ISOMAse
International Society of Ocean, Mechanical and Aerospace Scientists and Engineers

Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering-
4th October 2018. Vol.5 No.1

October 30, 2018

Improvement on Resistance Performance of Self-Propelled Barge in Indonesia

Cahyo Sasmito,[a,*] Masaaki Sano,[a] and Abdul Kadir,[b]

[a)] *Graduate School of Engineering, Hiroshima University, Japan*
[b)] *Center of Technology for Maritime Industrial Engineering, BPPT, Indonesia*

*Corresponding author: cahyo.sasmito@bppt.go.id

Paper History

Received: 15-September-2018
Received in revised form: 25-September-2018
Accepted: 4-October-2018

ABSTRACT

Self-propelled barge has been favorite fleet in Indonesia. It is because of their huge capacity and low in draught that fulfilled requirement for the shallow Indonesian waters. The Indonesian self-propelled barge fleets have various type of hull shape, from simple flat shapes to complicated streamlined shapes. This various hull shapes affect to their hydrodynamic performance and construction easiness. The streamlined hull shape may have better resistance performance, but more difficult to be constructed because they have a lot of 3-dimensional curvatures. On the other side, sharp hull shape which is dominated with flat shell plate will give easiness in construction, although resistance performance will be worse. In this study the authors would like to investigate the effect of hull's bow shape on resistance performance of self-propelled barge, and also try combining the merits of each hull shape to get a new design which has better resistance performance. The resistance test of modified hull models are evaluated by CFD calculation. Furthermore, the Gaussian curvature that represents flatness level of the hull surface is used to evaluate the simplicity of hull form.

KEY WORDS: *self-propelled barge, resistance, hull shape, CFD, gaussian curvature.*

NOMENCLATURE

B	Breadth
Cb	Block coefficient
CFD	Computational Fluid Dynamic
CSA	Curve of Sectional Area
C_f	Friction resistance coefficient
C_t	Total resistance coefficient
Fn	Froude number
k	Form factor
Loa	Length overall
Lpp	Length between perpendicular
Lwl	Length of waterline
R	Resistance of ship
R_f	Friction resistance
R_t	Total resistance
SPB	Self-Propelled Barge
T	Design draught
$TEUs$	Twenty-foot Equivalent Units
U	Ship speed (model scale)
∇	Volume displacement
WSA	Wetted Surface Area
ρ	Density of water

1.0 INTRODUCTION

1.1 Overview of SPB100 and SPB250

Since declared on November 4th, 2015, "Tol Laut" has become national maritime logistic freight system in Indonesia. "Tol Laut" or "Sea Freeway" is an ocean freight service with the amount and type of vessels in accordance to the demand, through the main line the central corridor that connects the waters of Indonesia main ports (hub), accompanied by continuous lines (feeder) which connects the ports feeder (spoke). This program aims to connect major ports around the Indonesia archipelago. By the connection between these ports, then smooth distribution of goods to rural areas can be realized [1].

To meet the needs of the national fleet of the "Tol Laut" concept, Indonesian government has built 15 fleets of 100 TEUs

Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering-
4th October 2018. Vol.5 No.1

October 30, 2018

feeder vessels to serve logistics transportation for feeder port (spoke). The vessels were built in sister ship system and spread out over several national shipyards. The type of the vessels is Self-Propelled Barge with a streamline hull shape like a conventional ship. On the other hand, there has been a similar fleet belonging to a national shipping company that has 250 TEUs in capacity and effectively proven as a container carrier vessel serving the logistic transport between feeder ports. These vessels have a sharp hull with bow shape looks like a couple of flat spoons and dominated with flat shell plate.

Each of these hull shapes has merits and demerits. The streamline hull shape may have better resistance performance, but more difficult to be constructed, because it has a lot of 3-dimensional curvature. On the other side, sharp hull shape which is dominated with flat shell plate would give the easiness in construction. Although resistance performance would be worse, but this point is very favorable for the constructor especially for small shipyard that grows from a traditional dockyard with less production facilities. The study on integrating the merits of each hull shape into a new design is very interesting to be discuss. In the following discussion, Self-Propelled Barge 100 TEUs and 250 TEUs are named as SPB100 and SPB250 respectively.

1.2 Motivation

SPB250 is one kind of self-propelled barges belonging to a national shipping company which has been effectively proven as a container carrier vessel serving the logistic transportation in Indonesia. This vessel has nice simple flat hull design. The bow part looks like a pair of spoons with the side shell was dominated by flat plates. Since Indonesian government succeed to launch SPB100 as a feeder fleet within the national maritime logistic freight system (Tol Laut), they want to add more fleets with a larger capacity. Therefore, SPB250 is one of design alternatives which can be offered. But, on the other side, SPB250 should have better performance or at least nearly same as SPB100's performance as the predecessor. The blunt shape of SPB250 hull's bow makes the resistance become worse. In this study the authors try to improve resistance performance of SPB250 by modifying the bow shape, maintain the hull flatness and minimize non-developable surface as an advantage of SPB250, and also investigate the effect of hull shape and modified bow on the resistance performance.

2.0 DESIGN CONCEPT OF MODIFIED HULL

2.1 Principal Dimension

SPB100 and SPB250 are two kind of vessels that has different capacity size. SPB250 has more than twice capacity than SPB100. Both of them also has different hull shape. The original shape of SPB100 and SPB250 as a reference hull, shown in Figure 1. For more detail, the principal dimension of SPB100 and SPB250 in full scale and model scale was described in Table 1. Model scale is used for experiment and simulation.

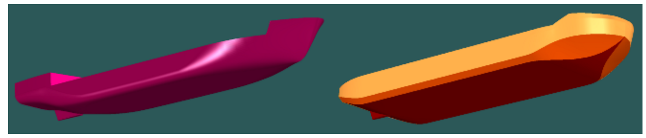

Figure 1: Hull form of SPB100 (left) and SPB250 (right)

Table 1. Ship Particulars of SPB100 and SPB250

Ship Particular	Unit	SPB100		SPB250	
		Ship	Model	Ship	Model
Loa	m	80.33	4.299	92.96	3.38
Lwl	m	76.54	4.096	91.39	3.32
Lpp	m	74.75	4.0002	89.76	3.26
B	m	17.4	0.9312	24	0.87
T	m	3	0.1605	4	0.15
WSA	m^2	1462.1	4.187	2591	3.426
∇	m^3	2968.3	0.455	7310	0.352
Cb		0.74	0.74	0.83	0.83
Scale factor		1	0.0535	1	0.0364

2.2 Design Constraint

The self-propelled barges are characterized by great values of the hull block coefficients, that ensures achieving large values of their displacement at assumed main dimensions. On the other hand, to decrease their building costs, usually is applied a simplified bow form consisted of practically developable surfaces divided by chine lines, thus relatively simple in building. Such approach is a rational and economical compromise [2] since service speed of ships is of 5 − 10 knots.

The modification is conducted based on SPB250's hull model. Modification was performed only on the hull's bow, keeping the hull flatness as a large as possible in order to minimizes non-developable surfaces or twisting surface. The principal dimension of the vessel was maintained as fix as possible. The wetted surface area and displacement of the hull are kept as an original in order to maintain the capacity of the vessel. If wetted surface area and displacement of each model is change due to modification, the changes are maintained as small as possible. The details of such parameters shown in Table 2.

The main principles of modification are creating the bow shape sharper and arranging the body plan curve elevation on the bow to be V-shape, in order to reduce the pressure resistance on forward hull. This modification can be done by re-arrange configuration of upper chine and lower chine especially on the hull's bow section.

2.3 Modified Hull Models

Modification conducted on 5 hull models. All of modified hull are based on SPB250 hull model. The five models are named as SPB250-M1, SPB250-M2, SPB250-M3, SPB250-M4 and SPB250-M5 respectively.

All of modified hulls has same shape on the rear half part, except SPB250-M1 and SPB250-M2. Both of them have a flat side shell that elongated from parallel middle body to the rear

POMAse | Received: 15-September-2018 | Accepted: 4-October-2018 | [(5) 1: 57-62]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2443-1710

Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering-
4th October 2018. Vol.5 No.1

October 30, 2018

section. While the other hull models have side shell that slightly curved on the stern. However, this condition does not have a big effect on sectional area of the ship stern such as illustrated in the Curve of Sectional Area (*CSA*) of each hull model in Figure 2. The *CSA* of all modified hull have mostly same shape in rear part and different in forward part. In addition, SPB100 has a *CSA* that totally different with SPB250 based models.

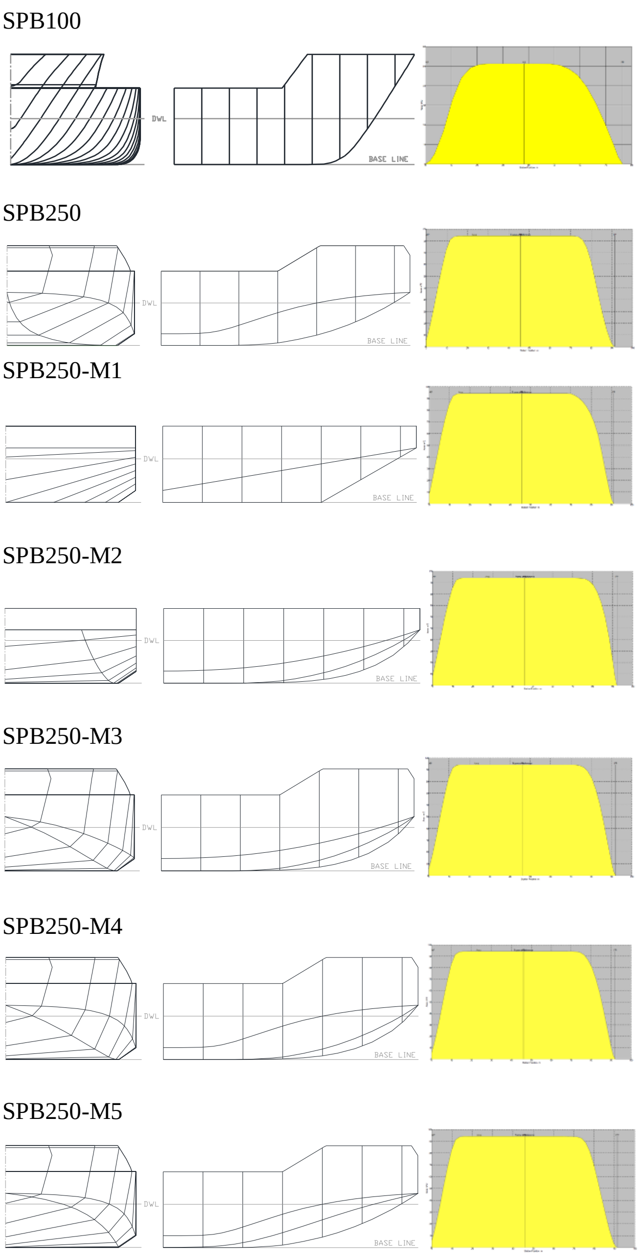

Figure 2: Hull form of SPB models and the CSA

This hull modification is inspired by Tomasz Tabaczek [2] and his colleague's research. They had collecting many kinds of European barge model and then analyze the resistance by CFD. From their conclusion, they said that the barge hull which have a straight, vertical or only slightly inclined stem, have greater resistance values as well. This observation suggests that the vertical or only slightly inclined stem is not favorable from the point of view of hull resistance [2]. So, in this modification, the bow which have sharp inclined stem with slightly rises bottom at lateral section were adopted.

Various shape of modified hull's bow was formed by chine line configuration. The upper chine curve of SPB250-M4 and SPB250-M5 was designed based on SPB250's upper chine configuration. They have a same configuration on the upper chine line, but the lower chine line and stem are different. The lower chine configuration makes a various rise of floor elevation along hull' bow. This is made a distinction bow shape for each model. SPB250-M3 has lower chine and stem which have same configuration with SPB250-M4, but the upper chine line is different. SPB250-M1 and SPB250-M2 are totally different from the others hull models. Both of them have straight flat side shell. SPB250-M1 does not has lower chine line same as SPB250.

In the Table 2, are given values of the *WSA*, displacement and block coefficient of all modified hull and SPB250's hull as a reference model.

Table 2. Ship Particular of modified hull in full scale

No	Hull Model	Ship Particular		
		WSA	∇	*Cb*
		(m^2)	(m^3)	
1	SPB250	2591	7310	0.83
2	SPB250-M1	2693	7454	0.85
3	SPB250-M2	2758	7724	0.87
4	SPB250-M3	2645	7531	0.85
5	SPB250-M4	2638	7507	0.85
6	SPB250-M5	2594	7290	0.83

2.4 Evaluation of Flatness Level Using Gaussian Curvature

Gaussian curvature is the product of the maximum and minimum curvatures at a point on the surface. Gaussian curvature will indicate whether the surface is locally elliptical/convex (positive Gaussian curvature), whether it is hyperbolic/concave (negative Gaussian curvature), or whether it is developable (zero Gaussian curvature) [3]. A developable surface is mathematically defined as a surface with "zero Gaussian curvature", which means that the maximum curvature times the minimum curvature is zero. This of course requires that one of the two principal curvatures be zero. The surface must contain straight lines which have zero curvature [4]. So, the flatness level of surface can be evaluated using Gaussian curvature. To be more precise, the following two statements are proved for ensure the surface flatness: (a) If every point on a surface of zero Gaussian curvature is a flat point, then the surface is a piece of a plane, (b) If no point on a surface of zero Gaussian curvature is a flat point, then through every point

POMAse | Received: 15-September-2018 | Accepted: 4-October-2018 | [(5) 1: 57-62]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2443-1710

ISOMAse
International Society of Ocean, Mechanical and Aerospace Scientists and Engineers

Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering-
4th October 2018. Vol.5 No.1

there is a unique asymptotic line, and the tangent plane is constant along this line [5].

The advantages of developable surfaces are it can be formed from flat sheets without stretching, so the forces required to form sheet materials into developable surfaces are much less than for other surfaces. In some cases, the forces required to form non-developable surfaces could be so large that the material is damaged internally when it is formed. Another advantage of developable surfaces is that the development, or flattened out shape, of such a surface is exact [4].

Evaluation of flatness level of hull models was described in Figure 2. Blue color indicates positive Gaussian curvature, that is mean the shape is convex. Red color indicates negative Gaussian curvature or concave shape and green color indicates flat shape or zero Gaussian curvature.

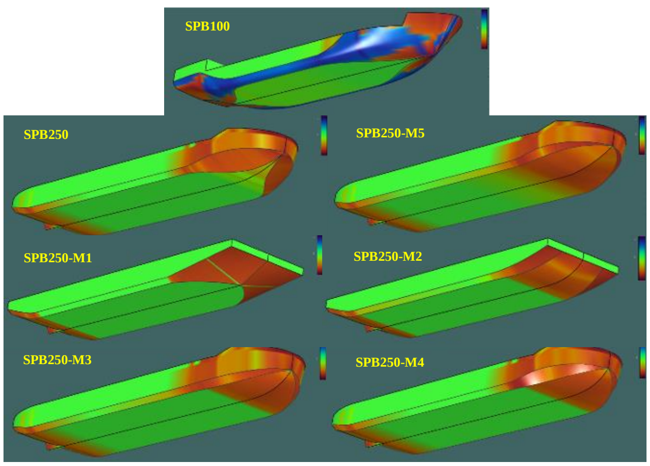

Figure 2: Gaussian curvature on the hull models

From the figure above, we can say that SPB100's hull model has more complicated curvature than the others hull models. It is indicated by two thick color on the hull surface. It is mean that there are two shape convex and concave in a surface section. Contrast with the other models which is dominated by green color on their hull surface. The orange color on the forward and rear hull indicates that the hull models have concave shape only on the bow and stern section, not on whole hull surface. This is describing that all of modified hulls have more of developable surface which indicates their simple flat shape.

3.0 OUTLINE OF NUMERICAL CALCULATION

The hydrodynamic force acting on the modified hull models in straight running was calculated by CFD. The steady-state solver for incompressible, turbulent flow supplied with OpenFOAM [6] ver.2.3.0 was chosen for this purpose. K-Omega-SST model was used for the turbulence model. There is a well-known three-dimensional extrapolation method for ship resistance analysis. It assumes that the total resistance can be calculated by linear summation of three components: viscous friction resistance, viscous pressure resistance and wave-making resistance.

The coordinate system of computation domain was defined at the right-hand side coordinate system where the transom end of the vessel was set at x=0 in the longitudinal direction, the center-plane was placed at y=0 in the lateral direction and the water surface was at z=0 in the vertical direction. Because the hull is left-right symmetrical with respect to the center plane, only the left domain was selected for computation. The computation domains subdivided into about 5~6 million cells.

4.0 RESULT AND DISCUSSION

4.1 Validation of Resistance Test Simulation

The resistance of SPB100 with attached appendages on the hull is evaluated by CFD and it is compared with the experimental results to validate the CFD calculation. The experimental result was taken from the resistance test of SPB100 which had conducted in Indonesian Hydrodynamic Laboratory. The experiment was made in model scale with scale factor 0.0535 and executed in various speed, from 0.119 m/s that correspond to 1 knot in full scale, up to 1.666 m/s or 14 knots in full scale. For comparation, both of such result, was presented in two way; dimensional and non-dimensional. The non-dimensional value that represented by C_t are obtained by dividing the total resistance with function of *WSA* and square of ship speed.

$$C_t = \frac{R_t}{0.5 \times \rho \times WSA \times U^2} \qquad (1)$$

Froude number *Fn* also used to represent non-dimensional term instead of ship speed as a dimensional term.

Figure 3 shows the comparison of the total resistance between CFD calculation and experimental results. The graph shows that the result of CFD calculation have looks good agreement with experimental results.

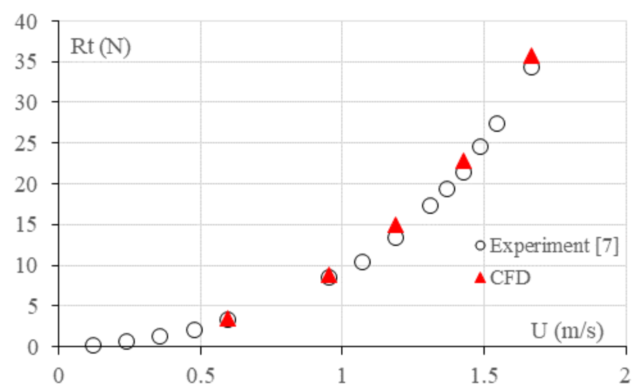

Figure 3: Total resistance of SPB100 in model scale

Comparison of the total resistance coefficient C_t between CFD calculation and experimental results shown in Figure 4 as below.

POMAse | Received: 15-September-2018 | Accepted: 4-October-2018 | [(5) 1: 57-62]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2443-1710

ISOMAse
International Society of Ocean, Mechanical and Aerospace Scientists and Engineers

Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering-
4th October 2018. Vol.5 No.1

October 30, 2018

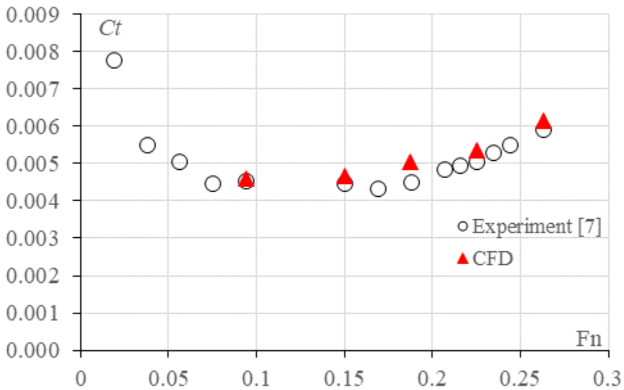

Figure 4: Total resistance coefficient of SPB100

In the Figure 4, shows that CFD calculation successfully catches the tendency of the experimental results. Both of such graphs gave indication that the CFD calculation of SPB100 have been well validated by experimental result.

4.2 Resistance Reduction on Modified Hulls

4.2.1 Reduction Rate of C_t

Because of slightly distinction of *WSA* and displacement on each modified hull model, the comparation of resistance reduction based on modification must be made non-dimensional. Therefore, non-dimensional parameter of total resistance coefficient C_t is used to describe such resistance reduction as in previous explanation.

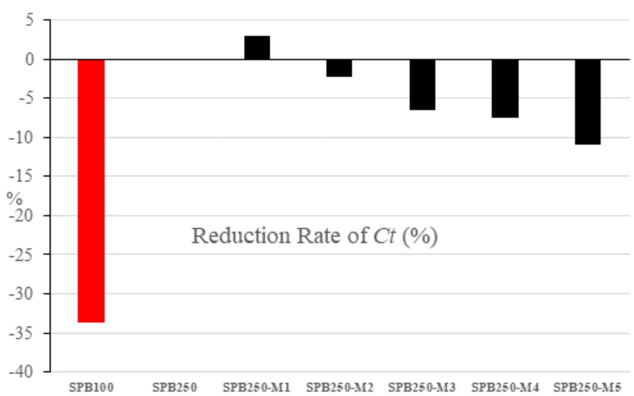

Figure 5: Reduction rate of C_t for modified hull

Figure 5 shows the resistance reduction of modified hulls which is represented by reduction rate of C_t. The graph shows that SPB250 has zero value rate because it is as reference hull model. The modified hull sequentially has down tendency of C_t value, except SPB250-M1 which has positive value. Positive value of reduction rate means that the hull model has bigger C_t value than reference hull model. The biggest reduction occurs on SPB250-M5 which has more than 10% reduction. It is means, the hull's bow modification had successfully reduced the total resistance. If compared with SPB100 as a reduction target that have reduction rate more than 30%, SPB250-M5 might be three times smaller than SPB100. However, the achievement of total reduction up to 10% are reasonable value to be accepted.

4.2.2 Form Factor *k* Comparison

Form factor is one of parameter that could be used to evaluate the effect of hull form on resistance performance. The form factor *(1+k)* is determined for each hull from low-speed resistance or propulsion measurements when the wave resistance components are negligible. In the case of the resistance measurement of form factor then this is based on the relationship [8]:

$$(1+k) = \lim_{Fn\to 0}\left(\frac{R}{R_f}\right) \qquad (2)$$

In low-speed experiment with *Fn* around 0.1, that mean wave-making effect are negligible, the form factor can be determined by following formula:

$$(1+k) = \frac{C_t}{C_f} \qquad (3)$$

Equation 3 shows that the form factor is proportional with total resistance coefficient C_t and inversely proportional with friction resistance coefficient C_f. This is mean, if wetted surface area is fixed, and friction resistance coefficient C_f are constant, then the form factor would be main component that affects the total resistance in calm water. Figure 6 shows the reduction of form factor based on bow modification.

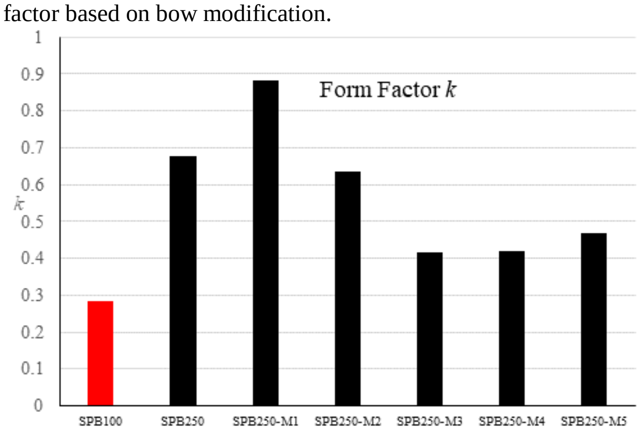

Figure 6: Comparison of form factor *k* all of model

Figure 6 shows that the hull's bow modification successfully reduce the form factor except SPB250-M1. The SPB250-M1 has higher form factor than SPB250 as a reference hull. Although still higher than form factor of SPB100 as a reduction target, the three last modified hulls have a significant reduction. The most significant reduction occurs in SPB250-M3 which is slightly lower than SPB250-M4.

4.3 Visualization of Resistance Reduction on The Hull's Bow

The resistance reduction based on hull's bow modification could be described in visualization of pressure drag contour on the hull as seen in Figure 4 as follow.

POMAse | Received: 15-September-2018 | Accepted: 4-October-2018 | [(5) 1: 57-62]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2443-1710

ISOMAse
International Society of Ocean, Mechanical and Aerospace Scientists and Engineers

Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering-
4th October 2018. Vol.5 No.1

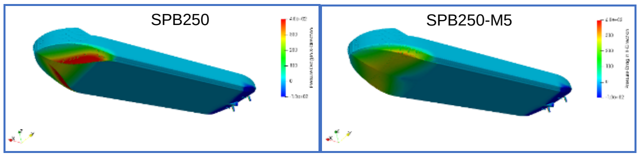

Figure 7: Visualization of pressure drag contour on the hull

On the SPB250 as a reference hull we can see the red color dominating on the bow area between upper chine and flat bottom. This is means that the original shape of SPB250 has huge pressure drag on her bow. On the other hand, after modifying the hull's bow by re-arrange lower chine configuration, making it higher in order to get flat bottom inclination so that the V-shape could be formed on the bow section, the smooth distribution of pressure drag on the bow area finally obtained as seen on the SPB250-M5's hull.

5.0 CONCLUSION

- The hull's bow modification conducted on 5 hull models based on SPB250. The such models are: SPB250-M1, SPB250-M2, SPB250-M3, SPB250-M4, SPB250-M5.
- All of modified hulls have a simple-flat shape which are indicated by domination of zero Gaussian curvature on their hull surfaces.
- The accuracy of CFD calculation was validated by experimental results of SPB100.
- The resistance reduction based on hull's bow modification evaluated by comparing the reduction rate of C_t and the form factor k.
- The biggest reduction rate of C_t occurs on SPB250-M5 which has more than 10% reduction. The lowest form factor owned by SPB250-M3 which has k value is about 0.415. Both of such points, implied that the aim of hull's bow modification has been successfully achieved.
- The best hull model candidate to be offered based on modification is SPB250-M5, since it has significant resistance reduction and also has principal particulars which almost same with SPB250 as a reference hull.

ACKNOWLEDGEMENTS
The authors would like to convey a great appreciation to Ministry of Research, Technology and Higher Education of Indonesia for granting him a Master Program Scholarship under the Research and Innovation in Science and Technology Project (RISET-Pro).

REFERENCE

1. Nyoman, B.R.M. (2017). *Development of Ferry Port as a Complement of "Tol Laut": Case Study on Ferry Port Ketapang*, International Refereed Journal of Engineering and Science (IRJES) Vol. 6, PP.31-37
2. Tabaczek T., Kulczyk J., Zawislak M. (2007). *Analysis of Hull Resistance of Pushed Barges in Shallow Water*, Polish Maritime Research Vol 14, pp: 10-15.
3. Anoname. (2013). *Maxsurf Modeler Program & User Manual*, Bentley Systems, Incorporated.
4. Barry C.D. (2003). *Working with Developable Surfaces*, (https://www.boatdesign.net/articles/developable-surfaces/)
5. Massey W.S. (1961). *Surfaces of Gaussian Curvature Zero in Euclidean 3-Space*, Yale University, New Haven, Conn. (https://projecteuclid.org/download/pdf_1/euclid.tmj/1178244205), (accessed to 2018-9-20).
6. The open source CFD toolbox, OpenFOAM, (http://www.openfoam.com/), (accessed to 2018-9-10).
7. Anoname. (2014). *Resistance Test Report: Container Carrier 100 TEUs*, Indonesian Hydrodynamic Laboratory-BPPT, Surabaya, Indonesia.
8. Molland A.F. (2008). The Maritime Engineering Reference Book: A Guide to Ship Design, Construction and Operation, Butterworth-Heinemann, Oxford, UK.