CFD ANALYSIS FOR A BALLAST FREE SHIP DESIGN

Avinash Godey[1], Prof. S.C.Misra[1], Prof. O.P.Sha[2]

1. Indian Maritime University Visakhapatnam Campus, India.
2. Dept. of Ocean Engg. & Naval Architecture, IIT Kharagpur, India.

Paper presented at MABB 2014 Conference in Chennai from 04.03.2014 to 07.03.2014

Abstract

Shipping transfers approximately 3 to 5 billion tonnes of ballast water internationally each year. This ballast water transferred between different ports is a serious environmental problem. There are many marine species like bacteria, small invertebrates and the eggs etc, that are carried in ship's ballast water which are small enough to pass through a ships intake at ports and when discharged, lead to severe ecological problems. To overcome this, a concept of ballast free ship has been developed in which ballast water exchange and treatment is avoided by providing flow-through longitudinal pipes in the double bottom instead of conventional ballast tank. During the design of the ballast free ship, different hull forms have been generated with altering hull shape forward and aft which have been studied with regard to hydrodynamics. Finally one hull form has been selected for further study. The present work aims to estimate the penalty on resistance using CFD techniques using SHIPFLOW$^{®}$ software. This have been be validated by model experiments for the conventional and the proposed ballastless form at the loaded and ballast drafts in the Hydrodynamics Laboratory of the Department of Ocean Engineering and Naval Architecture, IIT Kharagpur.

1. Introduction

The introduction of marine species like bacteria, small invertebrates and their eggs, etc., far beyond their normal geographic ranges through ship ballast water is becoming increasingly common. Such introduction may set up circumstances that allow the population of a particular speciesto grow unhindered by the absence of their natural predators. Many species of bacteria, plants, and animals carried through ships can survive in a viable form in the ballast water, even after journeys of several months duration. Subsequent discharge of ballast water into the waters of port of call may result in the establishmentof harmful aquatic organisms and pathogens which may pose threats to indigenous human, animal and plant life,and the marine environment.

Shipping moves over 80% of the world's commodities and transfers approximately 3 to 5 billion tonnes of ballast water globally each year. Ballast water is essential to the safe and efficient operation of modern shipping, providing balance and stability to un-laden ships. However, it may also pose a serious ecological, economic and health threat. The development of larger and faster ships completing their voyages in short time, combined with rapidly increasing international trade has led to an increase in transportation of invasive species. The problem has been compounded due to larger quantities of ballast transported leading to increased number of species moved from one place to another.

Aquatic invasions – considered the second greatest threat to global bio-diversity after habitat loss are virtually irreversible, and increase in severity over time.

To overcome this, a concept of Ballast Free Ship has been proposed in which ballast water exchange and treatment is avoided by providing flow-through longitudinal pipes in the double bottom instead of conventional ballast tank. The paper aims to find the flow in the pipes of the ship and find if any stagnation of water is there with in the pipes through CFD analysis using SHIPFLOW$^{®}$.

2. Ballast Water Management Convention

The involuntary transfer of harmful aquatic organisms and pathogens in a vessel's ballast water has been determined to have caused significant adverse impact to many of the world's coastal regions.

One of the strategies incorporated into the Ballast Water Management Convention is Ballast Water Exchange (BWE). Ballast water exchange is the process of exchanging coastal water, which may be fresh water, salt water or brackish water, for mid ocean water. During the exchange process, biologically laden water taken on in the last port of call is flushed out of the ballast tanks with open ocean water, typically 200 nautical miles from the nearest land.According to the ballast water exchange standard the vessels performing ballast water exchange must achieve a 95% volumetric exchange of ballast water. To achieve this target, ballast water must be pumped through three times the volumetric capacity of each ballast water tank.

The Ballast Water Exchange Methods for the replacement of water in a ballast tank are sequential, flow-through, dilution or other exchange methodologies recommended or required by IMO.

Sequential Method

The sequential method entails completely emptying ballast tanks of the coastal waters and refilling with open-ocean water. Emptying of certain tanks may lead to significantly reduced stability, higher vessel structural stresses, high sloshing pressures and/or reduced forward drafts which may then increase the probability of bow slamming. Margins are to be provided for stability and strength for all seagoing conditions, as specified in the vessel's approved trim and stability booklet and the loading manual. The loading conditions for the selected ballast water exchange method or methods are to be taken from the approved loading manual or trim and stability booklet.

Flow-through Method

The flow-through method involves pumping replacement ballast water into the bottom of a full ballast tank, forcing existing ballast water out through an overflow or other arrangement. Ballast water equal to approximately three times the tank capacity must be pumped through the tank to achieve 95% effectiveness in eliminating aquatic organisms.

Dilution Method

In the dilution method, replacement ballast water is filled through the top of the ballast tank and simultaneously discharged from the bottom at the same flow rate while maintaining a constant level in the tank throughout the ballast exchange operation. As with the flow-though method, ballast equal to approximately three times the tank capacity must be pumped through the tank to achieve 95% effectiveness in eliminating aquatic organisms. The dilution method has the advantages over the flow-through method with regard to maintaining the stability and strength and other similar benefits. By discharging water from the bottom of the ballast tanks, sediments are more easily removed. This method avoids the use of air vent pipes and the removal of manhole covers to discharge water over the deck.

3. Ballast Free Ship Concept

A design solution, to overcome the problem of carrying ballast water, is to change the view i.e. from adding weight for increasing draft to reducing buoyancy to achieve the draft needed. Therefore, the ballast tanks remain empty in fully loaded voyage but in ballast condition,the ballast tanks do not provide buoyancy as they are open to the sea. This approach is shown in Figure 1. In ballast condition, ballast tanks are left open,resulting in a loss of buoyancy and therefore achieve the required minimum ballast draft. A ship designed to have open ballast tanks in ballast condition need to be investigated for the following:

- Increase in hull resistance.
- To ensure that there is adequate water flow inside the ballast tanks. Also, the ballast tanks are internally smooth so that stagnant regions which may lead to deposition of sedimentsare avoided.
- Thestructural requirements arising out of the flow through pipes are satisfactory.

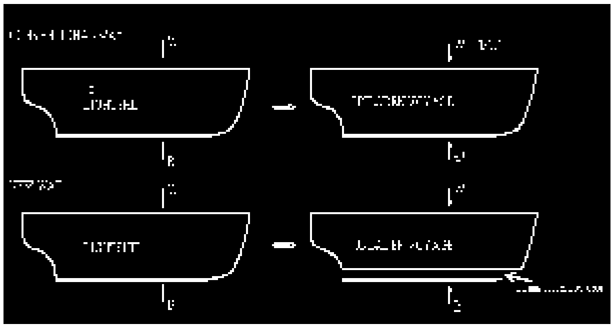


Fig. 1: Representation of the ballast water problem

In the present concept, for reducing buoyancy of the ship in ballast condition, flow-through elliptical pipes in the longitudinaldirections are provided in place of the conventional double bottom tanks throughout the length of the ship. These pipes function as longitudinal ballast tanks with valves at fore and aft ends of the ship which can be controlled. This is somewhat different from the plenum chamber concept suggested by Kotinis et al [2004]. Valves are to be open to the sea during the ballast voyage to ensure loss in buoyancy and closed during the loaded departure with pipes emptied of ballastwater. Water enters the pipes at the bow region of ship and flows out from stern region of ship. By this mechanism, local sea water is present in the ship at any point of time during the ballast journey.

Initial studies on the flow-through pipes withthree different types of sections,i.e. circular, elliptical and rectangular sections were carried at IIT Kharagpur. The study indicated that the optimum pipe configuration for minimum drag was elliptical. To carry out the no-ballast ship concept a 1,05,000 deadweight tonnes crude oil tanker was selected. This was considered as the base tanker for all subsequent studies. The principal particulars of this base tanker are given in Table 1.

Table 1:Main particulars of the base tanker

Displacement	129305	tonnes
Volume	126151	m3
Lpp	233	m
Draft (loaded)	14.75	m
Draft (ballast)	8.0	m
Breadth	42	m
Prismatic coefficient Cp	0.848	
Block coefficient Cb	0.847	
Speed (service)	15.2	knots
Minimum aft draft to have propeller immersion	7.8	m
Minimum forward draft to reduce bow slamming	5.825	m

A design exercise was carried out to design the hull formalong with space allocation of the base tanker. The base tanker was designed as a single screw ship in which the double bottom was modified to accommodate elliptical pipes along the length of the ship. Because of this, the ballast capacity reduced from 40000 $m^3$for a conventional hull form to 13785.74 m^3 for the proposed no-ballast tanker. This reduction in ballast capacity was due to wing tanks which cannot be used for ballasting due to the low forward draft. The results of the CAD model for flow through condition and full load condition are shown in Table 2. From the results it was observed that the forward draft was very low compared with the original tanker and does not meet the IMO requirements of minimum forward draft in ballast condition. This is due to the low ballast water capacity and the shift in center of gravity of the entire ballast water in the double bottom to the aft of midship.

Table 2: Difference between flow through condition and full load condition

	Flow Through condition	Full Loaded Condition
Draft Aft (m)	7.915	14.02
Draft For'd(m)	2.148	15.899
Draft Mid(m)	5.032	14.96

To achieve the minimum draft forward and aft according to IMO requirements it has be decided to create a hull form in such a way, so that the required forward and aft drafts are achieved. Aspects like modification in hull shape, pipe height of double bottom and position of the tank location were considered andaccordingly different alternative designs were generated. For different alternatives the draft aft, draft forward and cargo capacity were calculated for the fully loaded condition and flow through (ballast) condition and one hull form was finalized.

4. Model Test

Resistance test was conducted on a 1:71 scale model for the finalized hull format the Hydrodynamics Laboratory of the Department of Ocean Engineering and Naval Architecture at IITKharagpur. For comparing the resistances for a conventional vessel and proposed ballast-free ship two ships were selected and their scale models were manufactured so that the following calculations could be carried out:

- Resistance in full loaded and ballast condition for the conventional tanker form without pipes which is like a conventional tanker (Fig. 2).

- Resistance in ballast condition for the proposed ballast free tanker form with pipes in the double bottom (Fig. 3).

Figure 2: Model of Conventional Hull Form

Figure 3: Model of Ballast Free Ship

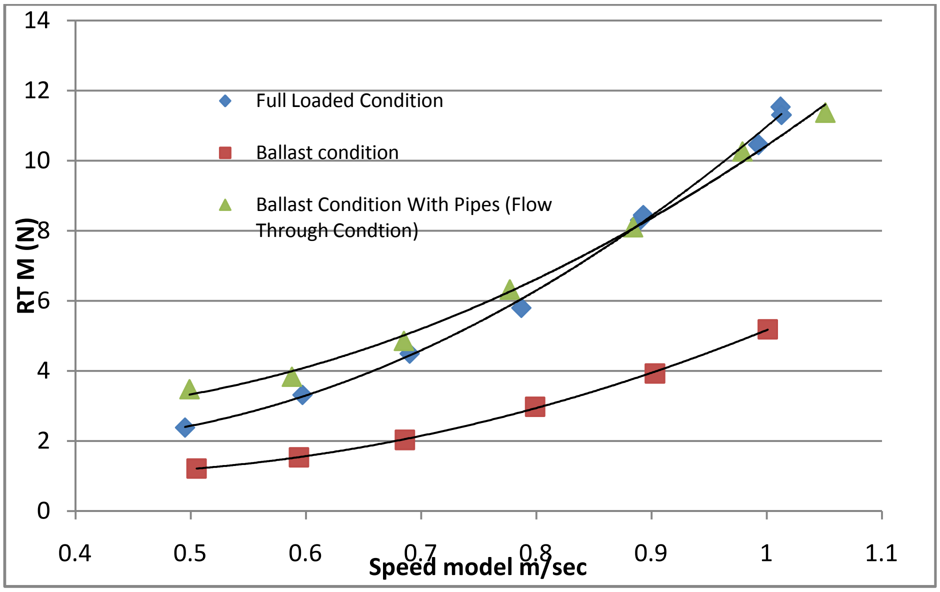


Figure 4: Resistance Comparison of models at ballast drafts with, without pipes and full loaded condition.

During the manufacture of the ballast free ship model, i.e. ship with pipes in the double bottom some simplifications have been incorporated in the model which are not in the proposed design. These are:

- Due to the non-availability of elliptical configuration pipes, circular pipes of the same cross-sectional area were used as flow through pipes.
- The circular pipes in the double bottom region led to increase in light weight of the model. Therefore, the experiment was conducted at a higher draft than the required ballast draft.

The model test shows that there is an increase in resistance which was expected as shown in Fig. 4 for the proposed ballast free ship.The increase in resistance is due to the additional wetted surface area of the pipes which resulted in an increase in frictional resistance. It was also observed that the bow wave height was reduced because of the flow in the pipes when compared to the conventional hull form (tested for the same draft).

During the operation in ballast condition, i.e. flow through condition, the vessel operates with ballast pipes open to sea until the open ocean water after which the valves are to be closed and vessel moves like a normal ship in ballast condition. Before entering the coastal waters of the port of call the valves are opened so that the flow is continuous and no invasive species are carried.

Though there was an increase in resistance in the model test, the ship is expected to operate in this flow through condition for approximately 6% to 8% of its total voyage between two ports.

5. CFD Analysis using SHIPFOW

A steady state CFD solver for ship hydrodynamics, SHIPFLOW for predicting the flow around the ship and its resistance components, developed at Chalmers University of Technology and FLOWTECHInternational, AB is used in the present work. To solve the flow around the hull a global approach has been used which is available in SHIPFLOW. A global approach means that the Navier-Stokes equations are solved in the whole flow domain. For the specified boundary conditions, the available options are: inflow, outflow, no-slip, slip and interior conditions. a) Inflow condition is normally satisfied at an inlet plane of the computational domain to guarantee an undisturbed flow in front of a hull. In XCHAP it specifies a fixed velocity equal to the ship speed. The pressure gradient normal to the inlet plane is set to zero. b) Outflow condition: describes zero normal gradients of velocity and fixed pressure at a downstream outlet plane of the domain far behind a hull. c) No-slip condition: simulates a solid wall boundary (e.g. a hull surface) by designating zero value to velocity components. d) Slip condition: specifies the normal velocity component and normal gradient of all other flow quantities (e.g. pressure) as zero. It simulates a symmetry condition on flat boundaries. e) Interior condition: describes the boundary data by interpolation from another grid. In the present analysis the computations are done for different loading conditions i.e. full loaded condition, ballast condition and ballast condition with pipes i.e. the flow through condition which are validated with experimental results. The main focus of the analysis is to check if there is any stagnation point in the flow through condition with in the pipes how the fluid particles are moving within the pipe.

Resistance computation is done using SHIPFLOW for full loaded and ballast condition for a series of speeds at model and full scale and the viscous resistance is compared with experimental results extrapolated with ITTC-78 are shown in the Figures 5&6.The comparison of SHIPFLOW and model test results shows that there is 10% to 13% difference in the two methods of simulation of resistance.

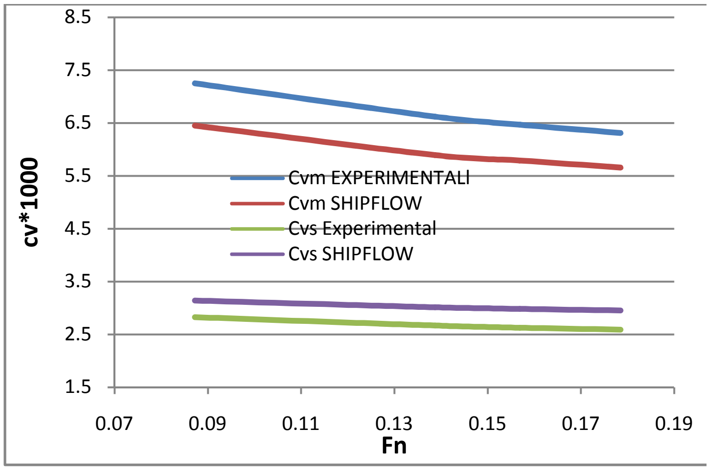


Figure 5: Viscous Resistance Comparison of Experimental and Shipflow results at models and full scale for full loaded condition

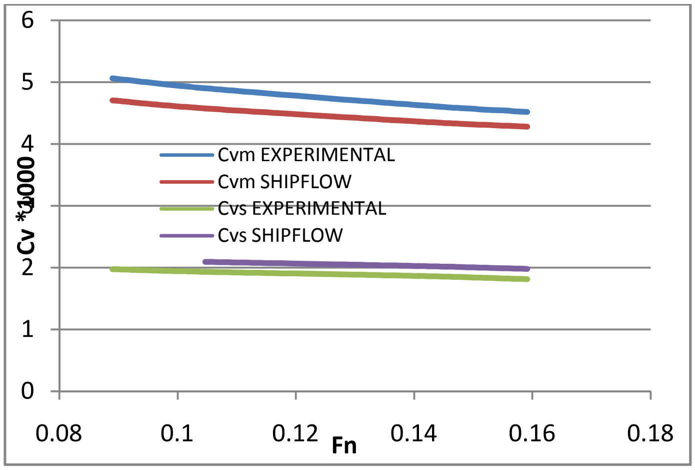


Figure 6: Viscous Resistance Comparison of Experimental and Shipflow results at models and ship for ballast condition without pipes

For the flow through condition, since there is some uncertainty in calculating the form factor (1+k) from the experiments and from SHIPFLOW Froude's extrapolation method is usedto compare the results at model and full scale which are shown in the figure 7&8.Analysis of the SHIPFLOW velocity contour plots in x direction shows that there are no stagnation points within the pipes. Though there are some areas in the forward which indicate the velocity is low but not stagnation which is visible from the figure 9&10. To check that the low velocity is not causing any problem flow lines are also traced as show in the figure 11.

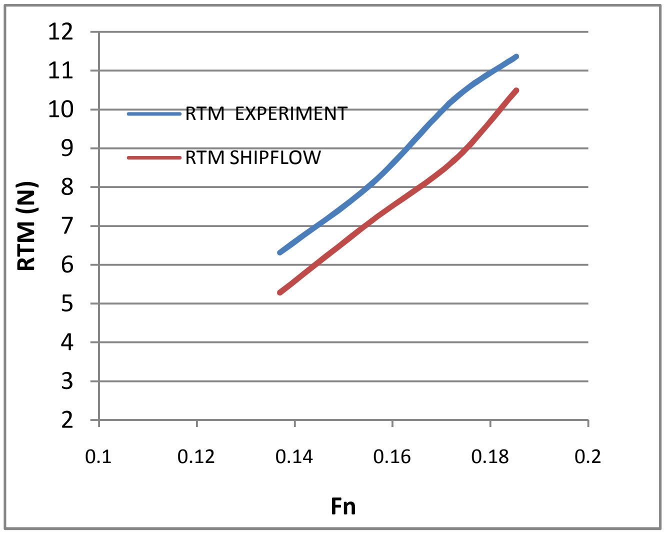


Figure 7: Resistance Comparison of Experimental and Shipflow results at models scale forflow through condition i.e. with pipes

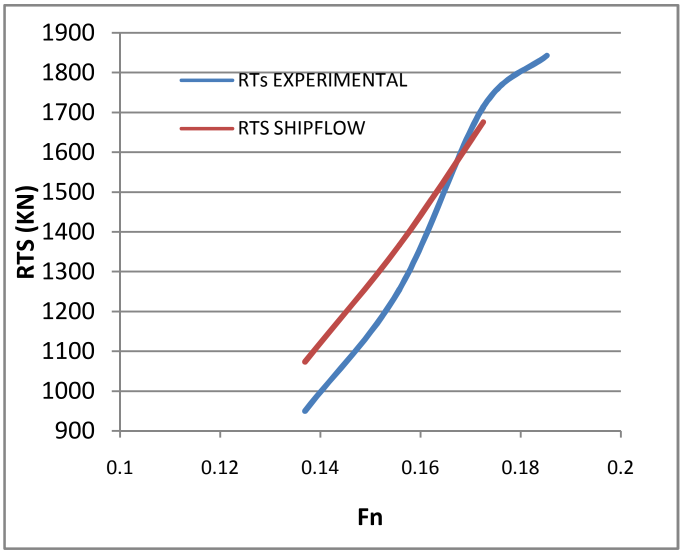
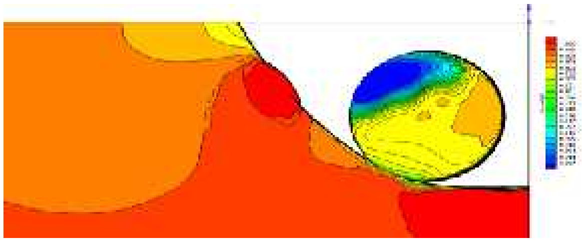
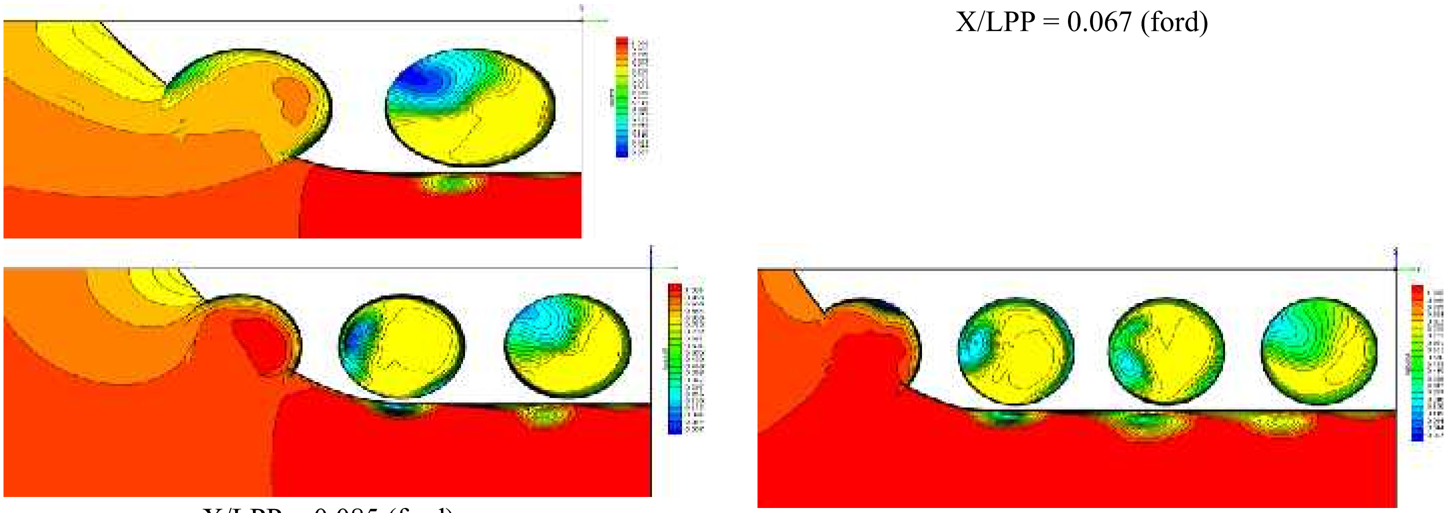


Figure 8: Resistance Comparison of extrapolated and Shipflow results at full scale for flow through condition i.e. with pipes



X/LPP = 0.047 (ford)

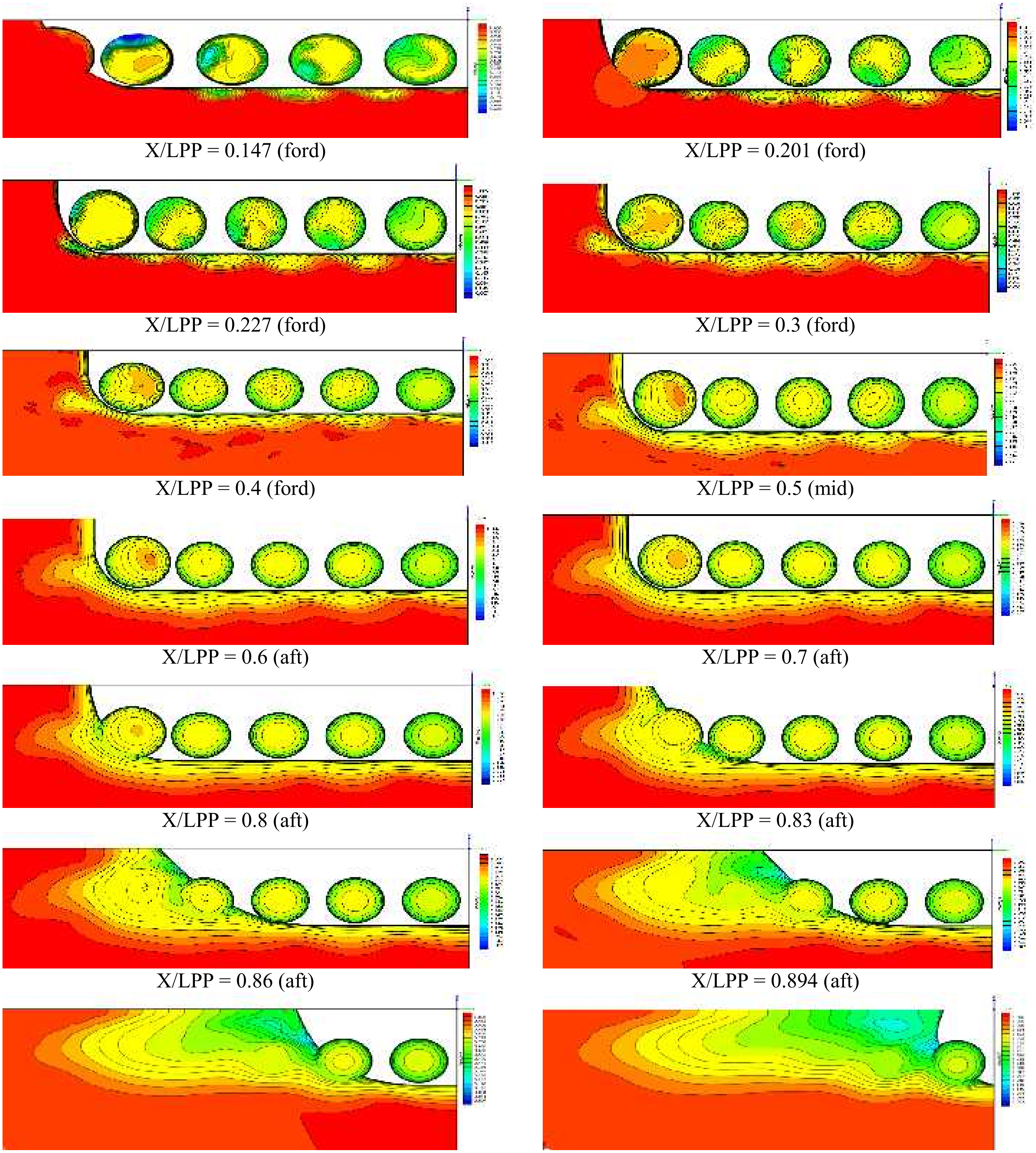


X/LPP = 0.067 (ford)

X/LPP = 0.085 (ford)

X/LPP = 0.119 (ford)

Figure 9 : Velocity contours in x direction



X/LPP = 0.147 (ford)

X/LPP = 0.201 (ford)

X/LPP = 0.227 (ford)

X/LPP = 0.3 (ford)

X/LPP = 0.4 (ford)

X/LPP = 0.5 (mid)

X/LPP = 0.6 (aft)

X/LPP = 0.7 (aft)

X/LPP = 0.8 (aft)

X/LPP = 0.83 (aft)

X/LPP = 0.86 (aft)

X/LPP = 0.894 (aft)

X/LPP = 0.918 (aft)

X/LPP = 0.950 (aft)

Figure 10 : Velocity contours in x direction

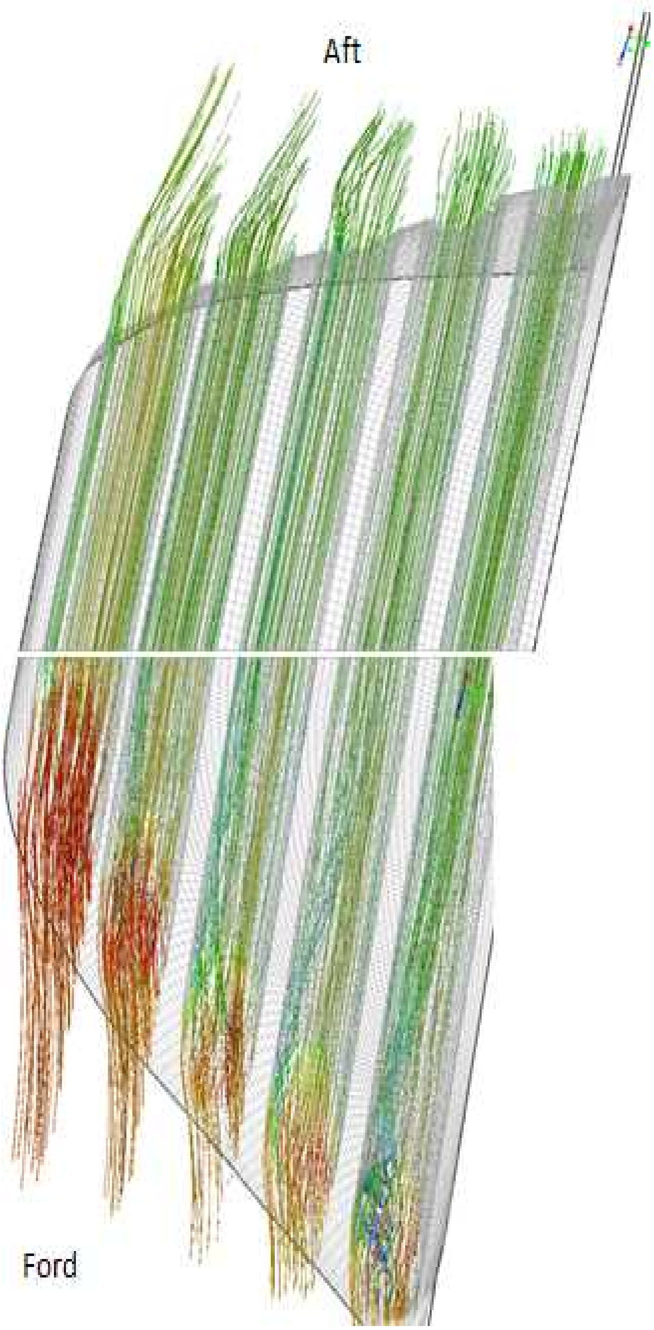


Figure 11: Flow streamline in the pipes

6. Conclusion

The analysis of the flow lines and velocity contour plots that are obtained from SHPFLOW for the flow through condition indicating that no stagnation of water with in the pipe which run throughout the length of the ship in the double bottom. The CFD analysis gives an idea on the flow in the pipes, which is not visualized in the model experiments. These results are quite interesting and indicating that there are some low velocity regions in the forward, where the water start entering the pipes. The experimental and CFD results show a deviation of 10 to 13% in the viscous resistance which can be reduced by refined grid and further studies need to be carried out for the form factor being considered.

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