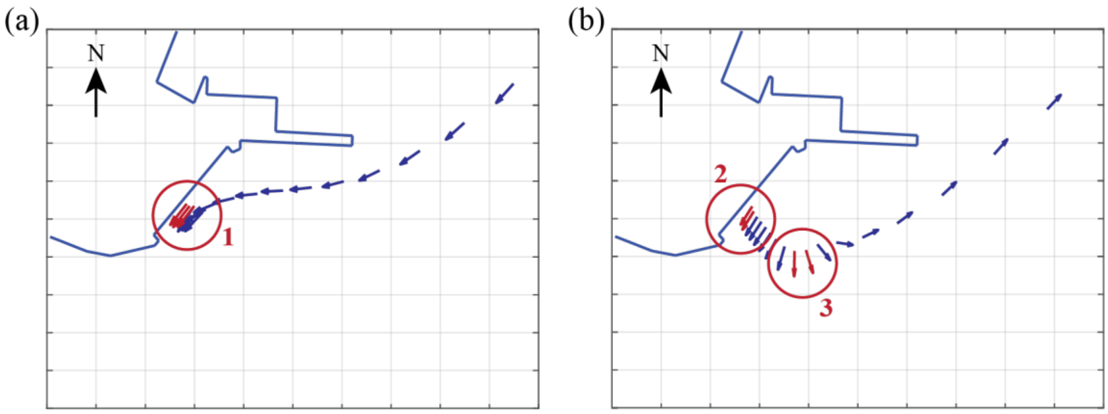

Figure 2. Vessel's heading arrows and details of the instants with maximum scouring potential from the stern propellers. (a) Arrival. (b) Departure.

The engine power, pitch ratio and speed revolution used in the particular moments described previously can be observed in the results obtained from the simulator in **Figure 3**. At the arrival maneuver, **Figure 3**a, during the last minutes of the maneuver, starboard engine is working astern using high engine power in order to stop the vessel. Although it is working astern and the flux is not directed towards the docking Ro-Ro wall, the high values of engine power and speed rotation, may create a scouring hole underneath the propellers. At the same time, the port propeller is working ahead with the flux impacting to the wall increasing the scouring action according to [5]. During the departure maneuver, **Figure 3**b, both at the beginning of the maneuver, number 2 in **Figure 3**b when the propellers are 28 m far from the docking wall, and during the turning action, number 3 in **Figure 3**b when the propellers are 155 m away from the docking wall, one of the propellers is working astern using higher engine power and speed rotation, while the other is working ahead with also relatively high values of engine power. The scouring potential of the latter but, is enhanced by the quay wall, which the propeller generated stream is directed to.

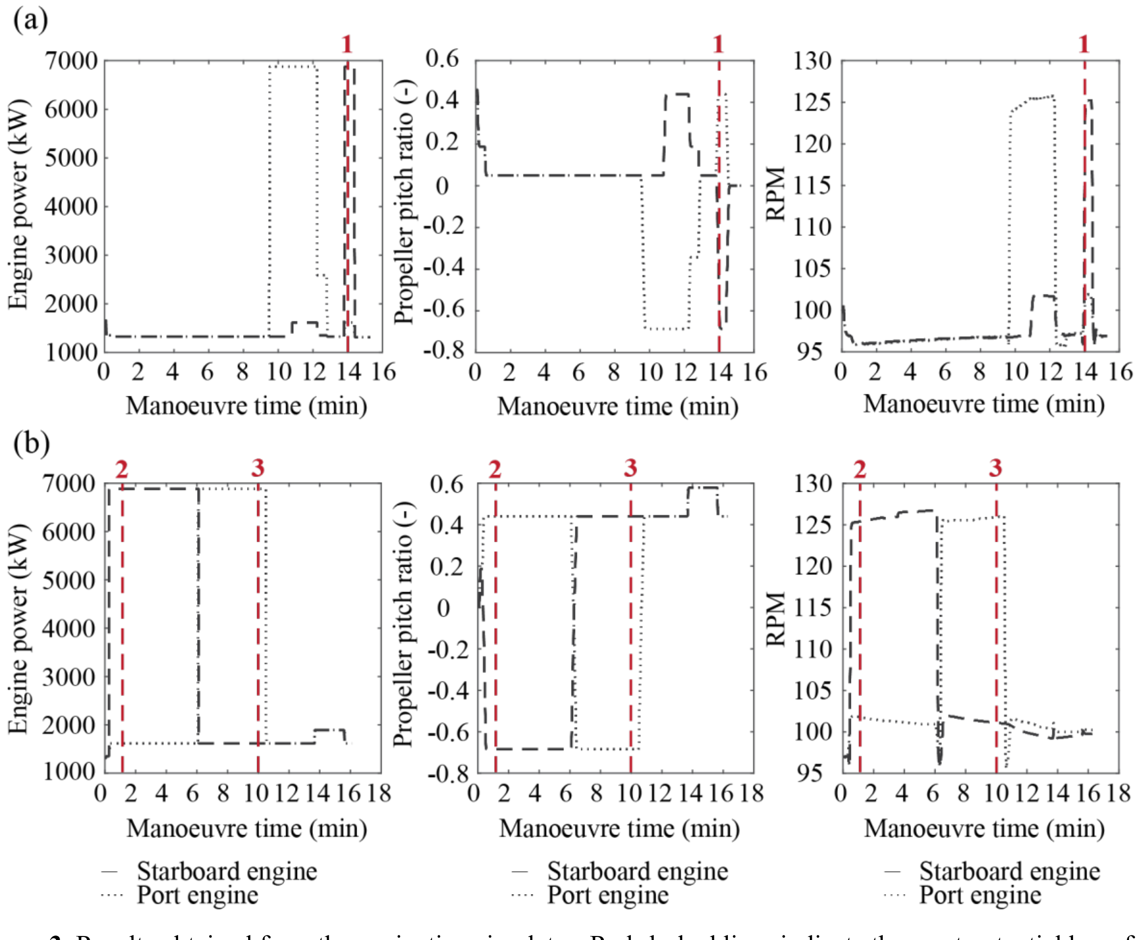

Figure 3. Results obtained from the navigation simulator. Red-dashed lines indicate the most potential harmful actions shown in Figure 2. (a) Arrival. (b) Departure.

If the values of the variables obtained from **Figure 3** using the navigation simulator are introduced to obtain the efflux velocity, Eq. (1) and the bed velocity, Eq. (4), final values are more scarce for the efflux velocity, as seen in Figure 4, although Eq. (4) already introduces the uncertainties in efflux velocity values. Maximum efflux velocity results are obtained during the first instants of the departure maneuver. Consequently, maximum values in bed velocity are also found at the same moment since the bed velocity is proportional to the efflux velocity. Therefore, apparently, the maximum scouring depth shall be produced at the first instants of the departure maneuver by the port propeller, which is working ahead.

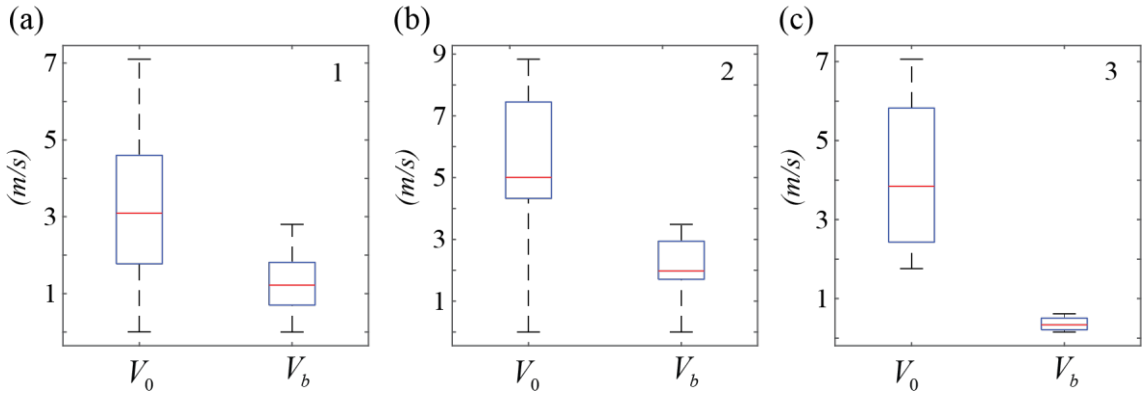

Figure 4. Efflux velocity and bed velocity results for the maximum potentially harmful instants according to Figure 2. (a) Arrival -1. (b) Departure -2. (c) Departure -3.

Scouring results obtained using Eq. (5), plotted in Figure 5 use only the values of speed rotation and engine power of the propellers working with the flux towards the wall, this is positive pitch values. According to Hamill et al. [5], the presence of a wall can increase the maximum erosion depth up to a factor of 1.5. Results are within the expected order of magnitude using real values of the maneuver. Figure 5 shows that the maximum scouring depth is found at the beginning of the departure maneuver. The last times of the arrival maneuver, red line in Figure 5a are also more harmful than the moment when the ship is turning during the departure, Figure 5b, due to the closer position of the stern with respect to the docking wall.

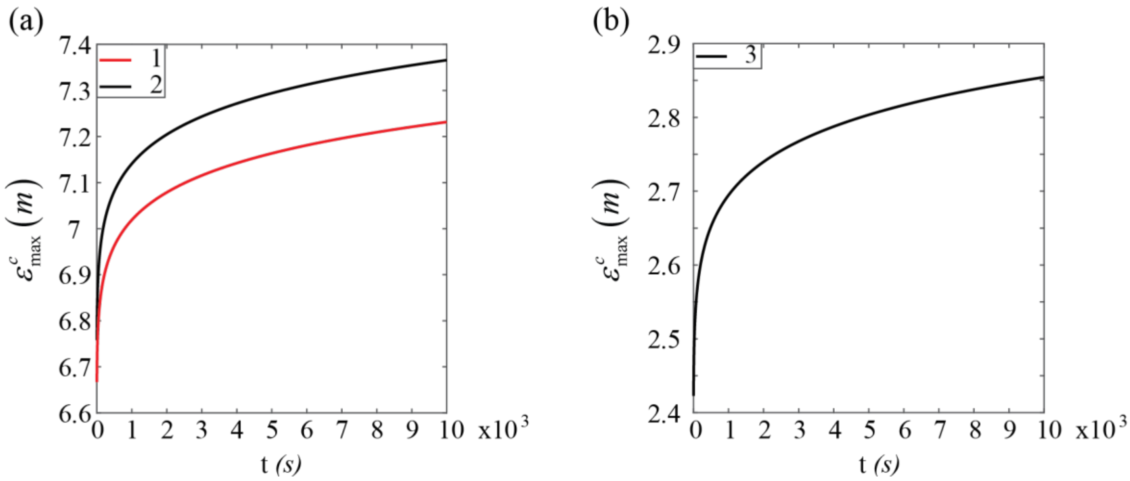

Figure 5. Maximum erosion depth for confined situations at the instants detailed in **Figure 2**. (a) Arrival -1 and Departure -2. (b) Departure -3.

5 CONCLUSIONS

In the present paper, the reproduction of the arrival and departure maneuvers using a navigation simulator is introduced as a methodology to estimate the maximum scouring depth. The simulation, performed after analyzing the AIS data of each maneuver, permitted to obtain the variables needed in the formulas used to predict the maximum scouring depth. After introducing the value of these variables, the results help to conclude that:

- The use of the simulator is needed to predict maximum scouring depth. Otherwise, variables value far from reality in terms of speed rotation, pitch and engine power can yield unrealistic results.
- AIS data analysis turns to be very useful to find out the manoeuvre patterns of a particular ship on a particular basin to later mimic the manoeuvre.
- Departure maneuver is more dangerous since it produces larger scouring holes and, therefore, can damage the docking structures. Moreover, the time interval within which the propeller generated wash is impacting against the wall is larger during this manoeuvre.

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