Analysis of stability characteristics for modern passenger multirole boat

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Abstract. A modern passenger multirole boat (MPMB) is designed to serve specific requirements and missions but when it comes to pleasure crafts it has to dispose certain functional characteristics with a specific hull weight distribution, while having certain stability along with aesthetic appeal and stream lined hull. In recent years, there has been greater focus towards issues related to diversity of MPMB leading to development of newer designs and improved stability. The performance of these MPMB comprises of two distinct phases: the design analysis and the identification of the materials used for boat construction. Maximum value MPMB Righting Arm is 1.34 m was determined for 21.76 degrees. This paper will present the design analysis and stability characteristics for modern passenger multirole boat with a calculated stability for passenger use.

1. Introduction

MPMB which are used for sports and leisure activities, fall into two main categories: sailing and motor boats. The process of designing the MPMB has garnered greater emphasis, as unlike commercial vessels, the aesthetic appeal of MPMB is very important. In fact, the exterior design, the construction, the interior design and the material used for the design of the MPMB are considered as a whole, which implies that there must be a close collaboration between designers and engineers. This is a multidisciplinary design problem that deals with different aspects such as structure, shape, stability, hydrodynamics, purpose of the boat, etc.

There are a lot of factors that affect the design of boats, such as purpose, size, materials used, production costs and weight.

The choice of materials is one of the most important design factors of boats as well as other design objects. Additionally, the growing market demand for recreational craft has made materials and production methods very important [1].

There are different materials used in the MPMB construction industry, such as steel, ferrocement, aluminium, wood and composites. All these materials have different properties and manufacturing processes. Currently, for MPMB, the most commonly used material is fiberglass (fibre reinforced plastic). For this reason, this document shows the mechanical and resistance characteristics of the materials used in the construction of recreational craft. In a subsequent study it will be shown which material is most suitable by comparing all the materials used in the construction of boats, in terms of
heat resistance, ease of repair, reduced maintenance, competitive cost, reduced mass, production time and reduced workmanship [2].

Boat building is an integration of manufacturing methods, material choice and design process. For the design process we need to establish 3D geometry and sea keeping characteristics.

2. Design process for MPMB

The design process is an initial stage of construction of each MPMB. During this process several factors must be considered and clearly defined, such as:

- Defining the purpose of the MPMB: sports or leisure activities;
- Design requirements of the owner;
- Design restrictions;
- Conceptual design: determines whether the MPMB described in the design statement is feasible and how the objectives stated in the design statement need to be modified to make a feasible and successful project;
- Preliminary design: formulation of the initial concept by preparing the plans and specifications that are the basis of a construction contract;
- Completion of the shape definition: the ratios between $L_w / B$ and $B / T$ dimensions can vary between quite wide limits, depending on the destination of the ship. The higher the $L_w / B$ ratio, the faster the ship. The speed of the ship is also influenced by the relative volumetric displacement. The $B / T$ ratio influences the transverse stability, the road stability and the speed of the ship;
- Perform detailed structural analysis for the MPMB: include the type of construction material, the thickness of the material, the location and dimensioning of the frame, as well as the location and dimensioning of all the strings;
- Completion of interior design;
- Determination of hydrostatic and stability requirements;
- Re-evaluation of the resistance, propulsion power and performance of the boat;
- Calculation of the detailed costs for the MPMB.

MPMB design is an iterative process, a “trial and error” procedure in which the final result must meet certain requirements that are specified at the beginning of the design process. For a new design, the designer must start with a number of hypotheses and work with them throughout the design process until all the hypotheses meet the requirements [3,4].

Computer based programs are normally used in all design phases, such as determining the body of the MPMB, drawings, to perform detailed structural analysis, to calculate the detailed costs for the boat, to evaluate the strength, power and performance of the boats and the interior arrangements, etc. In addition to using the computer for the design process, the computer can be used for the production process with the fully computerized 3D model of the craft.

Worldwide, the tendency to standardize and simplify shipbuilding leads to hull projects being adapted to operating conditions. Subsequently, the equipment and structures necessary for the fulfilment of the proposed purpose are added [5-7].

The plans below contain details regarding the construction of the hull of a river MPMB easily adapted to the dimensions and functional requirements. Features of boat designed are presented in figure 1:

- Length $L = 10$ m;
- Width $B = 3.1$ m;
- Maximum draft $1.1$ m;
- Moment of inertia of the floating surface with respect to the longitudinal axis $I_L = 21.23$ m$^4$ (longitudinal moment of inertia);
- Moment of inertia of the floating surface with respect to the transverse axis $I_T = 245.24$ m$^4$ (transverse moment of inertia)
- Maximum volume at the draft of 1.1, \( V = 24.5 \, \text{m}^3 \);
- Block coefficient \( CB = 0.72 \);
- Transport capacity: 20 persons;
- Enlarged area for the possibility of installing solar panels on board \( Aw = 30.2 \, \text{m}^2 \).

![Figure 1. General drawing of MPMB.](image1)

3. Software design of MPMB
Based on the plans presented, the body of the MPMB is constructed with the help of Solidworks software, evaluated with the mass of the hull realized and the position of the centre of gravity [8, 9, 10]. In the figure 2 we have a side view of the 3D model made in Solidworks where one can observe the simplicity of the concept and the limited curvature requirements of the sheets from which it is made.

![Figure 2. Trimetric 3D model view made in Solidworks for MPMB.](image2)

The approximate calculation of the number of persons that can safely be boarded on the MPMB, can be done as presented in equation (1):

\[
\text{No. pers.} = \frac{L \times B}{1.5}
\]  

(1)

where: \( L \)-length of the boat, \( B \)-width of the boat
For the present case \( L = 10 \text{ m}, B = 3.1 \text{ m} \) and thus the result

\[
\text{No. pers.} = \frac{(10 \times 3.1)}{1.5} = 20.6.
\]

Which means that 20 passengers can safely board and cross.

The body of this MPMB was evaluated at a mass of 780kg for carbon fibre, 1190kg for aluminium and 1800kg for steel. The centre of gravity of the body of the boat is located 0.47 m above the keel.

4. **Initial stability calculations**

This MPMB has a hull volume of 24.5m\(^3\) and can accommodate 20 people with a total mass of approximately 1600 kg which can carry luggage up to 400 kg adding up to 2000 kg which will modify the draft by 8 cm. Thus, the proposed boat can be equipped with superstructures with a varied configuration and even with a massive keel to increase stability.

| Heel Angle (deg) | MPMB Righting Arm (m) |
|------------------|-----------------------|
| 0                | 0                     |
| 5                | 0.34268               |
| 10               | 0.698511              |
| 15               | 1.081886              |
| 20               | 1.331266              |
| 21.76            | 1.346898              |
| 25               | 1.300496              |
| 30               | 1.113896              |
| 35               | 0.84938               |
| 40               | 0.540447              |
| 45               | 0.205459              |
| 47.93            | 0.001241              |

Using the values in table 1 we have drawn the graph of static stability for the present MPMB and determined the following parameters:
- initial transversal metacentric height 1.30 m presented in figure 3.
- maximum right arm of static stability has the value 1.34 m corresponding to the angle of 21.7 degrees.
- maximum angle for positive stability is 47.93 degrees.

![MPMB Righting Arm](image-url)

**Figure 3.** Static stability diagram.
The technical data presented indicate that the MPMB has adequate transverse stability and can be equipped with light superstructures without difficulties. The boat can cope with an external moment calculated up to 32kNm, in the case of a static action, corresponding to the angle of 21.76 degrees.

For the installation of solar panels, construction similar to one in figure 4, made of light materials and having a sail area correlated with the corresponding height. The external moment must not exceed the value of 16 kNm.

![Figure 4. Motor powered pleasure boats.](image)

5. Conclusions
The multifunctionality of MPMB causes many contradictory requirements, which must be met to a certain extent. Thus, the design problem is one of achieving a balanced and adaptable solution, in which the uncertainties are minimized. Stability values presented for the MPMB are calculated for a specific load of 20 persons and according the designed 3D model presented in SolidWorks.

Computer based programs can be used in all design phases of MPMB, such as determining the body of the boat, drawings, to perform detailed structural analysis, to calculate the detailed costs for the boat, to evaluate the strength, power and performance of the boats and the interior arrangements, etc. In addition to using the program for the design process, the program can be used for the production process with the fully computerized 3D model of the craft with improved stability for passengers.

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