SHIP SQUAT FOR A THEORETICAL HULL MODEL IN TRAPEZOIDAL VARIABLE CROSS-SECTION CANAL

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ABSTRACT

This paper deals with ship squat phenomenon, which, in general, appears in shallow waters navigation, but with a more pronounced effect on canals passage. Therefore, theoretical calculations of ship squat have been made for a theoretical hull model of a general cargo ship, designed in Autoship, transiting a canal with various trapezoidal cross sections. The paper can be useful for ship designers, naval architects and naval officers, who have to know squat's effects, in order to prevent any shipping accidents.

1. Introduction

In the last decade it was observed a continuous increase of the main dimensions of certain ship, especially for container carriers, crude oil tankers, 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. 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; therefore it interests port designers as much as masters and naval architects [1].

Current researches on this phenomenon are limited to experiments or model scale for an accurate mathematical expression of ship squat. The literature presents various formulas of ship squat, the most commonly used being those of Barrass (1979, 2004) [2], Millward (1990), Norrbin (1986) and Tuck (1970).

The aim of the present paper is to explain and calculate the squat that occurs on a theoretical hull model for some variations of water depths and widths of a canal with trapezoidal cross-section.

2. Ship Squat

Squat is the decrease of underkeel clearance caused by the movement of the submerged ship's body through water. Compared with the static position, the hull goes deeper into the water and trims for a few degrees.

A moving vessel pushes the water in front of her bow, which must flow back under and at the sides of the ship to replace the volume of water displaced by the ship's hull. In shallow and/or narrow waters the water particles' velocity of flow increases which results a pressure drop, according to Bernoulli's Law.

The pressure drop under the ship causes a vertical sinking of the ship's hull and depending on the vessel's block coefficient it will trim forward, aft or will sink deeper on even keel. The amount of all vertical sinking and trim is called ship squat.

When ships navigate in shallow water at too great speed, grounding may occur at the bow or at the stern due to excessive squat. Full-form ships such as Super tankers or Ore-Bulk-Oil ships may experience grounding generally at the bow. Fine-form vessels such as Passengers Liners or Container ships may experience grounding generally at the stern.

If block coefficient, C_B, is greater than 0.7, then maximum squat will occur at the bow. If C_B is less than 0.7, then maximum squat will occur at the stern. If C_B is very near to 0.7, then maximum squat will occur at the stern, amidships and at the bow. In this case, squat will consist only of mean bodily sinkage, with no trimming effects.

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 [2] 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, $\delta_{max,}$ formula is determined by block coefficient C_B, blockage factor S and ship speed V_K, as follows [3, p. 327]:

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

Equation (1) was used for squat determination of the theoretical hull model in all cases of the considered canals.

3. Hull Model

The hull model was developed using Autoship by ASC, a powerful ship design tool, dedicated for naval architecture and marine shipping industries. This software supports naval architects and engineers in designing vessels, from small boats to large vessels. Through its complexity, the software offers naval engineers the ability to design and study the nautical qualities of a ship and to determine the requirements of drag and stability [4].

The model used for squat determination is a general cargo vessel of radius-bilge design. It also has a bulbous bow with thruster and a faired-in stern bulb. The final form of the hull model is shown in Figure 1. Autoship enables visualization of the vessel in all three projection planes and also three-dimensional.

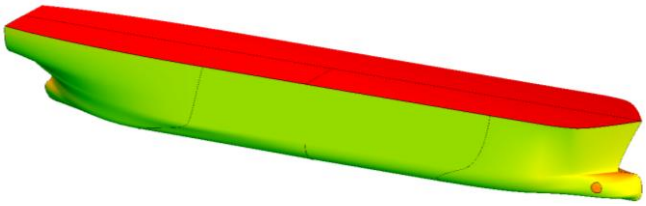


Figure 1. 3D view of the hull model

For exemplification, the authors designed a theoretical general cargo ship hull, after a thorough study of the specific literature and present ship dimensions. The main properties of the vessel are summarized in Table 1 and the body plan is shown in Figure 2.

Table 1

Main properties of theoretical hull model

Hull model characteristic	Dimension	Unit
L_{OA} (length over-all)	128	[m]
B (breadth)	20,5	[m]
T (draught)	6,5	[m]
C_B (block coefficient)	0,700	-

The steps for modeling the cargo ship are to: create a midship section with a radius bilge, generate a forebody shape as an extruded surface from the midship section, develop the bow rounding, generate the aftbody shape as a surface lofted from curves, add a bow thruster by projecting a curve and by surf-surf intersection, add a deck with camber and shear.

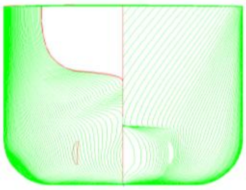


Figure 2. Body plan of the cargo ship model including stations lines

According to Barrass [2], the maximum squat for this hull model will occur at the stern, amidships and at the bow, because the block coefficient is 0.700. Therefore, trimming effects on the hull shouldn't be observed, as squat is represented by a mean bodily sinkage.

4. Hull model squat analysis for various trapezoidal cross section canals

The problem of squat calculation is important for ships, especially in shallow waters and confined waterways. To see how ship squat varies depending on actual speed limit in channel navigation for the model considered, there have been made calculations.

Initial parameters for the hull are the block coefficient, C_B, equal to 0.700 and the model speed, V_K, which has been varied from 0 up to 15 knots (~7.7 m/s), the higher speeds being only feasible in the deeper and wider canals. Also, for blockage factor determination, model breadth and draught were taken into account.

For a trapezoidal cross section canal there has to be known the bottom width W, water line width W_S and water depth h. In this study, the theoretical canal was modified from a wide and deep fairway, up to underkeel clearances of only a few percent of the vessel's draught. The application range of the proposed hull is constrained to canals with a trapezoidal cross section and to vessels sailing without drift and parallel to the longitudinal boundaries of the canal [5].

Therefore, the bottom width W of the canal section was varied from 1.05 up to 2.50 times the ship's beam B. Also a range of water depths was tested from 1.05 T to 1.50 T (Fig. 3). The blockage factor S (or the ratio between the midship section A_M and the cross section of the fairway A_C) is summarized in Table 2.

Table 2

Overview of blockage factors S

	Canal bottom width W; water line width W_S = 3.0 W			
Water depth h	**1.05 B**	**1.25 B**	**1.70 B**	**2.50 B***
1.05 T	0.431	-	-	-
1.10 T	0.411	0.345	0.254	0.197
1.35 T	0.335	0.281	0.207	0.161
1.50 T	0.302	0.253	0.186	0.145

* Canal water line width for this case is 2.5 W

Before calculations it was supposed that the vessel sails at a constant speed V_K in a waterway with trapezoidal cross section A_C with a constant water depth h (at rest) and width W. For midship section area determination it was taken into account the rounding of the bilge and it was introduced a midship coefficient $C_M = 0.95$. Therefore, midship area equals to:

$$A_M = 0.95 \cdot B \cdot T \ \ \mathrm{m}^2. \tag{2}$$

Analyzing the squat for all the configurations of the canal and speeds of the hull we obtained four graphs (Fig. 4) for each considered canal depth. For the first configuration of the canal (Fig. 4a) the hull is in a very confined environment and its static underkeel clearance is only 0.325 m. It can be observed that at only 4 knots the grounding will occur. Therefore, it is not feasible to continue with other canal widths because the ship will run aground even at slow speeds.

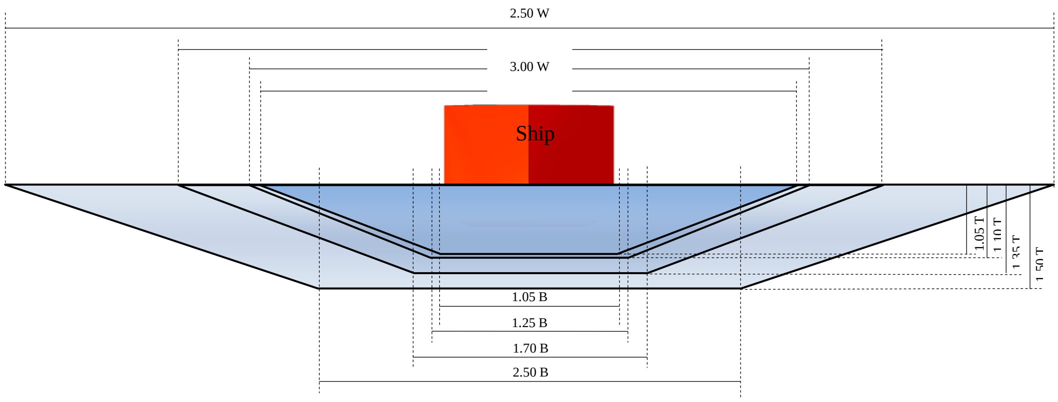
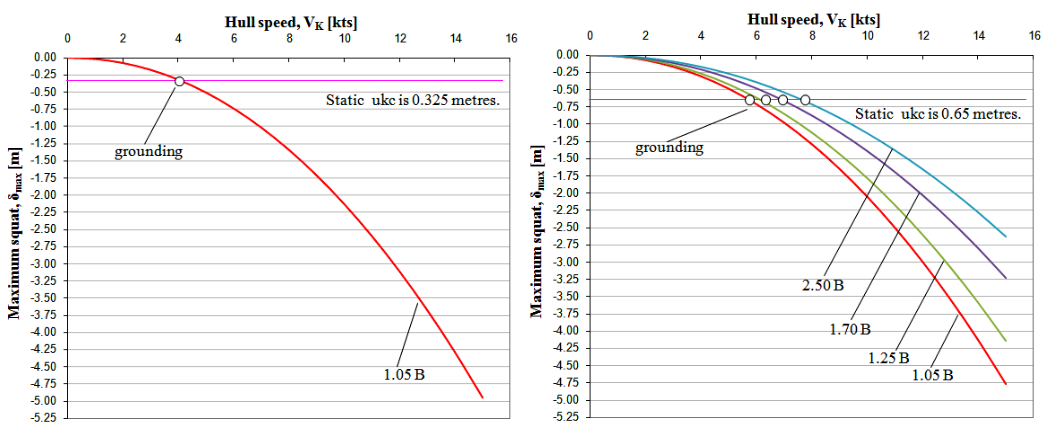
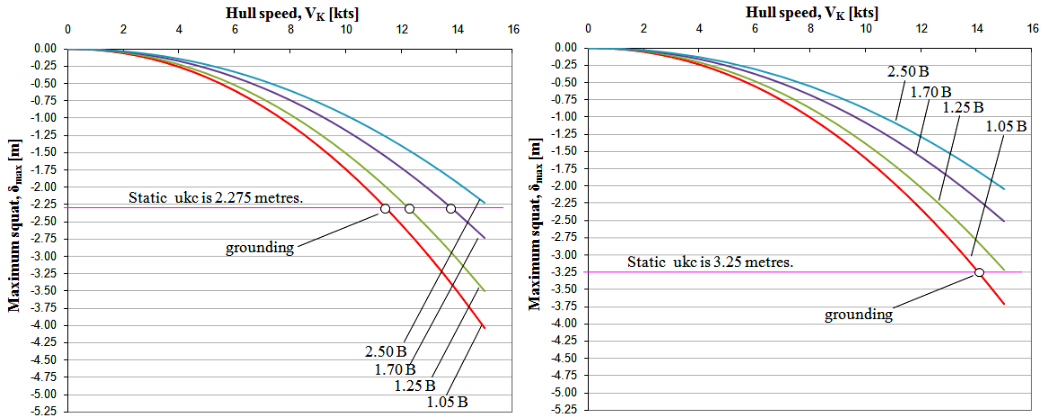


Figure 3. Overview of all cross section configurations



(a) h = 1.05 T (b) h = 1.10 T



(c) h = 1.35 T (d) h = 1.50 T

Figure 4. The calculated squat for all canal widths, at all speeds and water depths considered

When the depth of the canal is 1.10 T (Fig. 4b), static underkeel clearance increases at 0.65 m. For every considered canal width, grounding may occur at speeds between 5.74 knots, the narrowest canal, and 7.64 knots, the widest. For this scenario, ships in real canals with similar configurations still have to navigate with caution because grounding may occur even at slow speeds.

Increasing the depth of the canal also increases the static underkeel clearance of the hull and with greater widths the risk of running aground is diminished when sailing with high speeds. It can be observed that for 1.35 T and 2.50 B (Fig. 4c) configuration of the canal there is no grounding for 15 knots. That is also the situation for 1.50 T and 1.25 B (Fig. 4d). Even so, the underkeel clearance is still low and caution is required.

For the last considered depth grounding occurs only for the narrowest canal at 14.08 knots. For other conditions, such as 1.70 B and 2.50 B, the hull can pass the canal without grounding even if the maximum squat is 2.507 m, respectively 2.044 m at 15 knots.

5. Conclusions

Calculations have been carried out with a theoretical hull model of a general cargo vessel in a trapezoidal cross section canal with various configurations of width and depth. It was supposed that the vessel sails at a constant speed V_K in the canal, without drift and parallel to the longitudinal channel boundaries.

In the narrowest canal configuration the squat increases rapidly with speed from 0 to 4.76 m but because of the low underkeel clearance, the hull will run aground even at 4 knots. Increasing the depth of the canal also increases the static underkeel clearance of the hull and with greater widths the risk of running aground is diminished when sailing with high speeds.

The fairway can vary from 2.5 times the hull's breadth and 1.5 times hull's draught to a very restricted canal in width and water depth with a trapezoidal cross section.

The authors have proposed that in the near future to conduct experimental research on various ship models. For their design and construction will be used Autoship software, which proved to be an easy tool and complex enough to meet the demands of such a project.

Maximum squat determination for shallow and/or narrow waters remains an important issue for safety of navigation. Masters should know before entering such areas, where and how much the draught will increase to take actions to combat the squat effect.

Acknowledgement

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References:

[1] P. S. Șerban, *Interacțiunea navelor la navigația în strâmtori* (Ship interaction when navigating in straits), disertation paper,”Mircea cel Bătrân” Naval academy, Constanța, 2012.

[2] B. Barrass, *Ship Design and Performance for Masters and Mates*, Ed. Elsevier, London, 2004.

[3] B. Barrass, R. Derrett, *Ship Stability for Masters and Mates*, 6th ed., Ed. Elsevier, London, 2006.

[4] ***, *Autoship for Windows User's Guide*, Autoship Systems Corporation, Vancouver, 2008.

[5] E. Lataire, M. Vantorre, G. Delefortrie, *A prediction method for squat in restricted and unrestricted rectangular fairways,* in Ocean Engineering, nr. 55, 2012, pg. 71-80.