Numerical investigation of monohull ship type effect on ocean waste collection behavior

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Abstract. In this paper an attempt has been made to assess how effective waste-collecting use monohull ship with conveyor in the front. Numerical investigation based on Reynolds Averaged Navier Stokes (RANS) for predicting the flow pattern characteristics, velocity contour, and ship resistance. The focus of the present study is the impact of mohohull ship front shape on waste collection in calm water through the application of numerical methods. The three variations of the front of the monohull used are hardchine type, round bilge type, and monomaran type. It is done using speed variations of 1 to 4 knots. The results show round bilge type has the smallest total resistance value than others. In addition, analysis of the flow pattern in front of mohohull shows that monomaran type is the easiest to make waste closer to conveyor. From analysis of velocity contours also shows that monomaran type has fastest to make the waste close to conveyor.

1 Introduction

Ocean waste that continues to move due to waves and currents in the sea remains a problem until now [1] [2]. Ocean trash ranges in size from tiny particles measured in micrometers and centimeters, such plastic bags and soda bottles, to massive particles measured in tens of meters, like shipwrecks and lost cargo containers [3] [4]. Predicting from these circumstances and based on the amount of marine debris in 2010, the total mass of plastic in 2025 will grow between 100 and 250 million tons with the same business expectations [5]. Communities around seas and rivers have a significant influence on this issue [6].

Ships can perform a variety of tasks in the cleaning of ocean pollution, including collection and processing [7]. Design of a ocean waste collection ship using a monohull can also be done [8]. Using digital technology to involve communities nearby rivers and the sea is another approach to address this issue [9]. Monohull type hull has long been used in the world of sea transportation, large loading capacity, relatively low development cost [10].

Based on this, the current study aims to simulate and analyze the possibilities of using several types of monohulls that installed conveyor in front of ship to collect ocean waste. The three monohull ship models used are hard chine type, round bilge type, and monomaran type. This study uses computational fluid dynamics (CFD) based on Reynolds Averaged Navier Stokes (RANS) for predicting flow pattern characteristics, velocity contour, and ship resistance. Then simulation results of three models are compared to which one is the most effective in collecting waste. Flow pattern affects whether or not ocean waste is collected easily, velocity contour affects whether or not ocean waste is collected quickly, and ship resistance affects the size of fuel consumption.

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2 Methodology

The ship data used in this study is as shown in Table 1. This data was taken from previous research on ocean waste collection ships for Surabaya [8].

Table 1. Ship main dimension [8]

Type	Collecting Waste Ship
Length of waterline	16,448 m
Length between perpendicular	15,431 m
Breadth	4,8 m
Height	2,38 m
Draft	1,2 m
Block coefficient	0,687
Velocity	4 knots
Crew	4

While conveyor data is as shown in Table 2. The conveyor data was taken from product catalogs of Dorner conveyor industry project guide with the Aquapruf 7400 series [11].

Table 2. Conveyor main dimension [11]

Brand	Dorner
Series	Aquapruf 7400series
Height	0,176 m
Length	5 m
Bold	2,5 m
Belt Type	Cleated Straight Belts
Cleat Height	0,074 m
Maximum angle	45 degrees

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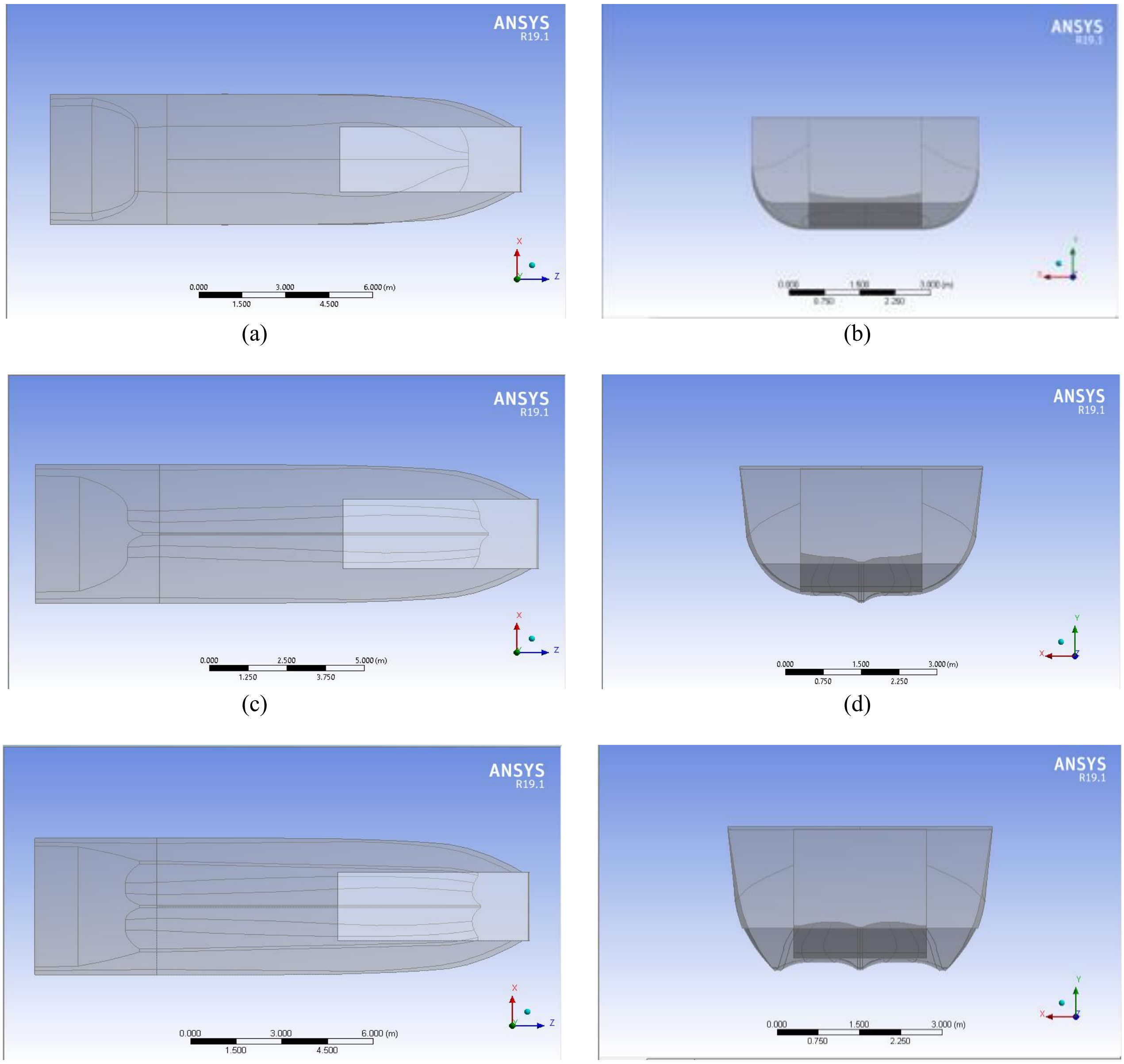


(a) (b) (c) (d) (e) (f)

Fig. 1. Monohull model: (a) round bilge top view (b) round bilge front view (c) hard chine top view (d) hard chine front view(e) monomaran top view (f) monomaran front view

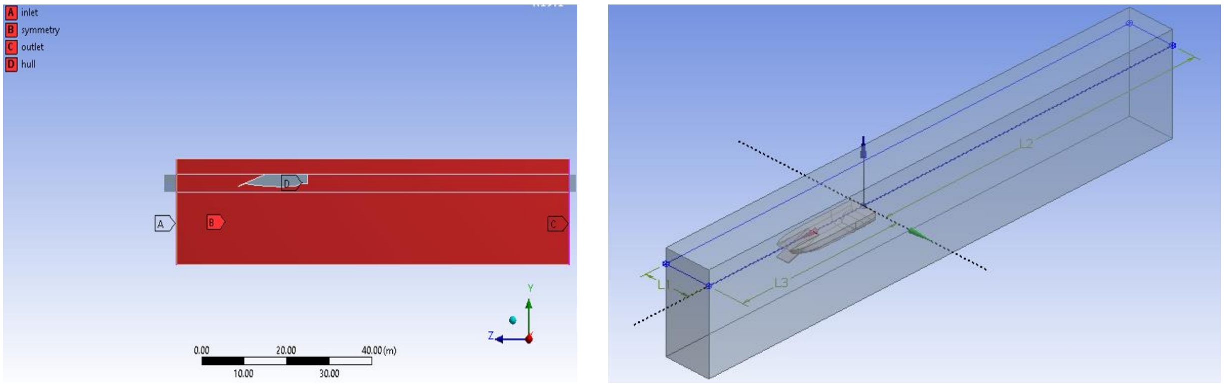
Because it is best to collect ocean waste at a speed of less than or equal to 4 knots, the maximum speed of the ocean waste ship applied is 4 knots [12]. So, speed variations used in simulation are 1 knot, 2 knots, 3 knots, and 4 knots The three monohull ship models used are hard chine type, round bilge type, and monomaran type as shown in Figure 1.

Computational fluid dynamics software used is 19.1 type. The fluid domain constructed is as shown in Figure 2. Monohull ship model is in a computational tunnel. Furthermore, object definitions are given in all domains. The 0 coordinates of X, Y, Z axes are located at the ship centerline and are at the edge stern of ship. Distance between model to side wall is 0.4L, outlet distance to model 4 is L, inlet distance to the model is 1L, distance from model to upstream is 0.2L, and distance from model to downstream is 1L. The results are as shown in Table 3.

Boundary conditions at the model are determined as non-slip conditions, while the fluid domains at the outermost part, namely top, side, and bottom, are determined as slip boundary conditions. The object declaration in the meshing process also be done before continuing the next process, the object declaration is shown in Figure 2a.

Table 3. Fluid domain geometry

Parameter	Symbol	Formula	Data (m)
Model to *side wall*	L1	0,4 L (+0.5 Bmld)	8.5724
Outlet to model	L2	4 L	61.724
Inlet to model	L3	1 L (+L)	30.862
Model to upstream	FD1	0.2 L	3.0862
Model to downstrea m	FD4	1 L (+H)	17.881



(a) (b)

Fig. 2 (a) Fluid domain (b) Monohull model: (a) object declarations in domain

Inlet is section located in fluid domain section in front of bow ship. This is used as initial location of flow entry to tunnel. Outlet is back area of model. This area is location where fluid is out of tunnel. Hull is a model object that is subjected to fluid and its location is within the tunnel. While the symmetry is the area that signifies half of tunnel modeled in this simulation.

Meshing or also called discretization in CFD process, is the process of converting continuous fluid domain into discrete computational domain so those fluid equations can be solved using numerical methods. The type of mesh used in the model and fluid is tetrahedral. The mesh size of model and around the model is smaller than that of other fluids. The results of meshing on model and fluid domain are as shown in Figure 3.

Meshing validation needs to be carried out to maintain the accuracy of meshing process, namely independent process grid, which is meshing process that is carried out several times with different sizes. This is necessary to obtain convergent results. It is not acceptable for there to be a meshing result difference of less than or greater than 5%. [13] Variations in meshing size used are five types at two different locations as shown in Table 4. This is done on a round bilge model with a speed of 2 knots. From Figure 4, it is known that the last four variations have shown convergence because the error is below 5%. The meshing size used for the next process and other models is meshing with body sizing of 0.4 and face sizing of 0.2. This error with the previous one was 1.73%.

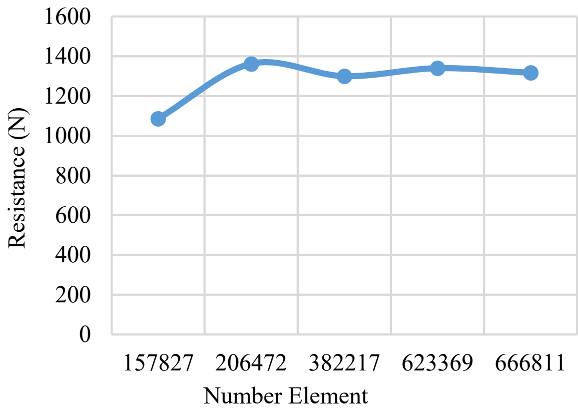
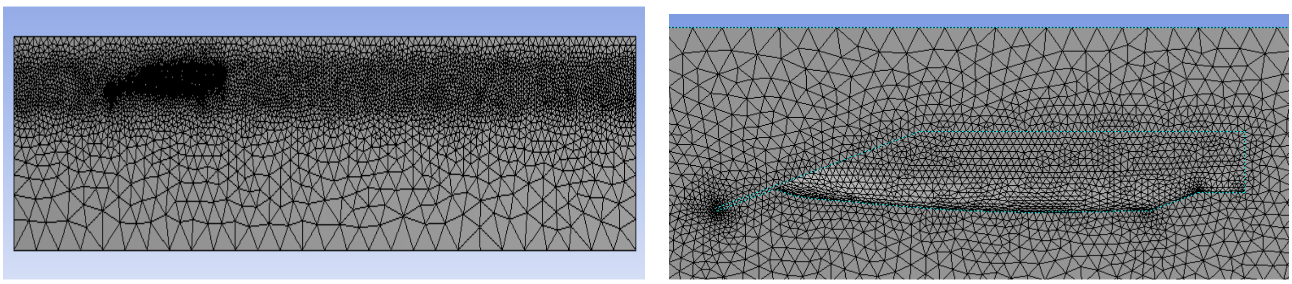


Fig. 4. Grid independent.

Table 4. Fluid domain geometry.

Velocity	**Body sizing**	**Face sizing**	**Number of Element**	**Node**	**Resistance (N)**
2 knots	0.9	0.7	157827	29450	1085.486
	0.7	0.5	206472	38187	1361.900
	0.5	0.3	382217	68960	1299.792
	0.4	0.3	623369	110817	1339.792
	0.4	0.2	666811	118925	1316.958



(a) (b)

Fig. 3. (a) Meshing in fluid domain (b) zoom in model.

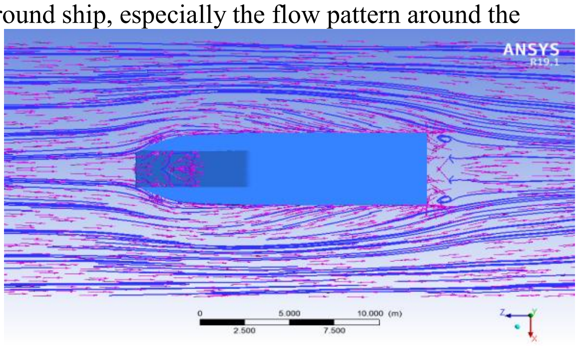
Table 5. Setting configuration.

General		Boundary conditions	
Options	Single precision	Inlet	Pressure inlet, multiphase
Processing option	parallel	Multiphase	Phase 2
Processor	3	Free surface	-1.18 m
GPU	1	Bottom level	-17.811 m
Solver-Time	Steady	Velocity magnitude	0.5144 m/s or 1 knots
Solver-Type	Pressure base		1.0288 m/s or 2 knots
Gravity	9.81 m/s^2 (Z axis)		1.5433 m/s or 3 knots
Model			2.0577 m/s or 4 knots
Viscous	k-epsilon (2 eqn), standard	Outlet	Pressure inlet, multiphase
Multiphase	Volume of fluid, open channel flow, implicit, implicit body force	Initialization	Standard initialization
		From	inlet
		Open channel	Flat
		Run calculation	
Phase 1	Air	Timescale factor	0.5
Phase 2	Water liquid	Number of iterations	200

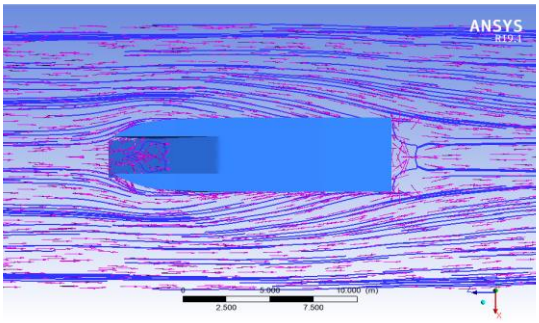
The computational settings on simulation are in form of environmental variables so that the results of the analysis can be simulated according to wanted conditions as shown in Table 5. In the setup process, many things need to be paid more attention to because they are related to determining the boundary conditions in the simulation. In this process, almost all research parameters are processed at this stage such as model condition, fluid type, cell zone conditions, boundary conditions, mesh interfaces, dynamic meshes, solution methods, solution initialization, and run calculation.

3 Results and Discussion

The fluid flow pattern is needed to see flow distribution flow around ship, especially the flow pattern around the ship's conveyor. After ocean waste is caught on the conveyor, it is collected onboard the ship. In flow pattern there is purple vector direction line, while blue line is for fluid flow on water surface that moves from inlet to outlet direction. Figure 5 is fluid flow pattern of three monohull variation models. From comparison of flow patterns at 4 knots speed, it is known that direction of flow pattern in the round bilge model and hard chine model turns towards outside of conveyor. this causes ocean waste to be difficult to collect. While monomaran model still shows straight flow pattern towards the conveyor, so that ocean waste is easier to collect.



(a)



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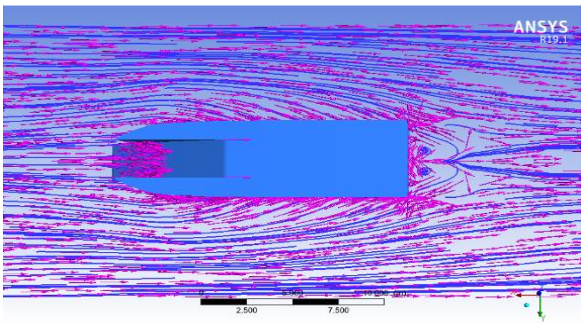
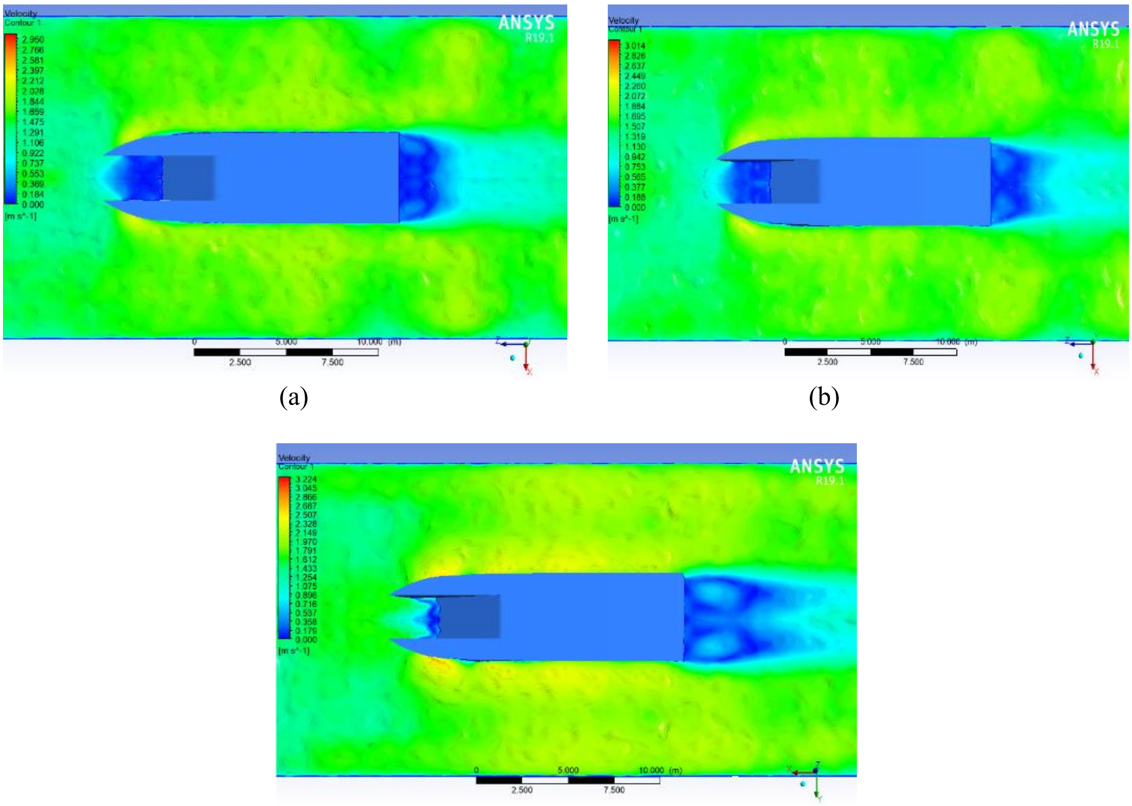


(c)

Fig. 5 Flow pattern of monohull model (a) round bilge (b) hard chine (c) monomaran



(a) (b)

(c)

Fig. 6. Velocity contour of monohull model (a) round bilge (b) hard chine (c) monomaran

In addition, from the analysis of flow patterns at bow of ship from 3 variations of the monohull model with 4 variations of speed, it shows that the most ideal speed for ocean waste collection ships is at 3 knots speed. This happens because at 4 knots speed the flow pattern turns towards the outside of the conveyor so that ocean waste is difficult to collect While at 1 knot speed the flow pattern. indicates better flow direction to the conveyor, but at this speed, it takes longer to collect marine debris, as well as for a speed of 2 knots. However, when compared to all these flow pattern analyses, monomaran model still has good flow distribution compared to others for easy ocean waste to collect on the conveyor compared to other models at all speeds.

Velocity contour is used to determine flow velocity around the ship's hull, especially around conveyors of ocean waste collection vessels. Color of contour shows the flow velocity, the highest flow velocity up to the lowest is red, yellow, green, and blue, respectively. Figure 6 shows speed contour model of three variations of monohull around the conveyor at 4 knots. Monomaran model has flow rate of 1.0716 m/s around the conveyor, hard chine model has flow rate of 0.565 m/s around the conveyor, and round bilge model has flow rate of 0.553 around the conveyor. From comparing these 3 models, it is known that the fastest in collecting ocean waste s to the conveyor are monomaran, hard chine, and round bilge, respectively. This is because ocean waste moves with the flow. In addition, when the speed is 1 to 2 knots, three variations of model still have same relative flow velocity of 0.1 m/s around the conveyor. However, at a 3 knots speed, it can see difference in speed around the conveyor. Monomaran model is 0.773 m/s while round bilge model and hardchine model are 0.16 m/s. This also makes monomaran model the fastest in collecting ocean waste.

Resistance forces of three monohull models at 4-speed variations are as shown in Table 6. From comparing results of the three models, it is known that the resistance forces from smallest to largest are round bilge model, hard chine model, and monomaran model, respectively. This resistance force will affect the ship's power calculation. Then it will affect the selection of ship's main engine. The next most important effect is fuel consumption and operational costs of garbage collection ships. Validation of the results is carried out in ways by comparing type of flow generated behind the three models. Figure 5 It shows that the turbulent flow behind three monohull models correlates with the Reynolds number. [14] .

Table 6. Resistamce force of monohull model

Velocity	Round bilge resistance (N)	Hard chine resistance (N)	Monomaran resistance (N)
1 knot	349.94	362.292	3.620.586
2 knot	847.554	1.318.224	1.316.958
3 knot	2924.96	3450.04	3181.36
4 knot	5909.38	6122.44	6206

4 Conclusions

The effect of three variations in shape of monohull hull was investigated by CFD analysis. The results show that direction of flow pattern in round bilge model and hard chine model turns towards outside of the conveyor, this causes ocean waste to be difficult to collect, while monomaran model still shows straight flow pattern towards the conveyor, so that ocean waste is easier to collect. Furthermore, from comparing the velocity contours of the three models, it is known that the fastest in collecting ocean waste s to the conveyor is monomaran, hard chine, and round bilge, respectively. Meanwhile, from the resistance force analysis of the three models, it is known that resistance forces from smallest to largest are round bilge model, hard chine model, and monomaran model, respectively.

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References

1. S. Miyagi et al., “Human footprint in the abyss: 30 year records of deep-sea plastic debris,” Marine. Policy, vol. 96, no. April, pp. 204–212, 2018.
2. M. Bergmann, M. B. Tekman, and L.Gutow, “Marine litter: Sea change for plastic pollution,” Nature, vol. 544, no. 7650, pp. 297–297, 2017.
3. USA EPA, “A Learning Guide on Marine Debris,” 2007.
4. UNEP, Marine Litter Vital Graphics. United Nations Environment Programme and GRID-Arendal. Nairobi and Arendal. www.unep.org, www.grida.no. 2016.
5. O. Hoegh-Guldberg et al., “2014: The Ocean,” Clim. Chang. 2014 Impacts, Adapt. Vulnerability. Part B Reg. Asp. Contrib. Work. Gr. II to Fifth Assess. Rep. Intergov. Panel Clim. Chang., pp. 1655–1732, 2014.
6. World Bank Group, “Hotspot Sampah Laut Indonesia,” Public Discl. Auth., no. April, pp. 1–49, 2018.
7. Sugianto E., Chen J. H, “Ships for Waste Management in Indonesian Seas: Contexts and Challenges,” in 12th International Indonesia Forum Conference: Rising to the Occasion: Indonesian Creativity, Ingenuity, and Innovation in a World in Transition, 2020, pp. 67–90.
8. Sugianto E., Chen J. H, “Preliminary Concept of Ship Use to Waste Management in Sea Shallow Water,” in 33th Asian-Pacific Technical Exchange and Advisory Meetings on Marine Structures (TEAM 2020), 2019, p. S-27.
9. Sugianto E., Chen J. H, “‘Buy Marine Debris ’: A Digital Platform for Sustainable Marine Debris Management Involving Fishermen,” vol. 3, no. 1, pp. 36–48, 2021.
10. G. Arena and V. Farinetti, “Introducing Eurofast.,” no. 26433, pp. 1–13, 2013.
11. Dorner MFG Corp, “Full Specification Dorner Aquapruf Aquagard,” 2009.
12. A. G. Pramoko and H. A. Kurniawati, “Studi Perancangan Trash-Skimmer Boat di Perairan Teluk Jakarta,” vol. 2, no. 1, 2013.
13. J. D. Anderson and T. J. Chung, Computational fluid dynamics, second edition, vol. 9780521769. 2010.
14. USNA, “Resistance and powering of ships,” Resist. powering ships, p. 12, 2002.
15. Sugianto E., Winarno A., Indriyani R. and Chen J. H. Hull Number Effect in Ship Using Conveyor on Ocean Waste Collection Kapal: Journal of Marine Science and Technology 18 129-142 , 2021. https://doi.org/10.14710/kapal.v0i0.40744
16. Sugianto E., Chen J. H. and Purba N. P. Numerical investigation of conveyor wing shape type effect on ocean waste collection behavior E3S Web of Conferences 324 01005 . 2021. https://doi.org/10.1051/e3sconf/202132401005
17. Sugianto E., Chen J. H. and Purba N. P “Cleaning technology for marine debris: a review of current status and evaluation,” Int. J. Environ. Sci. Technology 2022. doi:10.1007/s13762-022-04373-8.
18. Sugianto E., Chen J. H. and Purba N. P “Effect of Monohull Type and Catamaran Hull Type on Ocean Waste Collection Behavior Using OpenFOAM,” Water, 14 (17), 2623 , 2022 https://doi.org/10.3390/w14172623
19. Sugianto E., Chen J. H. 2022 Experimental Study of the Effect of a Solid Wing Conveyor on Marine Debris Collection, Journal of Marine Science and Technology https://doi.org/10.51400/2709-6998.2584
20. Sugianto E., Chen J. H. Hollow Wing Technique to Enhancing Conveyor Performance on Marine Debris Collection, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, **9** (4) 2022
21. Sugianto E., Chen J. H, Sugiono R, Prasutiyon H 2022 Effect of portable conveyor placement in ship on ocean waste collection behavior, IOP Conf. Ser.: Earth Environ. Sci. 1095 012015. doi:10.1088/1755-1315/1095/1/012015