Bulletin of the *Transilvania* University of Braşov • Vol. 2 (51) - 2009
Series I: Engineering Sciences

PROPULSION ENERGY VERSUS FREE BALLAST SHIP CONCEPT PART ONE

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Abstract: *The ballast issue where ships are concerned has become a big problem lately,together with the invasive species transported between different areas of the ocean .Consequently , there are possibilities of replacing the classic ballast systems with another type to avoid "aliens invasion". In the first part of this work we are introducing fundamental issues and the "free ballast ship" concept .Equally, we introduce the basic scheme of the new ballast system.*

Keywords: *ship, ballast system, invasive species, free ballast ship concepts.*

1. Introduction

A doctoral thesis presented at the Maritime University of Constantza in feb. 2009 , raised the matter of a new ballast system which permanently stays in touch with the sea . Two issues are in attention here :

- the increase of ship's resistance and propulsion power demand due to openings in the ship's structure;
- the advantages and disadvantages of permanent communication with the sea where the ballast system is concerned.

The current stage of this research project focuses on further hydrodynamic investigation of the BFS concept ; both experimental and numerical.

The experimental investigation was performed by using a Bulk-Carrier model and equally a General Cargo Ship.

The initial investigation of the BFS concept proved the feasibility of the concept through a thorough examination of various design aspects.

The effectiveness of the concept, in terms of eliminating the transport of foreignballast water from ship operating in ballast condition, was also demonstrated by utilizing Computational Fluid Dynamics (CFD) software to simulate the flow in the double bottom ballast trunks of the vessel . Nevertheless , this initial investigation did not succeed in showing the full cost-effectiveness of the concept. The main reason was a significant fuel penalty that resulted from an increased power requirement found in the initial hydrodynamic testing of a non-optimized discharge configuration on an existing ship with a non-optimum propeller.

Within this first part of the work we go into details with the issue's geometry and the basic concept of the new BFS .

Within the second part of the work we present the experiments consisting of detailed resistance and propulsion testing with and without the ballast trunk flow .

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Finally , the third part , presents the CFD. The numerical investigation was performed CFD software, namely: FLUENT 6.0 .

2. Background

Overall, the investigation of the Ballast-Free Ship Concept has shown that it provides a viable alternative to the addition of costly ballast water treatment systems in order to meet the evolving performance requirements for ballast water treatment.

The concept essentially eliminates the transport of foreign ballast water. This should be more effective than current treatment methods in reducing the potential for the further introduction of nonindigenous aquatic species into the Great Lakes and coastal waters.

Furthermore, it should be equally effective as international requirements extend below the 50 micron range (IMO 2004).

The traditional approach to ballast operations, since the introduction of steam machinery, has been the use of water ballast to increase the weight of the vessel in the light cargo condition. A paradigm shift in thinking here views the ballast condition as a change of buoyancy rather than an addition of weight in order to get the vessel to its safe ballast drafts.

In this concept, the traditional ballast tanks are replaced by longitudinal, structural ballast trunks that extend beneath the cargo region of the ship below the ballast draft. The arrangement of an equal capacity conventional Seaway-size bulk carrier is shown on the left in Fig. 2.1; the arrangement of a Ballast-Free Ship Concept Seaway-size bulk carrier is shown for comparison on the right. In this example, the three ballast trunks per side are connected to the sea through a plenum at the bow and a second plenum at the stern.

Schematic trunk and plenum arrangements at the bow and stern of the vessel are illustrated in Fig. 2.2 and 2.3, respectively. These trunks are flooded with seawater to reduce the buoyancy of the vessel in the ballast condition in order to get the vessel down to its ballast drafts.

Since there is a natural hydrodynamic pressure differential created between the bow region and the stern region of a ship due to its motion through the water, a slow flow is induced in these open ballast trunks.

This ensures that the ballast trunks are always filled with slowly-moving “local seawater.” This should ensure that there is no transport of nonindigenous aquatic species across the globe. Therefore, the vessel becomes foreign “ballast-free” from the traditional viewpoint

When the ballast voyage is completed, the ballast trunks can be isolated from the sea by valves and then pumped dry using conventional ballast pumps. The need for costly ballast water treatment equipment or ballast water treatment chemicals would, thus, be eliminated.

This approach would also be equally effective for biota smaller than 50 microns. During the full load condition or any condition where ballast is not necessary, the double bottom ballast trunks can be segregated utilizing sluice gate valves. This is needed to provide the vessel adequate damage survivability.

In order to provide adequate intact stability, equivalent damage survivability, equivalent cargo capacity, etc, the entire vessel design needs to be developed to support this concept of ballast operations as illustrated in Fig. 2.1. The ship requires a higher tank top in order to locate enough ballast trunk volume below the ballast draft and requires a greater hull depth in order to maintain the vessel’s capacity to carry light cargos, such as grain.

The Ballast-Free Ship Concept also includes features to minimize the buildup of sediment within the ballast trunks and facilitate their required cleaning; i.e., easier to clean 2.4 m high ballast trunks and the elimination of the lower part of the floors next to the shell.

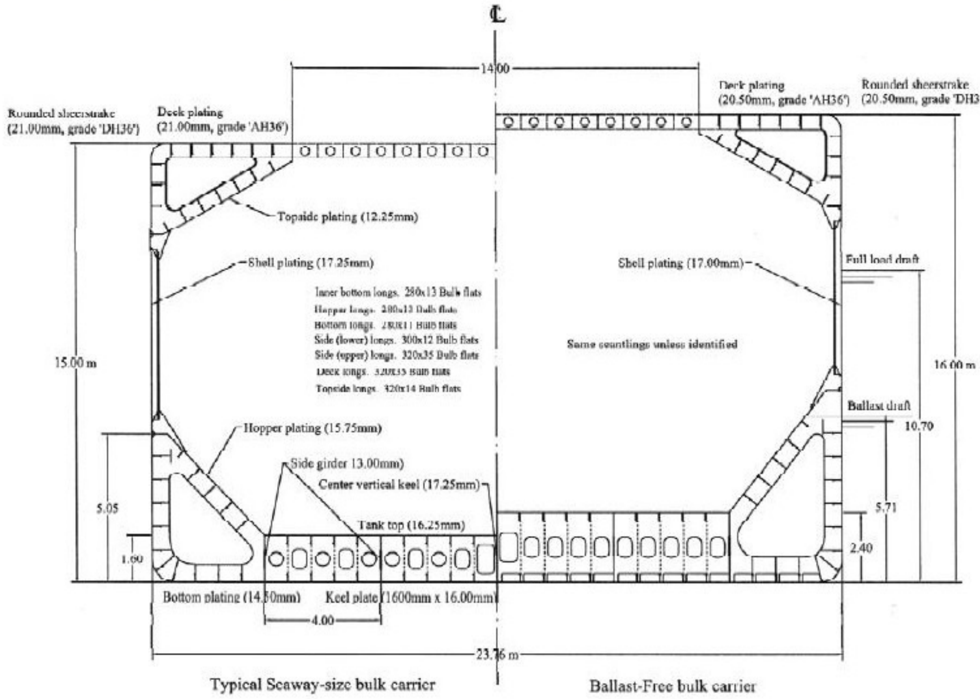

Fig. 2.1: *Typical Seaway-size Bulk Carrier (left) and Ballast-Free Concept Bulk Carrier (right)*

As noted, the initial research on the development of the Ballast-Free Ship Concept was limited by its required comprehensive research scope and limited associated budget.

For budgetary reasons, it was only feasible to support model testing that utilized an existing model. Although the vessel type of greatest interest for the Great Lakes nonindigenous aquatic species introduction problem is the Seaway-size bulk carrier, the best available model was of a relatively finer, higher-speed barge-carrying Lighter Aboard Ship (LASH) vessel.

This existing model was modified to utilize a more conventional stern, but the model test results were not directly applicable to the Seaway-size bulk carriers studied in detail in the rest of the research effort.

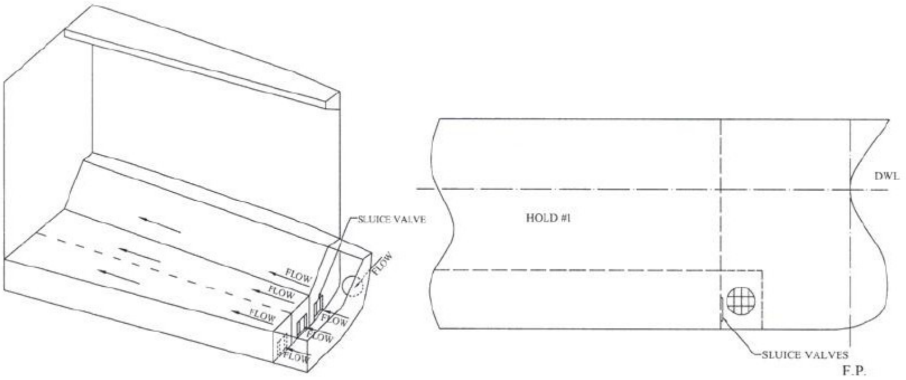

Fig. 2.2: *Typical Forward Plenum and Collision Bulkhead Arrangement*

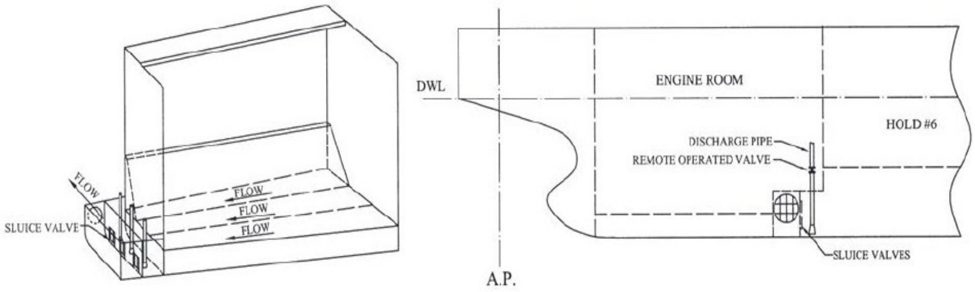

Fig. 2.3**:** *Typical Aft Plenum Arrangement*

Budget restrictions in the initial investigation phase also required that the model tests be limited to a single system design for the existing model. There was no opportunity to optimize the hydrodynamic design of the system to minimize the economic impact of the Ballast-Free Ship Concept design. Model tests and Computational Fluid Dynamics (CFD) simulations using the modified LASH vessel hull showed that the specific ballast intake and discharge locations and method tested in the initial investigation resulted in a modest 2.2% increase in resistance but a more significant 7.4% increase in the required propulsion power. This specific result assumed a change in the ballast water within the ballast trunks once every two hours, which would meet the environmental intent of the Ballast-Free Ship Concept. The large power increase could result in an undesirable engine size increase and would result in fuel cost penalties. In that investigation, it was concluded that further hydrodynamic optimization could eliminate most, if not all, of this significant added power requirement.

3. Experimental Investigation

The main particulars of the ship are shown in Table 3.1. The characteristics of the model in the ballast condition are presented in Table 3.2. The bow and the stern of the constructed amodel are shown in Figs. 3.1 and 3.2, respectively. All the tests were carried out at the ballast drafts at which the Ballast-Free trunks would be in use.

Main Particulars of the Ballast-Free Bulk Carrier Table 3.1

Waterline length (m)	195.5
Maximum beam (m)	23.76
Depth to main deck (m)	16.00
Full-load draft (m)	10.70
Block coefficient C_B	0.835

Characteristics of the Ballast-Free Bulk Carrier Model in the Ballast Condition Table 3.2

Geometric scale ratio λ	37.92
Waterline length (m)	5.00
Maximum beam (m)	0.627
F.P. draft @ 40% DWL (m)	0.113
A.P. draft @ 70% DWL (m)	0.198
Wetted surface area (m^2)	5.34

3.1 Arrangements and Design of Inlet and Outlet Plena

A full-scale diameter of approximately 1 m was chosen for the plena inlet and outlet to ensure a smooth inflow and outflow without imposing severe constraints on the structural arrangements.

The corresponding inlet/outlet diameter at model scale is approximately 2.6 cm. The flow rate in the longitudinal trunks was calculated assuming a full-scale volume of ballast water equal to 18,500 m^3. This value was obtained from similar ships, under the assumption of flooding both the normal ballast tanks and a central cargo hold for a heavy weather ballast condition. Assuming an exchange time of 90 min and utilizing Froude scaling, the internal flow rate at model scale is :

$$Q_m = Q_s \lambda^{-5/2} = 3.9\cdot10^{-4}\ m^3/s. \qquad *(1)$$

Fig. 3.1. *Bow View of the Seaway-sized Bulk Carrier Model*

Fig. 3.2. *Stern View of the Seaway-sized Bulk Carrier Model*

Using the continuity equation and assuming a symmetrical plenum about the centerplane, the average discharge fluid speed is 0.382 m/s.

The selection of the inlet location was based primarily on providing a pressure differential capable of sustaining a steady trunk (internal) flow. In addition to this, the inlet must be adequately submerged to avoid air ingestion and interaction with the free surface and the bow-generated wave system. An important design constraint is the low forward draft in the ballast condition. It was decided to locate the water inlet right on the face of the bulbous bow in the area around the stagnation point to take advantage of the high positive pressure in this region. Therefore, the centroid of the water inlet was placed at approximately 25% of the design waterline (DWL) above the keel as shown in Fig. 3.3. In this way, the water exchange goal of 99% in less than two hours can be reached, or even exceeded (Kotinis 2005). The fluid exchange at the ballast speed of 15.5 knots (assuming no voluntary speed reduction due to heavy weather) can then be achieved in a distance less than 30 nautical miles.

Fig. 3.3. *Location of Forward Ballast Trunk Inlet*

In order to investigate the effect of the water discharge on the flow at the stern, two different discharge locations were selected; one close to Station 17 and one close to Station 19 as shown in Fig. 3.4. Station 17 is approximately at the location of the forward engineroom bulkhead in the full-scale ship; Station 19 is approximately at the aft engineroom bulkhead. The discharge at Station 17 was located about the 45% DWL and the discharge at Station 19 was located at about the 30% DWL. The flow was discharged at about 10 degrees to the local hull surface. In this way, the effect on the boundary layer flow, as well as the effect on the propeller inflow, could be investigated in a systematic manner.

The choice of the discharge locations investigated was based on the results of a numerical CFD investigation of the stern flow. These results are presented in the next section. If trunk flow rate maximization were the only criterion, the water outlet should be located in an area with high suction pressure to maximize the pressure differential. On the other hand, when the propeller operation is taken into account, the objective is to minimize the power requirement subject to achieving adequate ballast trunk flow.

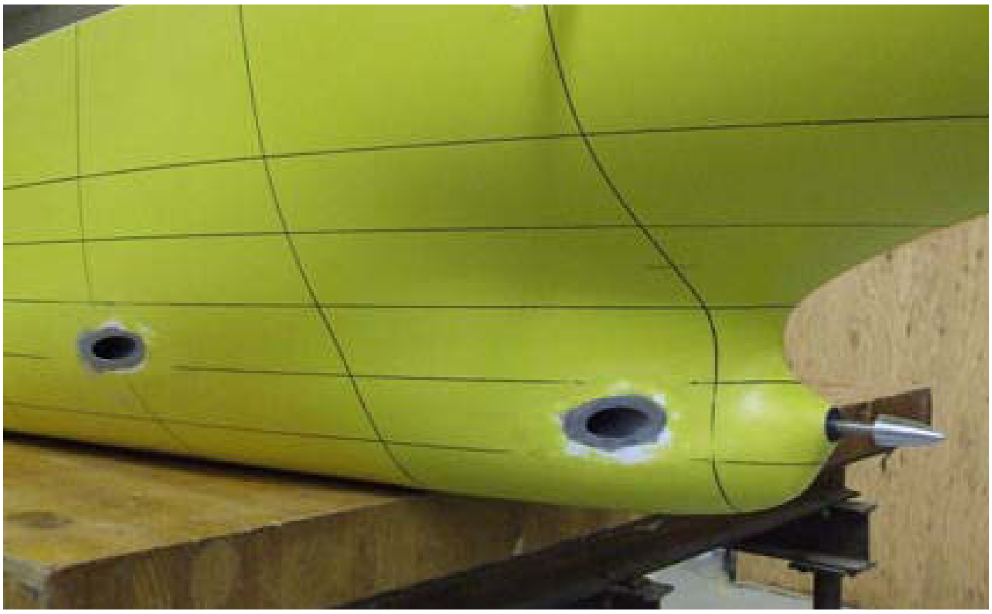

Figure 3.4. *Location of Two Ballast Trunk Discharges Investigated*

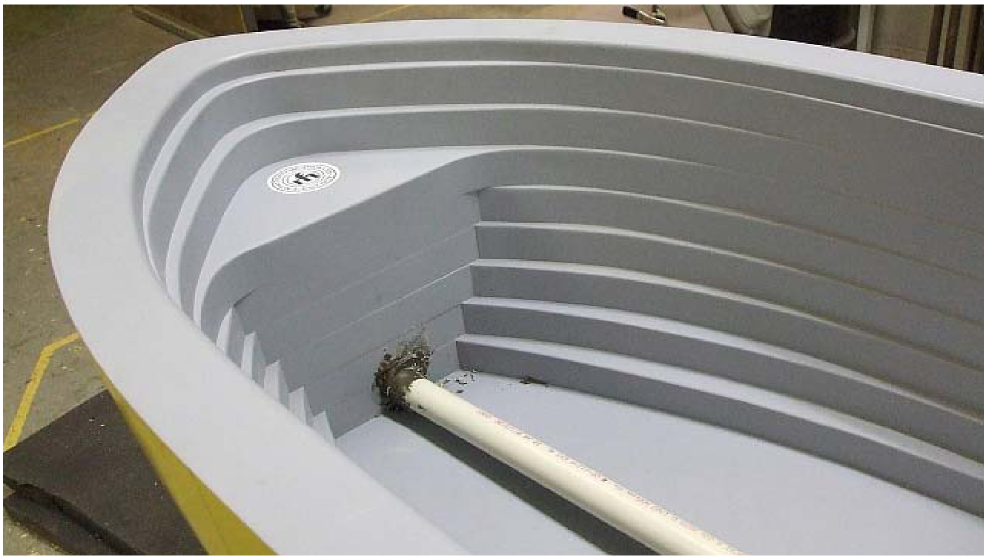

Figure 3.5. *Internal Flow Arrangements in the Bow Region*

Figure 3.6. *Internal Flow Arrangements in the Stern Region – Looking Forward*

3.2 Experimental Setup

Because the modeling of the internal flow trunks could not be reliably scaled at the small model scale utilized, the scaled total trunk flow was pumped rather than using natural flow. The trunks were modeled by a 1-inch internal diameter pipe that was connected to the water suction at the bow and the water discharge at the stern. The steady internal flow was created and maintained by a flexible-impeller pump. The flow rate was controlled by a high-precision needle valve and monitored by a flow meter. The flow was diverted to the selected discharge location and subsequently split to provide a symmetric water discharge at the stern of the model. Details of the internal flow model are shown in Figs. 3.5 and 3.6.

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