Abstract: The paper presents the selected problems of design and operation of amphibious craft for rescue purposes. The results of research on the amphibious rescue units allowed formulating the general conclusions with respect to the proper selection of the main design parameters, program of model tests and full scale trials for the amphibious craft. The most important design problems related to the water characteristics are presented and discussed.

Keywords: AMPHIBIOUS CRAFT, RESCUE, DESIGN, OPERATION

1. Introduction

The problems presented in the paper are concerned with modelling of the underwater part of the hull of amphibious craft. The presented methodology used in preliminary design of rescue amphibious craft is based on the methodology of complex technical system design (Gerigk 2004) The following aspects are included: functionality, effectiveness and safety of the vehicle operation.

This type of vehicle can be used during flood, train and air crash rescue operations as the most autonomous unit combining the good terrain and water characteristics. One of the main problems in the design of the amphibious craft for rescue purposes is to satisfy the requirements of the proper manoeuvring characteristics in the water. However it cannot be the main design assumption because amphibious craft cannot be treated as a boat on the wheels. It should operate on the public roads and in off-road conditions (Jersak 2011).

The practical aspects of design and operation of amphibious craft are presented on the basis of three examples: prototype of the mobile amphibious system (ASD) for command, observation, reconnaissance and communication (Zubr Mariner) and two vehicles built as the functional models within the R&D project (Burciu 2013a). The prototype and the first model were constructed as conversions of the existed cars: a wheeled armoured personnel carrier Zubr and Toyota Tundra Crew Max “Toyota Tundra Mariner”. The second model “Bukovina” was a new invention (see Fig. 1). Both the models allow testing several systems of the amphibious craft, especially the propulsion systems. Two types of propellers were tested: Schottel pump-jet SPJ 20/II on “Zubr Mariner” and “Toyota Mariner” and water jets on “Bukovina”.

The design process starts with collecting the information about the existed solutions, following with the selection of main design parameters, concept drawing and numerical calculations based on CFD methods, physical model tests and work out of the technical documentation (see Fig. 1) (Burciu 2013a).

The architecture of an amphibious craft should implement aesthetic design and material choice combined together with analysis of hydromechanics and technical systems. It is recommended to follow all the functional characteristics of the designed object since the concept drawing (Burciu 2013b).

2. Methodology of the amphibious craft design

The main characteristics of the amphibious rescue craft are as follows:
1. vehicle type and range of operation,
2. principle dimensions: length, width, height, draught, weight, displacement, dead weight capacity
3. crew number,
4. space division, volume of watertight compartments,
5. on-road, off-road characteristics
6. characteristics in the water: floatability, stability, power-resistance characteristics, manoeuvrability

The designing process consists of the following stages:
1. definition of the function and main technical-tactical assumptions,
2. estimation of the principle dimensions,
3. definition of the construction type and material,
4. weight estimation,
5. estimation of volume of internal spaces,
6. estimation of power capacity of the propulsion system,
7. estimation of buoyancy, reserve buoyancy in case of damage,
8. estimation of stability and mobility,
9. estimation of manufacturing cost,
10. preparation of design specifications.

The design criteria are formulated to achieve the following goals (Burciu 2013c).
- the lowest possible vehicle weight,
- modern and effective propulsion system,
- possibly the best hydro-mechanical characteristics.

The process of preliminary design combines three modules: general design, static performance, dynamic performance. Module general design consists of principle technical specifications, vehicle shape and space division. The module of static performance consists of the vehicle hull characteristics (shell and structure), propulsion system, vehicle on-land rolling system and vehicle weight (crew, fuel and equipment). The performance of the vehicle – when driven on land and when afloat are included in the dynamic performance module.

The preferred method of design is based on the performance and risk-based complex approach.

In the pre-design stage the performance based approach concerning the water characteristics is focused on the buoyancy (balance of the vehicle), stability, damage stability and mobility (power-resistance and manoeuvring characteristics).

The risk based approach integrates the risk analysis with risk reduction as one of the design and operational objectives. The design process starts with creation of a realistic vision of a vehicle. Sketches and computer modelling is followed by studies and engineering calculations.
3. Results and discussion

4.1. Stability characteristics

Stable equilibrium condition in vertical direction of a watercraft is met when the gravity force P and hydrostatic buoyant force D are balanced.

\[ \sum F_y = P + D = 0 \]

where:

\[ D = \rho \cdot V \cdot g \]

\[ \rho \] - mass density of water [kg/m³],

\[ g \] - gravitational acceleration [m/s²],

\[ V \] - volume of the immersed part of the watercraft hull [m³]

The buoyancy can be ensured by watertight internal spaces, watertight tanks filled with closed-cell foam or empty and flexible air tanks. Empty tanks can be used as ballast tanks to improve stability, defined as the watercraft capability to return to the original position after the heeling forces vanished.

Insufficient reserve buoyancy may result in the loss of stable equilibrium and decrease of flooding time in case the craft is damaged. The reserve buoyancy and stability in damaged condition are the significant characteristics influencing the time of sinking.

The intact stability at small angles of heel, up to about 10°, depends on the positions of vertical centre of gravity (VCG) zg and vertical centre of buoyancy zg and small metacentric radius mr:

\[ r_m = \frac{J_z}{V} \]

where:

\[ J_z \] - moment of inertia of the waterline with respect to the waterline central longitudinal axis,

\[ V \] – volume of the underwater part of the craft.

The general outline of the algorithm for stability calculations is presented in Fig. 2.

![Algorithm for stability assessment](image)

**Fig. 2 Algorithm for stability assessment.**

The example of calculations of the geometrical characteristics of the underwater part of the hull allows for prediction of craft stability in the water in the whole range of angles of heel (see Fig. 3) (Burciu 2013).

![Statical stability curves for the assumed waterline and two positions of VCG of model "Bukovina"](image)

**Fig. 3 Statical stability curves for the assumed waterline and two positions of VCG of model "Bukovina".**

2.2 Water entry characteristics

The capability of crossing the boundary between the land and water is one of the most important characteristics of amphibious craft. The studies of the process of entering the water can be studied on the basis of CFD numerical calculations and physical model tests.

The basis for the calculation is the preliminary defined body shape (see Fig. 4).

![Preliminary defined body shape of the designed amphibious craft "Zubr Mariner"](image)

These preliminary design satisfying adequate buoyancy and road performance characteristics has to be modified to ensure protection against flooding, over accelerations and instantaneous trim angles.

The water entry manoeuvre can be described as a process of water entry by the craft moving on wheels at certain speed from a land sloped at a certain angle. The initial stage of motion depends on the above mentioned speed, slope angle, vehicle mass and speed are presented in Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Land slope angle [deg]</th>
<th>Vehicle speed [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>1</td>
</tr>
</tbody>
</table>

The dimensions of the amphibious crafts allow for full scale CFD computations. The main assumptions are as follows: the vehicle freely enters the water – the wheels are not driven, the brakes are not applied, the water propeler is not active. The impact of the ground on water flows and dimensions of the experimental water reservoir should be also assumed.

The results of calculations are the time histories of the vehicle motions:

- trim angle,
- position of centre of gravity,
- velocity,
- acceleration.

The examples of the results of computations are presented in the coordinate system shown in Figure 5.

![Coordinate system](image)

**Fig. 5 Coordinate system.**

The results of computations allow formulating the conclusions of the necessary shape corrections. In the next stage the computations should be repeated for the corrected shape or the physical model tests can be performed.
The visualisation of water entry process for the case of land slope $20^\circ$, initial speed $1\text{ m/s}$ is presented in Figure 6. In this worst case the submersion of the whole front part of the craft was observed (Kraskowski 2010b).

![Image showing water entry process](image)

**Fig. 6** Water entry process – visualisation for the case of land slope $20^\circ$, initial speed $1\text{ m/s}$. The curves of trim angle versus time are presented in Fig. 7.

![Image showing trim angle curves](image)

**Fig. 7** Changes of trim angle in time during water entry process.

The accelerations are important for safety and comfort of the crew. For the case of land slope angle $20^\circ$ and initial speed $1\text{ m/s}$ in both directions they are relatively low, no greater than $0.3\text{ g}$ (see Fig. 8).

![Image showing accelerations](image)

**Fig. 8** Accelerations $a_x$ and $a_z$, land slope angle $20^\circ$, initial speed $1\text{ m/s}$.

The program of physical model tests included more cases than the numerical simulations. In the presented example 5 angles of land slope ($10^\circ$, $15^\circ$, $20^\circ$, $25^\circ$, $30^\circ$) and four run-up distances allow for a wide range of land slope and initial water entry speeds combinations.

The example of water entry tests results of the physical model are presented in Figure 9 (Kraskowski 2011b).

![Image showing water entry test results](image)

**Fig. 9** Accelerations $a_x$ and $a_z$, land slope angle $20^\circ$, initial speed $1\text{ m/s}$.

The real scale tests of water entry of “Zubr Mariner” are presented in Figure 10.

![Image showing real scale tests](image)

**Fig. 10** Real scale tests of water entry process of “Zubr Mariner”.

### 2.3. Power-resistance and manoeuvring characteristics

Power-resistance and manoeuvring characteristics are necessary to predict speed, acceleration, stopping, turning, yaw checking and course keeping abilities of the amphibious craft (Burciu 2013b).

The big influence on the resistance has the shape of the fore body and initial trim of the vehicle. The example of resistance calculations - distribution of pressure resistance coefficient on the hull and generated wave system of Zubr Mariner using CFD methods is presented in Figure 11 (Burciu 2013a, Kraskowski 2010a).

![Image showing CFD calculations of resistance](image)

**Fig. 11** Example of CFD calculations of resistance of “Zubr Mariner”.

To predict the manoeuvring abilities some of the standard manoeuvring trials used in watercraft design can be applied. The example of turning circle and pull out manoeuvres are presented in Figure 12 (Kraskowski 2011a).

![Image showing CFD calculations of manoeuvring characteristics](image)

**Fig. 12** CFD calculations of manoeuvring characteristics – turning circle manoeuvre on the left and pull out manoeuvre on the right.

### 5. Conclusion

Architecture can present the future effect by generating a virtual model which structure can be a simulation of the real world structure. This should be the basis of creation of a utile mobile unit despite of this is the conversion of an existed vehicle or a new build. The new design allows for the lighter construction, boat shaped underwater part of the hull follows with the good power-resistance and manoeuvring characteristics in the water. The main problem is the long time and expensive trials necessary to get the homologation.

The conversions of existed vehicles are always connected with many problems. The main problem is sealing of the vehicle, mainly the mechanisms. The maintenance of mechanical parts submerged in the water is time-consuming and expensive.

The design of the rescue craft needs close collaboration with the end users.
Model “Bukovina” during real scale tests carried out in the lake Silm together with the rescuers from Fire State Services is presented in Figure 13.

Fig. 13 CFD calculations of manoeuvring characteristics – turning circle manoeuvre on the left and pull out manoeuvre on the right.

6. References


