A Feasibility Review for an Uneven Baseline Basis Minimal Ballast Ship

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ABSTRACT: Although there are many kinds of advanced ballast water management systems, pioneering studies for ballast-water free ship and minimal ballast water ship concepts are in progress. In this study, the existing alternatives of ballast water are reviewed and a new design concept is studied on the basis of the existing bulk carrier hull form. To develop a new design alternative which has minimal ballast for ballast water discharge free operation, the new concept should have technical feasibilities that are related to the role of the ballast water, berth access, loading constraints, etc. For this purpose, a simplified systems engineering basis design approach is adopted using a business model as the system analysis and control tool. To check the performance feasibility of the new concept, ship resistance performance is reviewed based on a model scale ship resistance performance analysis.

Abbreviations

AUBAFL OW automatic ballast flow
BW ballast water
BWE ballast water exchange
BWM ballast water management
BWTS ballast water treatment system
CFD computational fluid dynamics
CSR-H harmonized common structural rules
Cfr friction resistance coefficient
Cp prismatic coefficient
Ctm total resistance coefficient of model-scale ship
Cfm Cf of full-scale ship
Ct residuary resistance coefficient
Cr total resistance coefficient of full-scale ship
D-1 regulation about ballast water exchange
D-2 regulation about ballast water treatment
DHP delivery horsepower
DISV displacement volume
DWT deadweight tonnage
EARS E explicit algebraic Reynolds stress model
EHP effective horsepower
FOC fuel oil consumption
IGES initial graphics exchange specification
ISO/IEC international organization for standardization/international electro-technical commission
KPPs key performance parameters
KB vertical distance between the keel and the center of buoyancy
MIBS minimal ballast water ship
MOE measure of effectiveness
MOP measure of performance
NOBS non-ballast water ship
RANS Reynolds-averaged Navier-Stokes
TA trim aft
TF trim forward
Tm mean draft at a midships
TPMs technical Performance measures
WAVIS wave and viscous flow (proprietary brands)
VLCC very large crude oil carrier
ULCC ultra large crude oil carrier

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1. Introduction

Because the measures from the Ballast water management (BWM) convention are being enacted in order to reduce the environmental damage caused by the global movement of marine life in the ballast water of ships (Albert et al., 2013), the negative effect of treated ballast water on the marine environment is another urgent issue (Werschkun et al., 2014). Notably, research on non/minimal ballast water vessels is actively underway in response to the D-1 or D-2 discharge standards of the convention. When considering the role of ballast water, as shown in Table 1, the ballast water contributes to the ship’s stability via proper maintenance of the draft and the center of gravity of a ship during voyage. Another aim of the ballast water is to maintain the appropriate immersion depth of the propeller for propulsion efficiency.

### Table 1 Roles of the ballast water in a ship (Isbester, 2010)

| Role of Ballast Water | Description |
|-----------------------|-------------|
| Maintain the stability of the ship | Trim and heel control |
| Secure immersion depth of the propeller | Reduction of slamming |
| Reduction of the bending moment of the ship | Relieve the shear force of the ship |

Ballast water is also used to adjust the trim and heel of a ship. The bending moment and shear force can also be adjusted by the ballast water.

Depending on the ship types and routes, generally, 30% to 40% of the deadweight tonnage (DWT) is used as ballast water (Kerr, 1994). Many pioneering studies have been conducted to meet the D-1 or D-2 discharge standards of the BWM convention without needing to discharge the environmentally harmful ballast water. Table 2 shows alternatives for the BWM methods (GEF, U. and IMO, G. P., 2011).

### Table 2 Alternatives for the BWM methods [derived and edited from GEF, U. and IMO, G. P. 2011]

| Alternative methods | Features | Benefits | Penalties | Suitable Ship type/s |
|---------------------|----------|----------|-----------|----------------------|
| No ballast water    | (a) Novel hull design (b) Use of ‘solid ballast TEUs’ | Avoids all cost associated with BWM | Higher hull build/ operating cost | (a) Ro-ro pax, car, container, high volume cargo ships |
| No or minimal discharge | Wide beam V-hull design | Avoids cost of large BWTS | Higher building cost, berth access or loading constraints due to wider beam | New dry bulk carriers |
| Storm ballast (must meet D-2) | Fresh water shifted from tank to tank | Avoids all cost of BWTS | Reduces cargo capacity, air-draught, tank survey/inspection | Existing and new container ships, ro-ro pax, liners, livestock carriers |
| Internal ballast (must meet D-2) | Only drinking water is added to clean tank/s | Avoids costs and loss of space for BWTS | Cost of potable water production/purchase | Super yachts, cruise liners, some livestock carriers, pax and military vessels |
| Continuous flow | Replaces ballast tanks with buoyancy trunks | Avoids costs of large BWTS and propeller efficiency gain/s | Higher build costs, risk of biota/sediment accumulation prevent | New Seaway-size and other large bulk carriers |
| Loop ballast exchange (above D-1 and may approach D-2) | Multiple valves convert each BW tank into a free flooding buoyancy compartment | Avoids costs of BWE pumping and very large BWTS | Costs of multiple valves and control systems, valve servicing, coating and cleaning, slight increase to hull drag | Existing and new cargo ships |
| Dyna ballast (exceeds D-1) | Enhanced bluewater BWE pumping | Avoids costs of BWTS | Any sediment/biota accumulating in a low-flow zone | Most types of existing and new cargo ships |
2. Feasibility Study

To design a new minimal ballast vessel, a ship must be designed that has the functions of ballast water without or with the minimum use of ballast. The perspectives of performance, ship stability, resistance, trim and heel controllability, berth access and loading constraints should be considered. Technical complexity and cost related matters are also considered to ensure technical and economic feasibility.

To compensate for the existing BWM alternatives’ penalties, an appropriate approach and design process are required. In a systems engineering process, it is essential to identify, validate, and verify the various constraints of shipbuilding and operation in the design phase for the development of minimal ballast water vessel. Generally, the systems engineering basis design process involves a “system analysis and control tool”, which allows for the effective management of various design entities from various viewpoints, including technical and economic feasibility (Leonard, 1999; Kang et al., 2016). In this study, the business model was used as a system analysis and control tool, which was suggested by Kang et al. (2016). The business model consists of six elements: the design of a new concept for a minimal ballast vessel (Task); the required value of the enhanced berth access and loading capability compared to the existing ‘MIBS’ (Value); the expected revenue of the designed concept, such as a decrease in the ecosystem disturbance (meeting D-2) and the reasonable hull build cost (Revenue); the available and considered infrastructure, such as port facilities, ships in operation, rules and regulations, ship yards (Infra); the channels to enable the design concepts, such as technical and economic feasibilities (Channel); and the stakeholders of the task, including ship owners, ship builders, port authorities, classification societies, and fishing industries (Stakeholder). The factors considered in this study are shown in Table 3.

By adopting a business model for the systems analysis and a control tool for the design process, the ISO/IEC 15288-based “Vee” design process was adopted and modified, as shown in Fig. 1. In the early phase of the design process, the measure of effectiveness (MOE), key performance parameters (KPPs), measure of performance (MOP) and technical performance measures (TPMs) should be identified in order to validate and verify the feasibility of the design results in the early phase of the design process. During the design process, all the design aspects should be analyzed and determined within the boundaries of

Table 3 Business model for a new non / minimal ballast ship design

| Task          | Minimal ballast operation of a ship |
|---------------|-----------------------------------|
| Value         | Enhanced berth access and loading capability compared to existing ‘MIBS’ |
| Revenue       | Decrease in ecosystem disturbance (meeting D-2), a reasonable hull build cost |
| Infra         | Port facilities, ships in operation, rules and regulations, shipyards |
| Channel       | Technical and economic feasibility |
| Stakeholder   | Ship owners, ship builders, port authorities, classification societies, fishing industries |

![Fig. 1 Design process for a new minimal ballast ship design [derived and edited from (Kang et al., 2016)]](image-url)
the defined business model.

2.1 Requirement analysis
To achieve this goal, eight requirements were derived, as shown in Table 4. R1 to R7 are the general requirements for a non/minimal ballast water ship. The new design should meet the requirements at the same level as the previous alternatives. R8 is the requirements to overcome the existing difficulties of a ‘storm ballast’ of the ‘no or minimal discharge’ alternatives.

R1 is a requirement related to the stability of a ship. When changing the existing hull form, such as the MBIS, it is difficult to achieve the same stability as that of the existing ship. In such cases, the placement of the keel or stabilizer should be reviewed in terms of the dynamic behavior, propulsion power of the ship, and cost. R2 is a requirement for the trim and heel control, considering the weight distribution of cargo. R3 stipulates the immersion depth required for securing the self-propulsion capability of a ship. R4 is a requirement related to the operation cost of the ship. R5 states the condition for bow slamming reduction, which should be considered together with R3 to ensure the proper immersion depth of the bow. R6 and R7 are requirements for managing the load applied to the ship according to the cargo weight distribution and the arrangement of the ballast of the ship. R8 requires that the designed concept should be able to utilize the existing port facilities. From the results of the analysis of the requirements, the TPMs are generated and shown in Table 5. The TPM is generated from each essential requirement for a minimal ballast ship, and the MOP is measured after all TPMs are satisfied. Then, the MOE / KPP can be evaluated as a considerable design result.

2.2 Functional analysis and allocation
Each requirement should be functionalized for the new minimal ballast ship design. To functionalize the requirements R1–R5 in Table 4, technologies pertaining to fluid performance are required. R6 and R7 are the requirements related to the structural strength, and R8 requires the ship be able to be adapted to existing harbor facilities. The functions to accommodate each requirement are listed in Table 6, including all the identified requirements.

2.3 Synthesis
In the synthesis process, the design alternatives shall be generated to implement the functions in Table 6 within the boundaries of the business model. To implement F1 and F4, any requirements for new rules and regulations should be minimized. In addition, the existing rules and regulations for ship stability and structural strength must be satisfied. For F2, a minimum level of the propeller immersion depth and bow draft must be achieved. For F3, any type of external attachment should be avoided to ensure the appropriate ship resistance performance. For F4 and F5, changes in the draft, beam, and bilge radius of the existing ship should be limited to ensure the berth access and usability of cargo loading facilities. The adjustment of the baselines of the bow and stern of a ship can be used to meet the functional requirements. However, when considering the required couplings and machinery systems among the bow, stern, and cargo hold parts of the ship for adjusting the baseline, the design concept shown in Fig. 2 does not meet the ‘revenue’ of the business model.

Since it is practically impossible for an adjustable hull form to meet the requirements of Table 4 and the business model of Table 3, to build

| Table 4 Redefined requirements for the new non/minimal ballast ship design |
|-------------------------------------------------|
| R1 Maintain the stability of the ship | R5 Reduction of slamming |
| R2 Trim and heel control | R6 Reduction of the bending moment of the ship |
| R3 Secure immersion depth of the propeller | R7 Relief of the sheer force of the ship |
| R4 Ensure the ship resistance performance | R8 Harbor operability (berth access / loading constraints) |

| Table 5 Criteria, thresholds and indicators for TPMs |
|---------------------------------------------------|
| Type | Criterion | Threshold |
| TPM1 | Ship stability | Meet the rules and regulations |
| TPM2 | Trim and heel control | Same as original hull form |
| TPM3 | Resistance performance | Minimum increase in EHP |
| TPM4 | Structural strength | Meet the related CSR-H ** |
| TPM5 | Harbor operability | Berth access/loading constraints |

** CSR-H: Harmonized Common Structural Rules

| Table 6 Function list for new non/minimal ballast ship design |
|---------------------------------------------------------------|
| F1 Function to maintain ship stability | TPM1 R1 |
| F2 Trim and heel control function | TPM2 R2, R3, R5 |
| F3 Function to maintain resistance performance | TPM3 R4 |
| F4 Function to sustain the structural strength of the ship | TPM4 R6, R7 |
| F5 Function for berth access and usability for loading facilities | TPM5 R8 |
A reasonable design alternative for the functions in Table 6, a fixed type uneven baseline hull form (modified) has been generated on the basis of an existing 176K bulk carrier hull form (original). Fig. 3 shows the body plan of an uneven baseline minimal ballast bulk carrier.

From the Fig. 3, the suggested ‘modified’ hull form has uneven baselines of the bow, stern, and cargo holds. These differences should be addressed because an uneven baseline can affect the ship’s resistance performance. In addition, an uneven baseline interferes with the fluid flow and affects the seakeeping ability for F1. Furthermore, measures should be taken to secure the longitudinal strength under repetitive hogging and sagging conditions. To reduce the adverse effects of the shear force and bending moment on the structural strength of the hull, the heel trim must be carefully weighed and controlled during the cargo loading process. For F1 and F4, a center-line bottom keel-based structural reinforcement can be used. While a fin-stabilizer for F1 has no effect on the normal concept of the static stability of a ship, it has a positive effect on the dynamic stability. Since the fin is usually not considered for a large ship, the cost effectiveness and possible capacity of the fin should be considered before implementation. To obtain the proper immersion depth of the propeller of the designed ship, a reduction of the propeller diameter can be considered by changing from a single-screw to twin-screw propulsion with an uneven baseline. In addition, for non-ballast exchange operation in certain loading conditions, a permanent ballast system will be required for F2 and F5. In this case, the operation of the permanent ballast should take the water depth and loading condition control ability of the port into account. The design should also consider the amount of required permanent ballasts for securing the appropriate immersion depth and a safe return voyage with empty cargo holds. By increasing the baseline of the cargo holds,

**Table 7 Initial dimensions of the designed ship**

|                  | Original     | Modified     |
|------------------|--------------|--------------|
| Length (p.p.)    | 282.00 m     | 282.00 m     |
| Breadth (mld)    | 45.00 m      | 45.00 m      |
| Draught laden (Draught ballast TA) | 17.70 m (7.70 m) | 17.70 m (6.70 m) |
| Trim             | -0.175 m     | -0.176 m     |
| Baseline of cargo holds | -           | 2.45 m elevated |
| GM (metacentric height) | 4.88 m    | 6.84 m      |
| Deadweight       | 168,310 t    | 127,935 t    |
6 H e e  J i n  K a n g  e t  a l.

the wetted surface area is decreased slightly, which can contribute to
the ship’s resistance performance. However, since the uneven baseline
may have a negative effect on the ship resistance performance, the
feasibility of design alternatives for F3 should be carefully examined.
For F4, in the hull form modification process the applicability of the
hull form to the existing rules and regulations is considered.

The provisional specifications of the designed ship are described in
Table 7. From the hull form modification of the existing 176K bulk
carrier, the wetted surface is reduced by approximately 4.4%
compared to those of the original hull form under full loaded
conditions. Under ballasting conditions, the required fixed ballast was
estimated at approximately 42,000 t for a 7.5 m TA.

The synthesis results of reviewing the technical alternatives for the
required functions are summarized in Table 8. The conceptually
designed ship was reconfigured from the existing 176K bulk carrier.
The tanks for the ballast are minimized and the auxiliaries and
superstructure have been relocated for the initial trim and heel
conditions. For S1, the uneven baseline of the cargo holds,
consideration should be given to the influence of these differences on
the ship’s resistance performance, structural safety, and workability at
shipyards. For S2, the amount of permanent ballast should be
minimized to consider the controllability of the loading weight
distribution. Finally, for S3 the bottom keel should be properly
configured to prevent it from detaching from the baseline of the bow
and stern.

3. Ship Resistance Performance basis

Feasibility Evaluation

The ship resistance performance affects the operating cost, and
especially the fuel oil consumption. For this reason, the ship resistance
performance should be determined in the early design phase. Although
the model ship basin test is recommended, for a fast and effective
evaluation in this study, a computational fluid dynamics (CFD)-based
evaluation was adopted with the model ship basin test results and the
sea trial data of an existing 176K bulk carrier. Thus, when the
evaluation results have economic feasibility, the model ship-based test
will be adopted in the next study. For the model scale CFD simulation,

\[
\begin{array}{c|c|c|c|c}
\text{Condition} & \text{Original} & \text{Modified} & \text{Original} & \text{Modified} \\
\hline
Tm (m) & 17.7 & 17.7 & 0.5429 & 0.5429 \\
S (m^2) & 19,981 & 19,113 & 18.8015 & 17.9843 \\
Design speed & 15 kt (7.717 m/s) & 1.3515 (m/s) \\
\end{array}
\]

※ Tm (Draft of the ship), S (Area of wetted surface)

Table 9 Geometry and principal particulars of the model ship for CFD

Fig. 4 GZ curves of the original and the modified hull form, (a) Laden condition (b) Ballast condition
a hull model is generated, as described in Table 9.

Regarding the ship’s stability performance, the designed uneven baseline hull form has a larger righting arm compared to the original hull form, as shown in Fig. 4.

For the model scale CFD simulations, the Reynolds-averaged Navier-Stokes (RANS) equation-based Wave and viscous flow (WAVIS) software which KRISO (Korea Research Institute of Ships and Ocean Engineering) developed and widely used in Korean ship yards was used. As shown in Table 10, understanding the simulation of the flow around the ship helps in generating an accurate grid arrangement. The grid includes the free surface area with a total of 3.6M grid points for the half domain, which is equivalent to the medium size grid in a previous study (Kim et al., 2011). Starting from the initial graphics exchange specification (IGES) description of the ‘original’ and ‘modified’ hull forms, the commercial program GRIDGEN (Pointwise, Inc.) was used to generate the H-O type multiblock structured grid systems. In the CFD simulation in this study, the free surface was captured using the level-set method, while for the turbulence closure, the Explicit algebraic reynolds stress model (EARSM) was used with Launder and Spalding’s wall function. The details of the numerical methods used can be found in Kim et al. (2011), Kim et al. (2014).

From the numerical resistance test, as shown in Table 11, the effective horsepower (EHP) was predicted to increase from 1.5 to 2.0%, depending on the speed of the bulk carrier, compared to the existing 176K bulk carrier. From the information on the differences between the predicted EHP and the actual instrumented delivery horsepower (DHP) of the existing 176K bulk carrier, the DHP of the

| Grid information and distribution |
|----------------------------------|
| **Grid information**             |
| Number of Grid points (half)     | 3.6M |
| Number of grid block             | 13   |
| Average y+                        | ~ 80 |
| Half domain size [x, y, z]        | [-1.5 L ~ 2.5 L, 0 L ~ 1.0 L, -1.0 L ~ 0.03 L] |
| **Grid distribution**             |
| Original (bow)                    |
| Modified (bow)                    |
| Original (stern)                  |
| Modified (stern)                  |
designed ship was estimated to have the same ratio for predicting fuel oil consumption as that of the designed ship at the actual scale.

For more detailed ship resistance performance comparison, model ship basin test has adopted. Fig. 5 shows model ships and Table 12 shows basin test results at same draft (17.7 m) conditions. From the test, EHP increased 5.25% and BHP (Breake horse power) increased 6.55% on average from 12 kt (6.173 m/s) to 15 kt (7.717 m/s) compare to ‘Original’ hull form.

Empirically, losses in the cargo capacity can be compensated with an enlarged freeboard by considering the bulk general cargo loading condition. Assuming that the modified and original hull form has same cargo amount, the ‘Original’ hull form’s draft can be reduced to 15.89 m when the draft of ‘Modified’ hull form fixed to 17.70 m. At this time, the BHP gap between ‘Modified’ and ‘Original’ hull form

| \( V_s \) (kt) | \( F_n \) (m/s) | \( Re \) | CFD (model scale) | ITTC | Full scale prediction |
|----------------|----------------|--------|------------------|------|----------------------|
|                |                |        | \( C_f \) | \( C_p \) | \( C_{tm} \) | \( C_{fm} \) | \( C_r \) | \( C_{ts} \) | \( R \) (kN) | \( EHP \) (kW) |
| Original       |                |        |                  |      |                      |          |        |                  |      |                      |          |        |                  |      |                      |          |        |                  |      |                      |          |        |                  |      |                      |          |        |                  |      |                      |          |        |                  |      |                      |          |
| 12             | 6.173          | 0.1174 | 9.55E+06         | 2.98151 | 0.60113 | 3.58264 | 3.02422 | 1.40958 | 0.55842 | 1.96800 | 768.7 | 4745.3 |
| 13             | 6.688          | 0.1272 | 1.03E+07         | 2.94135 | 0.59370 | 3.53505 | 2.98244 | 1.39624 | 0.55261 | 1.94885 | 893.3 | 5974.5 |
| 14             | 7.202          | 0.1369 | 1.11E+07         | 2.9053  | 0.59787 | 3.50317 | 2.94452 | 1.38406 | 0.55865 | 1.94271 | 1032.8 | 7438.5 |
| 15             | 7.717          | 0.1467 | 1.19E+07         | 2.86288 | 0.61369 | 3.47657 | 2.90987 | 1.37286 | 0.56670 | 1.93956 | 1183.7 | 9134.1 |
| Modified       | 12             | 6.173  | 0.1174 | 9.55E+06         | 2.97653 | 0.73649 | 3.71303 | 3.02422 | 1.40958 | 0.68881 | 2.09839 | 784.4 | 4842.0 |
| 13             | 6.688          | 0.1272 | 1.03E+07         | 2.92307 | 0.73461 | 3.65768 | 2.98244 | 1.39624 | 0.67524 | 2.07148 | 908.7 | 6077.3 |
| 14             | 7.202          | 0.1369 | 1.11E+07         | 2.87961 | 0.74548 | 3.62509 | 2.94452 | 1.38406 | 0.68057 | 2.06463 | 1050.4 | 7565.3 |
| 15             | 7.717          | 0.1467 | 1.19E+07         | 2.8348  | 0.75967 | 3.59447 | 2.90987 | 1.37286 | 0.68460 | 2.05746 | 1201.6 | 9272.6 |

* \( V_s \): Velocity of the ship, CFD: Computational fluid dynamics, ITTC: The International Towing Tank Conference, \( C_f \): friction resistance coefficient, \( C_p \): prismatic coefficient, \( C_{tm} \): total resistance coefficient of model-scale ship, \( C_{fm} \): \( C_f \) of model-scale ship, \( C_{ts} \): \( C_f \) of full-scale ship, \( C_r \): residuary resistance coefficient, \( C_{ts} \): total resistance coefficient of full-scale ship, \( R \): Resistance, \( EHP \): Effective horse power

Fig. 5 Model ships, (a) original and (b) modified hull form

| \( V_s \) (kt) | \( PE \) (kW) | \( PB \) (kW) | RPM (1/s) | BHP increase | RPM increase | EHP increase |
|----------------|--------------|--------------|-----------|--------------|--------------|-------------|
| Original       |              |              |           |              |              |             |
| 12             | 6.173        | 4391.0       | 6430.0    | 69.49        | -            | -           |
| 13             | 6.688        | 5528.0       | 8074.0    | 75.15        | -            | -           |
| 14             | 7.202        | 6871.0       | 10019.0   | 80.88        | -            | -           |
| 15             | 7.717        | 8538.0       | 12462.0   | 86.97        | -            | -           |
| Modified       |              |              |           |              |              |             |
| 12             | 6.173        | 4601.8       | 6832.0    | 70.62        | 6.3%         | 1.6%        |
| 13             | 6.688        | 5819.8       | 8609.0    | 76.43        | 6.6%         | 1.7%        |
| 14             | 7.202        | 7261.8       | 10716.0   | 82.32        | 7.0%         | 1.8%        |
| 15             | 7.717        | 8981.0       | 13248.0   | 88.36        | 6.3%         | 1.6%        |

Table 11 Numerical resistance test results

Table 12 Model ship basin resistance test results at same draft condition
increases more than 12.5% as shown in Fig. 6. Fig. 7 shows model ship basin test pictures, conditions and nominal velocity contour at propeller plane at same displacement condition and Fig. 6 shows RPM and BHP of ‘Modified’ and ‘Original’ hull forms.

To compensate loses in ship resistance performance of ‘modified’ hull form, flow stress intensive parts of hull geometry as shown in Fig. 8 shall be improved. Moreover, enlarged beam width can be considered to increase cargo loading capacity of ‘modified’ hull form.

Regarding the sea keeping ability, the characteristics of the ship motion in sea waves are important. As shown in Fig. 9, compared to the original hull form, although the modified hull form shows lack of sea keeping performance in heave and roll motion, the pitch motion characteristics of the ‘modified’ hull form do not significantly differ from those of the original hull form. To analyze ship behavior characteristics, SMTP (Ship motion total package), which is the KRISO’s in-house simulation tool (new version of SURVSHP (Survivability of ship)) has used (Lee, 2015). In the simulation, 0.02 second time step has applied. Figure 6 shows ship behavior characteristics in the regular wave with beam-sea (entrance angle of 90 degree) condition. Due to uneven baseline, suggested hull form shows
lack of seakeeping ability especially in heave and roll motions. In case of Heave motion, it is estimated that waves between bow and stern uneven baseline enlarges ship motion compare to ‘original’ hull form. For roll motion, it is estimated that shorten immersion depth of ‘modified’ hull form enlarges initial roll motion.

To compensate for the losses in the ship motion under waves, relationship between the geometry of mid-ship section and roll damping will be considered (Park et al., 2019). If the propeller diameter is decreased to accommodate for the adjusted ship speed and the engine performance, then the elevating height of the baseline of the cargo holds can be decreased to secure the proper cargo capacity, ship resistance, and seakeeping performance. When considering only the mid-ship section of the suggested uneven baseline minimal ballast bulk carrier, a decrease in the depth of the cargo holds will lead to a decrease in the ultimate bending moment capacity. To compensate for the decreased ultimate bending moment capacity, the weight of the ship’s structure can be increased. For this reason, in order to convince the technical feasibility of the suggested uneven baseline minimal ballast bulk carrier, the structural design evaluation under different sea states should be adopted in the next study.

4. Conclusion

To design a new minimal ballast ship which operate certain amount of permanent ballast for ballast-water free operation, the existing alternatives for ballast water were reviewed. To overcome the lack of berth access and loading constraints of the MIBS / NOBS ‘storm ballast’, the conceptually an uneven baseline basis ‘no or minimal
discharge’ alternative so called ‘modified’ hull form suggested. To generate the ‘modified’ concept, a simplified systems engineering-based design approach was adopted. By examining the roles of the ballast water and existing alternatives, seven general requirements for a new minimal ballast ship and one specific requirement for overcoming the penalties of a ‘storm ballast’ were identified. Then, five functional requirements were generated for the uneven baseline minimal ballast vessel. As suggested, the concept has wide and parallel sides compared to the existing V-hull design of a ‘storm ballast’, so the lack of berth access capability can be compensated theoretically. As for loading constraints, the smaller beam size of the suggested concept compare to exiting MIBS / NOBS concept can be helpful in compensating for the load constraints. However, during the model ship basin test, under the same draft conditions, the EHP of ‘modified’ increased 5.25% and BHP increased 6.55% on average compared to ‘original’ hull form. Given the loss in cargo loading capacity, the suggested ‘modified’ hull form’s economic feasibility is assessed at an awkward level. So, resistance performance at same displacement condition has also tested via model ship basin test. From the basin test, more than 12.5 loss in BHP has convinced. From this review result, losses in the cargo capacity and ship resistance performance shall be consider concurrently in the design phase to have technical and economic feasibility. By optimizing the geometry and dimension of the ‘modified’ hull form, a certain amount of loss in resistance performance and cargo capacity shall be compensated in the next study. Although the suggested uneven baseline basis ‘modified’ hull form has many rooms for commercializing, the suggested design, evaluation process and methodologies can be adapted to generate various attempts at developing non/minimal ballast ships to keep the healthy ocean environment from organisms of different ecosystems or a large amount of sterile sea water.

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