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Development Of A Ballast Free Ship Design

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Abstract:

Shipping transfers approximately 3 to 5 billion tonnes of ballast water internationally each year. Ballast water discharges non-native species leading to severe ecological problems. The present work aims at a design solution into the ballastless ship in which ballast water exchange and treatment is avoided by providing flow-through longitudinal pipes in the double bottom instead of conventional ballast tanks. During the design of the ballastless ship, different hull forms are generated with altering the hull shape in forward and aft out of which one was finalised. In addition to change in hull form the internal tank arrangement has been changed so that the propeller immersion and the minimum draft required in the ballast condition is achieved. Structural arrangement for the midship section was proposed for the modified hull form of ballast less ship as well as data on valves had been collected for the flow through condition. Finally, resistance tests were conducted on equivalent models of scale ratio 1:71 for the conventional and the proposed ballsatless form at the loaded and ballast drafts in the Hydrodynamic Towing Tank of the Department of Ocean Engineering and Naval Architecture, IIT Kharagpur. The model experiments on ballastless ship show an increase in resistance in ballast draft when compared to a conventional tanker due to the flow through pipes in double bottom.

1.Introduction

Entry of an aquatic species into a new environment is a normal evolutionary process when it takes place through a natural transport such as wind or ocean currents. However, it is becoming increasingly common, as a result of human activity, to have foreign species introduced far beyond their normal geographic ranges. Such introductions may set up circumstances that allow a species population to grow unchecked by their natural predators.

Shipping moves over 80% of the world's commodities and transfers approximately 3 to 5 billion tons of ballast water internationally 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 lead to increase in invasive species transportation which becomes pertinent due to the larger quantities of ballast transported leading to increased number of species moved from one place to another.

The species which have already been transported are causing enormous damage to bio-diversity. The valuable natural riches of our planet, upon which we depend, are under threat. Direct and indirect health effects are becoming increasingly serious and the damage to nature is often irreversible. Aquaqtic invasions – considered the second greatest threat to global bio-diversity after habitat loss- are virtually irreversible, and increase in severity over time.

The present study is based on the joint collaborative work between IIT Kharagpur and IMU Visakhapatnam for the past three years. The idea behind the present work is adapted from the work carried out by Kotinis et al [2004]

2.No Ballast Ship (NOBS) Concepts

There are three projects in which the concept of a ship with zero ballast water (BW) has been developed (GESAMP Reports -2011): (i) Delft University of Technology (DUT)- 'Monomaran Hull' (ii) Det Norse Veritas (DNV) - 'Volume Cargo Ship' and (iii) Daewoo Shipbuilding & Marine Engineering (DSME) - 'Solid Ballast Ship'. When a ship rolls during the unloaded condition, its stability without use of BW requires adequate buoyancy. Both the DUT and DNV concepts achieve this by widening the ship's beam and moving the displacement volume outward from the centerline. The DUT concept proposes a 'monomaran' hull by adopting a catamaran shape to the underside of a broad single hull, while the DNV concept indicates a tri-hull concept that provides a high level of stability. In the case of DSME' solid ballast (SB) concept, the conventional displacement hull is retained since the BW is replaced by 25 tonne SB in standard containers, and the method applicable to container ships only.

Shipbuilding Research Centre of Japan (SRC) has proposed a storm ballast ship concept and has carried out R&D work on NOBS designs mostly for tankers since 2003. The NOBS concept is based on a V-shaped hull form with optimal hull shape and buoyancy distribution, and it represents another major design change away from the flat-bottom hull of conventional ships. The V-hull alters the vertical distribution of hull buoyancy, causing a deeper draught in the light (unloaded) condition. By widening the beam by about 30%, displacement is kept at the same full load draught as that of an equivalent DWT conventional hull, while hull length is minimally altered. In the case of a NOBS-equivalent to a conventional suezmax tanker, the additional steel for the wider hull increases hull weight by roughly 4,500 tons. The main purpose of adopting the V-shape cross-section is to maintain sufficient unloaded draught and stability and avoid bow slamming and propeller racing without needing any BW for the majority of sea conditions

In the continuous flow method of Kotinis et al [2004] a buoyancy control method is used. When a ship moves forward it produces regions of increased water pressure near its bow and reduced water pressure at its stern. The longitudinal structural ballast trunks that surround the cargo hold below uses this pressure differential to drive water through a set of these below-waterline corridors without the need for pumps. The trunks, which occupy the double bottom (DB) space in place of the usual watertight DB ballast tanks of a conventional ship, are fed by a plenum near the bow and run almost to the stern of the ship. By opening the lower part of the hull to the sea rather than uplifting water into watertight tanks when not carrying cargo, the draught required for maintaining the ship's stability is achieved by reducing its buoyancy instead of increasing its displacement weight.

The Yokohama buoyancy control compartments concept converts conventional ballast tanks into a series of buoyancy control compartments. Each compartment is flooded to provide adequate draught in the unloaded condition then continuously flushed at normal voyage speeds to ensure efficient exchange without the need for pumps. The concept is similar to the longitudinal trunk approach except it can be retrofitted to existing conventionally-ballasted ships, as well as installed for new builds. The Yokohama concept seeks to avoid these problems by converting ballast tanks into multiple independent buoyancy compartments to achieve the required ballast draught and trim. Each compartment is fitted with intake and outlet valves that are optimally designed and positioned for each compartment so as to maximize its flushing rate during normal voyage speeds. The concept remains theoretical, with the patents based on numerical modelling of water flow and exchange for a series of inlet and outlet valve configurations for unspecified tanks, plus in-tank weirs to further improve tank flushing. No empirical investigations or specific testing, such as changes to hull resistance as a result of the multiple inlets and outlets, or the design and additional weight of fitting a weir inside each compartment have been reported. As shown in Figure 1, seawater enters each compartment via a forward intake then exits via one or two valves positioned at the compartment's aft end, while an air vent on the ceiling of each compartment ensures they can remain fully flooded.

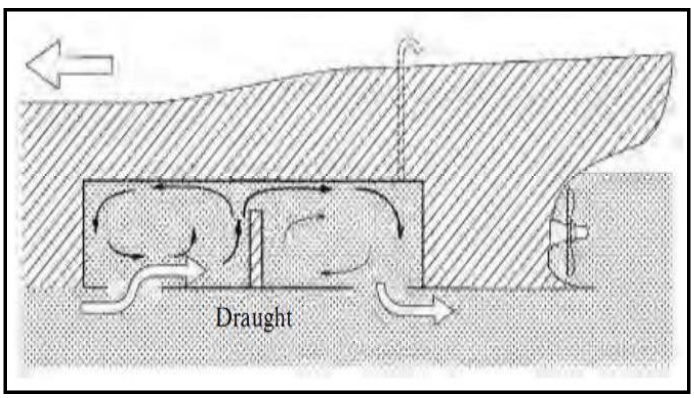


Figure 1: Flooded buoyancy compartment

3.The Ballast Free Ship (BFS)

A design solution is to change the view if adding weight for increasing draft to reducing buoyancy to achieve the draft needed ie ballast tanks remain empty in fully loaded voyage and full in ballast condition. This approach is shown in Figure 2. In ballast condition, ballast tanks can be left open to lose the buoyancy and achieve the required drafts. A ship can be designed to have open ballast tanks in ballast condition such that:

- Hull resistance increases.

There is adequate water flow inside the ballast tanks and the ballast tanks are internally smooth

- so that there are no stagnant portions and no deposition of sediments.
- Hydrodynamics and structural requirements of the hull form must be satisfactory.

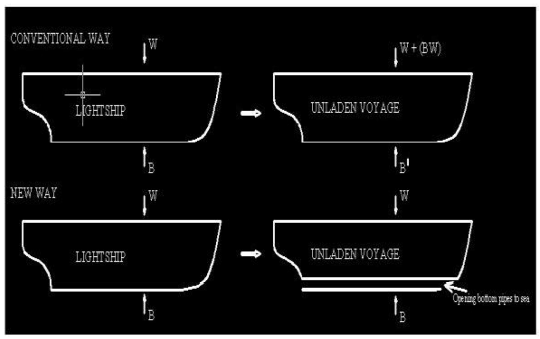


Figure 2: Pictorial representation of the ballast water problem

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

The initial studies were carried at IIT kharagpur on the flow-through three types of sections namely circular, elliptical and rectangular with circular ends. The study indicated that the optimum pipe configuration for minimum drag was elliptical. To carry out the no ballast ship concept a crude oil tanker selected that is taken as the base tanker for all subsequent studies. The principal particulars of this vessel are given in Table 1. Resistance test was carried on equivalent barge shaped models for the conventional hull form and the proposed Ballast free form was fabricated on a scale of 1:100 to investigate the penalty in resistance. Analysis of results shows that the effective power increase in the loaded and ballast conditions are around 20% and 11% respectively at the design speed of 15.2 knots.

Displacement	**129305**	**tonnes**
Volume	126151	m3
Lpp	233	m
Draft (loaded)	14.75	m
Draft (ballast)	8.0	m
Breadth	42	m
Cp	0.848	
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

Table 1: Main particulars of the base tanker

4.Structural Arrangement of BFS

The BSF concept requires longitudinal flow through pipes which are continuous throughout the length of the ship. For which gate valves are provided at the forward and aft end of the pipes. In a conventional tanker the double bottom structure is divided into different compartments in which the ballast water is stored. But in case of BSF form the DB is modified such that it accommodated the flow, for which the DB is provided with elliptical pipes configuration with required stiffening as shown in the figure Structural scantlings of the midship section are calculated following the ABS class of rules. The scantlings for conventional ship are verified by MARS 2000 software from BV. The figure 3 shows the mid ship configuration in MARS 2000 software. The design for the

BFS is done by including the pipes in the double bottom and midship section modulus for both the sections is maintained the same. The stiffening members in the double bottom are kept outside of the structured elliptical pipes such that they won't obstruct the flow through pipe. Pipes are smooth from inside so that there are no complicated inside the pipes where the microbial species may reside in sediments. Structural designs of midship section are shown in figures 4 and results are shown in the table 2.

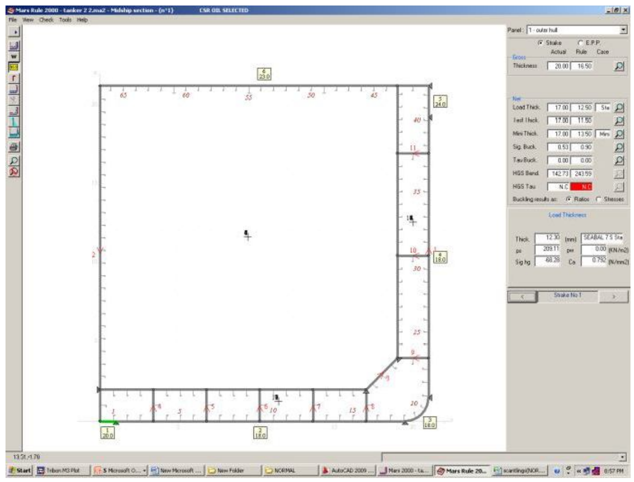


Figure 3: Mid ship configuration in MARS 2000 software

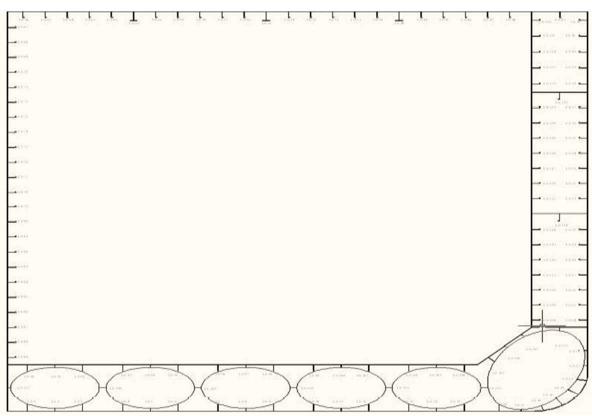


Figure 4: Midship Structural Drawing for Conventional Tanker with rectangular with circular sections at the bottom

	For normal section	For elliptical section
Total Area(m^2)	6.637	7.318
Neutral Axis (m)	9.290	8.641
Weight (t/m)	49.650	54.730
Z ON DECK(m^3)	29.627	30.808
Z ON KEEL(m^3)	38.300	45.135

Table 2: Section modulus two types of section

5.Development Of New Hull Form

Due to modification of the double bottom of the basic ship with the elliptical pipes which run throughout the length, the ballast capacity is reduced from 40000 m3 to 13785.74 m3. This reduction in ballast capacity is due to vacantly left wing tanks which cannot be used in this case due to the low forward draft. The results of the CAD model for flow through condition and full load condition are show in the table 3. From the results it is observed that the forward draft is 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.

	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

Table 3: Difference between flow through condition and full load condition

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 forward and aft drafts are achieved and which is feasible option for construction. While forming the new hull form it has been take care that the length, breadth and depth are same as that of the basic tanker configuration. The proposed options for creating the hull form are:

- Bottom structure with a bottom plate below the elliptical pipes
- Modification in hull shape at forward and aft
- Bottom structure without the bottom plate below the elliptical pipes
- Pipe height in double bottom is increased
- Changing the position of the tank location

Taking the above aspects in to consideration seven different alternatives with had been developed. In which some alternatives have combination above mentioned aspects.

For all the above alternatives the draft aft, draft forward and cargo capacity are calculated for full loaded condition and flow through (ballast) condition. The results of all the alternatives are shown in the table 4 out of which the alternative 7 is most feasible

Alternatives	Description		Draft aft(m)	Draft for'd(m)	Trim by stern +(m)	BW (t)	Cargo (t)	Fuel oil(t)
1	The double bottom height of the basic tanker has been increased from 2.46 to 3meters	Flow through condition	8.17	2.43	5.739+	16323.6	0	3132.1
		Full loaded condition	13.63	15.52	1.893-	0	98771	3132.1
2	The forward shape of the basic ship has been changed to a U-shape section and the bulbous bow was also avoided as shown in the figure 5(a). The double bottom height was increased to 3 m	Flow through condition	7.77	3.02	4.745+	16749	0	3809.8
		Full loaded condition	13.08	16.67	3.589-	0	99322.4	3809.8
3	Forward shape of the basic ship has been changed as shown in the figure 5(b).	Flow through condition	7.38	2.7	4.686+	13411.1	0	3884.4
		Full loaded condition	13.87	15.72	1.848-	0	97246.6	3884.4
4	The ford shape was changed like V-shape hull form and the aft was modified by extending the sections below the base line, so that the additional volume below the base line will increase the forward due to more buoyancy in the aft as shown in figure 5(c)	Flow through condition	6.91	3.55	3.358+	16819.8	0	3840.2
		Full loaded condition	12.12	17.5	5.381-	0	98411	3840.2
5	the ford shape has been changed to that of a cylindrical bow and parallel middle body was increased as shown in the figure 5(d)	Flow through condition	7.09	2.59	4.506+	14715.2	0	3690.1
		Full loaded condition	12.2	16.77	4.574-	0	100230.4	3690.1
6	the ford shape has been changed to that of a high speed vessel form like that of a naval ship, the parallel middle body was increased to the maximum extent possible shown in the figure 5(e)	Flow through condition	7.63	3.16	4.471+	16739.9	0	3840.4
		Full loaded condition	12.92	16.76	3.843-	0	97317.2	3840.4
7	The ford shape and parallel middle body are same as that of the previous iteration and aft bulb is provided in the stern region as shown in the figure 5 (f). It has been seen that large trim by forward is generated in full loaded condition due to the cargo hold CG being ford of midship. To reduce the trim by forward the cargo hold space has been changed and the fuel oil tanks are given both in the aft and forward region as show in the figure 5 (g).	Flow through departure condition	6.41	4.23	2.188+	17151.4	0	3376.3
		Flow through arrival condition	5.73	4.05	1.667+	17120.3	0	337.3
		Full loaded departure condition	14.41	14.31	0.097+	0	96295.4	3376.3
		Full loaded arrival condition	13.97	14.01	0.040-	0	96295.4	210.7

Table 4: Results of various alternatives

Different Alternatives

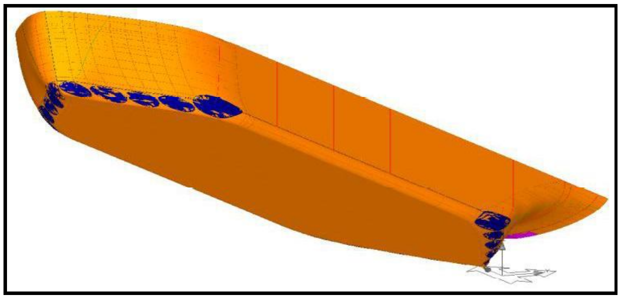


Figure 5(a): Form with u shaped section in forward (Alternatives 2)

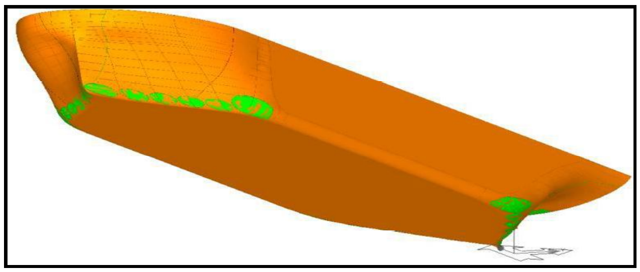


Figure 5(b):Form with v shaped forward bottom and fuller shape in the top (Alternatives 3)

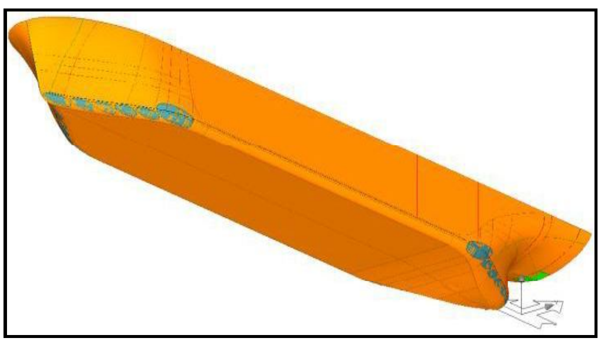


Figure 5(c): Form with v shaped forward sections and fat section going below base line

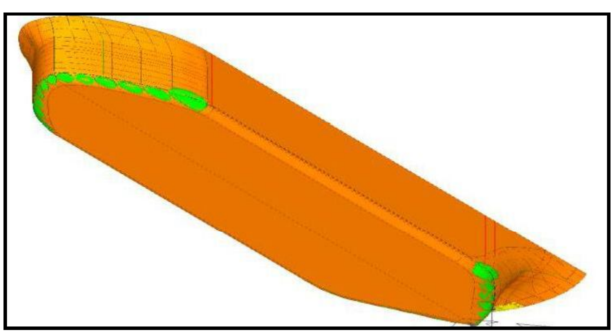


Figure 5(d): Form with cylindrical bows forward sections (Alternatives 5)

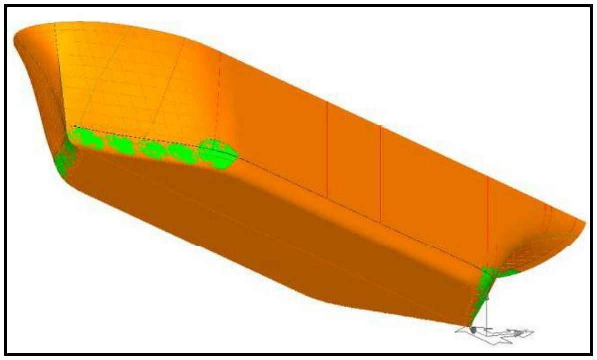


Figure5 (e): Form with v shaped forward sections (Alternatives 6)

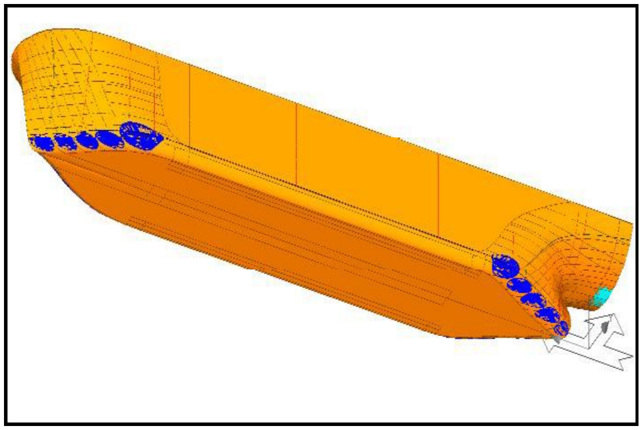
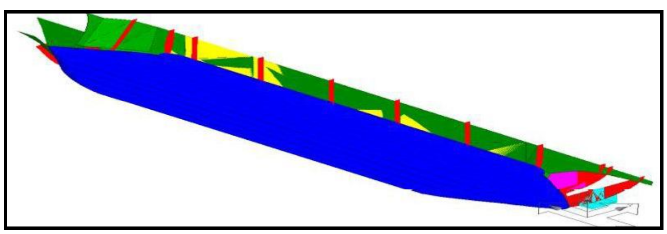


Figure 5(f): Form with v shaped with aft bulb (Alternatives 7)

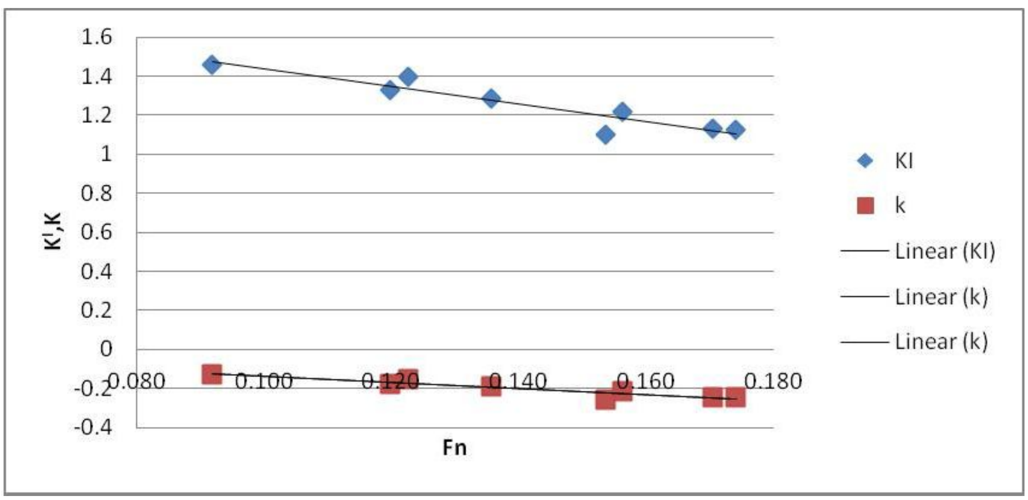


Figfure 5(g): Compartment division in TRIBON (Alternatives 7)

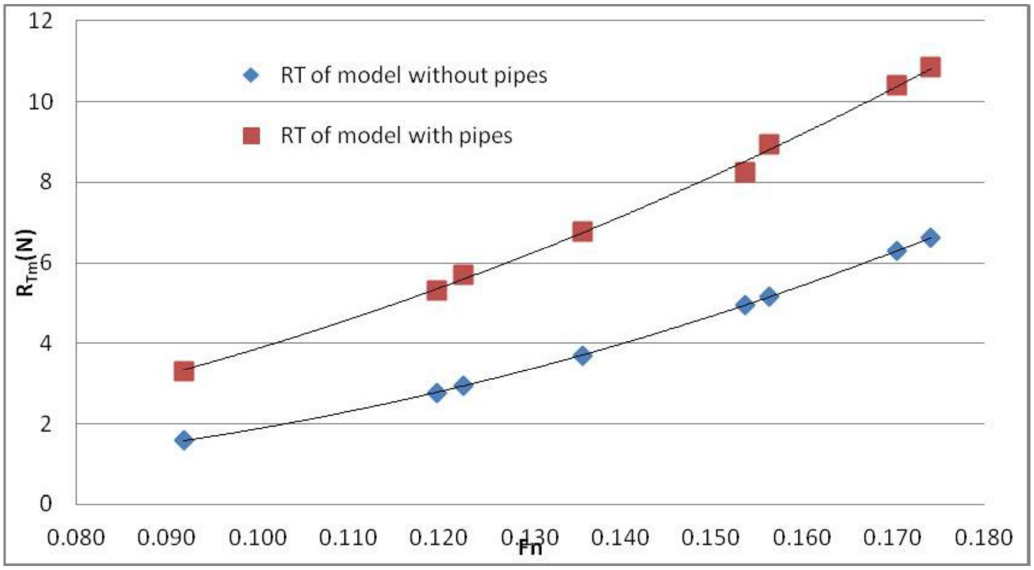
6.Model test and results

To investigate the penalty in resistance for the proposed BFS for the alternative 7, resistance test was conducted. It was decided that two models will be fabricated on a scale of 1:71 because in a single model it is difficult to provide pipes with valves due to which the weight of the model would be high and it would be hard to test at low drafts. There for it was decided to make a model with its original shape and test it for full load and flow through (ballast) condition which will serve as the base for comparison. The flow through pipes condition was tested on second model in which the longitudinal pipes are running throughout the length of the ship. While the second model was being manufactured it was observed that the weight of the model has increased do to which the test was conducted at a higher draft. So the model test was done at the new draft for the comparison of resistances in two cases.

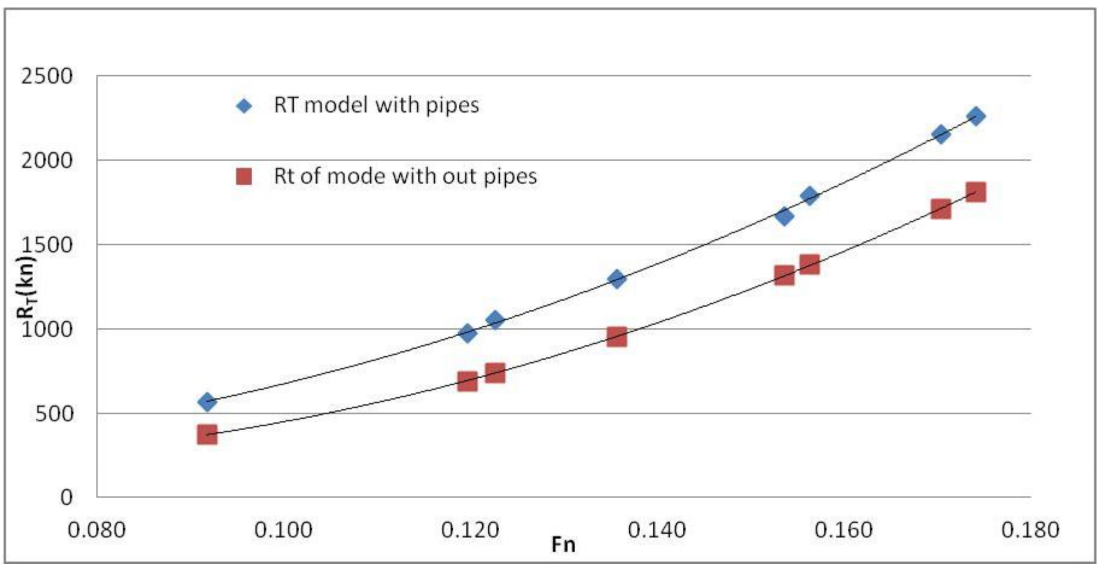
For the first model resistance values are extrapolated using ITTC 1957 method to the ship scale. When comparison of the ship with pipes and ship without pipes it was observed that the increase in resistance is predominately due to the drag generated because of the pipes immersed in the water. So an exercise was carries out to find out the increase in resistance due to the drag as a percentage of form factor, keeping residuary resistance of both the ships constant. The form factor is calculated with wetted surface area (WSA) $s_m^{/}$ (model with without pipes) and s_m (model with pipes). From which the values of $k^{/}$ and K are obtained which are plotted in the graph1. The total resistance of both the ship and model are calculated which are shown in the graph 2 & 3.



Graph 1: Comparison between $k^{/}$ and K values



Graph 2: Comparison between total resistance of model with and without pipes at a constant draft



Graph 3:Comparison between total resistance of ship with and without pipes at a constant draft

7.Conclusion

The preliminary results are shown here, still tests are being conducted at IIT kharagpur. Form the graphs it can be observes that increase in resistance of the ship in flow through condition in the order of 30 to 35 % and with increase in speed the difference will be still reduced.

8.Reference

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