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EFFECT OF THE BOW SHAPES ON THE SINKAGE OF SHIPS

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ABSTRACT

The scope of knowledge about sinkage currently suggests that this hydrodynamic effect is caused by the changes occurred in the dynamic pressure field of a ship-hull when it sails. Consequently, this hydrodynamic effect could be optimized by changing the hull forms design, and at this respect, it has been stated that the bow shapes might be the most related part of the hull forms towards sinkage. The aim of this work is to continue studying the geometry-sinkage issue, deepening in how the bow shapes can influence this phenomenon. Based on the towing tests results of a ship database it was confirmed that sinkage leads to significant drag increase, which in some cases can be up to more than the 20% of drag, reinforcing the need of studying how to address its optimization. As well, the idea of the key effect of the bow shapes on the sinkage of ships was refused based on the following results. Firstly, there were two pair of hulls which share the particularity of just differing in the bow – one of each had a bulbous bow while the other presented a straight bow – and each pair showed similar levels of sinkage for both designs. After that, the sinkage acquired in two loading cases by a double bow ferry ship was studied showing similar results. These results have been complemented with the numerical study of the problem with Star-CCM+.

Keywords: Sinkage, Bow Shapes, Simulations, CFD

1- INTRODUCTION

One of the first descriptions of dynamic sinkage was made by H.E. Saunders (1957) [1], who describes that phenomenon as a consequence of the dynamic hull pressure field fluctuations which occur at sailing. Those changes in the hull pressure field makes the buoyancy-weight equilibrium to get disrupted and as a consequence of that, a vertical downward force – lift – and a pitch moment appear which restore that equilibrium by making the ship to sink and trim. A more recent approach, is the one provided by the International Towing Tank Conference (ITTC) at their Dictionary of Hydromechanics (2014) [2], where they define sinkage as "The steady state of lowering of a ship's position of flotation in the water, to be distinguished from heaving, which is an oscillatory motion". One of the first studies found about this phenomenon were made by Suzuki et al. (1979) [3], who stated that even though sinkage tends to have a small value, the force cause of this hydrodynamic effect can reach values of up to 10 times the wave resistance, and based on that suggestion, they studied sinkage effect on wave resistance through a Neuman-Kelvin problem. Further research was made at the respect of the relation between sinkage and wave resistance by Kim, Y. et al (1981) [4] showing differences of 10-20% in wave resistance between fixed and free to sink and trim model in their experimental results, what in contrast to their conclusions – in which they reject that relation – reinforces the idea of the connection between wave resistance and acquired sinkage, as both have their origin in the dynamic pressure field.

Since the contribution mentioned above, sinkage did not catch hydrodynamic community attention until the present century, when they began to study squat effect – sinkage and trimming phenomenon at shallow water, where suction loads are higher – since there is an appreciable risk of grounding on vessels. At this respect. Gourlay, T.P. et al (2001) [5] studied sinkage and trimming at shallow and non-shallow water both with Finite Depth Theory (FDT) and they found that this theory is accurate enough for both situations as well as the fact that the maximum sinkage of a certain ship tends to occur when it reaches its critical speed. Another remarkable and more recent research work around squat effect is that developed by Yao, J. et al (2010) [6]where they analyse this phenomenon by using a 3D Panel Method applied to a Series-60 model.

Soon after the beginning of the studies around squat effect, the research works towards sinkage optimization aroused, as it can be observed in the research work carried out by Saha, G.K. et al. (2004) [7] in which they modify the shapes of a theoretical hull (Wigley) and a Series-60 hull using a numerical method and they obtained lower values of sinkage and wave resistance. The effect of sinkage in drag evaluation is studied in several research works whether it is on total resistance, as it is done on [8] (2012) with an INSEAN-2340 model, or on wave resistance as Yang, C. et al [9] do in their study (2013), where apart from sinkage they took as well the effect of trimming and other non-linearities into account.

The consideration of sinkage effect on drag calculation, especially when its influence has been specifically studied on wave resistance, has helped the study of its mitigation. Referring to this problem, Deng, R. et al (2015) [10], studied how dynamic sinkage and trimming effect changed on multi-hull ships when a T-Foil was implemented on them, and they as well remarked the need of study this effect with a higher range of hulls in order to lead to stable rules which can help to predict sinkage behaviour. Another point of view at tackling the negative effects of sinkage on drag is through ship geometry since hull forms affect directly to dynamic pressure field distribution. A crucial contribution on this aspect is that provided by Steven Toby, A. (2016) [11] since he studied the potential link of form coefficients and sinkage – due to the fact that they are hydrostatic parameters, and by confirming this relation sinkage analysis process would be eased – specially with prismatic and waterplane coefficient. An example of a complete research work on sinkage-geometry relation are those done by Ma, C. et al in 2016 [12] with 22 different models, where they got a dependence relation between sinkage and some geometric parameters, and in 2017 [13] when they continue with the first research and where they lead to the conclusion that sinkage does not affect drag significantly at Fn<0,25 but for higher values, sinkage effect on drag experienced a fast growth.

In terms of tackling sinkage and its optimization through hull forms design, Computational Fluid Dynamics (CFD) tools can be really useful, hence the ITTC Specialist Committee on CFD and Hydrodynamics encouraged the research community to deepen in CFD verification and validation at sinkage estimation on its 2014 report [14]. In line with these recommendations, Saha, G.K. et al. (2017) [15] carried out a research work in which they analysed the uncertainties obtained with the CFD commercial software SHIPFLOW at resistance, sinkage and trim estimation but they obtained inconclusive results, suggesting to use finer meshes on future research works. Regarding ITTC recommendations on sinkage studies, on its 28th Resistance Committee Report, they showed the need of increasing experimental data on acquired sinkage and trim at low Froude Numbers [16].

Taking into consideration the state of art of sinkage exposed above, the aim of this work is to deepen into the ship sinkage-geometry problem by continuing with the latest research work developed by CEHINAV at this respect [17], in which they suggest the potential key role of the bow shapes on acquired sinkage. Consequently, this work will use a wider ship database to analyse the effect of the hull geometry, focusing on the bow shapes, on sinkage both experimentally, with the towing test results, and numerically with the commercial software Star-CCM+.

2- MATERIALS AND METHODS

To tackle the sinkage-geometry problem, a wide range of hull form design, which were studied both experimentally – by taking the results obtained from their respective towing tests – and numerically, was tried to be covered so as to broaden the ship database used in prior studies developed by CEHINAV. The objective which is being pursued by doing this, is to eventually get a relation between sinkage and some geometric parameters so the sinkage optimization process can be addressed by slight changes made on the hull forms.

Main geometric parameters from the ships used are displayed in table 1

Table 1. Ship Database

	Lwl (m)	*B (m)*	*D (m)*	∇ *(m3)*	C_B	C_P	C_M	C_{WP}	***Bulb.***
Purse Seiner A	85,730	14,350	6,310	3979,940	0,513	0,547	0,937	0,749	No
Purse Seiner B	80,130	14,350	6,340	4106,580	0,563	0,592	0,951	0,792	Yes
Purse Seiner I	70,906	13,650	4,038	2077,58	0,553	0,600	0,929	0,696	Yes
Trawler I	39,652	11,500	4,302	1032,113	0,526	0,586	0,898	0,786	Yes
Trawler II	43,390	11,000	4,500	1399,420	0,650	0,713	0,912	0,915	Yes
Research Vessel	55,820	13,000	4,500	1737,304	0,565	0,617	0,910	0,817	No
Ferry	37,349	10,750	2,822	508,579	0,470	0,643	0,733	0,771	Yes
Ro-Ro	118,000	22,000	4,800	4654,631	0,433	0,579	0,748	0,742	No
Ro-Pax	108,440	16,700	4,600	4601,420	0,588	0,618	0,951	0,823	Yes
Outrigger Trawler	30,939	8,500	3,450	559,570	0,617	0,664	0,929	0,864	Yes
Fishing Vessel A	8,362	3,01	0,983	8,623	0,370	0,623	0,595	0,752	No
Fishing Vessel B	8,970	3,01	0,983	9,179	0,365	0,609	0,603	0,716	Yes
Double-Bow Ferry	78,202	15,50	3,645	1854,100	0,419	0,517	0,811	0,746	Yes

As it is shown the ships compounding the database were a total of 13 ships which corresponded to three large purse seiners, two trawlers, a research vessel, a ferry, a Ro-Ro, a Ro-Pax, an outrigger trawler, two small fishing vessels and a double-bow ferry.

3- RESULTS

3.1.- Analysis of the main bow geometric parameters

The importance of studying sinkage optimization through hull form modifications comes firstly from the fact that this hydrodynamic effect is related with pressure drag, and therefore, it can be mitigated by changing the hull forms design of a certain ship, and secondly from its negative influence on ship drag which was quantified from the ship database towing test results as up to more than a 20% of increase on drag (see figure 1).

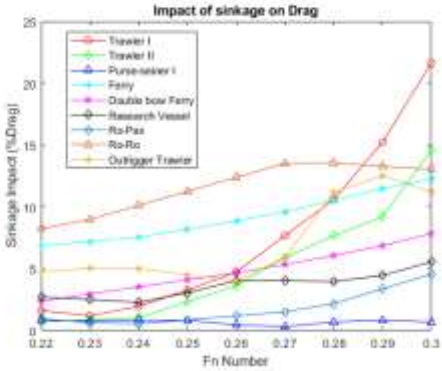

Figure 1– Drag Increase (%). vs. F_n

Based on the research work from CEHINAV mentioned above, the sinkage-geometry problem was studied in detail by analysing the potential relation between waterplane coefficient and sinkage, since they as well found that this form coefficient was the one which affects sinkage the most. Representing sinkage towards waterplane coefficients for the ships from the database used, CEHINAV considerations on the potential relation between waterplane coefficient and sinkage could be confirmed especially at low speeds and for slender hulls (see figure 2).

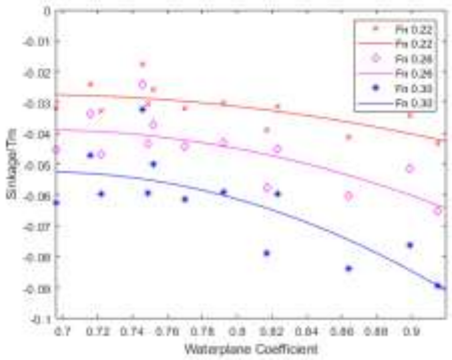

Figure 2 – Sink/D_m vs. C_{WP}

Concerning the fact that the waterplane coefficient of a certain ship is highly affected by the slenderness of its bow, from the correlation between sinkage and the waterplane coefficient it seemed reasonable to analyse how the bow shapes can affect the sinkage of ships.

3.2.- Analysis of the effect of the bow shapes on the sinkage of ships

For the purpose of studying the specific effect that the bow shapes might have on sinkage, two pair of ships from the database in which the bow shapes effect could be isolated –both had the peculiarity of just differing in their hull form designs in the presence of a bulbous bow – were taken to analyse their sinkage towing test results. The ships which formed part of this specific analysis were purse-seiners A and B and fishing vessels A and B and the results obtained are shown in figures 3 and 4.

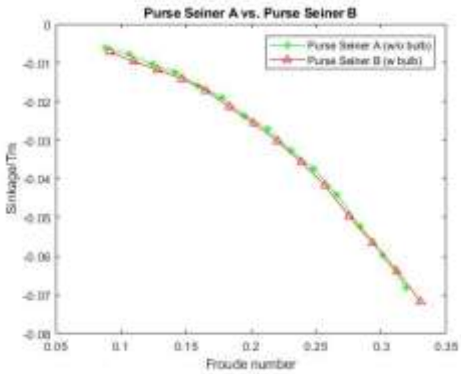

Figure 3 – Sinkage/Dm. vs. F_n Purse Seiners A and B

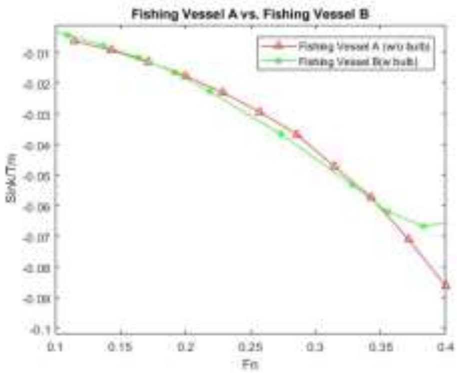

Figure 4 – Sinkage/Dm. vs. F_n Fishing Vessels A and B

From the analysis of purse-seiners A and B, it was appreciated that sinkage did not experience a perceptible change of its value and evolution when the bow shapes were changed from a straight to a bulbous bow and at the fishing vessels case, for the Froude number range studied (0,22-0,30) similar results were obtained, but for Fn=[0,30-0,35] the bulbous bow design, showed a smoothing of sinkage growth with the speed and from Fn=0,35 on began to decay, which can be explained due to the appearance of dynamic lift effects.

Another way to change the ship forms which are involved in dynamic sinkage when a ship is sailing is by changing the loading situation of the vessel, since the draft changes and in consequence the submerged hull forms, and thus the distribution of the dynamic pressure field, get modified. To study this potential way of influence sinkage behaviour on ships, the double bow ferry towing test results were used (see figure 5).

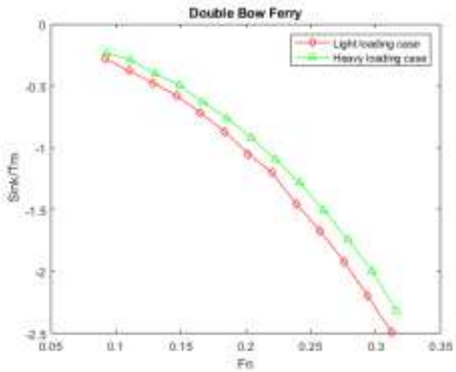

Figure 5 – Sinkage/Dm. vs. F_n

It was observed that unlike what might be supposed at first sight, the heavy loading case presented better sinkage values which can be explained due to the fact that when the submerged forms are changed, they do not change the pressure field linearly due to the complex geometries of ship hulls. That strengthen the relation of sinkage with pressure stress and drag but also suggest the idea that there must be and optimum draft at which the sinkage of a certain ship is minimum.

3.3.- CFD Results

In addition to the experimental results analysis, the numerical study of sinkage was addressed with the aim of studying the different hull pressure diagrams – since the dynamic pressure field is straight related to the sinkage of ships – as well as to deepen into the reliability of CFD on sinkage estimation. The software used in the present paper was the commercial software Star-CCM+ and due to the simulations weight, HPC (High Performance Computing) resources were needed (2 x Intel® Xeon® Gold 6230 of 20 cores @ 2.10 GHz).

The numerical study of sinkage was focused on those ships which were more relevant within the bow shapes effect study, which were purse seiners A and B and fishing vessels A and B. The main information which was extracted with CFD tools were the sinkage and drag results (see figures 6 and 7) – in order to deepen in CFD tools' reliability on sinkage estimation – showing good levels of consistency at drag estimation but high uncertainties at sinkage evaluation, as it has been suggested by the ITTC.

As well, the dynamic hull pressure field diagrams were analysed at Fn=0,23 and Fn=0,30 (see figures 8 to 11) since they represent a solid source of information to study sinkage qualitatively especially at determining which parts can affect the most to this phenomenon. From those graphics, it was observed that while the ships bow presented similar pressure distributions at both speeds, the stern of ships had bigger pressure fluctuations and thus, the pressure field changes at the stern due to the ship geometry and the propeller action might affect considerably to acquired sinkage.

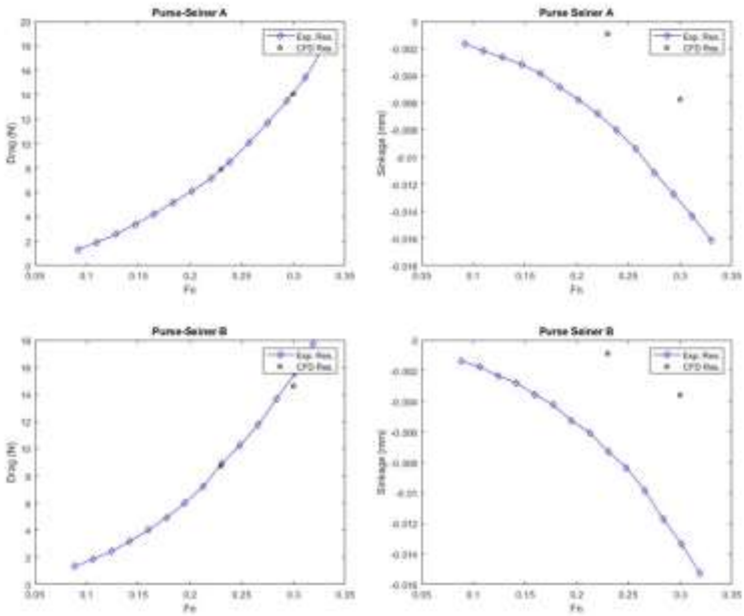

Fig. 6. Drag (left) and sinkage (right) results validation. Purse-Seiners A and B.

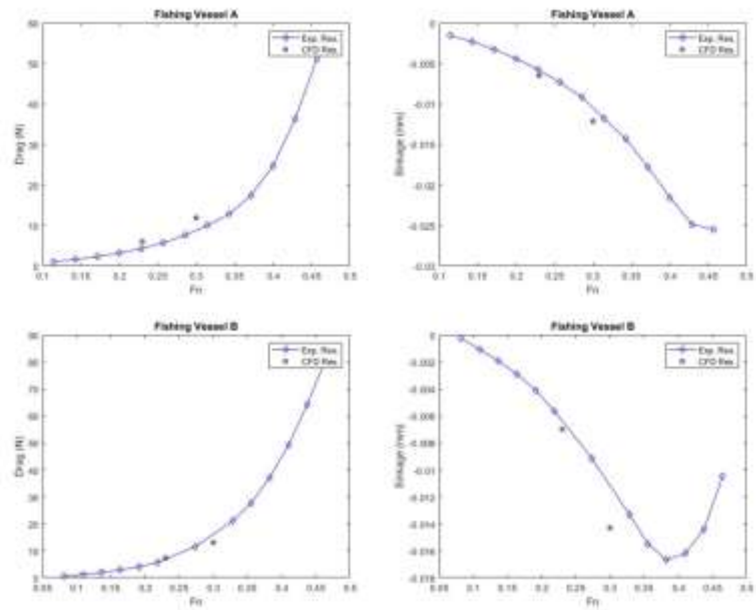

Fig. 7. Drag (left) and sinkage (right) results validation. Fishing Vessels A and B.

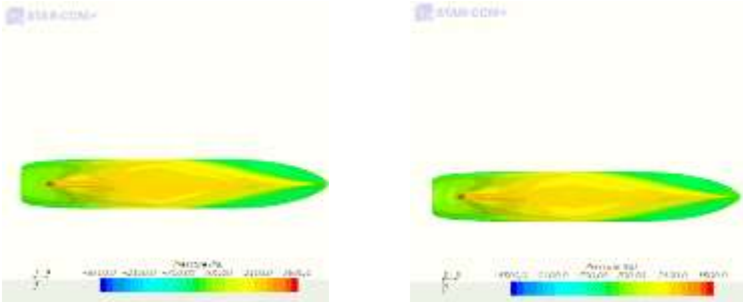

Fig. 8. Purse-Seiner A Hull Pressure field at Froude numbers of 0,23 (left) and 0,30 (right).

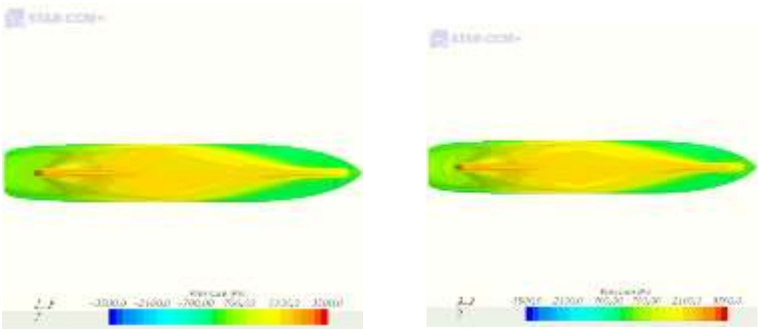

Fig. 9. Purse-Seiner B Hull Pressure field at Froude numbers of 0,23 (left) and 0,30 (right)

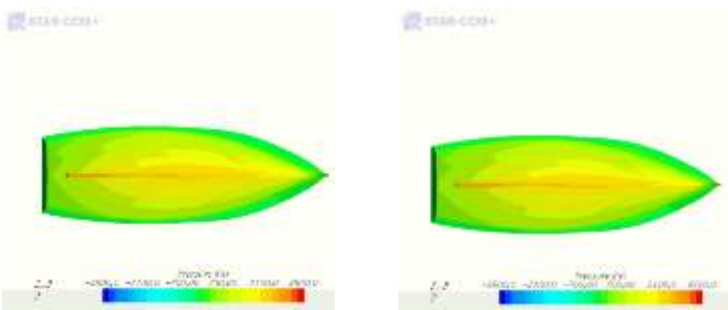

Fig. 10. Fishing Vessel A Hull Pressure field at Froude numbers of 0,23 (left) and 0,30 (right)

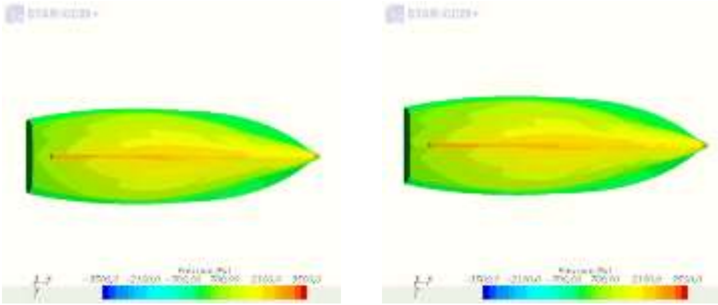

Fig. 11. Fishing Vessel B Hull Pressure field at Froude numbers of 0,23 (left) and 0,30 (right)

4- CONCLUSIONS

The main conclusions that were drawn from the research work presented on this paper are the following:

- Sinkage can cause a drag increase of up to more than the 20%, which makes it important to tackle its mitigation.
- In respect of the sinkage-geometry problem, the potential effect of the bow shapes on the sinkage of ships has been rejected based on the results provided by two pair of hulls in which the bow effect was isolated. By contrast greater dynamic pressure fluctuations has been found at the stern of the ships suggesting that sinkage could be mitigated by acting on the stern hull forms or the propeller of ships.
- The results provided by the towing tests done with a double bow ferry in two different loading cases confirmed the effect of the submerged hull forms on sinkage and suggested the existence of an optimum loading case (draft) at which acquired sinkage would be minimum.

As it has been encouraged by the ITTC, further research must be carried out at the respect of sinkage verification and validation at sinkage evaluation.

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