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SHIP CONCEPT FOR CLEANING THE NAVIGABLE INLAND WATER OF FLOATING DEBRIS

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ABSTRACT

Rivers like the Danube crossing many countries gather floating debris. These countless times block locks, access roads to ports, access walkways on the berths of passenger ships and more.
The paper presents the studies carried out in order to design a ship for the collection of these floating debris. Several variants have been chosen, of which one will be presented that is optimal from the point of view of the propulsion installation and especially of the wave front that it produces during the operation of waste collection and navigation to the place of unloading.
In order to optimize the shapes of the ship, the NUMECA calculation program was used. It provides important data on the wavefront produced by the ship.

Keywords: CFD, hydodinamic problems.

1. INTRODUCTION

Water is a natural resource which is indispensable for life, a source of energy, a raw material for productive activities and at the same time, a valuable way for transport of goods and passengers. On the other hand, it is vulnerable and limited, and it has to be used sustainably and kept clean. That is why it became mandatory to maintain the ecological balance and to take all necessary precautions to find solutions to clean inland waters of floating debris, in order to achieve:

- Pollution decrease;
- Risk reduction of infections and possible epidemics when these debris accumulate and decay in populated areas;
- Reduced number of accidents such as collision of speed boats with the floating debris;

The concept presented in this paper is original and tries to meet the above-mentioned requirements. In order to select the hull shapes, specific literature and internet sources were taken into considerations. None of the studied forms seemed to optimally solve the requirements imposed for such a vessel. This led to the concept of a vessel for cleaning inland waters from floating debris. According to the author's opinion, the "scoops" type form adopted represents the optimum solution fulfilling the imposed requirements.

2. CONCEPT

Given the requirements for the collection of floating debris on inland waters, the literature was studied to find the most common shapes for such a ship. Another aspect taken into account when choosing the shapes, was the specificity of the aquarium in which such a ship operates. In the conditions of Romania and specific to the Danube River, which has a current velocity of approximately 5 m/s, none of the forms found in the literature corresponded entirely. Thus, the choice of the form that will be presented in the paper was studied.

The basic idea of the concept is that the vessel can sink by fast ballasting to collect debris and then be able to de-ballast quickly and navigate with the collected debris to discharge points. The specificity of the inland waterfronts was considered by either steep (large shore depths) or smooth (shallow shore depths) variants. In establishing the concept, these types of banks were considered so that the operation of collecting debris can be performed regardless of the type. Therefore, the "scoops" shape was adopted for the main hull with an U-shaped form for the debris warehouse zone.

Towards the stern there is a narrow area, which creates a pump effect that leads to suction of debris in the way of the warehouse. Several shapes were investigated, adopting a "scoops" shape, as shown in Figure 1.

The hull consists mainly of:

- Two floats joined with a bridge at the bottom. This deck, together with the floats will limit inside the space for storing the floating debris. The floats will be constructed so as to ensure in the stern area a suction effect of the floating debris. Along the vessel length, the largest area of a float is used for ballast tanks and the remaining area by technical compartments where there are required tanks and electricity generators.
- At the top, in the stern area, the floats will be joined with a bridge over to accommodate the wheelhouse. In the wheelhouse, all the equipment that ensures navigation, as well as the safe operation of the ship will be located.

For the bow shapes, three variants were chosen.

These variants were chosen based on the idea that in the bow area there would be no system to retain the collected debris such as watertight gates or similar. The bow area will be an open one.

The collection system is simple:

- The empty, but ballasted ship, sails towards the place of collecting the floating debris;
- The vessel collects the floating debris in the space created in the body using the suction pumps;
- Simultaneously with the collection of floating debris, the ship is gradually de-ballasted to ensure the draft;
- After the storage space of the floating debris is full, the ship is completely de-ballasted until the collection deck comes out of the water;
- After that the ship go to the place of taking over the floating debris. Here is unloaded with the pontoon facilities (cranes, etc.).

The shape shown in figure 1 is named "*straight bow*".

This shape was preferred because it was assumed that the waves produced would not be higher, this disrupting the operation of collecting floating debris.

This assumption will be validated by numerical modeling of naval hydrodynamics.
Further, with the help of the NUMECA calculation program, numerical tests will be performed to confirm or refute the previous assumption.

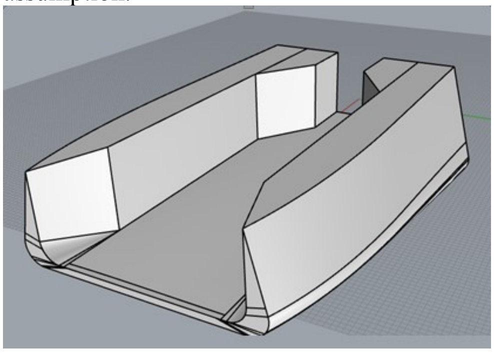


Fig. 1. General view of the adopted principle

After selecting the hull shape, the general arrangement of the ship was developed. Therefore, the stern part has a bridge for the wheelhouse layout.
In order to better use the volumes of the hull and the bottom area, the propulsion is assured by using two electric outboard engines. A diesel generator supplies the energy needed for the propulsion engines, with an emergency generator for backup situations. For the floating debris to be sucked in the warehouse, two pumps will be arranged on the inner edges. The water jet drives the debris towards the stern of the ship where a grillage will be arranged for its collection.

3. MAIN DIMENSIONS

When choosing the main dimensions of the ship, the following points were taken into account:
- Operating area. The Danube River has depths ranging from 1 m to 40 m and banks with various meanders;
- Ship berthing area. Here a depth of maximum 4 m is expected. The length of the pontoon is limited to 40 m. The chosen length is also conditioned by the floating debris unloading equipment.
- Maneuverability of the ship.

Taking into consideration these requirements, the main dimensions chosen are:
- Length between perpendiculars, L_{pp} = 10 m;
- Length of waterline, L_{WL} = 15 m;
- Breadth, B = 7 m;
- Depth, D = 3 m;
- Draught, d [m], according to the loading cases;
- Volumetric displacement, $\nabla = 86.86\ m^3$

During the preliminary stage, the main dimensions of the ship have been selected in order to fulfill the basic requirements taking into account the limitations like water depth, narrow canals, etc. A special care has to be considered for this type of ships due to the necessity to have good maneuverability [6] qualities to be able to operate in restricted conditions.
Also, the choice of the main dimensions above was made for economic reasons. The result was a relatively small ship, estimating a~~n~~ light body weight with all installations on board of about 30 t.
Precisely because of this, the structure of the ship will be simple, without the need for additional reinforcements of the body inside. There is the possibility of making the hull of the ship from aluminum, which will lead to the reduction of the weight (therefore decreasing the draught) and implicitly increasing the amount of floating debris collected.

4. CFD STUDIES

Because the resulting wave heights were important for any of the specified time intervals, they were considered to be relative to calm water from a sufficiently large distance so that the influence of the ship's hull did not count in the analysis.
The numerical analyzes performed took into account various loading conditions. These loading conditions determine the calculation

draught. The paper presents the results obtained for navigation in the condition of maximum load. This was preferred because the importance was placed upon the wave height created by the fully loaded ship. In this condition, waves can appear to determine the scattering of floating debris from the aquarium or even from the hold of the collection vessel. Also, at full load the waves produced can affect the shores of the cleaned aquarium.

Also, future studies will have to show the influence of the two absorption pumps that will be mounted in

the body on the way of collecting the floating residues. These pumps, which will be contained in a water-to-water ejector absorption system, will be dimensioned so as not to substantially influence the flow around the ship during the floating debris collection operation.

The hydrodynamic performance of the vessel was investigated during debris collection operations. During these operations the vessel does not produce own significant wave heights (low speed operations) The simulation has been carried out using NUMECA [7] software for a range of loading cases and ship speeds. The number of discretization panels, was reduced to only 2500 for half of the hull, using the shape symmetry along the length of the vessel. The analysis was carried out according to literature recommendations considering the main dimensions of the ship.

In Figure 2 the results of the numerical analysis performed with NUMECA software are presented for the investigated ship shapes, loading conditions, draught and speeds.

A range of speeds from 3.6 m / s to 5.4 m / s was chosen, as this was the range of variation of the flow velocities of the Danube river.

In spring, due to melting snow upstream, the Danube's flow rate is higher and towards autumn it is lower. This is the reason to choose this speed limitation.

The shapes for the numerical analysis are those in figure 1.

The numerically analyzed phenomena took place over a period of approximately 18 minutes as follows:

- For the speed adjustment phase from marching speed to collection speed, the time of 2 min was chosen. The choice of this calculation time was made on the basis of information gathered from the experience of seafarers on ships of this size;
- For the collection phase of the floating debris, the time of 14 min was chosen. This stage of the collection process is the most important because the behavior of the chosen shapes had to be observed in direct connection with the generation of own waves;
- For the speed adjustment phase from the collection to the march, the time of 2 min was chosen.

Because the resulting wave heights were important for any of the specified time intervals, they were considered to be relative to calm water from a sufficiently large distance so that the influence of the ship's hull did not interfere in the analysis.

Studies conducted over time by various teams of researchers have led to the establishment of the methodology for numerical calculation of free surface flow around a hydrodynamic profile. In the numerical studies in the future paper, the turbulence model $k-\omega$ SST will be used. By Froude similarity, the height of the wave in the bow area can be approximated so that the discretization grid accurately captures the deformed free surface.

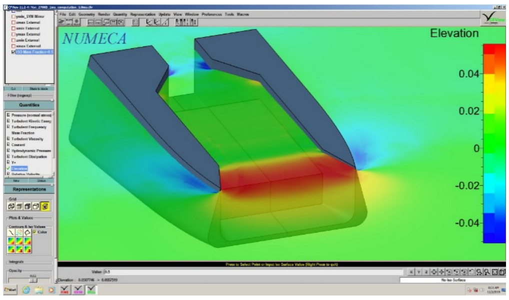
The use of these methods was determined by the good results obtained by researchers in the field of naval hydrodynamics. This numerical method has been well experimentally tested so that the results can be commonly applied for such analyzes.

The results obtained from numerical

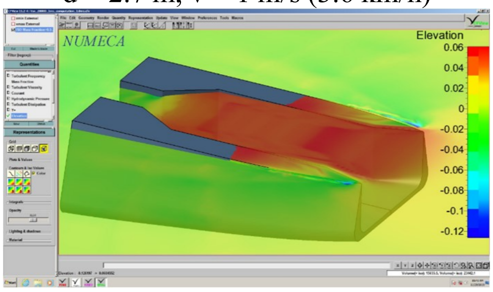
modelling will lead to the adoption of technological solutions, if necessary, to reduce the height of the waves created by the body in ballast navigation.

The results of the numerical analysis are summarized in Table 1.
Table 1. Numerical Results at draught 2.7 m and full load

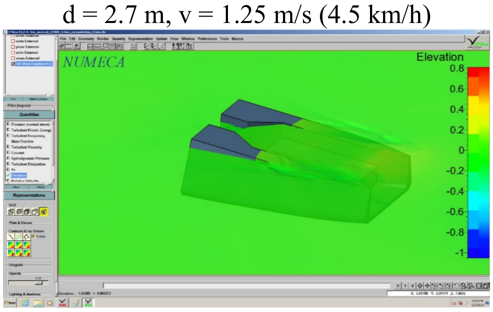
Speed (m/s)	Wave height (m)	Figure
1.00	0.04	2a
1.25	0.06	2b
1.50	0.80	2c



a) Straight bow, full load condition,
d = 2.7 m, v = 1 m/s (3.6 km/h)



b) Straight bow, full load condition,
d = 2.7 m, v = 1.25 m/s (4.5 km/h)



c) Straight bow, full load condition,
d = 2.7 m, v = 1.5 m/s (5.4 km/h)

Fig. 2.

The maximum own wave height of 0.80 m was observed for the straight bow for a speed of 1.5. m/s in full loaded conditions.

It can be observed that at speeds of 1.00 m / s and 1.25 m / s respectively waves of approximately the same height are obtained (fig. 2a, 2b). However, although they are not important in size, they affect the operation of collecting floating debris.
It can also be seen that at a speed of 1.50 m / s the body generates waves with a height of 0.80 m (fig. 2c). The created wave covers approximately the entire storage area of the collected floating debris. This can lead to their scattering, so that the collection operation has no effect. Then, it is recommended not to use this speed when collecting floating debris.
Another limitation related to navigation speed is given by the river banks. The waves produced, by amplitude and wavelength, can destroy the already made arrangements.

5. SOME HYDRODYNAMIC ASPECTS

During the preliminary stage the evaluation of the initial stability of the ship is mandatory. According to Figure 3, the metacentric height has to be positive and consequently, the condition to be met is that $z_M > z_G$ which, in other words, means that the vertical position of the metacenter has to be above the vertical position of the center of gravity.
G – Center of gravity taking into account all weights on board, including the vessel's lightweight.
B – Center of buoyancy which is practically the centroid of the submerged volume. Its position depends on the draft corresponding to the loading case, heeling angle or trim modifications.
GM – The metacentric height which is the distance between the center of gravity G and the position of the metacenter MT. The GM value is a measure of the vessel's stability.
GZ – righting arm, its position depending on the relative position between the center of gravity G and
center of gravity G and the center of buoyancy B.

A mention should be made that initial stability refers to the case of small heeling angle.

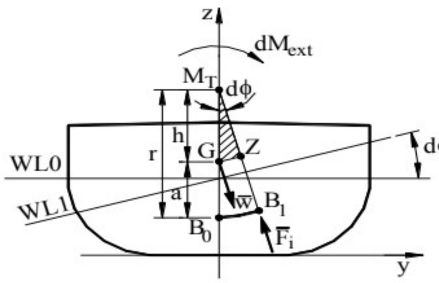


Fig. 3. Main elements for the analysis of transversal initial stability

Table 2. Numerical Results

z_G	2,948	m
z_B	0,656	m
L_{WL}	15,000	m
I_X	264,490	Kg m^2
∇	86,860	m^3
BM_T	3,045	m
M_T	3,701	m
GM_T	0,735	m

Lloyd Register of Classification [4] provides a series of three crucial criteria meant to determine whether a floating unit is stable or not:

a) "The righting arm at a transversal inclination of 10^0 must be greater than 0,05 m."

Using the formula [1], [4]:

$$GZ = GM_T \sin(d\Phi)$$

the following results were obtained: GM_T, GZ_T.

For the 10^0 tilt it results

GM_T = 0.735 m and

GZ_T = 0,130 m > 0,05 m ⇒ the first condition is fulfilled.

b) "The area of equilibrium must be greater than 0,02 m2."

For BM_T =3.045 [m] this area [1], [4] is equal with

0.034 m^2 ⇒ the second condition is fulfilled.

c). "The metacentric height must be greater than 0,1 m." This is the most important condition to be met.

The metacentric height result is GM_T = 0.735 m > 0,1 m ⇒ the third condition is fulfilled.

In conclusion, it had been illustrated that the cleaning ship concept complies with the Lloyd's Register of Classification rules, resulting in a stable floating unit.

In order to reach the required performances several investigations have been carried out.

As a first step, the evaluation of ship resistance was performed using the already mentioned numerical method NUMECA [5] and the method developed by Holtrop-Mennen [3]. The comparative results show a very good approximation obtained by using classical methods as compared to more sophisticated numerical applications:

NUMECA software simulation	13.2 kN
Holtrop Mannen method	13.9 kN

The difference of 5% between the result of that two methods can be easily accepted.

The main observation is that, for further evaluations, during the next design stages, the simpler method can be used. The evaluation of the resistance has to be used, as a next stage, to the evaluation of the propulsion power and then, to the choice of the required engine.

The preliminary seakeeping evaluation has been performed using a computer code based on the well-known theory developed by Salvesen, Tuck and Faltinsen [7]. The program is able to calculate the response amplitude operators (RAO) and phases for all six degrees of freedom, i.e. surge, sway, heave, roll, pitch and yaw motions. The main assumptions of the program refer to the nature of the fluid, considered to be inviscid, the ship geometry allowing the assumption and draft and the displacements of the ship and the waves are small. In other words, the slender body theory is assumed and the three-dimensional hydrodynamic quantities are expressed in terms of solution to the sectional two-dimensional problem of a cylinder with the same shape as the individual cross-sections oscillating on the free surface [3]. The program is using the "closed fit source distribution technique" developed by Frank. The nonlinear roll damping is introduced using Tanaka method.

Based on the first set of results the calculations of the accelerations could be also performed in all defined points of interest. The coordinate system is presented in Figure 4.

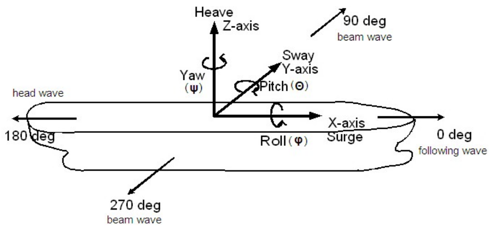


Fig. 4. Motion's and the coordinate system

The results regarding the motions of the ship are expressed in the form of Response Amplitude Operators (RAO) and presented in Figure 5, 6 and 7 for, roll motions, heave motions and pitch motions. The results could be used in order to evaluate the motions induced by wind, passing ships, etc.

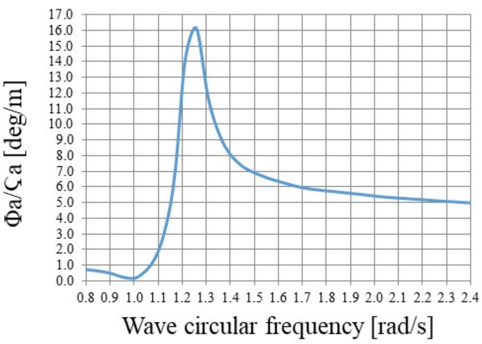


Fig. 5. Roll motion's

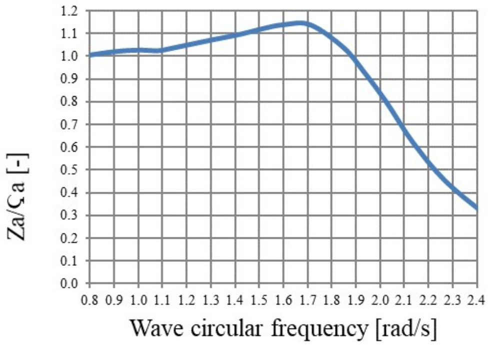


Fig. 6. Heave motion's

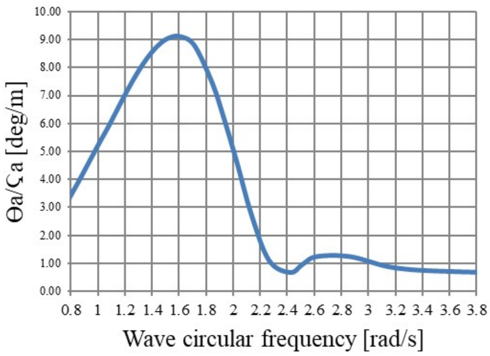


Fig. 7. Pitch motion's

6. CONCLUSION

Two hull shapes for the cleanup vessel were selected for the assessment: a straight bow and a knife bow in ballast and full load conditions. The minimum wave height for both the straight bow and knife bow is equal to 0.04 m, and 0.06 m being obtained at the same draught and speed under the same loading conditions. A maximum wave height of 0.8 m, was registered for the straight bow for a speed of 1.5 m/s in full load condition, significantly higher than 0.1 m, the peak value for the knife bow shape.

The explanation can be found in the slender shapes of the bow area in the case of the knife bow. The water flow is blocked in the case of straight bow so that the wave height of 0.8 m is obtained.

Sea keeping capabilities are assessed, obtaining values within the typical range for pitch, heave, and roll motions for inland navigating ships.

Given the better knife hull shape efficiency, the vessel is in line with the latest IMO regulations regarding Energy Efficiency Design Index (EEDI) [2] with a low impact on the direct surroundings.

Finally, it can be concluded that the optimal shape for the bow area of the ship for collecting floating debris from inland waters is the knife bow. The choice of this bow shape, together with the design of an optimal metal structure (steel or aluminum) can lead to the realization of a ship for the efficient collection of floating debris.

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