Analysis of hydrodynamic pressure fields of motorboats and pontoons in shallow water

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The article presents the results of calculations of the pressure fields generated by a motorboat at the bottom of a shallow sea. Calculations were made using the boundary elements method (BEM), arranged on the surface of the boat and the bottom of the sea. This method is described in [3], and applied on a free surface linearized boundary condition.
Results for four different lengths of motorboats, from 2.85 m to 9.5 m, sea depth from 1 m to 10 m, are presented in the form of a surface, approximated by a polynomial function whose coefficients are given. These functional relations allow one to calculate the maximum and minimum hydrodynamic pressure generated by the motor boat length, in the range as above, and the sea depth to about 10 m when flying at speeds of up to 20 m / s.
Given functional dependencies can be used, in the field of security and anti-terrorism defences, and can serve to identify the type and size of speedboats, up to about 10 meters and a displacement of about 8 tons.

Keywords: hydrodynamic pressure field around speedboats, pressure signature, boundary element method.

1. Introduction

The paper contains analysis of the hydrodynamic pressure field (HPF) around smaller speedboats with L_{WL} = 2.5-4m, and larger ones with L_{WL} of about 8m. Data describing all motorboats are in Table 1. HPFs of motorboats were calculated by modeling flow around the hull of the motorboats; boundary singularity method was deployed on the surface of the hull of the motorboats, and at the bottom of the basin. HPF was calculated taking into account the effect of shallow water, and presented in the forms of dimensional and dimensionless, which showed no differences in the shape of HPF for different speeds, while confirming its dependence on the depth of the seabed, H. Possible maximum speeds were determined after assessing the resistance and power, towing these vehicles based on NPL method for motorboats. Then calculating the hydrodynamic pressure field for four speedboats, with increasing size, as a function of the speed of minimum velocity of 1 m / s, to the maximum. The obtained surface HPF determines the maximum and minimum values of hydrodynamic pressure in the plane of symmetry of the boat, as a function of water depth H = [1m, 10m].

Tab. 1: Main dimensions and characteristics of the design of four motorboats.

Motorboat	1	2	3	4
Design length L[m]	2.518	4.155 m	6.279	8.399
Length over all L_{oa}[m]	2.848	4.700	7.102	9.501
Design beam B[m]	1.140 m	1.250	1.889	2.526
Beam over all B_{oa}[m]	1.140	1.250	1.889	2.526
Design draft T[m]	0.228	0.320	0.483	0.646
Midship location [m]	1.259	2.078	3.139	4.200
Displaced volume [m^3]	0.351	0.892	3.076	7.364
Displacement [tonnes]	0.360	0.914	3.153	7.548

2. Hydrodynamic pressure field (HPF) for motor boats of varying sizes

For the calculation of HPF adopted launches the shape shown in the following figure and different displacement 0.36 t, 0.9 t, 3.15 t and 7.55 t, hereinafter referred to as the speedboat with numbers 1, 2, 3 and 4. Changes in the relative depth of the sea H_{ND}, H_{ND} = H / L is the depth divided by the length of motorboats, adopted in the field of [0.1; 4].

The shape of speedboat 2, similar to the other boat, shown in Figure 1. Dimensions of launch 2 are included in Table 1.

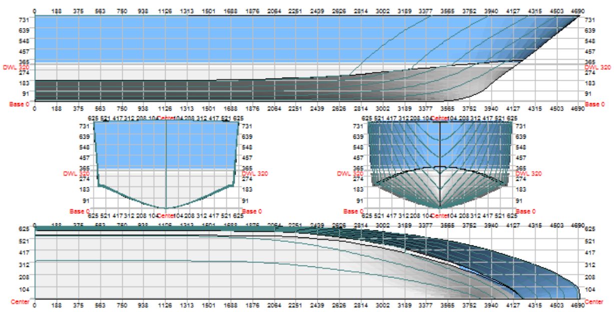

Fig. 1. Shape of launch 2 of displaced volume 0.892m^3 and main dimensions LxBxT[m]=4.155 x 1.25 x 0.32 [m].

Calculation of hydrodynamic pressure field (HPF) were performed for the depth of the seabed H = [1m; 10m]. Below are the results of calculations of HPF for two speeds, 2 m/s and 5 m/s, at the bottom depth H = 1m.

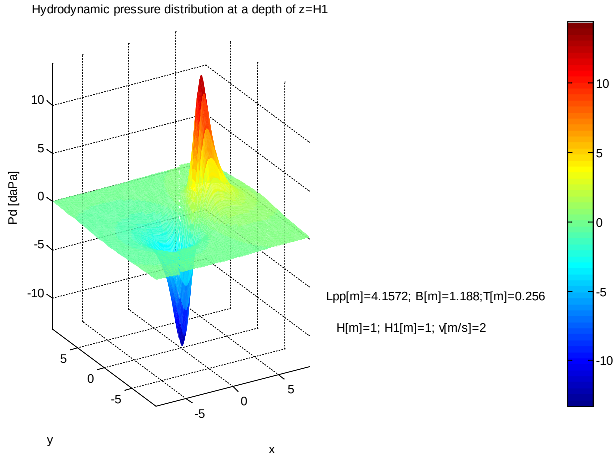

Fig. 2. HPF launch 2 with a length of 4.155m for v = 2m/s and H = 1m.

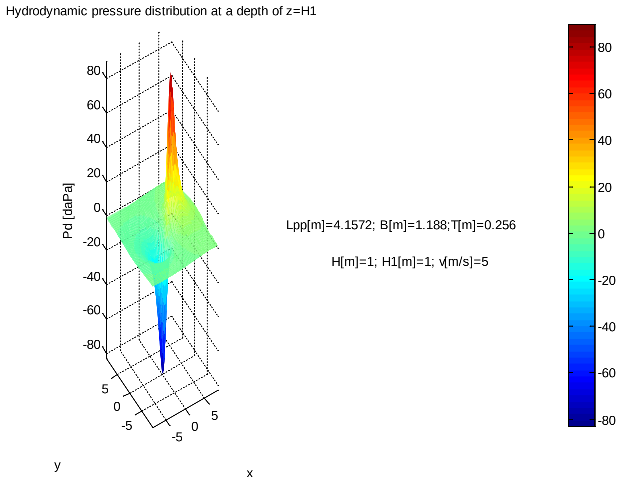

Fig. 3. HPF launch 2 with a length of 4.155m for v = 5m/s and H = 1m.

Then, these widely different pressure fields are normalized to a dimensionless form. The pressure is divided by the dynamic pressure $0.5\rho v^2$ while the linear dimensions are divided by the length of the vessel.

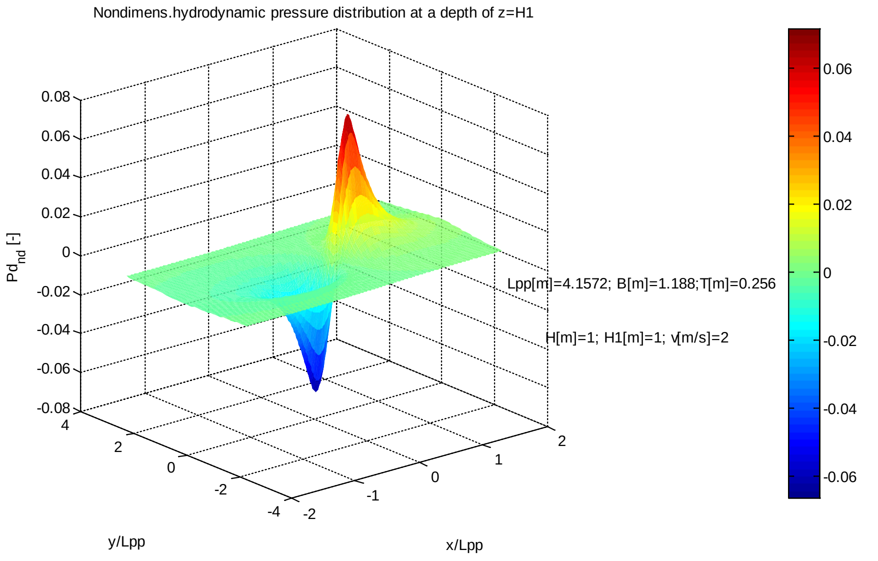

Fig. 4. Hydrodynamic pressure field (HPF) in Figure 2 in a dimensionless form (divided by the dynamic pressure $0.5\rho v^2$) produced by the boat number 2 (L = 4.155m) at a speed of v=2m/s, and the water depth H = 1m.

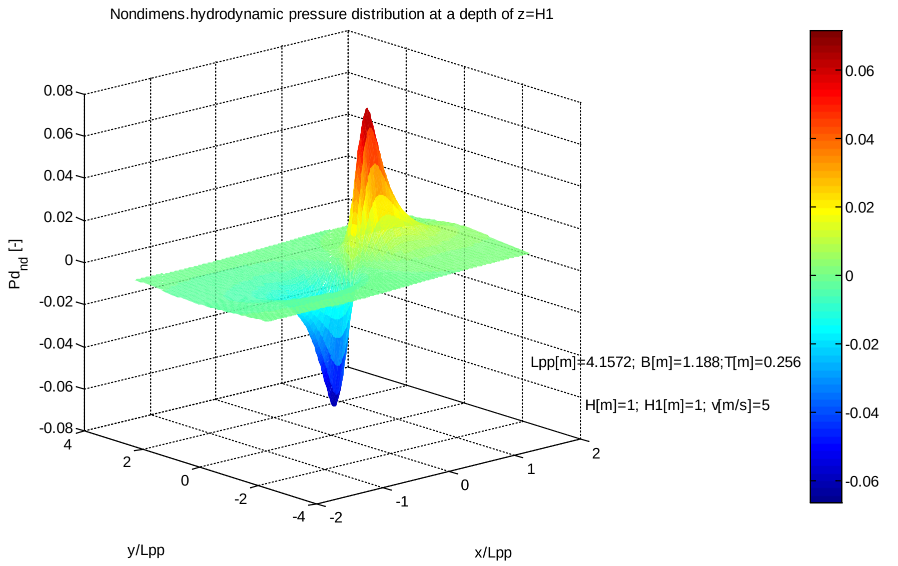

Fig. 5. Hydrodynamic pressure field (HPF) in Figure 3 in a dimensionless form (divided by the dynamic pressure $0.5\rho v^2$) produced by the boat number 2 (L = 4.155m) at a speed of v=5m/s and the water depth H = 1m.

As shown in these figures, dimensionless hydrodynamic pressure fields (HPFs) are the same for a boat moving on the sea at the same depth but at different speeds.

3. Results of calculations of the minimum and maximum values of the hydrodynamic pressure field (HPF) for all motorboats

To estimate the resistance and power towing a boat, the NPL method was used. For motorboat 2, calculated resistance to the speed of more than 6 m / s, for higher speeds results were extrapolated. Estimates for the maximum speed for motorboat 2 can be based on the following figure. Assuming that it can be equipped with an engine with a power output of about Ps = 16 kW, is the propulsive efficiency of about 60% speed motorboat 2 will be: about 7.5m/s-8 m/s.

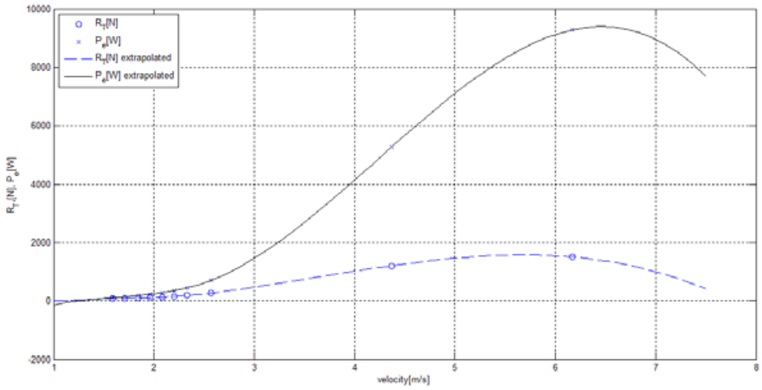

Fig. 6. Chart extrapolated value of total resistance R_T [N] - solid line and towing capacity P_e[W] - the dotted line as a function of velocity for motorboat 2 with waterline length L_{WL} = 4.155m. The selected data points are measured above the speed of 6m/s extrapolated values.

Resistance, and the corresponding power calculation was made for all the boats, and the estimate of the maximum speed is given in Table 4. Subsequently, the minimal pressure near the center of the boat towards the stern, and maximum at the bow, for all motorboats in a wide speed range from 1 m/s to maximum speed and the depth of the sea from H = 1m to 10m.

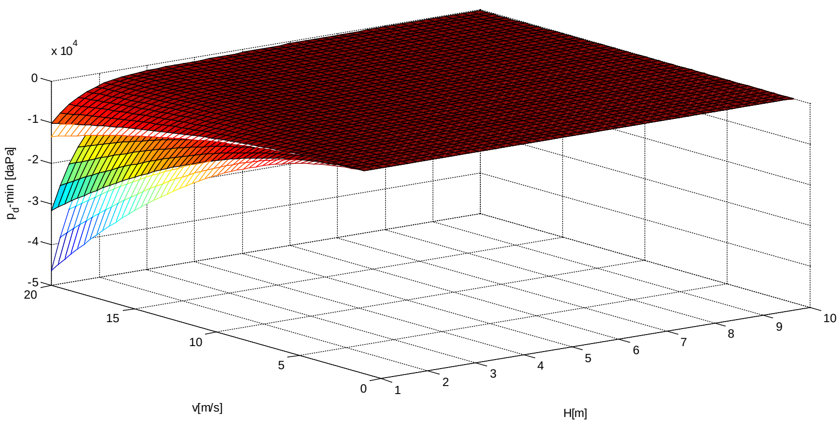

Fig. 7. The calculated minimum pressure surfaces near the center of the boat towards the stern for motorboats 1-4, the highest surface area for the smallest motorboat 1.

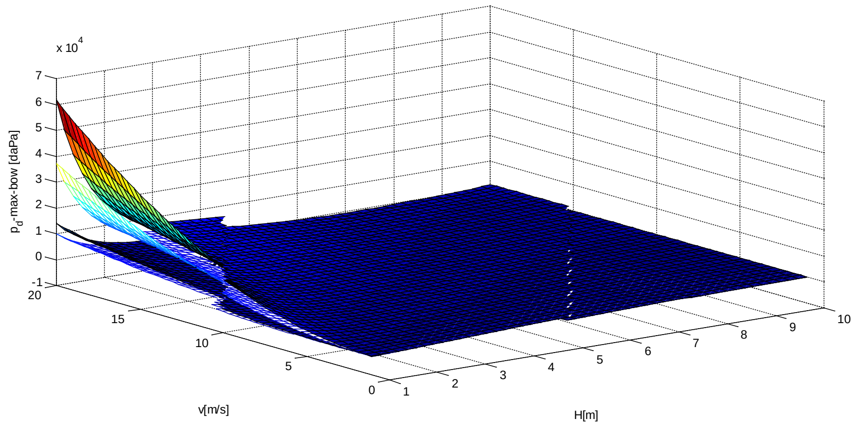

Fig. 8. Calculated surfaces of maximum pressure on the bow of the boat 1-4, the highest surface area for the biggest motorboat 4.

Then, all of the surfaces of the figures 7 and 8 are approximated by the polynomial surfaces according to the formula (1) and the coefficients are given in Table 2.

$$pd_{\min(max)} = \sum_{i,j} pij * x^i y^j \tag{1}$$

where pd [daPa] – hydrodynamic pressure maximum on the bow and minimum between the stern and the center of the ship, x=H[m], y=v[m/s], and 15. coefficients pij (with 95% confidence bounds of the first value) in table 2:

Tab. 2. Main dimensions and characteristics of the design of four motorboats.

Motorboat	1		2		3		4	
Boat length Loa [m]	2.848		4.700		7.102		9.501	
Max. speed [m/s]	4.5		8		13		20	
Coefficient	p_{dmin}	p_{dmax}	p_{dmin}	p_{dmax}	p_{dmin}	p_{dmax}	p_{dmin}	p_{dmax}
p00 =	-1197 (-1409, -985.6)	1281 (1056, 1506)	-1388 (-1640, -1136)	1628 (1338, 1919)	-2720 (-3233, -2208)	4097 (3368, 4825)	-3317 (-3970, -2665)	6440 (5278, 7601)
p10 =	2217 (1983, 2450)	-2361 (-2610, -2113)	2614 (2336, 2892)	-3031 (-3351, -2711)	5244 (4679, 5809)	-7637 (-8440, -6834)	6555 (5836, 7275)	-1.208e+4 (-1.336e+4, -1.08e+4)
p01 =	-345.8 (-377, -314.7)	361.7 (328.6, 394.8)	-435.8 (-472.9, -398.7)	483.5 (440.7, 526.2)	-949 (-1024, -873.6)	1225 (1117, 1332)	-1284 (-1380, -1188)	1987 (1816, 2158)
p20 =	-1329 (-1425, -1234)	1412 (1310, 1513)	-1585 (-1699, -1471)	1824 (1693, 1956)	-3229 (-3460, -2998)	4601 (4272, 4930)	-4099 (-4393, -3804)	7312 (6787, 7836)
p11 =	396.6 (372.6, 420.6)	-414.8 (-440.4, -389.2)	499.8 (471.2, 528.4)	-554.4 (-587.4, -521.5)	1088 (1030, 1146)	-1404 (-1487, -1322)	1472 (1398, 1546)	-2279 (-2411, -2147)

p02 =	-33.39 (-34.75, -32.03)	34.41 (32.96, 35.86)	-44.29 (-45.92, -42.67)	47.53 (45.67, 49.4)	-105 (-108.3, -101.7)	124.5 (119.8, 129.1)	-155 (-159.2, -150.8)	204.4 (197, 211.9)
p30 =	334 (315.4, 352.6)	-354 (-373.8, -334.2)	401.3 (379.1, 423.4)	-459.5 (-485, -434)	825 (780, 870)	-1159 (-1224, -1095)	1057 (999.9, 1115)	-1848 (-1950, -1746)
p21 =	-138.8 (-144.7, -132.9)	145.2 (138.9, 151.5)	-174.9 (-182, -167.9)	194 (185.9, 202.2)	-380.9 (-395.2, -366.5)	491.5 (471.1, 511.9)	-515.2 (-533.5, -496.9)	797.6 (765, 830.1)
p12 =	16.45 (15.48, 17.42)	-17.04 (-18.07, -16.01)	21.36 (20.21, 22.51)	-23.24 (-24.57, -21.92)	49.2 (46.86, 51.54)	-60.38 (-63.71, -57.05)	70.17 (67.19, 73.16)	-97.8 (-103.1, -92.49)
p40 =	-36.63 (-38.36, -34.89)	38.77 (36.93, 40.61)	-44.23 (-46.29, -42.16)	50.48 (48.1, 52.86)	-91.5 (-95.7, -87.31)	127.4 (121.5, 133.4)	-118 (-123.3, -112.6)	203.5 (193.9, 213)
p31 =	18.68 (18.07, 19.3)	-19.54 (-20.19, -18.88)	23.54 (22.81, 24.28)	-26.12 (-26.96, -25.27)	51.26 (49.77, 52.75)	-66.15 (-68.27, -64.03)	69.34 (67.44, 71.24)	-107.3 (-110.7, -104)
p22 =	-2.623 (-2.819, -2.427)	2.728 (2.519, 2.936)	-3.363 (-3.596, -3.13)	3.694 (3.425, 3.962)	-7.649 (-8.122, -7.175)	9.595 (8.921, 10.27)	-10.73 (-11.33, -10.13)	15.37 (14.29, 16.44)
p50 =	1.448 (1.386, 1.51)	-1.531 (-1.597, -1.465)	1.755 (1.681, 1.828)	-1.998 (-2.083, -1.913)	3.646 (3.496, 3.796)	-5.045 (-5.258, -4.831)	4.721 (4.53, 4.913)	-8.065 (-8.406, -7.725)
p41 =	-0.8492 (-0.8746, -0.8237)	0.8881 (0.861, 0.9152)	-1.07 (-1.1, -1.04)	1.187 (1.152, 1.222)	-2.33 (-2.392, -2.268)	3.007 (2.919, 3.095)	-3.152 (-3.23, -3.073)	4.879 (4.739, 5.019)
p32 =	0.1328 (0.1211, 0.1445)	-0.1384 (-0.1509, -0.126)	0.1687 (0.1547, 0.1827)	-0.1868 (-0.2029, -0.1707)	0.3822 (0.3538, 0.4107)	-0.4888 (-0.5292, -0.4484)	0.5324 (0.4962, 0.5686)	-0.77 (-0.8345, -0.7055)

4. Conclusions

Using a polynomial function of the form (1), and the first coefficients in Table 2, can be calculated the maximum value of the hydrodynamic pressure on the bow, and minimum hydrodynamic pressure on the stern, of boat lengths to L_{oa} = [2.85-9.5m], and the sea depth from 1m to 10m, or even more.
These formulas allow, for example, anti-terror services to assist in the identification of risks to the protected areas or objects. With the help of equations (1) and the coefficients of the table (2), to determine the size of the upcoming high-speed motor boats, and at the same time, the size, and kind, of threats.

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