*Fishery Technology* 59 (2022) : 132 - 139

# A Study on the Influence of Bulbous bow on the Resistance of Fishing Vessel Hull form Using CFD Analysis

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## Abstract

Bulbous bow forms have a significant effect on the ship resistance components and are today an integral part of many ship designs. The hydrodynamic effect of the bulbous bow is based on the change of flow distribution around the bow, creating waves that interfere with the waves created by the hull, improving the flow around the bow. A properly designed bulb affects nearly all the hydrodynamic properties of the ship. The advancements in structural hydrodynamics is limited in Indian fishing industry and mechanised fishing vessels are not fitted with bulbous bows. This study illustrates the influence of bulbous bow on the resistance of fishing vessels. Computational Fluid Dynamics (CFD) analysis was used for optimisation of ship hull forms, full-scale predictions, and to appraise physical effects of bulbous bow. Geometrical 3D modelling of three reference hull forms namely conventional hull form, hull form with oval type bulbous bow and hull form with Nabla type bulbous bow created using Maxsurf software was chosen to perform test cases to evaluate the influence. Experimental data of three reference hull forms were collected for validation with results of CFD software. The CFD numerical setup stages were illustrated to estimate resistance components such as viscous resistance and wave making resistance. The mesh independency study of hull models were created with results of previous numerical studies. The comparison between the reference hull models and bulbous bow models show the amount of reduction in wave making resistance due to fitting of bulbous bow. The Nabla type hull form gave 14.99% reduction in drag compared to the conventional hull form.

Received 26 August 2021; Revised 09 February 2022; Accepted 03 April 2022

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**Keywords:** Bulbous bow, fishing vessels, carbon emissions, CFD analysis

## Introduction

According to FAO (2020) the total number of fishing vessels in the world in 2018 has been estimated at 4.6 million of which 64% were engine-powered. The fishing fleet in Asia was the largest, consisting of 3.1 million vessels accounting for 68% of the global fleet, followed by Africa (nearly 20%), Americas has (10%), and Europe (2%) and Oceanea's share is less than 1%. In 2016 India had about 1, 66,333 fishing vessels (CMFRI, 2016) among which 84% use fossil fuels for propulsion and fishing, and is a case of concern considering GHG emission. As the fishing industry uses 1% of the total fossil fuel consumed in the country. This implies that 1.03 kg of $CO_2$ is emitted for every kg of wet fish landed in the marine sector. Design of fishing vessel has a vital role in ensuring fuel efficiency. Optimization of hull forms for minimum resistance is the most effective and logical way to reduce the drag force which can increase fuel efficiency and reducing carbon emissions and considerable saving in expenditure of fishing operations. (Abramowski et al., 2010); Szelangiewicz & Abramowski, 2009; Schneekluth & Bertram, 1998; Park et al., 2015, Blanchard et al. (2013) studied the usefulness of a bulbous bow in a fishing vessel for drag reduction using an automated shape optimization procedure and hydrodynamic simulations. Today the bulbous bow is a normal part of a modern sea going vessel. As model experiments reveal, a ship fitted with bulbous bow requires far less propulsive power because of reduction in resistance and has increased cruise speeds, which gives an overall reduction in fuel consumption.

Generally, a bulbous bow is constructed to reduce wave resistance because the bulbous shape is proven to attenuate the bow wave system. Additionally, the bulbous bow also tends to reduce viscous resistance. When the flow around the body is smooth, the total resistance can be reduced significantly which can be achieved if an optimum bulbous bow is integrated in the hull. The superposition of bulbous bow wave and ship front wave can form favourable interference, which can reduce the wave resistance effectively. Therefore, a suitable bulbous bow can improve speed to achieve better economic benefits.

In recent years, with the continuous upgrading of computer hardware, computational fluid dynamic (CFD) has also seen rapid development. CFD has become an important auxiliary tool to optimize ship design and shorten the period of performance forecast. Picot et al (2012) could achieve a significant reduction of around 33% of the ship resistance, from the initial shape without a bulbous bow to the final shape with a bulbous bow at constant overall length for an optimized mono hull fishing vessel. Fore body optimization of a fishing vessel operation at relatively high Froude number by a combination of a computational hull resistance/flow analysis and optimization technique was carried out by Sampson et al. (2005). Fishing vessel hull design and towing resistance calculation by the CFD methods was carried out by Sugalski (2014).

Thus study was undertaken to design an energy efficient hull for combination fishing vessel through a 3 step process of parent ship analysis, simulation using CFD software and model testing. The reduction in drag for the new design was compared with that of a conventional hull of a similar sized fishing vessel which was estimated using CFD. The work was carried out under a project that aimed to develop a green marine fishing vessel.

## Materials and Methods

An all India baseline technical survey of marine mechanised fishing vessel was carried out during October 2012 to September 2013, for the creation of a comprehensive database and published by Edwin et al. (2014) and Baiju et al. (2017). The fishing harbours and landing canters in 41 locations along the maritime states of India and the islands of Andaman & Nicobar and Lakshadweep were selected for survey. The survey and documentation of fishing vessel designs was done as per FAO standards (Fyson, 1986). Data on vessels, engines and operation were collected from fishermen, vessel builders and vessel operators supported by secondary data from state departments, fishermen cooperative societies and log books which are maintained onboard fishing vessels (Edwin et al., 2014).

By analyzing the designs of popular commercial fishing vessels collected during the survey, the basic design drawing of a new fishing vessel was developed. The design was refined and finalised through stakeholder consultations. Stakeholder meetings were conducted at Goa, Kochi, Mangalore, and Chennai. The preliminary of lines plan of fishing vessel was created using integrated naval architecture software tools 'Autoship' and 'Maxsurf'.

Navier- Stokes equation was used to calculate hull resistance of a moving vessel. In the case of turbulent flow the Navier-stokes equation can't be applied. So a modified form of Navier-stokes equation called Reynolds-Averaged Navier-Stokes Equation (RANSE) was used (Alfonci, 2009).

Pressure and velocity field of the hull has been estimated using RANSE method as follows.

$$\frac{\partial V_i}{\partial t} + \frac{\partial V_i V_j}{\partial x_j} = F_i + \frac{1\partial \tau_{ij}}{\rho \partial x_i}$$

Where:

$i,j$ = 1,2,3

$\tau_{ij}$ = Turbulent stress tensor

$V_{ij}$ = Components of main velocity vector

$F_i$ = Components of mass force

$\rho$ = Fluid density

$\mu$ = Dynamic viscosity; t - time

Fixing boundary conditions is an important step before starting a mathematical modeling. The boundary conditions in this case allows the flow to enter and exit the solution domain. The geometry is refined and appropriate boundary conditions are provided to solve RANS equations. Grid generations were done with the help of Star CCM+ software simulation.

To visualize and optimize the initial design a 3D model of a conventional fishing vessel hull was created in Maxsurf 3D modelling software with prefixed dimensions. The Maxsurf software generated 3D model was then simulated in CFD software Star CCM+ to find out the drag. Star CCM+ software calculates the total force on the surface; normal and tangential forces, i.e., pressure and friction (shear) forces.

The force on a surface is computed as:

$$f = \sum_{f} (f_f^{pressure} + f_f^{pshear}).n_f$$

Where $f_f^{pressure}$ and $f_f^{pshear}$ are the pressure and shear force vectors on the surface face, f and $n_f$ is a user-specified direction vector that indicates the direction in which the force should be computed.

## Results and Discussion

Lines plan, general arrangement, relevant technical specifications of 34 most common fishing vessels including trawlers, purse seiners, gillnetters and long liners were documented from the data collected from the preliminary survey. The percentage wise representation of principal dimensions such as length, depth and breadth of different fishing vessels operating in the Indian coastline is shown Fig. 1. About 54.31% hull forms were in the $L_{OA}$ of 15-18 m, in breadth wise 40% 6 m breadth and around 37% had 2.40 – 2.83 m depth.

By analyzing the designs of popular commercial fishing vessels collected during all India baseline survey, collective proposals that came in from the stakeholder meeting and based on regulations for registration of fishing vessels (Director General of Shipping Circular No.NT (6) 2000-1dated 02.11.2014), the length of the new vessel was fixed to 19.75 m. Length/Breadth and Length/Depth range for the vessel was selected from the highest percentage interval of the respective ratios. (Fig. 2)

The dimension of the proposed fishing vessel hull was estimated as:

Table 1. L/B and L/D ratios

| Ratio | Highest percentage in Interval | Average (Range) |
|---|---|---|
| L/B | 3 – 3.58 | 3.25 |
| L/D | 6.60 – 7.37 | 6.985 |

L = Length, B = Breadth, D = Depth

Table 2. Estimation of Breadth and Depth

| Estimation of breadth of vessel | Estimation of Depth of vessel |
|---|---|
| L = 19.75 m | L = 19.75 m |
| L/B = 3.25 | L/D = 6.985 |
| B = 6.07 m | D = 2.8 m |

Length ($L_{OA}$) = 19.75 m

Breadth = 6.50 m ( for better deck area for equipment)

Depth = 2.80 m

Using the above dimensions, the fishing vessel hull form was generated in MAXSURF and Autoship

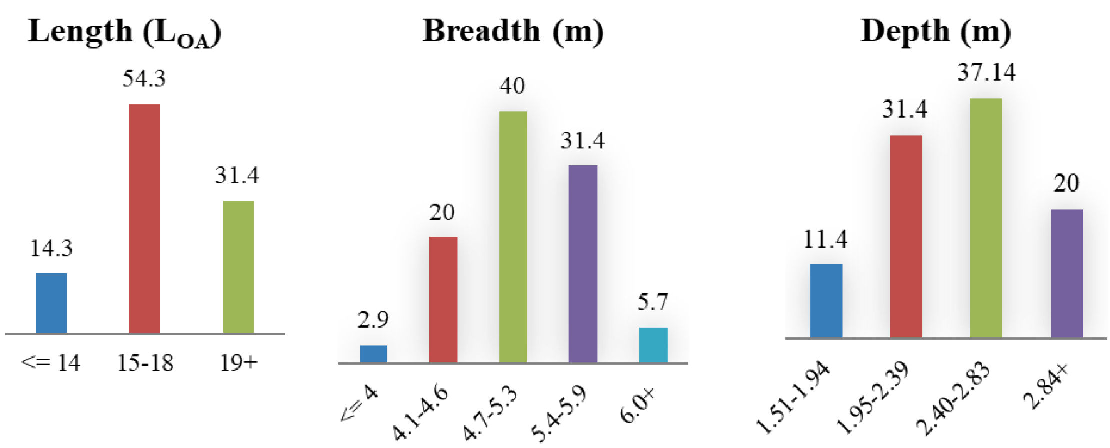



Fig. 1. Percentage wise representation of Length, Breadth, and Depth of fishing vessels in India.

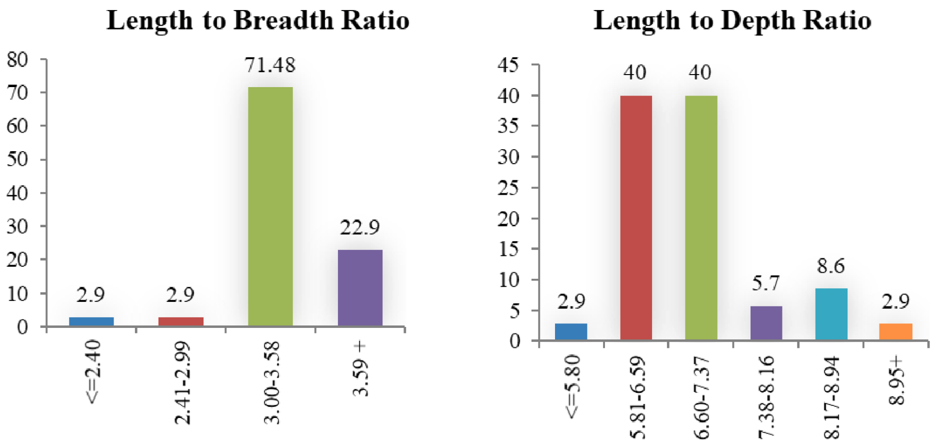



Fig. 2. Parameters considered for hull design

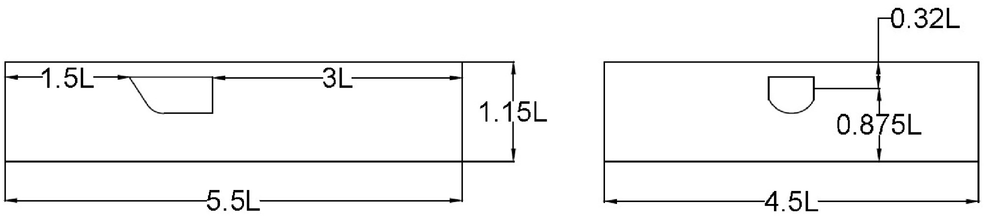



Fig. 3. Domain selected for the simulation analysis (L= Ship length)

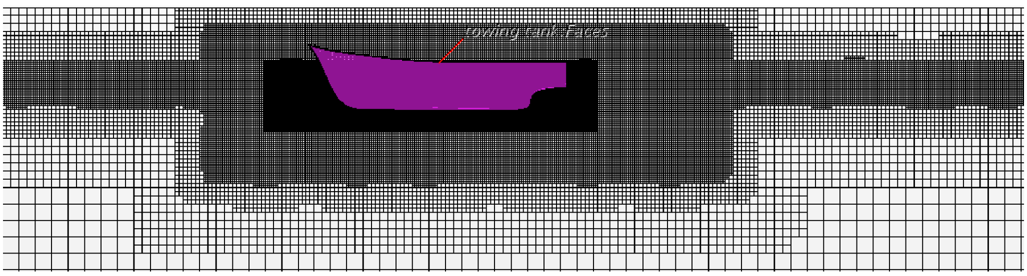


Fig. 4. Surface mesh generation in Domain

software. When solving the Navier-Stokes equation, appropriate initial conditions and boundary conditions need to be defined. The extreme ends of the grid are made far from geometry to avoid the influence of boundary conditon on solutions (Sugalski, 2014). The surfaces of the rectangular prism, which defines boundaries in the computational domain, are named Inlet, Outlet, Top, Bottom, Symmetry and Side. The surfaces, which represent the ship form, is the Hull.

The domain for testing the vessel is fixed as follows. In the direction of vessel travel the domain will extend approximately 1.5 x shiplength (L) upstream of the bow and about 3 times of ship length downstream of stern. In lateral direction the domain will extend by 4.5 L so that all ship generated waves travel through the rear of the domain.The six block face boundaries are set to inlet, mid plane, bottom, side, top and exit. The mid-plane is set to Symmetry type, Exit to Pressure outlet and other four to velocity inlet. Fig. 3 and 4 show the mesh generation for the hull in domain. The mesh generated on the surface in the stern, bow and water line have fine refinement to capture the surface effect.

Grid generation or meshing is a very critical part within the CFD simulation process as it directly influence simulation time and accuracy of the results. For better results rectangular prismatic mesh structure were used for the free water surface flow. In computational domains 500 thousand, 1 million, 2 million, 3 million, 4 million and 5 million cells were tested and found that the resistance values for the 2 million cells had not changed. Hence the CFD analysis were made within the same cell range.

Computational 3D models of conventional and bulbous bow fitted 19.75 m $L_{OA}$ fishing boat hull were made for primary hull optimization. (Fig. 5). S scale of these models have been fixed as 1:10 for computational ease. The anlaysis using full scale model require more time as experienced in this analysis. One trial run needed 36 to 40 h and since three variants were to be studied for a range of speeds, a scaled down model has been analysed. Fig. 5 shows conventional hull form.

For the conventional fishing vessel, drag obtained from the CFD analysis was 30.7 N for a scaled down model of 1.975m. Keeping other parameters of the vessel fixed, bulbous bows were introduced in the new hull designs (Fig.6). Two linear parameters of bulb were changed to get two vessels having different bulbous bow shape named 'Oval type' and 'Nabla type' with decreasing order of their thickness and increasing order of their height to understand its effect in reducing drag.

CFD simulation analysis of the above mentioned models and the conventional hull model were done. The models were simulated under flat wave condition with no appendages. The flat wave velocity was set to 1.627 m/s corresponding to 10 kn for the scaled

Table 3. Comparison of Drag obtained in different hull forms

| Vessel Type | Drag (N) |
|---|---|
| Conventional hull | 30.7 |
| Hull with Oval type bulb | 27.6 |
| Hull with Nabla type bulb | 26.1 |

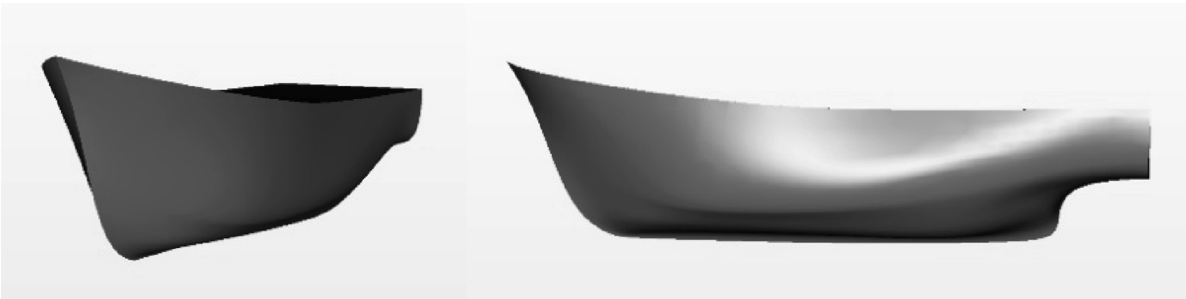


Fig. 5. View of the conventional fishing vessel hull

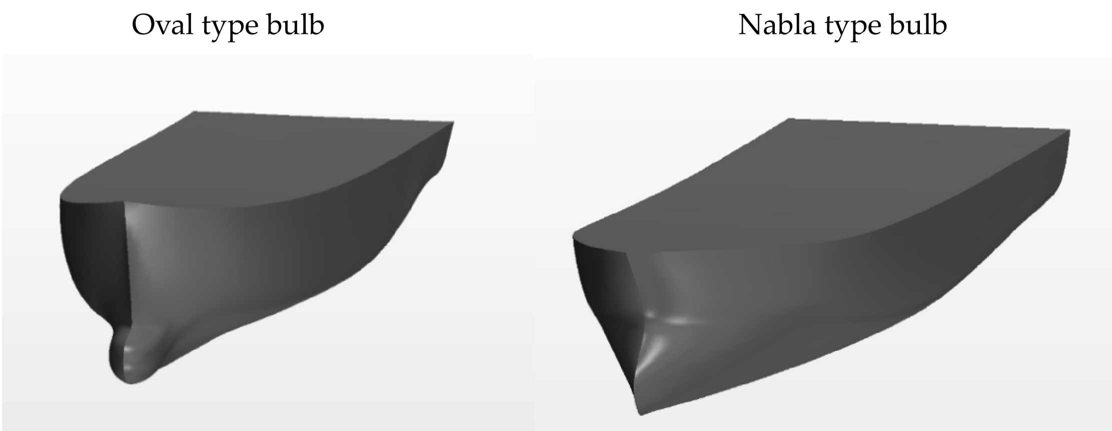
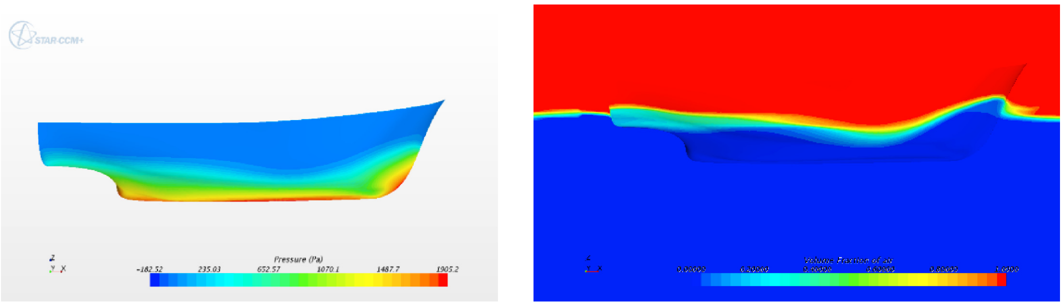



Fig. 6. 3D view of the Oval type and Nabla type bulb with hull

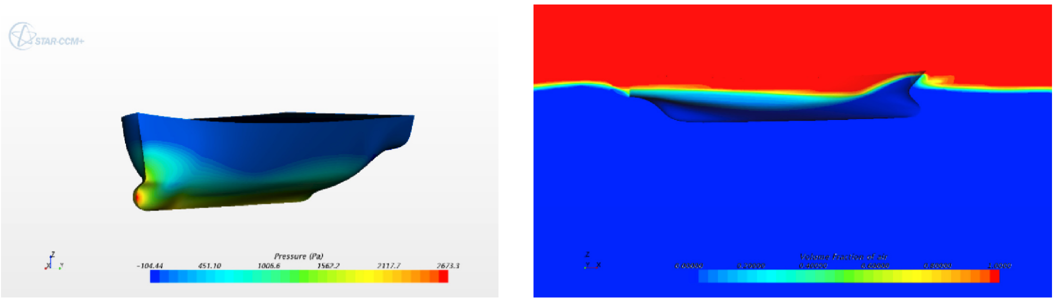
down models. Table. 3 shows monitored parameters such as pressure, volume fraction, and free surface effect for three different hull forms including conventional hull obtained after the analysis in CFD software. For the conventional vessel, drag was found to be 30.7 N and for the Oval type, 27.6 N and for the Nabla type 26.1 N.

Fig.7 shows the CFD output of hull surface pressure and volume fraction of the experimental models and Fig. 8 shows the CFD output of hull free surface and Wake formation of the experimental models. From the CFD results it has been observed that the hull from with Nabla type bulbous bow has low drag, and a drag redution of 14.99% compared to the conventional hull.

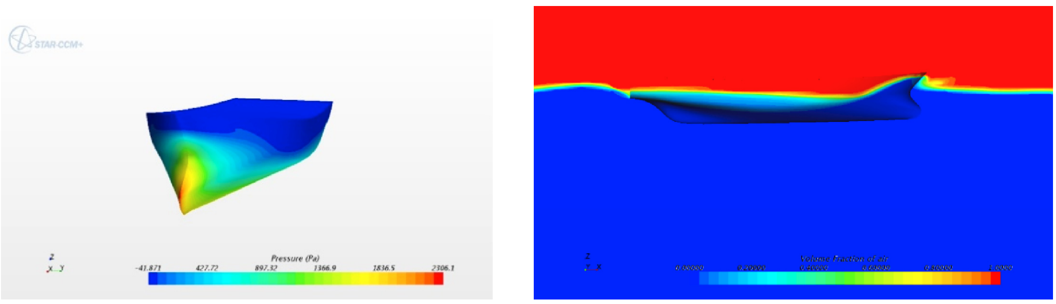
Sugalki (2014) used CFD methods for hull design and for calculating towing resistance 25.6 m $L_{OA}$ fishing vessel and obtained 18.879N as total resistance of bare hull (scaled down model of 1.024 m) Pécot et al. (2012) reported a 33% reduction in resistance for a shape optimized 24m monohull fishing vessel with bulbous bow in comparison with initial shape without a bulbous bow at constant overall length. The computational analysis tool used in the present study for the fishing vessels are practical and very reliable.



Conventional hull



Hull with Nabla Type- bulb



Hull with Nabla type bulb

Fig. 7. CFD output of Hull surface pressure and volume fraction of the experimental models

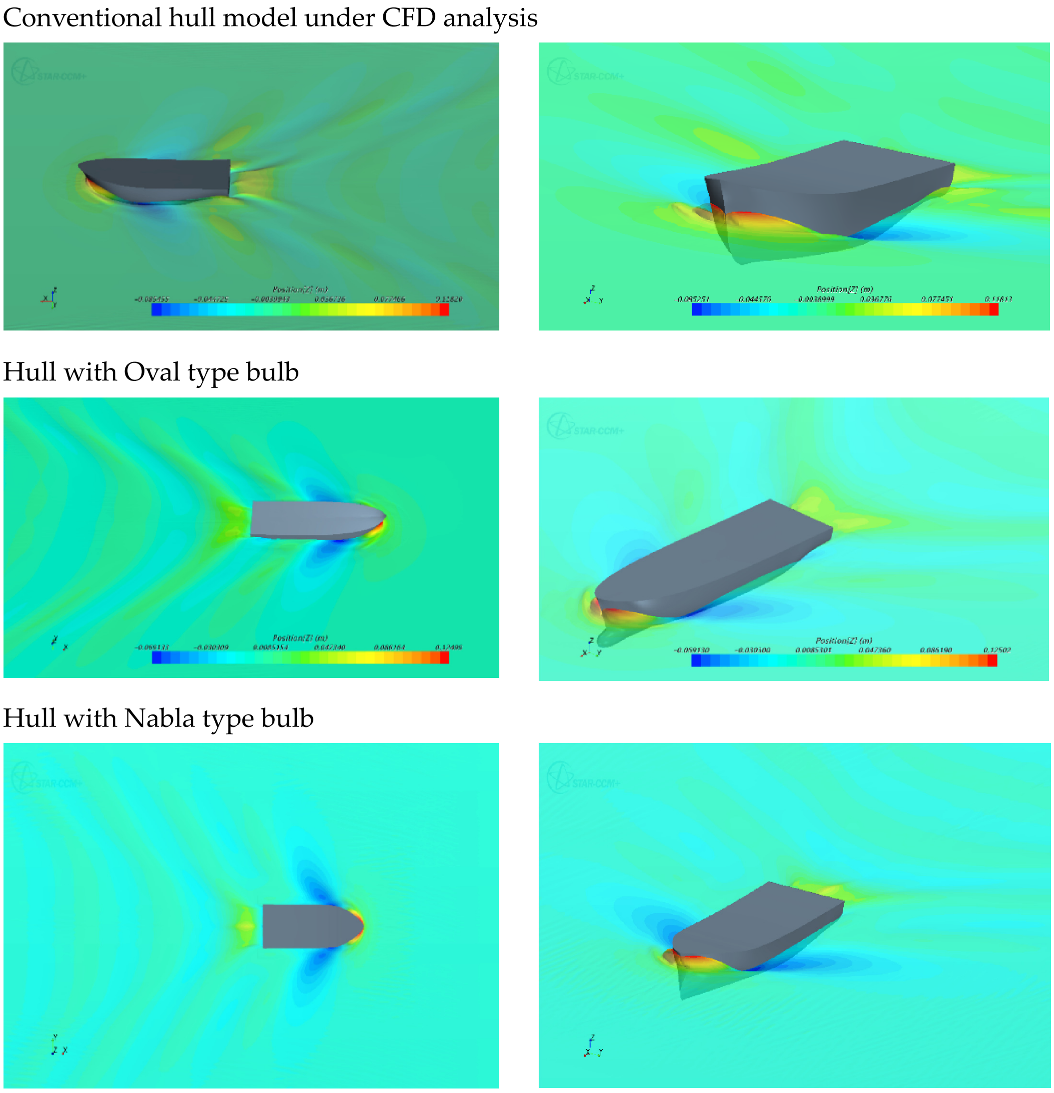



Fig. 8. CFD output of hull free surface and wake formation of the experimental models

Based on an all India survey of fishing vessels through stake holder consultations the length, breadth, depth parameters were arrived at a conventional hull from and two hulls with bulbous bow 'Ocai type' and 'Nabla type' were created using 3D modelling software. All hull forms were simulated using CFD software to understand the effect of drag. Among these hull forms with Nabla type bulb was found to have reduced drag compared to the other models. With a 14.99 % reduction in drag compared to other hull forms.

## Acknowledgements

The author would like to thank the Director ICAR-CIFT for permitting to publish this paper. This work was carried out under ICAR-NASF project "Green Fishing Systems For Tropical Seas" and Dr. Leela Edwin, Principal Investigator, ICAR-NASF project " Green Fishing Systems for Tropical Seas".

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