THE APPLICATION OF COMBINATION OF SOLID BOXES AND AIR BAGS TO SUPPORT THE UNSINKABLE SMALL PASSENGER BOAT

Wolter R Hetharia, Eliza R de Fretes, Fella Gaspersz, Jandri Louhenapessy
Department of Naval Architecture, Faculty of Engineering, Pattimura University, Ambon
hethariawr@yahoo.com

Abstract. Small fast passenger boats serve to carry passengers at certain routes particularly in short distance between the islands. The passengers preferred those transport mode due to its short travel time. In fact, there are many accidents occur during boat operation which end up with the loss of life and materials at sea. An intensive study was executed by the authors with the purpose to obtain an unsinkable boat. The boat data of existing boats were collected and be used for re-designing process. During the design process, some solid boxes, expanded bags were provided inside boat to reduce the incoming water. Meanwhile, the bags were fitted outside the boat (side floater) to provide additional buoyancy and righting moment for stability performance. A boat model was developed and tested to confirm the design results. In addition, a full-scale boat was developed and equipped with solid boxes, air bags and side floaters. The theoretical computation and extrapolated results from model proved that the required volume for inside solid boxes and air bags are 1.213 m^3 and 0.511 m^3 respectively. Meanwhile, the required volume of outside air bags is 0.357 m^3. It was found that the total boat weight, passengers and incoming water of 4.259 tons are balanced by weight displacement of 5.025 tons. There was reserve buoyancy of 0.766 tons that supports the boat to be float and side floater to prevent the boat from capsize. The result of sea trial showed that with all loading conditions the boat was still afloat (unsinkable).

Keywords: solid boxes, air bags, unsinkable,

INTRODUCTION

The contribution of small fast boats to serve inter-island transport is favourable for the passengers due to the short travel time. In many archipelago regions this kind of transportation mode is preferred due to the small input passengers on board and easy operation instead of bigger ships. In fact, those boats operate in the open sea with bad conditions such as high wind and big waves. Many accidents occur for those small boats such as sinking and capsizing which end-up with the loss of life and materials at sea (Basarnas, 2016; Hetharia, 2014; Hetharia, 2018).

A continuous study concerning this issue have been conducting by the authors. The first study was related to tuna long-line fishing boat (Hetharia, 2008; Hetharia, 2017; Hetharia 2018). In this study the boat was provided by inserting light solid boxes on board. The purpose of applying solid boxes is to reduce the incoming water on board. The sea trial has proved that the boat was still afloat even it was filled fully by sea water. In addition, the boat still afloat (unsinkable) in capsized condition due to reserve buoyancy provided by solid the boxes.

The concept of unsinkable small fishing boat was developed to the small passenger boats. The application of light solid boxes was introduced to the passenger boat. However, early study was fail due to insufficient light solid boxes provided on board. The study was continued by applying air bags on board. The computation of required volume of combination of solid boxes and air bags was made. In fact, the total volume required including inner light solid boxes and air bags including parts of passenger body. This volume was added with outside air bags (side floaters) to support buoyancy force and to improve the stability of boat in flooding condition.

A boat model was developed and tested at small tank. The purpose of model test was to verify the required solid boxes and air bags as determined in theoretical computation (Hetharia, 2019). The result of the test confirmed the required amount of solid boxes and air bags to keep the model afloat. In addition, a full-scale boat was built (hull material of Fibreglass Reinforced Plastic /FRP) and tested at sea. The purpose of the test was to confirm the results of computation at the sea. The full-scale boat was provided with light solid boxes, on board air bags, the system to inflate air bags on board and outside air bags (side floaters). The side floaters contribute to support additional buoyancy and righting moment in flooding condition. During the sea trial, fifteen passengers and equipment was placed on board and the water was filled into the boat. The results of sea trial proved that the boat still floats. In addition, the boat was quite stable due to the contribution of side floater.

Basic principal of a ship to be float is the weight displacement of the ship equals to the total weight of ship (Barras, 2006; Biran, 2003; Moore, 2010). This is showed in the equation (1) as follows:

$$\Delta = W \qquad (1)$$

where:

Δ = Weight displacement

W = Total boat weight

The total boat weight consists of lightweight (LWT) and deadweight (DWT) (Parsons, 2003; Watson, 1998; Lewis, 1988) and is represented by:

$$W = LWT + DWT \qquad (2)$$

The component of LWT consists of boat weight, propulsion system and equipment. The component of DWT consists of passengers and boat operator, luggage and fuel. Weight displacement of the boat (Δ) is computed as:

$$\Delta = C_B \times L \times B \times T \times \rho \qquad (3)$$

where:

L = ship length B = ship beam

T = ship draft C_B = block coefficient

ρ = specific weight (1.025 ton/m^3, salt water)

Therefore, for a ship to be float at the draft (T), then the total boat weight (W) equals to weight displacement (Δ).

In the case of a ship to be float or sink at ship height (H):

$$W_{total} > \Delta = C_B \times L \times B \times H \times \rho \rightarrow \text{sink} \qquad (4)$$

$$W_{total} < \Delta = C_B \times L \times B \times H \times \rho \rightarrow \text{float} \qquad (5)$$

During the boat operation the component of LWT is constant. The additional DWT component is coming from the water from outside the boat.

To reduce the incoming sea water on board, some materials should be provided. This concept is further explained with the help of Figure 1. The volume inside the boat consists of boat structures (red colour) and solid boxes (blue colour), which are used as passenger seats. In fact, there is still inside volume may be filled with sea water (yellow colour). To prevent incoming water on board some amount of air bags (green colour) should be provided on board. However, the boat may still sink because of the limitation of air bags. The limitation of air bags correlate to the spaces required for the passengers.

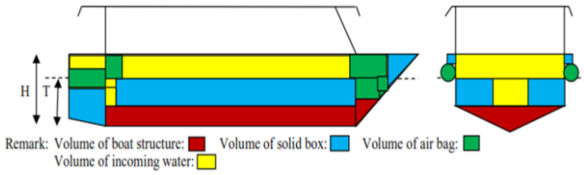

Figure 1. Composition of solid boxes and air bags

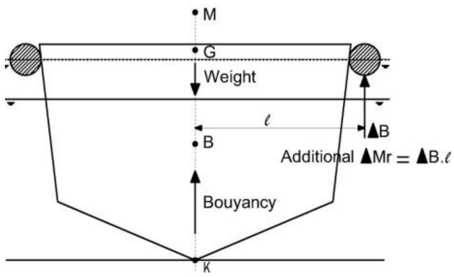

Figure 2. Contribution of side floater

An additional air bags should be provided at the outside boat or side floaters (green colour). The application of side floaters will increase the buoyancy and stability performance of the boat. Figure 2 shows the additional buoyancy force ($\blacktriangle B$) and righting moment:

$$\blacktriangle Mr = \blacktriangle B \times l \qquad (6)$$

The volume of boat structures is composed on frames and sheets of material Fibre Reinforced Plastic (FRP). This volume acts as double bottom and double skin of the boat. Other solid boxes are closed spaces fixed at the bow and stern of the boat. The air bags are formed from expanded bags installed on board and outsides the boat. The bags are connected to two units of compressed air tank installed inside passenger seats. The air bags are stored in small boxes on board and outside the boat.

METHODOLOGY

Collecting Boat Data and design Process

The existing boat data were collected in order to be used as input of re-design process. The boat data were collected at three local ports in Ambon Island. In this case the boat dimension and configuration are similar to the existing boat. The differences in re-design process are addressed to the application of light solid boxes, inside air bags and side floaters. Before developing a full-scale boat, a model was developed and tested to verify theoretical computation. A scale factor, **λ** = length of full-scale boat/length of model = 4 was determined. Dimensions of model and full-scale boat are presented at Table 1.

Table 1. The Dimensions of Boat and Model

No	Boat Parameters	Boat	Model	Unit
1	Length Overall, L_{OA}	6.61	1.652	m
2	Length of waterline, L_{WL}	6.35	1.587	m
3	Beam, B	1.40	0.350	m
4	Draft, T	0.40	0.100	m
5	Height, H	0.65	0.163	m
6	Speed, V	13.0	-	knot

Other boat data are described as follows:

Passenger	: 14 persons
Operator	: 1 person
Hull Material	: FRP
Luggage	: @ 20 kg for each passenger
Prime mover	: 40 HP (outboard)
Equipment	: anchor, rope, fuel tank

Developing Boat Drawings

The lines plan were developed by using the software Maxsurf in order to get boat parameters. In addition, the lines plan, together with general arrangement, will be used to develop the model and full-scale boat. The computation of boat weight and the volume required for inner solid boxes and side floaters will be verified at the real model and full-scale boat. The lines plan and general arrangement are presented in Figures 3 and 4.

Developing and Testing the Model

The boat model was constructed in three phases namely inner template, model template and the model. The solid boxes and equipment were attached during the construction phase. The configuration of the model consist of hull model, inside solid boxes and air bags, passenger model, equipment.

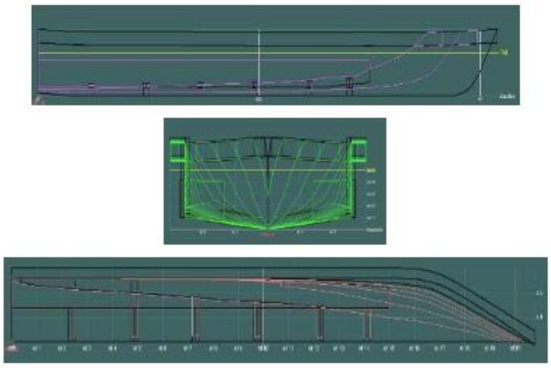

Figure 3. The lines plan

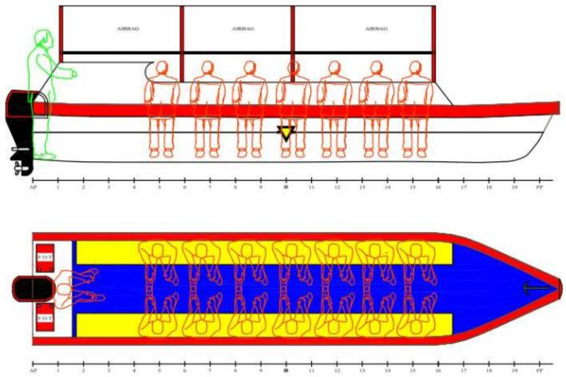

Figure 4. The general arrangement of boat

In addition, the side floaters were attached outside the boat (figure 5). The boat was filled fully with incoming water. Result of the test showed that with all configuration of solid boxes and air bags the model afloat. However, if the side floaters were removed then the model were sink and capsized.

Figure 5. Model test

Developing and Testing the Full-scale Boat

The full-scale boat was tested to confirm the result of theoretical computation to the real condition at sea. The boat was developed in several phase, namely drawing the lines plan on the mould loft, cutting and developing the frames, developing the parent boat template, developing the boat template and constructing the full-scale boat (Figure 6). The propulsion and mechanical system was installed at the boat. The mechanical system consists of two air compressed tanks (attached under passenger seats), connecting system (hose and valves) and plastic bags. The compressed tanks supply the air into the plastic bags inside and outside the boat. The plastic bags were expanded when the boat is in critical condition (figure 7). The solid boxes installed on board consist on the passenger seat and additional boxes fitted at the bow and stern on board.

Figure 6. Full-scale unsinkable boat

Boat launching and sea trial was executed at sea. Test unsinkable boat was executed for two conditions which are without passengers and with passengers as seen in Figure 7.

Figure 7. Sea trial of unsinkable boat

RESULTS AND DISCUSSIONS

Results

The results of computations of boat volume are presented in Table 2. The boat components include the weight and volume of boat, solid boxes and air bags. In addition, the scenario of solid boxes and air bags based on their configuration is presented. Six scenarios were performed in order to find the configuration of solid boxes and air bags to prevent the boat from sinking. The first scenario was presented for the boat was at the designed draft due to normal loading condition.

At scenario 2, the boat was provided with solid boxes and loaded with passengers and incoming water. The result was the boat was sinking due to greater total boat weight. Similar way to scenario 2, at scenario 3 was added with inside air bags but it can't avoid the boat from sinking. At scenario 4 to 6, the boat was provided with outside air bags (side floaters). In this scenario, the dimension of side floater was varied to reach the configuration to support the boat from sinking and capsizing. The configuration of solid boxes and air bags that installed on board consists of:

- The volume of solid boxes : 1.213 m^3
- The volume of inside air bags : 0.511 m^3
- The volume of side floaters : 0.357 m^3 (Third scenario)

Table 2: Weight components of full-scale boat

No	Boat Parameters	Value	Unit
A	**Loaded to designed waterline (T = 0.4 m)**		
	Scenario 1: Boat + solid boxes + passengers		
1	Boat weight	2.284	ton
2	Volume displacement	2.236	m^3
3	Weight displacement	2.292	Ton
	Testing Result: the boat floats at designed draft		
B	**Loaded to boat height (H = 0.65 m)**		
4	Volume displacement boat	3.612	m^3
5	Volume displacement fender	0,147	m^3
6	Volume displacement boat & fender	3.760	dm^3
7	Weight displacement boat & fender	3.853	ton
	Scenario 2: Boat + solid boxes + passengers + water		
8	Boat weight	2.284	ton
9	Weight of water on board	2.385	ton
10	Total weight boat + water	4.668	ton
11	Weight displacement	3.853	ton
12	Weight displacement – total weight	-0.816	ton
	Testing Result: the boat sinks		
	Scenario 3: B + SB + AB + P + W		
13	Boat weight	2.284	ton
14	Weight of water on board	1.920	ton
15	Total weight boat + water	4.204	ton
16	Weight displacement	3.853	ton
17	Weight displacement – total weight	-0.351	ton
	Testing Result: boat sinks		
	Scenario 4: B + SB + AB + SF 1 + P + W		
18	Boat weight	2.284	ton
19	Weight of water on board	1.92	ton
20	Total weight boat + water + floater 1	4.239	ton
21	Weight displacement	3.942	ton
22	Weight displacement – total weight	-0.297	ton
	Testing Result: Model sinks		
	Scenario 5: B + SB + AB + SF 2 + P + W		
23	Boat weight	2.284	ton
24	Weight of water on board	1.920	ton
25	Total weight boat + water + floater 2	4.249	ton
26	Weight displacement	4.053	ton
27	Weight displacement – total weight	-0.195	ton
	Testing Result: Boat sinks		
	Scenario 6: B + SB + AB + SF 3 + P + W		
28	Boat weight	2.284	ton
29	Weight of water on board	1.920	ton
30	Total weight boat + water + floater 3	4.259	ton
31	Weight displacement	5.025	ton
32	Weight displacement – total weight	0.766	ton
	Testing Result: Boat floats		

Note:
B = boat, SB = Solid boxes, P = Passenger, AB = Inside air bags, SF = Side floater, W = Incoming water

Discussions

The results in Table 2 show the scenario on which configuration the boat will float or sink. To ensure the boat still float then the weight displacement of the boat should be greater than the total boat weight which includes the boat, passengers and incoming water. It is clearly seen that in the scenario number 2 to 5 the boat sinks. In fact, this condition occurs when the total boat weight exceed the displacement weight which come from buoyancy force. At the scenario number 6, the weight displacement was greater than total boat weight. This condition makes the boat floats. Furthermore, a small righting moment created by side floater contribute to balance the boat from heeling and capsizing. The righting moment comes from this approach:

- The volume of one side floater : 0.179 m3
- The weight displacement : 0.183 tons
- The distance from midship : 0.900 m
- The righting moment : 0.165 ton.m

CONCLUSION AND RECOMMENDATION

Study concerning the unsinkable small passenger boat end-up with a good selection of configurations of solid boxes and air bags. It may be resumed from the result of study that:

- Selection a proper configuration of solid boxes and air bags will provide the buoyancy and righting moment to prevent the boat from sinking and capsizing.
- The solid boxes and air bags installed on board contribute to reduce the incoming water while the air bags outside the boat (side floaters) contribute to provide additional buoyancy and righting moment.
- To prevent the boat from sinking, it requires the volume of solid boxes 1.213 m^3 and air bags 0.511 m^3 inside the boat and side floaters (outside air bags) of 0.357 m^3.

- The total weight of boat, passengers and incoming water of 4.259 ton are ballanced by 5.025 weight displacement. In this condition, there are the amount of reserve buoyancy of 0.766 ton. This reserve buoyancy contribute to float the boat under flooding condition.

It is recommended that additional solid boxes should be fitted at the bow and stern instead of solid boxes for the passenger seat as used by the existing boats. Additional inside air bags and side floaters may be used as reference to be installed on unsinkable boat. The results of study should be considered by the authority boards for future application for the existing small passenger boats.

ACKNOWLEDGEMENTS

Special thank is given to The Ministry of Research, Technology and Higher Education, The Republic of Indonesia for the research grant of "Penelitian Terapan Unggulan Perguruan Tinggi" 2018 - 2019 to execute this research

REFERENCES

Anonymous,(2026), "Data Kecelakaan Kapal Laut, BASARNAS Ambon".

Barras, B. and Derret, D. R. (2006), *Ship Stability for Masters and Mates*, Butterworth – Heinemann, 6th edition, An Imprint of Elsevier Ltd., Linacre House, Jordan Hill, Oxford OX2 8DP.

Biran, A. B. (2003), *Ship Hysrostatics and Stability*, Technion – Faculty of Mechanical Engineering, 1st publication, Butterworth – Heinemann, An Imprint of Elsevier Ltd., Linacre House, Jordan Hill, Oxford OX2 8DP.

Lewis, E. V. (1988), *Principles of Naval Architecture, Stability and Strength*, SNAME Publication, Vol. I, Jersey City, New Jersey.

Hetharia, W. R., and de Lima, E. J (2008), "Design and Evaluating of Unsinkable Tuna Long Boats", Proceeding of The 6th Regional Conference on Marine Technology (MARTEC 2008), University of Indonesia, Jakarta 26 – 27 August, 2008.

Hetharia, W. R., de Fretes, E. R., Gaspersz, , F., and Tianotak, A. J. (2014), "Kajian Tentang Beberapa Aktifitas Masyarakat Maluku di Sektor Kelautan", Prosiding Kongres Budaya Maluku, Ambon.

Hetharia, W. R. (2017), "Design and Application of Unsinkable Tuna Longboat for Local Fishermen", OCCASIONAL PAPERS No. 58 (March 2017), Kagoshima University, Japan, 2017 www.http://cpi.kagoshima-u.ac.jp/index-j.html

Hetharia, W. R., Gaspersz, and F, Feninlambir, A. (2018), "Evaluasi Parameter Stabilitas Kapal Penumpang Kecil", Prosiding Seminar Nasional Fakultas Teknik Universitas Pattimura Ambon, 26 April 2018, ISSN : 2620-3995.

Hetharia W. R., de Fretes, E. R., Gaspersz, F., and Louhenapessy, Y. (2018), "The Application of Solid Box on Small Passenger Boat", Proceedings of International Conference on Marine Science and Technology – Sustainable Development on Marine Resources", Pattimura University Ambon, 24-25 October 2018, Ambon https://www.researchgate.net/publication/336866871 The application of solid box es on small passenger speed-boat

Hetharia W. R., de Fretes, E. R., Gaspersz, F., and Louhenapessy, Y. (2019), "A Model Scale of Unsinkable Small Passenger Speed-Boat", Proceedings of International Conference on Ship and Offshore Technology, Vol 2, Undip 25-26 November 2019, Semarang https://www.dropbox.com/s/ogiuq3nbg6ytud2/Porseeding%20Univ.Diponegoro.pdf?dl=0

Moore, C. S. (2010), *Intact Stability – The Principles of Naval Architecture Series*, The Society of Naval Architects, SNAME, Jersey City, New Jersey, 2010.

Parsons, M. G. (2003), *Parametric Design - Ship Design and Construction,* Chapter 11, Volume. 2., SNAME Publication, Jersey City, NJ, USA.

Watson, D. G. M (1998), *Practical Ship Design*, Elsevier Ocean Engineering Book Series, Volume I, ELSEVIER.