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Flushing ballast tanks

Zhixin Qi*, Ian Eames, Alistair Greig

University College London, Torrington Place, London WC1E 7JE, UK

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ABSTRACT

The International Maritime Organization requires ballast water tanks to be flushed through with three tank volumes to remove aquatic species. We apply a network model for multiply connected compartments to analyse the influence of internal geometry and inlet–outlet positions on how much of the initial water of each compartment is flushed in time. A complementary experimental study was undertaken to quantify the flushing from 2×2, 3×3 and 5×4 tank configurations by an optical method. The agreement between the predictions and measurements is good. The results show that the flushing in a multi-compartment tank is generally more efficient than perfect mixing. The 95% reduction is met after three exchange volumes in all cases. The outlet needs to be positioned far from the inlet to reduce bypassing through the tank. These results are finally discussed in the context of international regulations for flushing ballast tanks.

1. Introduction

The largest fraction of the world's trade is transported by ships with estimates varying from 66% to 80% (see Wright and Mackey, 2006). Ballast is essential for the safe operation of ships; it ensures stability, trim, and structural integrity by maintaining shear stresses and bending moments within acceptable limits. The ballast on most ships is usually achieved using water, and the amount of ballast water transferred globally each year is estimated to be 10 billion tonnes (see Wright and Mackey, 2006; MacPhee, 2006). Ships usually discharge ballast water in ports while loading and take up ballast water in destination ports while unloading, where the water is shallow and rich in aquatic organisms. Taking up non-indigenous species (NIS) in one port and transporting them to another sea can lead to significant environmental problems. Zebra mussels, native to the Caspian Sea region of Asia but transported to the Great Lakes via ballast water, reduce the amount of phytoplankton available for other organisms and cost \$100 M/year to manage control measures (see Pimentel et al., 2000). In order to prevent the transfer of aquatic organisms from one region to another via ballast water, the International Maritime Organization adopted the Ballast Water Management Convention in 2004. According to Ballast Water Exchange Standard, Regulation D-1 of the Convention, ships utilising the exchange method need to exchange ballast water at least 95% by volume; for ships exchanging ballast water by the pumping-through method, pumping through three times the volume of each ballast tank was considered to meet the standard. Pumping through less than three times the volume may be acceptable if the procedure can demonstrate that at least 95% of original ballast water is removed.

The original intention of the Ballast Water Convention was that the water exchange technique would be a short-term solution and be replaced by water treatment. When the Convention was written no ballast water treatment plants were in production. Their development has been slower than expected due to various reasons including an underestimation of the technical challenges, insufficient resources and market economics (see King et al., 2012). The magnitude of the logistical effort required for effective enforcement and regulation of various aspects of the Convention have also been identified as potential barriers to implementation (see Wright, 2012). These are some of the reasons that the Convention is still not ratified even though some of its initial deadlines for implementation have already passed. The situation is complex but the outcome is that ballast water exchange is still in widespread use and will continue to be so for quite some time. Moreover some authorities are now insisting on a combination of ballast water exchange and treatment. It is also becoming clear that a much more detailed understanding of the flow behaviour within ballast tanks is required for compliance assessment and enforcement once ballast water treatment is introduced.

Ballast tank designs are currently driven entirely by structural considerations of the vessel, customised for maximum cargo capacity and practicality of human access and construction. The tanks are structurally complex and composed of interconnected bays, longitudinal and transverse stringers/stiffeners to improve the strength of the vessel. The usual layout of ballast tanks on a bulk carrier consists of the tanks located at the fore peak, aft peak,

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* Correspondence to: Mechanical Engineering, University College London, Torrington Place, London WC1E 7JE, UK.
E-mail address: zhixin.qi.10@ucl.ac.uk (Z. Qi).

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upper/topside wing, lower/hopper wing and bottom. The double bottom tank and hopper tank are unified and in some cases are connected with the upper wing/topside tanks by a trunk that allows the ballast water to flow between them. Fig. 1 shows a schematic of the ballast tanks of a bulk carrier. Other tankers have slimmer ballast water tanks along the ship and do not alternate. These ballast tanks are large with a simple box design, and have a capacity of 40,500 m^3 of water serviced by pumps with a flow rate of 3000 m^3/h (or $\sim$1 m^3/s).

Inside the double bottom tank, individual compartments are generated by crossing longitudinal and transverse stiffeners and frames with lightening holes. The neighbouring compartments are associated with lightening holes, stringers and limber holes, shown in Fig. 2. The ballast tank flushing is achieved either from the inlet as shown in Fig. 1(b) by the sequential (empty/refill) method or through overflow arrangements by the flow through method. For the flow-through method, the overflow is achieved from two air/sounding pipes either on the deck or to the side, typically with a diameter of 0.15–0.2 m.

The NIS that can be drawn into a ballast tank range from bacteria, plankton, fish eggs or crabs to fish (see Wonham and Carlton, 2005). Associated with these is a settling or swimming velocity, ranging from 0.1 to 150 mm/s (see Wong and Piedrahita, 2000; Magill et al., 2006). The smaller species are essentially advected with the flow and can be regarded as essentially passive during flushing. When the species are passive, the fraction of the

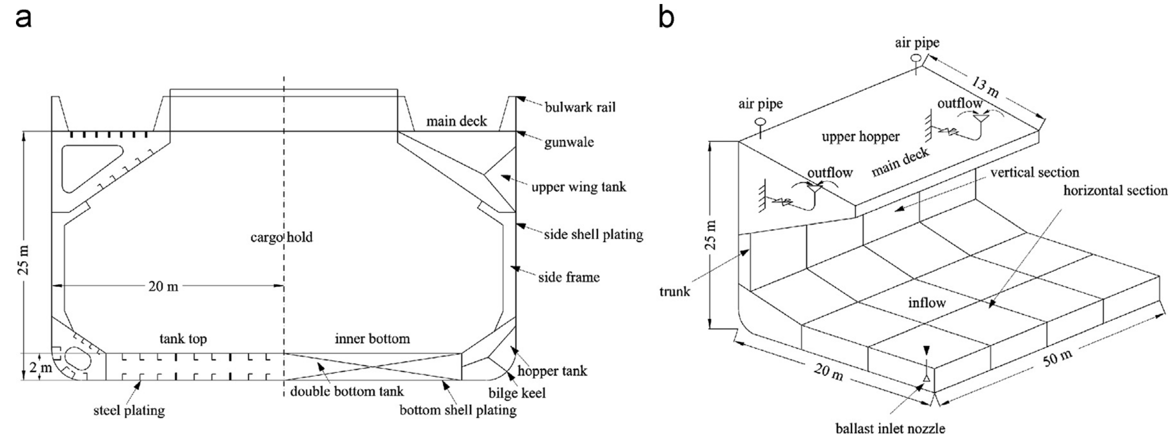

Fig. 1. Schematic drawings showing (a) oblique and (b) cross-section view of a ballast tank. The tanks are separated into port and starboard chambers (redrawn from Armstrong, 1997).

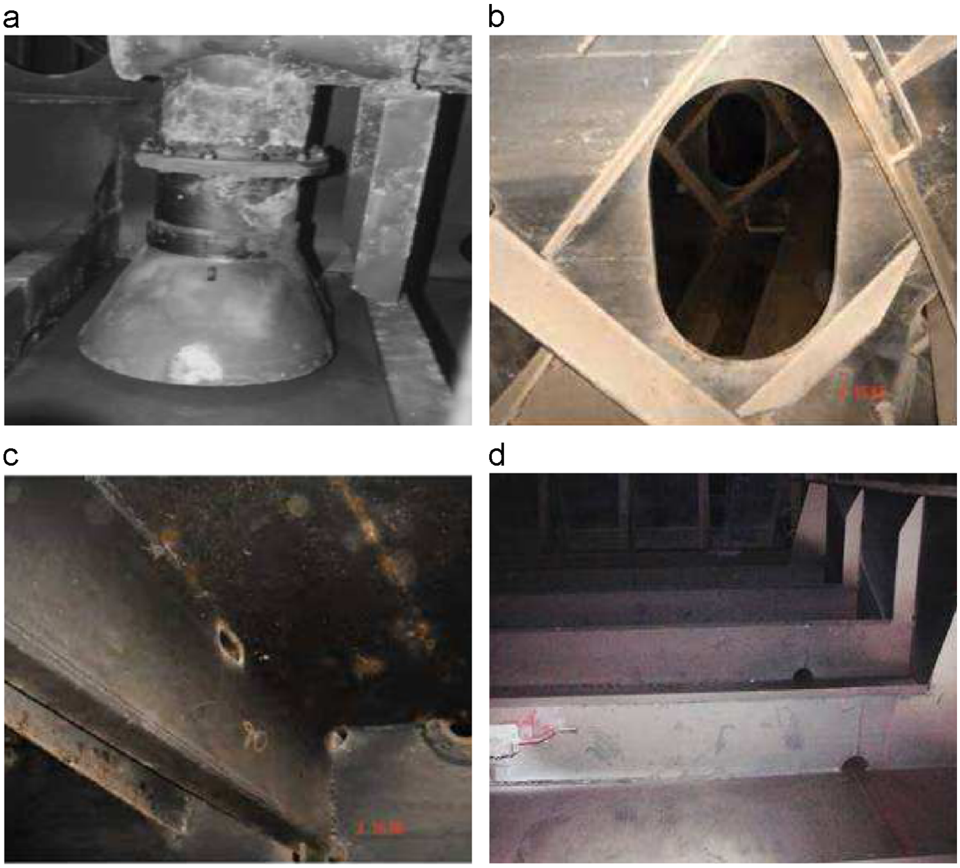

Fig. 2. Photographs of the interior geometry of a ballast tank showing (a) an inlet nozzle, (b) a lightening hole, (c) top limber holes, and (d) stringers with lower limber holes (taken from Steinhauer, 2007).