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CASE STUDY OF SHIP TO SHIP INTERACTION USING NTPRO 5000 NAVIGATIONAL SIMULATOR

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Abstract: *In the recent years research efforts in ship hydromechanics are devoted to the practical navigation problems in getting larger ships safely into existing harbors, which are usually characterised by narrow and shallow waters. This paper presents a case study of ship to ship interaction between a bulk carrier and an oil tanker passing through a narrow waterway in Suez Canal. This experiment was conducted using a navigation simulator which has the capability to represent the ships' motion, forces and moments that appear on ship's body, very close to reality.*

There had been studied the ship to ship interaction and also ship squat phenomenon, which, in general, appears in shallow waters navigation, but with a more pronounced effect on canals passage. The results analysis showed that the yaw moment and lateral force are strong enough to veer off course the smaller ship into the adjacent bank. The paper can be useful for ship designers, naval architects and naval officers, who have to know ship to ship interaction effects, in order to prevent any shipping accidents.
Keywords: *interaction, ship squat, canal, ship to ship, simulation.*

INTRODUCTION

In the last decade it was observed a continuous increase of the main dimensions of certain ship, especially for container carriers, RO-RO vessels and LNG carriers. In opposition, the dimensions of access channels, rivers, canals, and harbors where these vessels operate do not increase at the same rate. Therefore, the behavior of ships flow in harbors will be influenced by waterways restrictions.

A phenomenon that occurs on vessels in these areas is **ship squat**, which may be defined as the sinkage and/or trimming of the ship due to pressure changes along the ship length in shallow waters. Ship to ship interaction or ship to shore is also related to this phenomenon. The trim change can be explained by hydrodynamic interactions between the ship and the bottom due to speed and pressure distribution change. Large and fuller ships such as tankers and bulk carriers should pay extra attention when navigating in restricted waters. The squat effect is directly related to ship dimensions, its speed and water depth [1].

Squat formulas have been developed for estimating maximum ship squat for vessels operating in restricted and open water conditions with satisfactory results. Some have been measured on ships and some on ship models.

Barras's formula [1] is among the most simple and easy to use for all channel configurations. Based upon his research from 1979, 1981 and 2004, the maximum squat formula is determined by block coefficient C_B, blockage factor S and ship speed V_K.

Maximum squat, δ_{max} is equal to [1, p. 371]:

$$\delta_{\max} = \frac{C_B \cdot S^{0.81} \cdot V_K^{2.08}}{20} \text{ m} . \quad (1)$$

Ship to ship interaction is a phenomenon associated with ship squat and has been the subject of studies in many ways for a long time. In general, most researches still rely on empirical formulae, experimental tools or numerical (Computational Fluid Dynamics, CFD) techniques, among which the first two types are more widely used [4].

Ship to ship interaction has been studied since 1960, when *Newton* studied the effects of interaction during the overtaking of two ships, with two models vessels in deep water. *Müller* (1967) investigated both overtaking maneuver and passing of two ships in a narrow channel, while *Remerz* (1974), interaction forces on a moored ship due to the passage of another vessel. *Tuck* and *Newman* (1974) developed a slender-ship method for calculating sway forces and yaw moments for two ships moving on parallel courses in deep water. The ships could each have arbitrary speeds, so the solution was valid for head-on encounters, overtaking maneuvers or for one ship stationary. *Dand* (1981) investigated the effects of interaction when overtaking and passing, between two naval models on parallel paths. *Brix* (1993) presented a method to estimate the forces and moments that occur during overtaking, formulating approximations to the maximum longitudinal and transverse forces and moments of rotation. However, this method is valid only for overtaking maneuvers, water depth and vessels length ratio haven't been taken into account. *Varyani* (1999) present empirical formulas for calculation of the maximum lateral force and torsion's moment during the meeting maneuver [5].

Passing maneuvers of ships in shallow water can produce significant sway and yaw motions of each vessel, which can be dangerous if not properly understood.

SHIP TO SHIP INTERACTION

When vessels are approaching one another, each of them can "feel" the presence of the other to a greater or lesser degree, which is manifested in different ways, from involuntary changes of speed to unexpected changes of course that can lead to collision or grounding.

To avoid these situations, vessels must pass at a sufficient distance from each other, allowing them to maneuver safely. However, this is not always possible, especially when vessels pass a strait or channel, or when tugs which, by the nature of their work, are very near the ship they assist.

In navigation, interaction occurs when pressure fields around ships interact. If the system pressure acting on the hull of the vessel is changed, the ship steady state will be affected. This may increase or decrease ship speed and draft or trim. If a ship goes from deep water to shallow water, the presence of the bottom will affect the pressure on the hull as the depth decreases.

Interaction effects are multiple, some with serious consequences as grounding or collision. These include:

- squat in shallow and narrow waters increases when ships are on a passing or overtaking situation and is maximum when their amidships are in line;
- each ship will develop an angle of heel and the smaller vessel will be attracted to the larger vessel;
- rudder effect is reduced and ships will change course without a helm order;
- smaller vessel may veer off course to the adjacent bank;
- smaller vessel could veer into the side of the larger ship.

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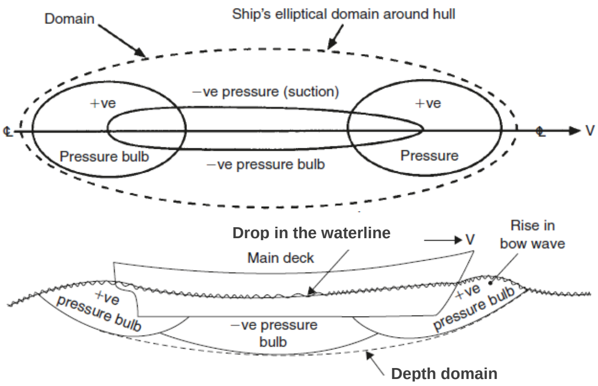
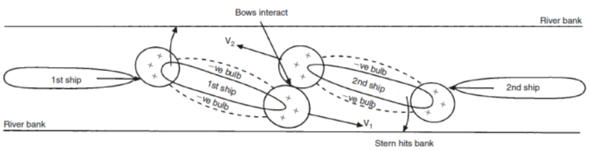


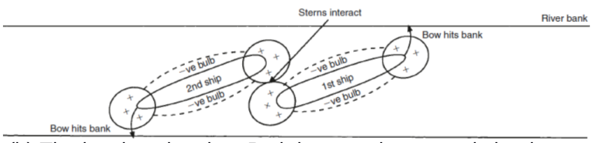
Figure 1. Pressure distribution around ship’s hull [1].

The cause of these effects is the interaction between hydrodynamic pressure fields of ships during movement (Figure 1). A moving ship will develop around the hull two positive pressure bulbs, fore and aft, and one negative along the body, creating together an elliptical pressure field. When these fields interact, the effects on ships are significant and they become more pronounced in shallow waters. Therefore, it is imperative for master, mates and pilots to know about the phenomenon of interaction.

By definition, vessels traffic, lightering operations or ships’ maneuvers in harbors are characterized by ship to ship interactions. Trials run on ship models showed that ship to ship interaction varies with the square of velocity and inversely proportional to the distance between the ship and the square root of under keel clearance and draft ratio. In other words, a higher speed, a smaller distance and under keel clearance produce a stronger interaction between ships. It should be noted that a correct speed and a sufficient distance is essential to avoid or minimize the effects of interaction.



(a) The approach situation. Both sterns swing towards banks.



(b) The leaving situation. Both bows swing towards banks.

Figure 2. Ship to ship interaction [1].

The situation of passing (Figure 2) is quick and often ships do not have time to react to the forces and moments that occur. The main effect which affects ships is a yaw moment that pushes both bows through the banks. When ships approach the yaw moment is smaller and the ship is easier to control, but in the leaving situation, this moment is greater and, if not anticipated, may cause course alteration of the vessels into adjacent bank.

SIMULATED TRIAL

In this paper it is presented a study case of a ship to ship interaction using the navigational simulator NTPRO 5000. Because ship to ship interaction has a greater effect in shallow and narrow waters, the location chosen for this simulation was a waterway of approximately 390 m breadth from the Suez Canal.

The ships used were an oil tanker as own ship and a bulk carrier as target ship. Their characteristics are described in Table 1.

Table 1. Ship’s characteristics

Characteristics	Own ship	Target ship
Vessel type	Oil tanker	Bulk carrier
Displacement [t]	77100	104510
Length [m]	242.8	250
Breadth [m]	32.2	43
Bow/ stern draft [m]	12.5/12.5	12/12
Max speed [knt]	15	14.8
Type of engine	Slow speed diesel	Slow speed diesel
Type of propeller	Fixed pitch propeller	Fixed pitch propeller

The environment condition of the trial can be considered ideal as the wind and current speed were 0 m/s, air temperature 22°C and pressure 1013 mbar, so that ships’ motion in water wouldn’t be affected by any external factors.

The water depth of the area was constant at 15 m and considering the ships’ drafts, it can be stated that they were in shallow water conditions. Therefore, when ships sail through water with speed they will be affected by squat. For own ship the increase of draft caused by shallow waters is presented in Table 2.

The ships were on parallel tracks coming from opposite directions. The passing distance was 50 m from board to board when the midships align.

Table 2. Draft increase caused by squat effect for own ship

Under keel clearance	Ship’s speed	Bow squat	Stern squat
3 m	13.72 knots	1.06 m	1.01 m
	12.79 knots	0.87 m	0.87 m
	10.89 knots	0.59 m	0.66 m
2 m	13.89 knots	1.23 m	1.15 m
	12.97 knots	1.03 m	1 m

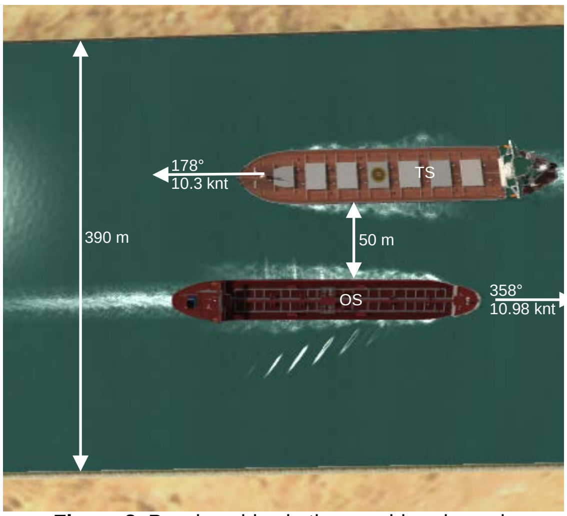


Figure 3. Passing ships in the considered canal.

The ships’ speeds are assumed constant. In his experiments, *Dand* (1981) concluded that head-on encounters and particularly overtaking encounters produce changes in resistance which translate into changes in ship speed at constant engine RPM [4].

RESULTS AND DISCUSSIONS

The simulation was run three times and the following results were obtained. The purpose of these trials was to observe the increase of draft due to ship to ship interaction and to see how the yawing moment evolves during ships' passing.

The meeting of the ships took place after approximately four minutes from the start of the exercise. During this time ships stabilized their course and speed so that in the moment of meeting these parameters would be constant. After passing, the exercise was stopped and a series of tables and graphs were generated.

Therefore, from Figure 4, it can be observed that the trend of own ship's draft is ascending when ships meet. The oil tanker (own ship) already has an increased draft caused by shallow waters conditions, from 12.5 m bow and stern, in static conditions, to 13.26 m at bow, respectively 13.30 m at stern when the ship undergoes with 10.95 knots. This squat is in correspondence with values presented in Table 2.

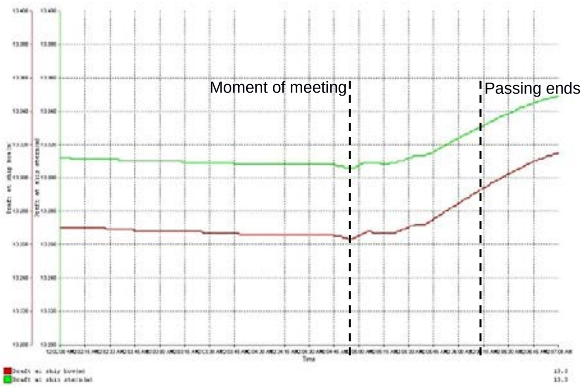


Figure 4. Draft at ship bow and stern.

The graph in Figure 4 was obtained using the results from Table 3 were it can be observed that from the moment of meeting the draft slightly decreases and then has an ascending trend. After the ships pass each other, bow and stern drafts continue to increase but this time due to bank effect. This phenomenon won't be discussed in the present article.

Table 3. Variation of draft during ships' passing

Time	Bow draft [m]	Stern draft [m]
04:31	13.266	13.308
04:46	13.265	13.307
04:51	13.264	13.306
04:58	13.264	13.307
05:00	13.266	13.308
05:03	13.267	13.309
05:24	13.268	13.31
05:28	13.269	13.311
05:30	13.27	13.312
05:33	13.271	13.313
05:41	13.273	13.314
05:45	13.275	13.315
05:46	13.276	13.316
05:48	13.277	13.317
05:49	13.278	13.318
05:51	13.279	13.319
05:54	13.281	13.32
05:56	13.282	13.322
05:58	13.283	13.323
06:00	13.285	13.324

Under keel clearance (Figure 5) is in accordance with ship's draft. It goes from 1.734 m at bow, respectively 1.692 m at stern right before meeting and 1.715 m at bow and 1.676 m at stern after passing.

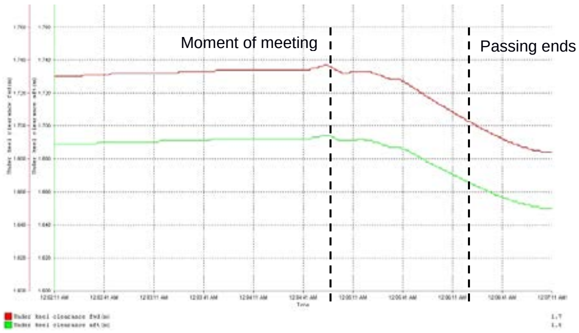


Figure 5. Under keel clearance at bow and stern.

Directly related to ships interaction and ship squat, it was observed a speed increase (Figure 6). Ship speed has an ascending trend just like draft. After a small decrease when ships meet, speed goes from 10.953 knots to 11.093 knots when ships already passed each other (Table 4). Speed continues to increase after this moment but this is because of bank effect, as the ship swayed to starboard and changed its course.

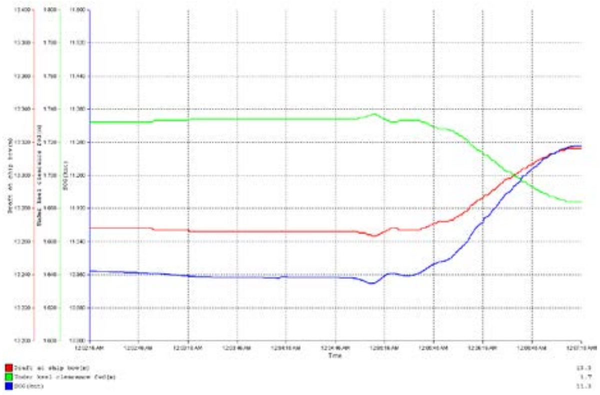


Figure 6. Ship's speed, bow draft and forward under keel clearance.

Table 4. Variation of speed correlated with bow draft and forward under keel clearance

Time	Bow draft [m]	Under keel clearance fwd [m]	Spee d [knt]
04:30	13.266	1.734	10.95 3
04:40	13.266	1.734	10.95 1
04:50	13.263	1.737	10.93 8
05:00	13.267	1.733	10.96 3
05:10	13.267	1.733	10.95 7
05:20	13.268	1.732	10.96 8
05:30	13.272	1.728	10.99
05:40	13.274	1.726	11.01 2
05:50	13.281	1.719	11.05 3
06:00	13.287	1.713	11.09 3

Other hydrodynamic parameters generated were the pitching and yawing moments of own ship (Figure 7). It can be seen that when ships meet yawing moment dramatically decreases at -8702.9 t*m followed by a return and an increased caused by bank effect. Ship to ship interaction also causes a pitching moment which has maximum values when ships meet and attenuates after interaction ceased to exist.

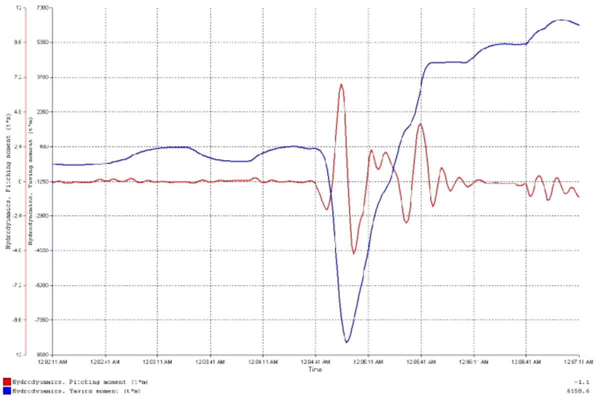


Figure 7. Own ship pitching and yawing moments.

When a single ship enters a shallow water area the natural pitch period of a bulk carrier or oil tanker will typically be about 10 seconds, while the time taken for two ships to pass each other will be in the order of 1 minute. Therefore, the changes in pitching moment happen over a much longer time scale than the natural pitch periods, giving the ship sufficient time to adjust its sinkage and trim.

Yaw angle and sway (Figure 8) are also related to pitching and yawing moments. When vessels meet, own ship swing towards bank with a maximum yaw angle of 1.245° and has a sway of 0.19 m to starboard.

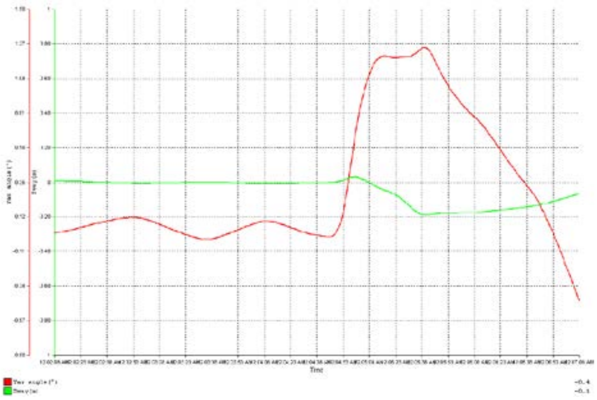


Figure 8. Own ship yaw angle and sway.

A lateral force (Figure 9) between ships appears when they meet and it continues to exist during the passing. In the approach situation, when ships meet with bows, the force has the maximum value. During the passing, it is decreasing until ships meet with sterns, when it reaches a negative maximum.

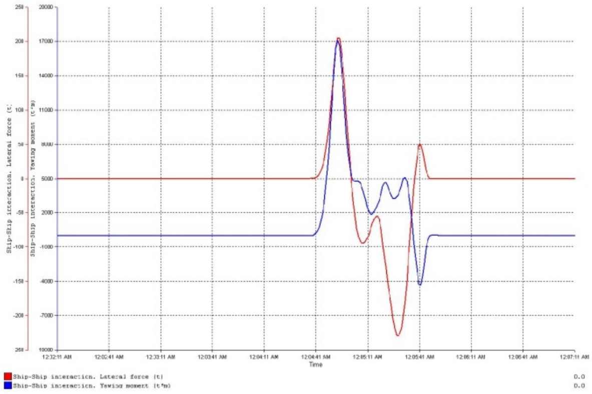


Figure 9. Ship to ship interaction. Lateral force and yawing moment.

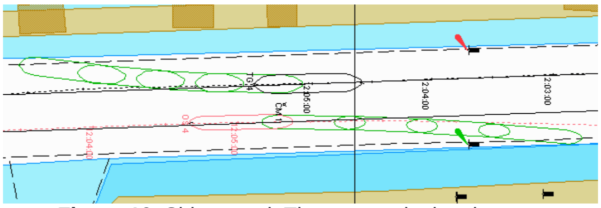


Figure 10. Ships trend. The approach situation.

Also, the yawing moment between ships has the same evolution (Figure 9). When approaching, ships have a tendency to reject caused by the positive pressure field at bow and swing towards adjacent bank (Figure 10). As the ships come closer together, the yawing moment decreases, as the high pressure area ahead of each ship’s bow causes a lesser force on the other ship. When sterns interact, the tendency of the ships is to swing toward opposite bank, but the decreased yawing moment has a smaller effect on ships [4].

CONCLUSIONS

Ship to ship interaction between a bulk carrier and oil tanker during a passing situation from opposing directions in shallow water with constant depth was investigated using NTPRO 5000 navigational simulator and reported in this paper.

Sample numerical results and graphic interpretations have been presented and it was seen that the main qualitative effects are an increase in bow and stern drafts when ships pass each other and a yawing moment that veer the ship off course. These effects are also linked with a speed increase. In other words, it can be stated that a higher speed, a smaller distance and under keel clearance produce a stronger interaction between ships.

An understanding of the phenomenon of interaction can avert a possible marine accident. For masters, mates, and pilots generally, a reduction in speed is the best preventive procedure.

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REFERENCES

1. Barrass B., Derrett R., *Ship Stability for Masters and Mates*, 6th ed., Ed. Elsevier, London, 2006
2. Șerban P. S., Panaitescu V. N., *Stadiul actual al cercetărilor experimentale efectuate asupra squatului navelor maritime*, Știință și Inginerie, An XIV, vol. 26, 2014
3. Șerban P.S., *Interacțiunea navelor la navigația în strâmtori* (*Ship interaction when navigating in straits*), disertation paper, ”Mircea cel Bătrân” Naval Academy, Constanța, 2012
4. Gourlay T., *Sinkage and trim of two ships passing each other on parallel courses*, Ocean Engineering, vol. 36, issue 14, 2009
5. Zou L., Larsson L., *Numerical predictions of ship-to-ship interaction in shallow water*, Ocean Engineering, vol. 72, 2013
6. Dand. I., *Ship-ship interaction in shallow water*, 11th Symposium on Naval Hydrodynamics, 1976
7. Eloot K., Vantorre M., et. al., *Squat during ship-to-ship interactions in shallow water*, 2nd International Conference on Ship Manoeuvring in Shallow and Confined Water: Ship to Ship Interaction, 2011
8. Fonfach J., Sutulo S., Guedes S., *Numerical study of ship-to-ship interaction forces on the basis of various flow models*, 2nd International Conference on Ship Manoeuvring in Shallow and Confined Water: Ship to Ship Interaction, 2011
9. Gronarz A., *Ship-Ship Interaction: Overtaking and Encountering of Inland Vessels on Shallow Water*, Marsim 2006 International Conference on Marine Simulation and Ship Manoeuvrability, 2006
10. Lataire E., Vantorre M., Vandenbroucke J., Eloot K., *Ship to ship interaction forces during lightering operations*, 2nd International Conference on Ship Manoeuvring in Shallow and Confined Water: Ship to Ship Interaction, 2011
11. Sadat-Hosseini H., Wu P. C., Toda Y., Carrica P. M., Stern F., *URANS studies of ship-ship interactions in shallow-water*, 2nd International Conference on Ship Manoeuvring in Shallow and Confined Water: Ship to Ship Interaction, 2011
12. Zou L., Larsson L., *Investigation of Ship-to-Ship Interaction during Lightering Operations in Shallow Waters Using a RANS Solver*, MARSIM 2012, 2012