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NUMERICAL APPROACH FOR THE TRADITIONAL FISHING VESSEL ANALYSIS OF RESISTANCE BY CFD

ALDIAS BAHATMAKA, DONG-JOON KIM*

Interdisciplinary Program of Marine Convergence Design, Pukyong National University,
45-Yongso-ro, Busan Nam-Gu, Daeyon 3-Dong, 48513, Busan, South Korea
*Corresponding Author: djkim@pknu.ac.kr

Abstract

This paper presents the numerical investigation of ship resistance of Indonesian traditional fishing vessel. The open-source Computational Fluid Dynamics (CFD) library, OpenFOAM, was used to predict three dimensional, incompressible, unsteady RANS equations for the ship resistance. The volume of fluid (VOF) method is used to predict the resistance. InterFoam solver is adopted to solve the computational problem. The KCS model was calculated and compared to the experimental result for validating the solver and relatively good agreement is achieved, therefore, can be used to simulate the present model. The present model was using Indonesian traditional fishing vessel from the north and south coastal of Java island. The water condition in this study is in calm water condition and the same Froude number (F_n) for both models. As endic result, the model was presented for preliminary resistance prediction in advance of the evaluation for the traditional fishing vessel performances.

Keywords: CFD, InterFOAM, OpenFOAM, Resistance, Traditional fishing vessel, VOF.

1. Introduction

Determining ship resistance is important for ship designer. The use of numerical simulation is needed for predicting the ship resistance. CFD method was based on the potential flow theory, which used the Navier-Stokes equations was difficult to solve, then the problem can be solved by Reynolds-Average Navier-Stokes (RANS) equations to compute the simulation for ship resistance. The traditional fishing vessel is one of transportation and livelihood support in Indonesia. The vessel was made based on generation to generation. Thus, the traditional fishing vessel design in each island is different.

Many studies on the ship resistances have been conducted, especially for the numerical analysis [1-4]. Another approach is to reduce the resistance with active methods as shot for the air under the hull [5]. Some studies investigate the free surface flow around at different Froude number by CFD [6].

The common of numerical models for predicting the ship resistance performance in preliminary step is using CFD method. CFD is computational fluid dynamics. The recent development in computing technology has still problems to solve because of the license of the software. The Open-source of CFD is one of the solutions in engineering problems, especially in CFD problems. OpenFOAM (Open Field Operation and Manipulation) CFD provides solver, which can be used to predict the CFD approach and can be compared with the experimental result and other commercial software.

In this research, the open source used for simulating the ship resistance. The CFD software with the use of finite volume methods, in this type is useful tools are the open-source program to reduce the costs. This study open-source software is used to predict the free-surface flow. Axner et al. [7] commented that, InterFoam is one of the basic application solvers from OpenFOAM was used. For proofing numerical analysis in comparing the experiments, results have been discussed for the planning hull [8] and using KCS model for validating the simulation was conducted [9].

2. Model Description and Numerical Methods

The research used 3600 KRISO Container Ship (KCS) in Fig. 1 is drawing by the Korea Research Institute of Sea and Ocean Engineering (KRISO). The KCS or KRISO Ship Container used in the model experiment. Table 1 lists of the particulars of the KCS. As listed in Table 2, the case set up of the simulation conditions include calm water and used interFoam to solve the resistance simulation. This solver is multiphase flow, which used the Volume of Fluid (VOF) method to solve the free surface for the incompressible flow.

The KCS model was scaled to 31.59 from the real size. The simulation conditions in calm water. This model calculated in OpenFOAM and used interFoam solver to predict the resistance. The computational domain was built as the rectangular block around the hull in the deep water with space coordinate range is determined as -2 L ~ 5 L in *X* direction 2.5 L in *Y* direction, and -0.5 L ~ 3 L in *Z* direction, where L denotes the ship length. According to Seo et al. [11], the domain grid and boundary conditions were created in OpenFoam, which can be seen in Fig. 2, and the mesh is solved by snappyHexMesh, the mesh strategies of OpenFoam.

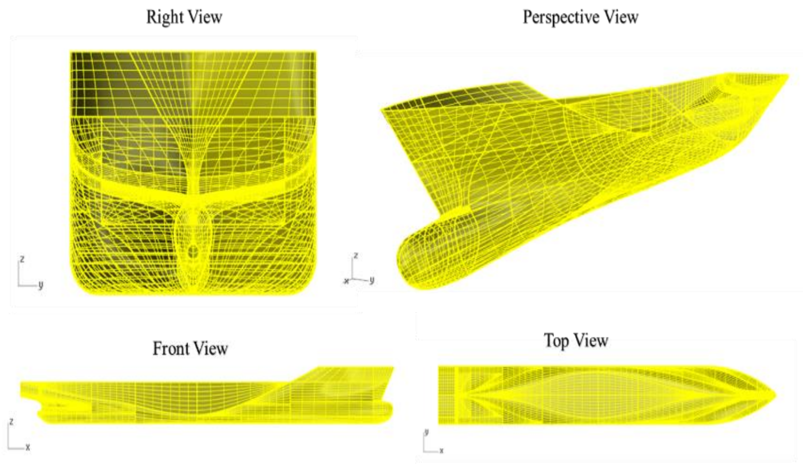


Fig. 1. KCS hull model [10].

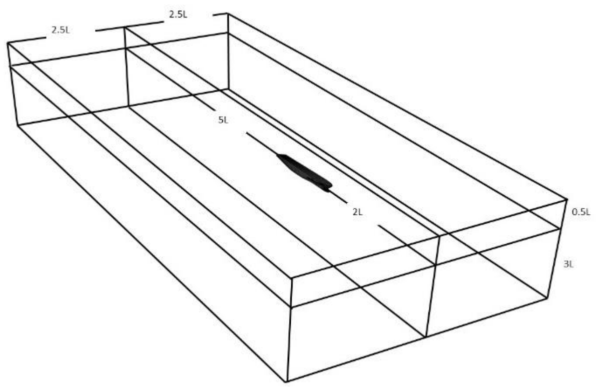


Fig. 2. Domain grid and boundary condition in OpenFOAM.

Table 1. Principal particulars of model scale KCS.

	Symbol	Unit	Real ship	Model
Length between perpendiculars	L_{pp}	m	230.00	7.28
Length of waterline	L_{wl}	m	232.50	7.36
Breadth	B	m	32.20	1.02
Depth	D	m	19.00	0.57
Draft	T	m	10.80	0.34
Scale ratio	λ		31.59	31.59
Block coefficient	Cb		0.6508	0.6508

Table 2. Case set up of simulation condition.

	Symbol	Unit	Set-up
Solver			InterFoam
Velocity	U	m/s	2.196
Start time	T_1	s	0
End time	T_2	s	5000
Delta *T*	Δt	s	0.455
Froude number	F_n		0.26

2.1. Governing equations

In the simulations of the unsteady incompressible viscous flow field, the Reynolds-Average Navier-Sokes (RANS) equations are adopted in this present study as governing equations. The equation of continuity and momentum equation can be written as:

$$\nabla . U = 0 \tag{1}$$

$$\frac{\partial \rho U}{\partial t} + \nabla . \left[\rho\left(U - U_g\right)U\right] = -\nabla p_d - g.x\nabla\rho = \nabla . \left(\mu_{eff}\nabla U\right) + (\nabla U).\nabla\mu_{eff} + f_{\partial +} f_s \tag{2}$$

where U stands for the velocity field while U_g means velocity of mesh points, p_d is dynamic pressure, whose value is equal to total pressure subtracting hydrostatic component, ρ is the mixed density of the two phases, g is gravitational acceleration, μ_{eff} is the effective dynamic viscosity computed by $\rho(V - V_t)$, V is kinematic viscosity coefficient and V_t is eddy viscosity, f_∂ is surface tension term, which impacts the free surface. According to Zha et al. [12], to protect the flow field from the interface of echo waves, the source term f_s is added to generate a sponge layer to absorb the generate wave.

The VOF method is used to solve the simulation with artificial bounded compression technique and simulate the free surface. The VOF transport equation is formulated as follows:

$$\frac{\partial \rho U}{\partial t} + \nabla . \left[\rho\left(U - U_g\right)\alpha\right] + \nabla . \left[U_r(1-\alpha)\alpha\right] = 0 \tag{3}$$

where α represents the volume of a fraction, the relative proportion of the two-phase fluid, α is used to distinguish the fluid of two phases [13].

In resistance simulation for the KCS model, the main dimensional parameters in the flow around the hulls are Froude number (F_n) and the Reynolds number (R_n) [14] expressed as:

$$F_n = \frac{V}{\sqrt{gL}} \tag{4}$$

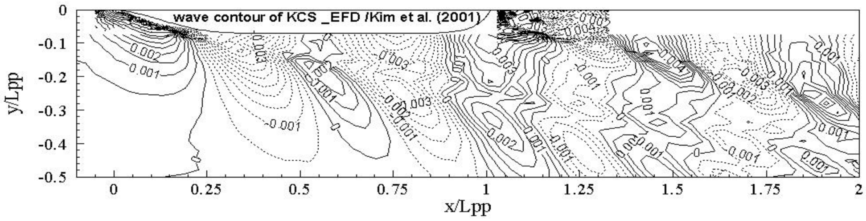
$$R_n = \frac{VL}{v} \tag{5}$$

where F_n is the Froude number V is the ship speed, g is the gravity, L is the longitudinal of perpthe endicular from the ship, which has relation with R_n is the Reynolds number, v is the kinematic viscosity.

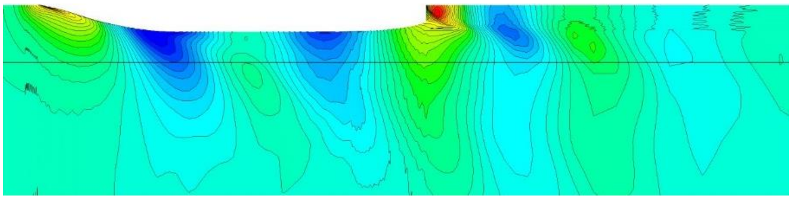
2.2. Validation of solver with experiment result

This study compared the result from numerical calculation to the experimental result. Kim et al. [15] commented that the Experimental Fluid Dynamic (EFD) data of KRISO Container Ship (KSC) were obtained through towing tank test and used for the validating the CFD simulations. For the numerical calculation used interFoam solver to solve the problem of resistance to measuring the parameters and continuing the research. For the simulation of KCS resistance model, the initial mesh created consisted of 0.8 M elements and increased to 7 M elements and 10 M elements. The wave pattern captured for all meshes from coarse, medium and fine mesh and the comparison made to the experimental data, it can be seen in Fig. 3. The increased mesh has a significant impact on the experimental. And for wave elevation on the surface of the hull can be seen in Fig. 4. This provides the wave height seen along the surface and fixed distance away and gap position between experiment results.

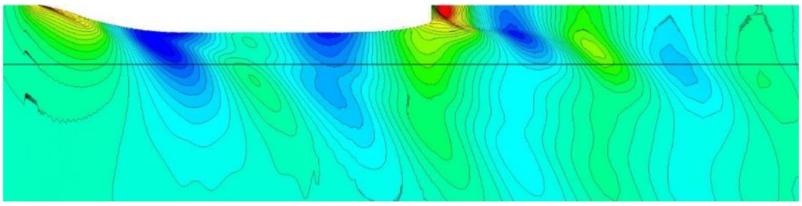
As the listed in Table 3, the grid convergence study for the coefficient of total hull resistance (C_T) of the numerical is slightly different from the experimental result. It can be seen that all the CFD data agree well with experimental data. The Fine mesh calculated value of 3.41 and less 4% than experimental data. It means the validation reach is satisfied. From this validation, we used the parameter to analysis the north and south fishing vessel design for the hull resistance.



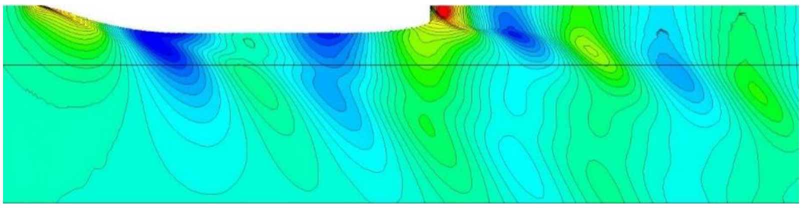
(a) Wave pattern for experimental data.



(b) Numerical result for coarse mesh 0.8 M.



(c) Numerical result for medium mesh 7 M.



(d) Numerical result for fine mesh 10 M.

Fig. 3. Comparison wave pattern for all meshes and experimental data.

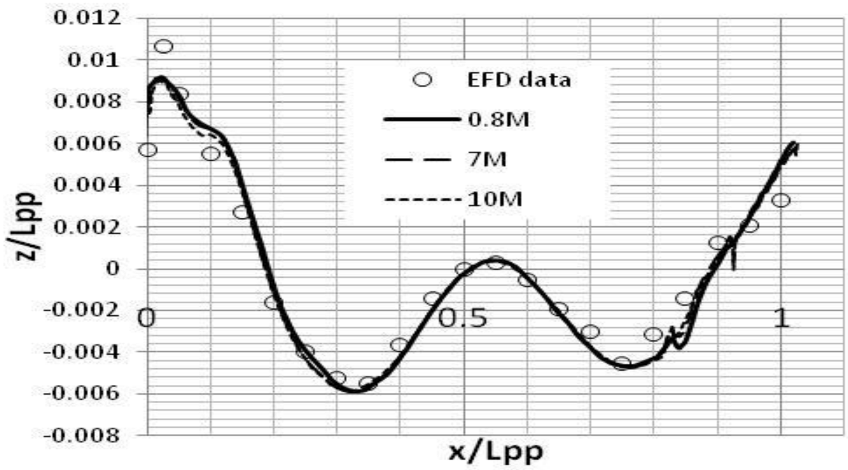


Fig. 4. Comparison experimental and CFD wave elevation on the free surface of hull.

Table 3. Comparison of resistant result.

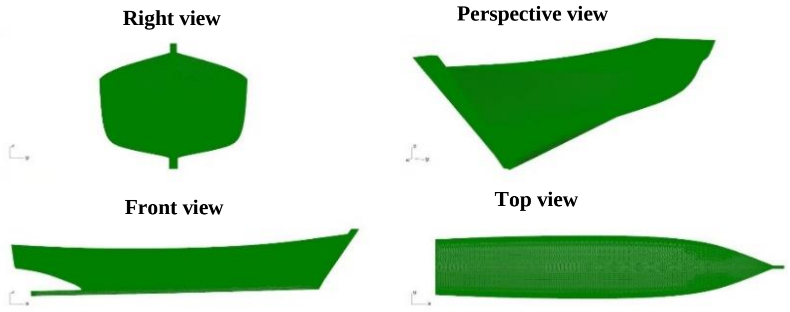
Mesh size	C_T CFD×10^{-3}	C_T EFD×10^{-3}	Error %
0.8 M (coarse)	3.81	3.55	7.32
7 M (medium)	3.75	3.55	5.63
10 M (fine)	3.41	3.55	3.94

2.3. Traditional fishing vessel

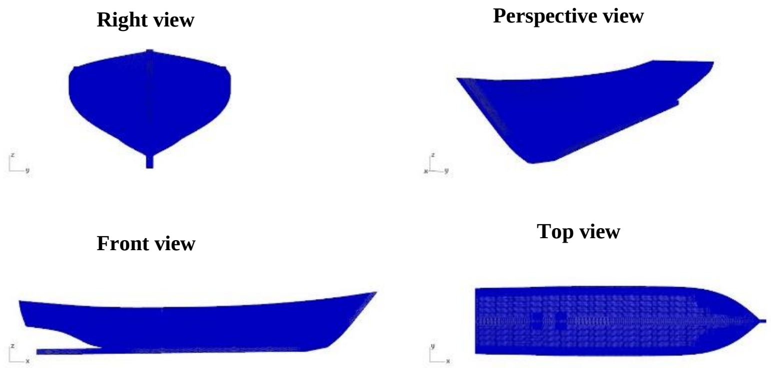
The traditional fishing vessel of the present study was mono-hull designed by Indonesian Shipyard for the north and south coastal of Java Island. The detailed design can be found from Figs. A-1 and A-2 (*Appendix A*) as lines plan of the north and south coastal. According to Bate [16], the deadrise angle effects to the resistance performance. In this study, the difference between the north and south coastal design is in the ratio of L/B or deadrise angle. The ratio of *L*/*B* for the north is bigger than the south. It means the deadrise angle for the north is smaller than the south. It can be seen in Fig. 5. This shows the different design between the north and the south coastal. Table 4 shows the principal dimension of the models.

Table 4. Principal dimensions of traditional Indonesian fishing vessel.

	Symbols	Unit	Designs	
			North	South
Length over all	*LOA*	m	17.65	20.00
Length waterline	*L*	m	15.75	18.09
Breadth	*B*	m	4.00	4.80
Depth	*H*	m	2.50	1.80
Draft	*T*	m	1.75	1.20
Gross tonnage	*Gt*	ton	30.00	30.00
Speed	V_s	kts	10.00	10.00
Block coefficient	*Cb*		0.36	0.30
L*/*B			3.93	3.76



(a) North coastal design.



b) South coastal design.

Fig. 5. 3D model for the north and south coastal.

3. Numerical Results

The traditional Indonesian fishing vessel for the north and south coastal design was performed in this research. The hydrodynamic analysis of the traditional fishing vessel was conducted in OpenFOAM with the interFoam solver. The results of the ship resistance for scale model can be compared between the north and the south coastal design as shown in Table 5.

The present study, OpenFOAM produced the difference wave pattern of both the designs. As seen in Fig. 6, the resistance result shows there is a gap of wave pattern between the north and south coastal design. The south coastal design rises slowly as the Froude number increases, while the north design rises drastically at the Froude number 0.4 to 0.6 and it makes the north coastal design has stronger wave pattern than the south design. It can be seen in Figs. 7 and 8, which show the difference wave pattern in post processing resistance simulation of OpenFOAM for both designs.

Based from studies by Kristensen and Lutzen [17], from the reference, resistance has effects to the power consumption of the ship. The greater value of ship resistance will be the greater power requirement of the vessel and automatically the fuel consumption is also greater. In this study, the north coastal design has greater resistance, it means the north design also has greater power requirement and fuel consumption.

Table 5. Resistance result for scale model.

Froude number (F_n)	Velocity of models (m/s)	North coastal resistance (N)
0.20	1.11	5.23
0.40	2.22	48.90
0.60	3.33	203.00
0.80	4.45	262.00

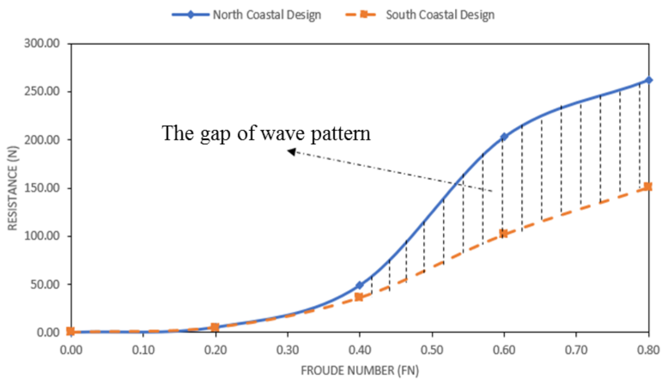


Fig. 6. Resistance result.

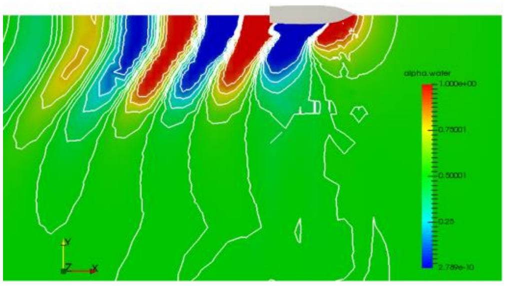


Fig. 7. Post processing of north coastal resistance simulation in OpenFoam.

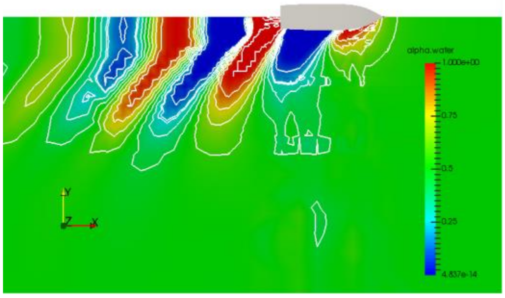


Fig. 8. Post processing of south coastal resistance simulation in OpenFoam.

4. Conclusions

In this research, numerical analysis of the traditional Indonesian fishing vessel was performed using the open-source CFD software OpenFOAM. The simulation was performed by the interFOAM solver to analysis the resistance performance. The validation of the simulation was compared with the experimental result using the KCS model. The results were in good achievement, thus, the boundary setting could be used in the traditional fishing vessel simulation. Due to the result, the north coastal design has greater resistance than the south coastal design for the calm water conditions. It happened caused by the hull-form of the south coastal design has larger deadrise angle than the north coastal design and it fits the theory. For the future research, will conduct the strategy to minimize the resistance of the fishing vessel, modify the design using several parameters and development the CFD analysis to reduce the time and get the best performance of the ships.

Nomenclatures

B	Breadth, m
C_b	Block coefficient
C_p	Prismatic coefficient
C_T	Total resistance coefficient
D	Depth, m
F_n	Froude number
G_T	Gross tonnage, ton
g	Gravity, m/s^2
L_{OA}	Length of overall, m
L_{PP}	Length between perpendiculars, m
L_{wl}	Length of waterline, m
R_n	Reynolds number
T	Draft, m
T_1	Start time, s
T_2	End time, s
U	Velocity, m/s
V_s	Speed, m/s

Greek Symbols

Δt	Delta time, s
λ	Scale ratio
ρ	Density, kg/m^3

Abbreviations

CFD	Computational Fluid Dynamic
EFD	Experimental Fluid Dynamic
KCS	KRISO Container Ship
KRISO	Korea Research Institute of Sea and Ocean Engineering
OpenFOAM	Open source Field Operation and Manipulation
RANS	Reynolds-Average Navier-Stokes
VOF	Volume of Fluid

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Appendix A

Lines Plan of Fishing Vessel

In the present study, we used lines plan to make 3D model. The detail lines plan can be seen in Fig. A-1 for the north coastal design and Fig. A-2 for the south coastal design.

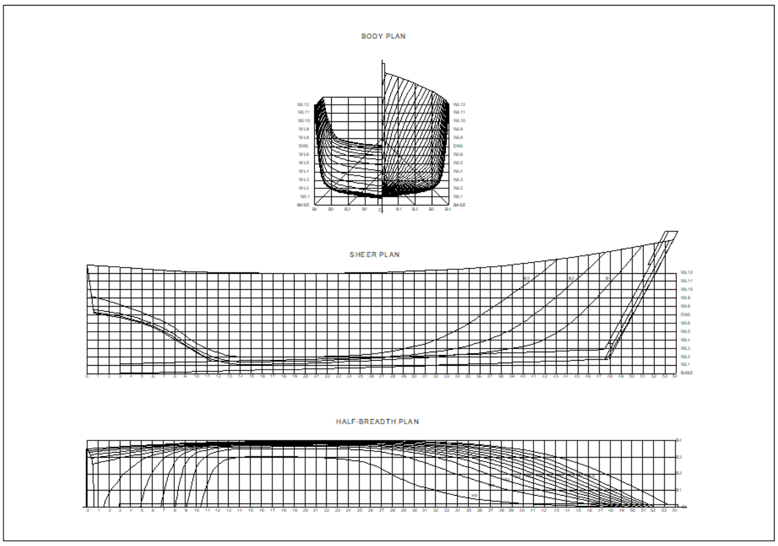

Fig. A-1. Lines plan of north coastal design.

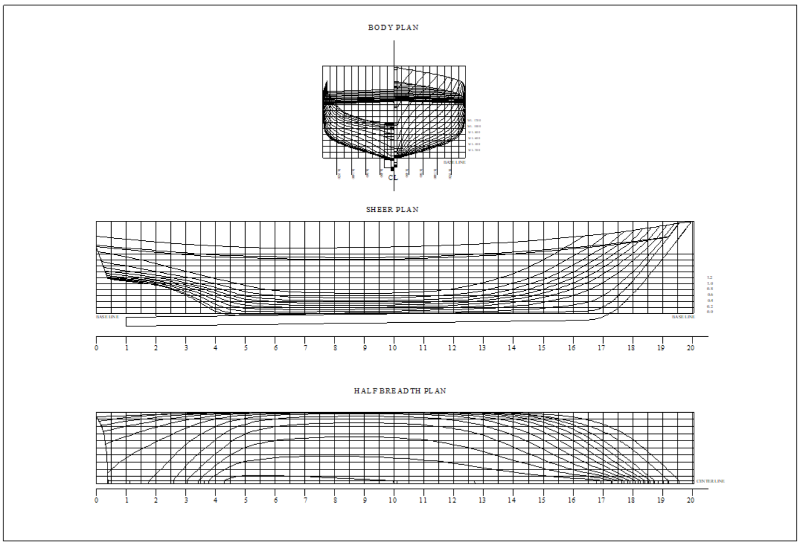

Fig. A-2. Lines plan of south coastal design.