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THE FLOATING HARBOUR TRANSHIPPER: NEW-GENERATION TRANSHIPMENT OF BULK ORE PRODUCTS

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ABSTRACT

Bulk products such as iron ore and coal are usually shipped directly from shore facilities using large bulk carriers. This often involves significant cost due to major dredging operations, long jetties, large storage sheds and the acquisition of large tracts of coastal land. The costs of direct shore to an ocean-going export vessel (OGV) loading often run into billions of dollars – prohibitive for small- to medium-scale mining operations, particularly in remote regions with only distant access to deep water ports. The current industry standard for mitigating these issues is transhipping; the bulk cargo is transported from a smaller shore based facility to the export vessel moored in deep water by a small feeder vessel. Transhipment, while mitigating many of these issues, does introduce other concerns with respect to limiting seastate, environmentally harmful dust and potential spillage during materials transfer.

The Australian company Sea Transport Corporation and the Australian Maritime College at the University of Tasmania are developing new technology for bulk ore transhipment: the floating harbour transhipper (FHT). The FHT is essentially a large floating warehouse with an aft well dock to support material transfer operations from the feeder vessel.

The major advantages to the mining export industry are in the form of environmental and economic improvements, in some cases completely avoiding expensive dredging while minimising the environmentally invasive onshore infrastructure. In addition, the whole process is enclosed, therefore eliminating grab spillage and dust transport issues common to other transhipping methods.

This paper presents an overview of the main hydrodynamic issues currently being investigated: primarily the interaction between multiple floating bodies close to one another in a seaway. The two primary ship-to-ship interactions that are being investigated are the effects experienced by the feeder vessel when it is docking or undocking within the FHT well dock and the interactions between the three vessels when operating in close proximity in an open seaway.

A combination of physical scale model experiments and numerical techniques is employed, with a significant portion of the experimental program dedicated to the validation of the numerical simulation codes used to investigate the behaviour of the vessels.

ShipMo3D is an object based library developed by DRDC for the purpose of analysing the seakeeping performance of vessels operating in a seaway in either the frequency or time domain. The capabilities of ShipMo3D are applied to this novel application in an attempt to provide realistic simulations of the interaction between the vessels of the FHT system.

DualSPHysics, an open source Smoothed Particle Hydrodynamics (SPH) code, is being applied to the domain within the very restricted water environment of the FHT well dock to investigate the fluid flow behaviour and the effect that this has on the feeder vessel when entering/exiting.

INTRODUCTION

The Floating Harbour Transhipper Concept

The Floating Harbour Transhipper concept has been developed for efficient and safe transfer of bulk cargo from shore to an ocean-going export vessel. The transfer process proceeds as follows:

1. Cargo is loaded onto a small feeder vessel (up to 10,000 dwt capacity) at shore;

2. The small feeder vessel transits and enters the stern well dock of the floating harbour transhipper, a large vessel that is moored semi-permanently in deep water off the coast;
3. Cargo is transferred from the small feeder vessel and stored on the floating harbour transhipper until an ocean-going export vessel comes alongside for loading. Cargo can also be loaded directly from the feeder vessel to the export vessel utilising the FHT's materials handling equipment.

The concept is depicted in Figure 1, with the feeder vessel situated in the well dock and the export vessel moored alongside. Figure 2 gives a schematic of the feeder vessel in the well dock.

The Need for an Alternative Transhipment Concept

It is now widely acknowledged that Australia's mining boom has peaked, that the future of the industry will rely increasingly on cost-efficiency to compete with emerging sources in Asia and Africa, and on increasing the volume of exports. Less widely known is the fact that Australia's potential to increase export bulk ores is dependent on growth in the number of small to medium sized companies/mines – many of which will operate in very remote locations.

Relocating the major stockpile of bulk products to a transhipment vessel can significantly reduce the capital and operating costs because the large, expensive sheds ashore and wharf facilities can be greatly downsized or eliminated. In mining applications, these sheds are often negative pressure environments to minimise the spread of dust, adding further capital and operating costs. It has been estimated that a transhipment solution can be operational in a quarter of the lead time of traditional infrastructure, resulting in positive cash flows much sooner. This is because the planning and approvals process to gain permits for the construction of large coastal facilities are challenging, costly and lengthy. Another compelling reason for adopting an FHT is that it will provide a more environmentally friendly solution with significant advantages for the national economy, and mining communities and companies. The FHT will:

- provide dust-free transhipment, eliminating grab spillage and dust issues, common to other transhipping methods;
- allow shallower draught feeder vessels to be used from very small ports or unprepared beaches at scheduled times, eliminating the need for costly dredging of sensitive areas;
- reduce the need for road transport (and associated greenhouse gases) by using small harbours closer to the mine.

Since the feeder vessels require only a small shallow harbour, the cost of dredging and constructing a major jetty structure and the bond for infrastructure removal at end of the mine life will be largely eliminated. On completion of the mine life, the small harbour will be available for the community or traditional land owners, for fishing and recreational boats, also minimising the environmental bond required by most governments.

The new technology will enable mining royalties to be secured within a shorter timeframe, reducing the capital and operating costs as well as the sovereign risk for the mining companies. Port charges, such as berthage, wharfage and tugs, will be reduced, and demurrage will be largely eliminated because the FHT will be capable of handling rougher seas than traditional transhipping operations. The FHT well dock arrangement will eliminate stevedoring damage to feeder and transhipment vessels and will provide safe handling of inbound fuel and other dangerous goods, such as ammonium nitrate.

The Australian Journal of Mining (AJM) ran a feature on transhipment, in which the advantages and disadvantages of eight different concepts were compared, including the FHT concept [1]. The article considered the following attributes of each concept: capacity, capital expenditure, operating expenditure, stockpile, blending of cargoes and environmental impact. In the ensuing discussion, AJM is quoted "Sea Transport's floating harbour terminal ... has the potential to be an innovation in the industry, as it reduces the reliance on onshore facilities. It has the potential to make transhipment more accessible to large volume offshore transfers, but it remains to be proven at this point".

EXISTING RESEARCH

Well Docks

Well docks are used by navies to enable operation of landing craft, which can transit between the mothership and shore. When operating a smaller vessel within the well dock of a ship, the presence of a seaway can introduce the risk of the smaller vessel striking the bottom of the well dock or overhead structure.

Several authors have examined well dock operations for small craft operating with large naval vessels. Hopman *et al*. [2] conducted model tests of well dock operations. Bass *et al*. [3] coupled a potential flow ship motion code with a commercial CFD code to simulate fluid motions within the well dock. Cartwright *et al*. [4] applied smoothed particle hydrodynamics (SPH) to simulate well dock operations.

Recent proof of concept investigations for the FHT [5, 6] examined motions of the feeder vessel operating within the FHT well dock. Here, model scale experiments confirmed that the FHT concept significantly reduces the motions of the feeder vessel over traditional side-by-side transhipment operations. Some motions of the feeder vessel, such as pitch and roll, were reduced by an order of magnitude when the feeder was located inside the well dock, compared with traditional operations.

Large Ships in Close Proximity at Sea

When two or more ships are in close proximity, hydrodynamic interaction effects can influence ship motions in waves. Hydrodynamic interaction effects are of practical interest to the offshore petroleum industry and to navies conducting replenishment at sea [7-21]. Comparisons between numerical predictions and model tests indicate that potential flow methods for seakeeping predictions can be successfully extended to ship interaction cases.

When two vessels are moored side-by-side, it is expected that the motion of each vessel will be affected by the presence of the other vessel, through both the mooring system and from hydrodynamic interaction. Thus, it is inappropriate to assume that the motions of any vessel alone in a known seaway will be the same as the case when that vessel is alongside any other vessel. In addition, the manner in which the vessels are connected and moored can have a significant effect on the resultant motions. This is one of the reasons why validation of numerical predictions, usually through the conduct of physical scale model experiments, is so important in such cases. One common general trend found from the published studies is when a smaller vessel is moored alongside a larger vessel, it is the smaller vessel that experiences greater motions.

Both Hong et al. [22] and van der Valk and Watson [23] investigated the forces and motions of both side-by-side and tandem (where one vessel is abaft the other) vessel arrangements through the conduct of physical scale model experiments. A similar study using a higher-order boundary element method was conducted by Choi and Hong [24]. Each of these studies indicated that the aft positioned vessel has lesser motions due to the shadow effect of the windward vessel. The tandem position is not under consideration in the present study as it is generally used for the transfer of liquid products, not solid materials.

CURRENT AND PROPOSED RESEARCH

The proof of concept studies by Macfarlane *et al*. [5] and Ballantyne *et al*. [6] have opened up the opportunity to focus on the fundamental science to overcome some challenges for implementing the FHT technology. This preliminary work was undertaken assuming a Panamax size FHT and OGV (80,000 dwt, with a feeder vessel load of up to 3,000 dwt). Australian exporters typically load onto Capesize ships (180,000 dwt and about 10,000 dwt feeder vessel loads), which are the focus of the current research. The sea conditions of interest pertain to several relevant remote regions of the Australian coast, including the Northwest Shelf, Spencer Gulf, and the Gulf of Carpentaria.

The project will involve physical scale model experiments, numerical predictions and associated analysis, with the aim to provide the essential data for undertaking the engineering design process. The experiments are being performed in the controlled environment of the AMC model test basin with a scale-factor of 1:60. This scale factor was selected to provide the largest possible scale to enable the exploration of the sea states of interest within the limitations of the testing facility. The scale of 1:60 resulted in models of both FHT and OGV exceeding lengths of 5 m.

As for any dynamic multi-body floating system in open ocean conditions, there will be a large number of variables to consider:

- wave environment (heading, height, wavelength, irregular wave spectra, multi-directionality);
- wind environment (direction relative to wave environment, strength);
- the load condition of each vessel (feeder vessel, FHT, and OGV). Note that in reality the loading of each vessel will be constantly changing during loading operations;
- the mooring systems of the feeder vessel, FHT and OGV;
- the propulsion system of the feeder vessel while manoeuvring.

Relative Motions of the Moored Vessels

One aim of the present study is to validate numerical predictions of the motions of the three vessels within the FHT system while one or two of the three vessels are stationary in their operational docked/berthed locations. Once validated, it is intended to use the software to predict the operational envelope (maximum sea states) in which the FHT is able to transfer product from the feeder vessel to the FHT, from the feeder vessel to the export vessel, or from the FHT to the export vessel.

The numerical package selected for this purpose, ShipMo3D, is an object-orientated potential flow code for predicting ship motions in calm water and waves in both the frequency and time domains [25]. The code has been primarily developed to support the safe design and operations of naval vessels but is also adaptable to most vessel types. Simulation with the frequency domain is very computationally efficient for analysing vessels that are operating at zero or steady speed in moderate or smaller seaways while time domain simulation is required for the analysis of a freely manoeuvring vessel or one that is operating in heavy seas [26].

The upcoming release of ShipMo3D Version 4.0 sees the introduction of multi vessel support, thus allowing more than one vessel operating simultaneously within a seaway to be simulated and the motions analysed.

A number of investigation methods for studying the behaviour of the FHT system operating in a sea state were considered. The primary options that were considered were an entirely experimental approach, a RANS equation based solution using one of the established CFD codes (Star-CMM+), a potential flow code, and a ship simulator based approach. A CFD approach based on the RANS equations was determined to be too computationally intensive for the vast matrix of conditions that are required to be investigated.

Similarly an entirely experimental approach was also identified as being excessively time intensive while still requiring another method to validate the findings. This validation could have been using RANS based simulation as the condition matrix would be vastly reduced for validation purposes. Ultimately a fully experimental approach would not provide the easily adaptable and versatile design tool that is ultimately desired at the conclusion of this study.

The ship simulator option appears to be the ultimate goal of this research as it will enable the crews that will operate the vessels within the FHT system to perform training in a cost effective and safe facility. This is of particular importance given the unique nature of the vessel operations proposed for the FHT concept. Unfortunately further investigation into the viability of proceeding directly to a ship simulator solution revealed the entire scope of operational and environmental conditions would be required to be solved using another method in order to develop that ship simulator capability. As such this approach was relegated to a downstream aim of the project rather than a feasible initial simulation tool.

The potential flow approach is capable of achieving the requirement for a computationally efficient simulation and has a good track record of providing robust solutions for sea state simulations. The major restriction of potential flow is assumption of inviscid flow which ignores all viscous effects. However, the recent advances within the application of potential flow to multibody situations have made very significant steps to mitigating the problems related to this restriction within the field of application required [8].

In order to apply the potential flow code selected, ShipMo3D, to the FHT system, there is significant development and validation required to ensure a robust numerical simulation tool. To achieve the desired simulation capability a building block approach was adopted for the development and validation process. This approach involved breaking the overall capability of the code into a number of stages which are intended to identify which parts of the system the code is already capable of simulating reliably and which areas require further development. An example of this approach is the way in which the capability is developed to simulate the motions of the OGV and the FHT while the OGV is berthed to the FHT. Firstly ShipMo3D is being used to simulate the motions of the FHT and OGV in isolation and these characteristics are compared to limited model tests to ensure that the numerical models of the vessels in isolation are reliable. Once each vessel in isolation has been validated, both the vessels operating simultaneously in their operational positions will be simulated and the result compared with limited experimental conditions.

Discrepancies between the numerical and experimental results at each stage will be investigated to provide a reasonable and scientifically sound explanation for the difference. If it is determined that a modification can be made to the ShipMo3D code that will yield more robust results then this will be implemented and the process repeated, thus developing the capability of the code to provide a robust numerical simulation tool for the FHT system.

Limitations of currently available numerical methods include:

1) Most approaches assume that the vessels are travelling with the same nominal steady speed and heading.

2) Most approaches assume small amplitude vessel motions when evaluating hydrodynamic forces.

3) Many approaches use the three-dimensional frequency domain Green function for zero forward speed. This method doesn't fully consider the influence of ship speed on the free surface boundary condition; thus, is generally limited to ship forward speed Froude numbers of less than 0.4.

Feeder Vessel Entering/Exiting the FHT Well Dock

A particular focus is on the fluid flow within the FHT well dock while the feeder vessel enters or exits. This scenario is highly complex due to the large amplitudes of water and feeder vessel motions relative to the dimensions of the well dock. Another aim of the present research is to quantify the flow characteristics by using numerical methods to model the well dock operations.

A Lagrangian numerical method called smoothed particle hydrodynamics (SPH) will be used to simulate the fluid behaviour within the well dock. SPH is a mesh-free numerical technique which is well suited to simulating highly transient and deformable free surfaces, as its time domain nature allows greater flexibility when modelling metamorphic control volumes. The technique has been successfully applied to scenarios common in ship hydrodynamics, such as simulating the flow around a submerged hydrofoil and quantifying the motions of a floating body in waves [27, 28]. Other work has seen SPH used to model vortices [29] and seafloor erosion due to ships' propellers [30].

An open source SPH code, DualSPHysics, is being utilised to simulate the feeder vessel operations within the well dock. Although the overall objective is specific, the fact that this numerical method is relatively undeveloped means that there is a need to validate various aspects of the model against existing and new experimental and analytical data. This will be achieved through several stages of validation against experimental results.

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Figure 1: The floating harbour transhipper concept. The bow of the feeder vessel of up to 10,000 dwt capacity (foreground) protrudes from the stern well dock of the FHT (grey, centre). A Capesize export vessel is moored alongside (red and white, background). The FHT provides the offloading equipment to transfer the ore from the feeder vessel to the FHT, or from the FHT to the export vessel as shown here.

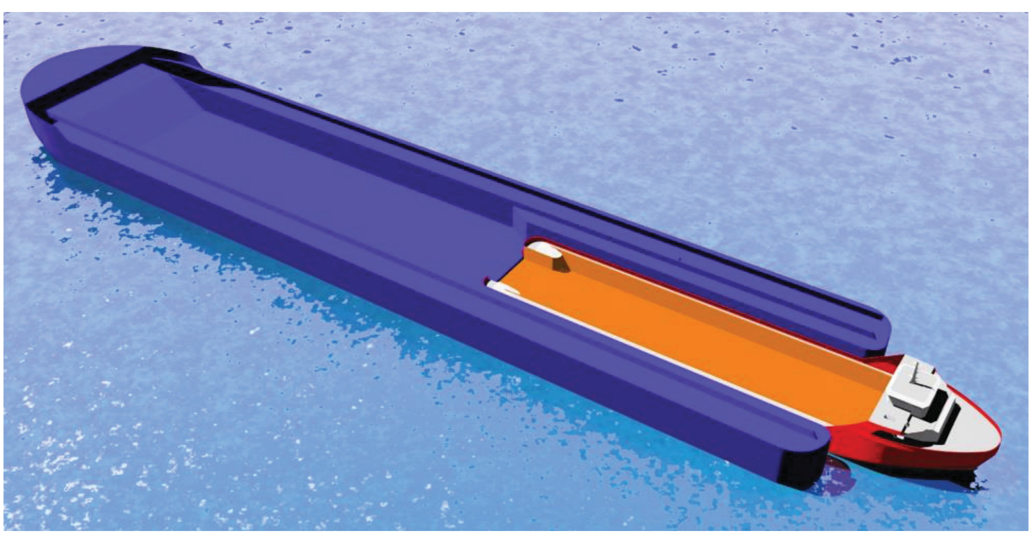

Figure 2: Stern-quarter view of floating harbour transhipper (FHT) with feeder vessel in well dock (FHT superstructure removed for clarity).