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The Analysis of Motion Dynamics and Resistance of the Multipurpose Boat Operating in Shallow Water

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ABSTRACT: Polish market of small boats has been developed very dynamically in recent years. Market competition forces the shipyards to build new more efficient hull forms and to cut the cost of production as well. This is why modern computer simulation programs are used more often by naval architects. Another trend is to design more universal ships that may be used by larger number of diversified customers. This paper presents project proposal of multipurpose boat hull form. The boat was design to fulfil the requirements imposed by public services like water police, fire brigades, and border guards. It is supposed to be operated on unexplored floodplains and other type shallow waters. The analysis of boat's motion was based on computer simulations. The resistance curve was evaluated with two methods: comparison study of model test results of similar ships and CFD methods. The results obtained from Ansys Fluent and FINE/Marine systems were compared in this paper. It was shown that taking into consideration dynamic trim and sinkage has a significant impact on free surface capture and resistance values.

1 INTRODUCTION

The primary task of the multipurpose boat is to conduct rescue operations during floods. The boat has to be adapted to: operate on unrecognised flood waters, transport people and animals, carry motor vehicles (e.g. ambulances). Hence, it is supposed to be equipped with life-saving equipment allowing intensive care treatment. The design of the boat (in particular hull geometry) should allow landing on the shore and safely returning to deep waters. It is necessary that main dimensions obey the law about transport objects on public roads. The problem-free transport is crucial. Propulsion must guarantee operation velocity at least 20km/h. The boat may be operated by such entities of the public service as: fire brigades, ambulance, border guards, WOPR (Volunteer Water Rescue Organization), water police. It is assumed that it can be also used as an inland cruiser with a wide variety of standard equipment. Following main dimensions were considered:

- Length over all 7 to 8 m,
- Maximal breadth 2,5m,
- Maximal draught 0,4m.

2 HULL GEOMETRY. PRELIMINARY RESISTANCE ANALYSIS

Several variants of the hull shape were designed. Figure 1 shows one of the final concepts of underwater hull part.

For initial variant, it was calculated resistance and the shape of free surface for range velocities: 4-22 km/h. It was observed that for velocities higher than 15 km/h there is a risk of flooding a deck by the bow wave. Figures 2 and 3 shows free surface shape for velocities 15 and 22 km/h.

Obtained results allowed developing new variants of the hull. 6th generation is final one. It is taking into account all of the requirements for construction technology, and the operational purposes (e.g. bow ramp - allowing small vehicle to enter on the deck). Figure 4 shows the theoretical hull lines.

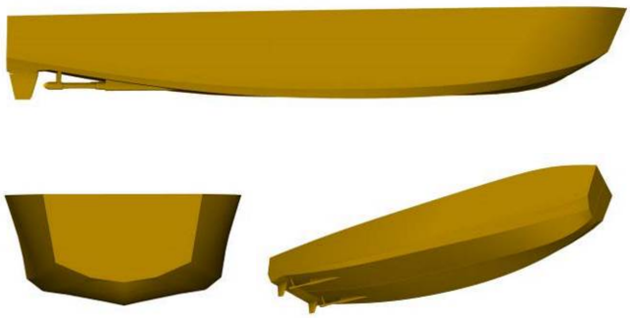

Figure 1. Proposed geometry of the underwater part of hull

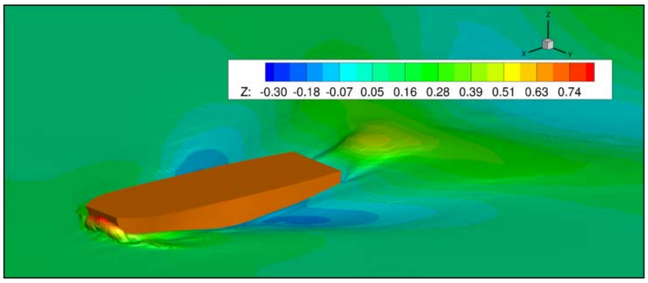

Figure 2. Free surface, Va= 15 km/h

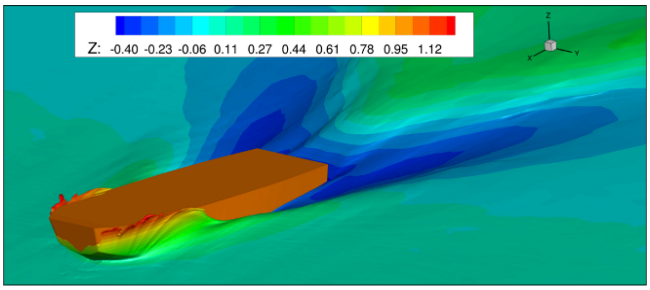

Figure 3. Free surface, Va= 22 km/h

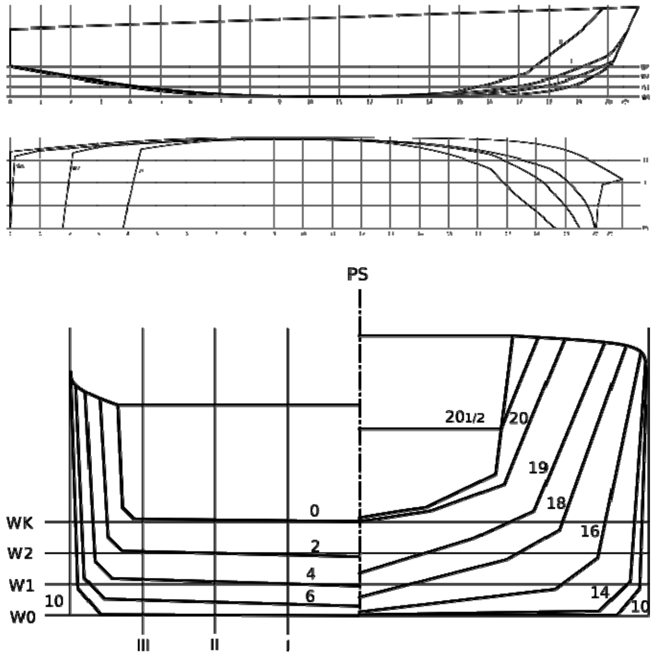

Figure 4. Final hull lines

The bottom was slightly rounded (spinned). Bow part was also risen. This allows obtaining higher maximal velocity, without risk of deck flooding. The basic hydrostatic calculations results for a range of draughts from 0.3m to 0.7m are shown in table. 1 and on Figure 5. The table shows also all the basic geometric parameters of the hull.

Table 1.

Draught Amidships	m	0,3	0,35	0,4	0,5	0,7
Wetted Area	m^2	17,476	18,966	20,447	22,582	26,595
Prismatic coeff (Cp)		0,663	0,666	0,667	0,709	0,76
Block coeff. (Cb)		0,645	0,65	0,653	0,695	0,745
KB	m	0,172	0,201	0,23	0,286	0,394
BMt	m	1,845	1,582	1,385	1,072	0,743
BML	m	16,784	16,05	15,503	12,528	8,801
GMt corrected	m	2,017	1,783	1,615	1,358	1,137
GML	m	16,957	16,25	15,733	12,814	9,195
KMt	m	2,017	1,783	1,615	1,358	1,137
KML	m	16,957	16,25	15,733	12,814	9,195
Length: Beam ratio		3,058	3,198	3,33	3,349	3,369
Beam: Draught ratio		7,92	6,806	5,968	4,794	3,448
Length:Vol^0.333 ratio		4,859	4,748	4,663	4,261	3,745

There were determined a preliminary resistance curves with the prognosis of required power. Resistance curve was determined on the base of model test results of similar ships [1]. In addition, the resistance was also calculated with commercial CFD software. Figure 6 presents the results of the resistance analysis. The graph shows ½ of total resistance. This method of presentation was selected because the boat was designed as a twin propeller construction. In further propulsion analysis the “optimistic" prognosis was used.

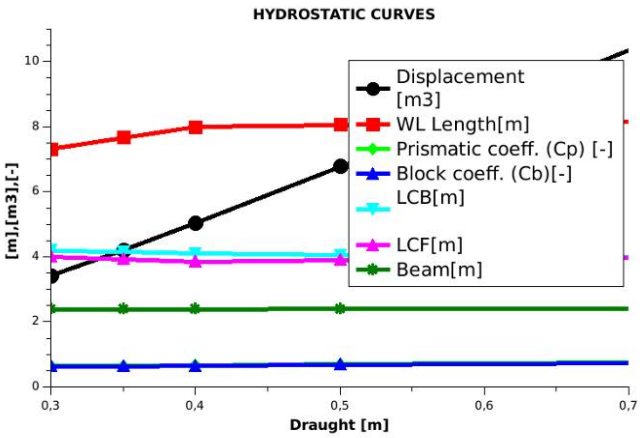

Figure 5. Hydrostatic results

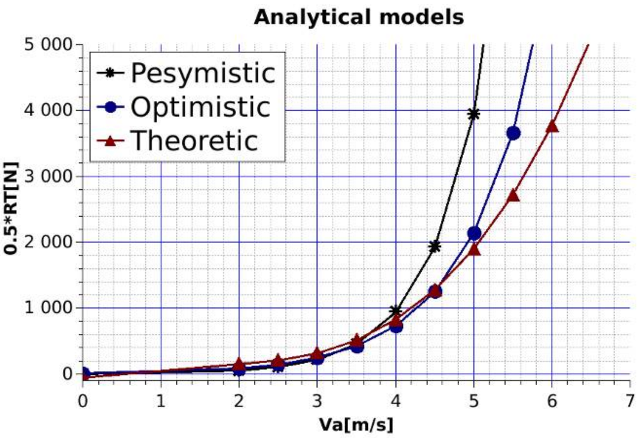

Figure 6. Half ship resistance - analytical models

CFD calculations

A final resistance curve was determined using CFD calculation. Numerical simulations were carried out with two commercial CFD codes: Ansys Fluent and Fine/Marine.

2.1 *Ansys Fluent*

Initially, simulations were calculated in the Ansys Fluent[2]. This software was repeatedly tested and it was proven that is excellent for the computations in the field of ship hydromechanics. Unfortunately, this program does not handle the dynamic simulation of sinkage and trim of the boat. Due to the high maximum velocities (Fn = 0.6) at which the boat was to be exploited, taking into account these phenomena was necessary.

The structural grid was used. Size of the grid was about 1 million of elements for half of the ship. During the construction of the computational domain the symmetry condition was used. Wall function model used to determine flow close to no slip walls (dimensionless size of the first element of y + = 40). To improve the stability calculations the ship was accelerated from the zero velocity to first and next measurement points, so unsteady calculation approach was used. Free surface was captured with "Volume of Fluid" method.

2.2 *FINE/Marine*

Dynamic trim and sinkage was computed with FINE/Marine software[2], this is a fully dedicated computational system for simulating ship hydrodynamics. In simulations there were used unstructured grids, with hexagonal type elements. Domains and their discretisation were made in Hexpress program. The initial grid size was of about 1.5 millions of elements. For some calculations it was used dynamic adaptive grid refinement method. Final size of the mesh was increased 3 times.

2.3 *Results*

Figure 7 presents a comparison of the resistance curves obtained with Ansys Fluent, Fine/Marine and the method of based on model test result of similar ships. For low Froude numbers, these results are very similar. With the increase of the speed differences are clearly noticeable. Resistance curve from FINE/Marine is bend beyond Va=4.5m/s. This is caused by increasing role of dynamic lift. Maximal wave resistance is expected for Froude number 0.5 in that case Va=4.5m/s.

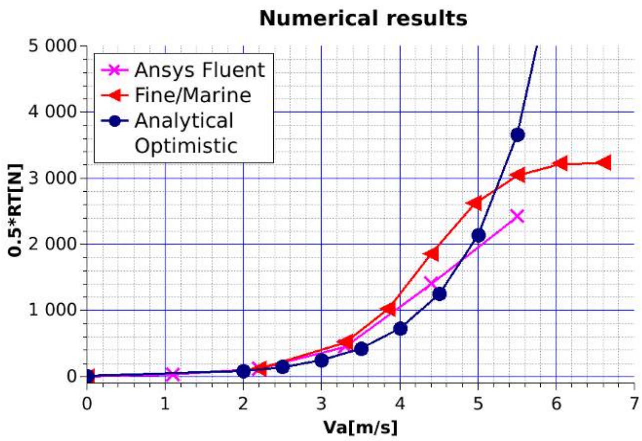

Figure 7. Half ship resistance - numerical simulations

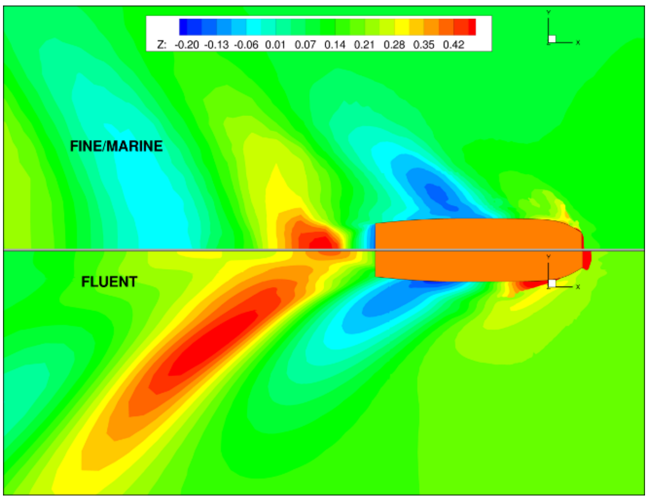

Figure 8. Comparison of wave system solved with Fluent and FINE/Marine, Va=15kmh.

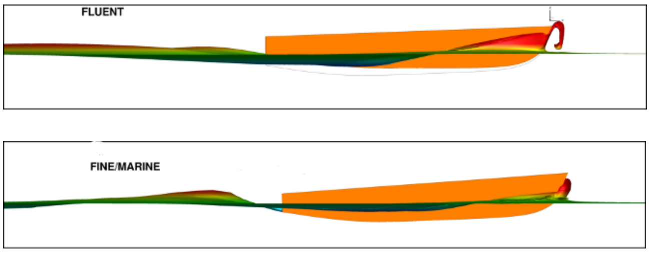

Figure 9. Wave system - side view. Va=15kmh.

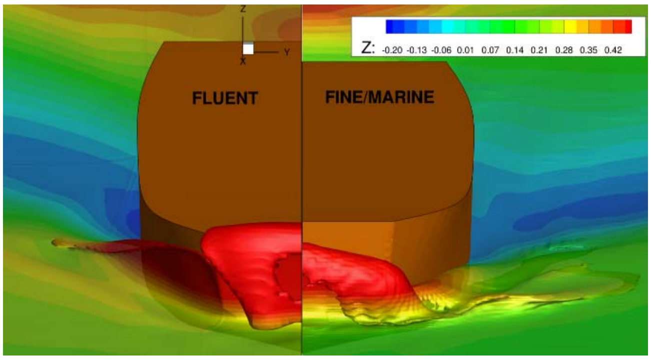

Figure 10. Comparison of bow wave. Va=15 km/h

Figures 7 to 9 show the differences in the capture of free surface generated by the two computing systems. Bow wave (Figures 8 and 9) captured by FLUENT seems to be unnaturally smoothed. The significant differences in the wave system (noticeable especially in Figure 7) are the consequence of different final dynamic draught and trim angle of the ship.

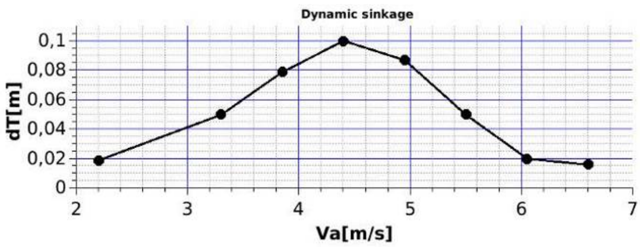

Figure 11. Dynamic sinkage in function of velocity

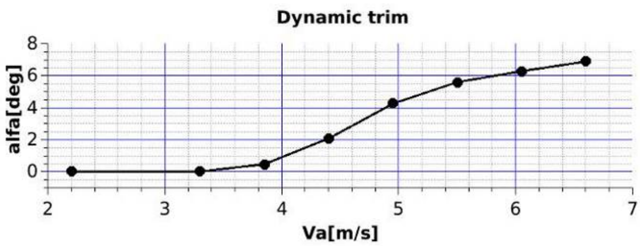

Figure 12. Dynamic trim in function of velocity

Figure 11 shows relation between draught of the ship and boat velocity. Above the velocity 4.5 m/s it begins to play a dominant role hydrodynamic lift acting on the flat bottom of the hull. Primarily boat will be exploited in low velocities (Froude number much less than 0.5). In case of higher operational velocities, flat bottom and sharply truncated stern will help to better utilize hydrodynamic lift force and to improve the motion behaviour.

Figure 12 illustrates the trim angle as a function of velocity. Boat has a tendency to trim to the stern. This is very beneficial because of the wide bow part. For design reasons the width of the bow was imposed as an external condition. There will be installed bow ramp.

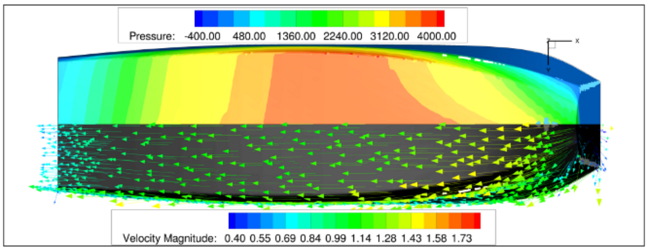

Figure 13. Pressure and velocity distribution on the hull.

Figure 13 shows the pressure distribution on the hull and velocity field close to boat surface. These distributions are uniform. There are no signs of local peaks. Streamlines are parallel to the symmetry plane, no recirculation zones were observed. Picture 14 shows dimensionless velocity distribution in propeller ring zone. Wake field in propeller area is very favourable. There is only small wake peak present in 12 o'clock.

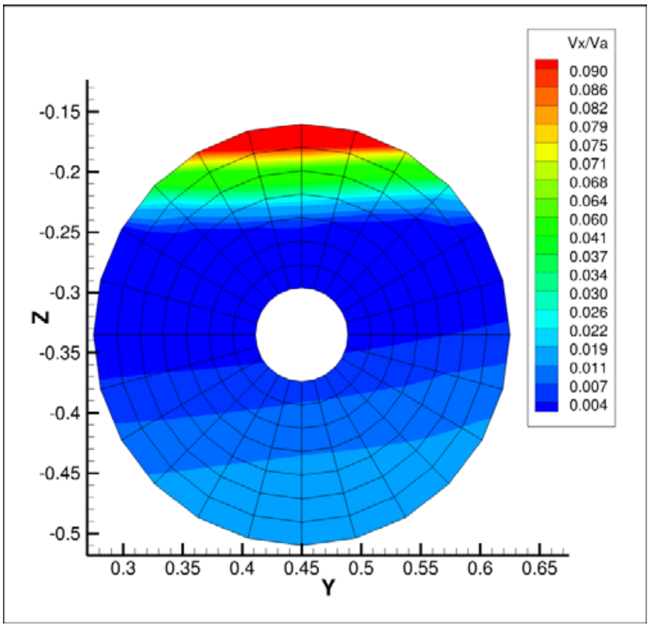

Figure 14. Wake field in propeller ring, Va=15km/h

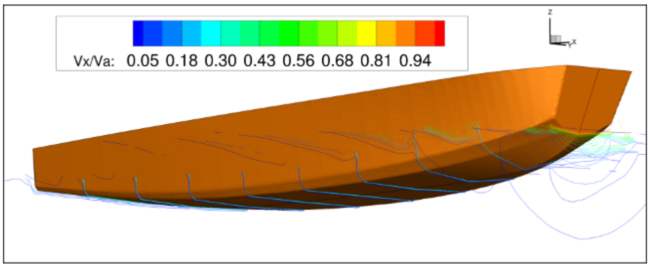

Figure 15. Boundary layer along the hull, Va=15 km/h

Distribution of dimensionless velocities close to the hull is presented on Figure 15. Boundary layer is formed evenly along the hull. There are no rapid increases or decreases of boundary layer thickness.

No flow separation is expected close to the hull surface.

3 SELECTION OF PROPULSION SYSTEM.

Initial determination of the parameters of the drive system was based on following assumptions:

- In further analysis the optimistic forecast is used,
- Twin-engine drive is used,
- Standard screw-type B-Wageningen is used,
- Power of one engine is analyzed for range from 50 to 125 kW,
- The efficiency of the transmission - eta = 0.94,
- The propeller diameter is analyzed for range from 0.3m to 0.6 m
- Impact factors t =0.1; w=0.1.

Selection of propulsion drive system was done with home-developed program. It is intend to design screw propellers on the base of the performance of the series of propellers. For designed boat draught, the boat could be equipped with two B-Wageningen type propellers, diameter D = 0.35 m, each driven by an engine power PB = 50 kW (2x50 kW total power). For propeller nominal revolution rate n= 33.3[1/s], it is imposed to use gear with ratio i = 1.5 (engine nominal revolution rate n = 50 1 / s). In table 2 there are presented results of calculations for the other driving motors and power ranges as well.

Table 2. The results of the preliminary calculation of parameters of the drive system

Nominal power [kW]	125	100	75	50
Min. diameter [m]	0,6	0,5	0,45	0,35
Gear ratio i [-]	3	2	2	1,5
Efficiency eta [-]	0,456	0,485	0,486	0,481
Velocity [m/s]	5,628	6,135	5,914	6,057
Velocity [km/h]	20,26	22,08	21,30	21,80

Taking into account the above results, it can be assumed that two engines with a power of 50 kW each are likely to provide operational velocity speed over 20 km/h. At a velocity of 6.057 m / s Froude number is 0.684. This means that the boat at this speed shall be travelling on hydrodynamic lift condition.

4 SUMMARY

During realization of this project underwater part of the hull was designed. Hull shape was selected to use the boat in water rescue services. The main dimensions of the hull must provide on the one hand maximum displacement on the other hand allows easy transport on public roads.

Hydrodynamic properties of the boat were analyzed using the methods of computational fluid dynamics. Resistance curve was determined using model test result of similar units. Power of propulsion system was selected to achieve high velocities and use hydrodynamic lift force, in the case when the boat won't be fully loaded.

ACKNOWLEDGEMENT

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[3] FINE™/Marine v3 Flow Integrated Environment for Marine Hydrodynamics. Documentation v3.1a, 2013