VOL. 12, NO. 4, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

INVESTIGATION ON THE EFFECT OF BULBOUS BOW SHAPE TO THE WAVE-MAKING RESISTANCE OF AN ULTRA LARGE CONTAINER CARRIER (ULCC)

Hamdan Nuruddin[1], Iwan Mustaffa Kamal[1], Muhammad Nasuha Mansor[1] and Nik Muhammad Hafidz[2]
[1]Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, Lumut, Malaysia
[2]Malaysia Marine and Heavy Engineering Sdn. Bhd. Malaysia
E-Mail: hamdann@unikl.edu.my

ABSTRACT
The bulbous bow of a ship reduce the wave-making resistance of the vessel by adding another wave system which is created by the bulb and this interfere with the wave system created by the bow of the vessel. These two wave system partially cancel out each other and reduce the wave elevation and the wave making resistance. The main aim of this project was to evaluate the effect of fore-body shape particularly the bulbous bow to the wave-making resistance of an ultra large container carrier. It was also the aim of this project to identify the optimised form of the bulbous bow design. The general idea is a set of bulbous bows is systematically created based on the bulb parameters. A commercial CFD code SHIPFLOW computes the flow and the pressure distribution around the hull. With these results the wave-making resistance of systematically varied were analysed. An optimised bulbous bow design was chosen over other 27 bulbous designs. It was found that the wave resistance can be reduced by lengthening the bulb protruding length, widening the bulb breadth and increasing the bulb height.

Keywords: CFD, bulbous bow, optimisation, wave-making resistance.

INTRODUCTION
The rising requirements for an increased dimensions and universal consensus on the efficiency and the environmental effects reductions of container carriers are the motivations for efficient vessel designs. One of the methods to achieve efficient vessels is to minimise its wave-making resistance. The wave-making resistance R_W is a component of resistance of a ship associated with the expenditure of energy spends by the ship's engine in generating gravity waves. At low speeds, the waves made by a ship are very small and the resistance is almost wholly viscous in character. With further increase in speed, the value of coefficient of total resistance C_T, begins to increase more rapidly, and at Froude number approaching 0.45, the resistance may vary at a power of 6. Therefore, it is crucial to minimise the total resistance by minimising the wave-making resistance at higher speed especially at Froude number approaching 0.45. This is critical for ship owner operating container carriers as this affecting the journey time and the fuel consumption in profit point of view.

The bulbous bow designs play a major role in reducing this wave-making resistance. The bulbous bow creates wave interference between the bulb wave and the bow wave system and hence reduce the wave-making resistance. The improvement of wave-making resistance of a container carrier by adding a bulbous bow was investigated by Park *et al*. [1]. Park *et al*. found that by varying the bulb shape, the wave-making resistance can be reduced even at lower Froude number (approximately *Fn* 0.173).

It is found necessary that a further research to be carried out to evaluate the effects of fore-body shape of a ship, specifically in identifying the optimised form of the bulbous bow. Huang *et al*. [2] highlighted that the change of wave energy, which in respect with wave making resistance is mainly influenced by extendable length of the bulbous bow, the height above the baseline of the bulbous bow and the transverse area of the bulbous bow at fore pole.

This research was focussed on the bulbous bow of an Ultra Large Container Carrier (ULCC). The ship length of the ULCC was approximately at 350m up to 400 m and not more than 14500 TEU capacity. The ULCC was modelled virtually using a commercial computer-aided ship design software, Maxsurf Modeller from Bentley Systems (formerly FormSys). A series of implicit bulbous bows using the bulb parameters as defined by Kracht [3] as shown in Figure-1 was adapted to the fore-body of the ULCC. The aim of this study is to obtain the optimised design by simulating the model in Computational Fluid Dynamics (CFD) using a commercial CFD code Shipflow® from Flowtech International AB.

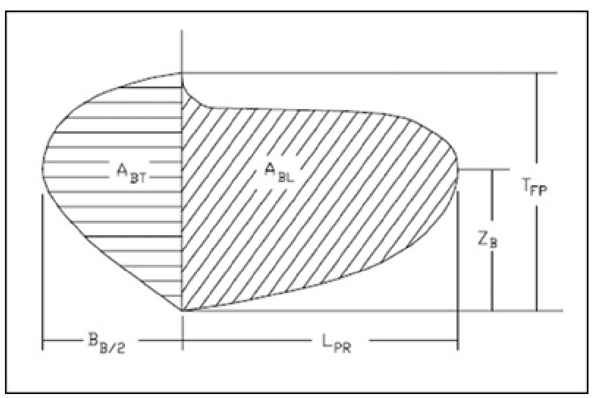

Figure-1. Bulb variables according to Kracht [2].

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CFD has become an essential part of ship design process particularly in ship resistance and powering. CFD provides local flow details around ship hulls. With this information, recommendation of design improvement can be proposed including the selection of ideal prospect design for model testing. To some extent, the prediction accuracy level of a CFD analysis is considerably as good as the outcome of a model test. It is highlighted by Wang [4] in his paper by comparing a resistance result of 9200TEU container ship using the CFD method and calm water model test in achieving the optimised ship lines design.

The fore-body hydrodynamics such as bulbous bow interaction was analysed using inviscid free-surface potential flow methods established on the boundary element approach. This was done using a free-surface potential flow method of Rankine-source type which is available in Shipflow®. This was accomplished using the XPAN module of Shipflow®, which is a potential flow solver within this code. This dynamical approach applies numerical based methods as the principles of determining the ship resistance components. The flow domain was fractioned and a computational method was formulated in the appropriate zone. The free surface potential flow method represents the first zone which covers the entire hull and a part of its surrounding free-surface.

POTENTIAL FLOW THEORY

It is not the intention of the author to elaborate in detail the underlying mathematical formulas which was applied in this code. However, it is worth mentioning a few basic on the theory itself. The details of this theory can be found in Hess and Smith [7].

A potential flow is defined as irrotational, inviscid and incompressible flow. The components of the velocity vector are no more independent from each other as they are coupled by the potential ϕ. The potential derivation gives velocity component in a direction and the three unknowns of velocity components are reduced to one as follows [5];

$$\underrightarrow{\quad v \quad} = \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \nabla \phi \tag{1}$$

Laplace's equation of potential flow is simplified using continuity equation as follows;

$$\Delta\phi = \phi_{xx} + \phi_{yy} + \phi_{zz} = 0 \tag{2}$$

If the fluid is homogeneous and incompressible then the equation of conservation of mass reduces to the equation of continuity;

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{3}$$

where u,v and w are the components of the fluid velocity vector.
Combining (2) and (3) lead to the Laplace equation;

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial^2 y} + \frac{\partial^2 \phi}{\partial z^2} = 0 \tag{4}$$

METHODOLOGY

The parent hull model for this investigation was based on a Containership Pro model available from Maxsurf Library. The vessel overall length is at 397 m, the breadth is at 56 m and its depth is at 30 m.

The parameters of the bulbous bow were then varied systematically in 27 different shapes of bulbous bow using parameter space according to bulbous bow linear parameter outlined by Kracht. The parameter space of 27 hulls is shown in Figure-2. Each node represents a hull model with each of the bow was varied from the main hull model *V22*. As there are three variables considered in the research, 27 hull models or nodes were required to change the parameters orderly and systematically.

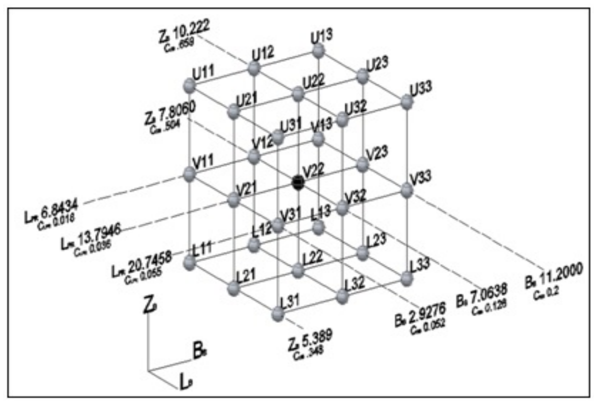


Figure-2. Parameter space of 27 hulls.

To simplify the parameter spacing, the number of hulls was reduced to only nine numbers at the extreme positions which combine the change of the height Z_B, the bulb breadth B_B and the bulb protruding length L_{PR}. The bulb part was altered accordingly for all those hulls and were designated as *V22, L11, L13, L31, L33, U11, U13, U31* and *U33* as shown in Figure 3. The parameter of the nine hulls (with different bow) are tabulated in Table-1;

Table-1. Parameter space.

No.	Vessel	LPR	C_{LPR}	B_B	C_{BB}	0.5 B_B	Z_B	C_{ZB}
1	U11	6.843	0.018	2.928	0.052	1.464	10.222	0.659
2	U13	6.843	0.018	11.200	0.200	5.600	10.222	0.659
3	U31	20.746	0.055	2.928	0.052	1.464	10.222	0.659
4	U33	20.746	0.055	11.200	0.200	5.600	10.222	0.659
5	V22	13.795	0.036	7.064	0.126	3.532	7.806	0.504
6	L11	6.843	0.018	2.928	0.052	1.464	5.390	0.348
7	L13	6.843	0.018	11.200	0.200	5.600	5.390	0.348
8	L31	20.746	0.055	2.928	0.052	1.464	5.390	0.348
9	L33	20.746	0.055	11.200	0.200	5.600	5.390	0.348

The finalised nine different bulb shape was then analysed individually to simulate the flow and the pressure distribution around the hull using Shipflow®. The flow domain is fractioned into three zones and a computational method is formulated for each zone. The modules used in Shipflow® were XMESH and XPAN. XMESH was used for creating meshes on the hull as panels, where each mesh panel is represented by a partial differential equation of the Laplace equation of the potential flow as in Equation (4). The XMESH used the offsets of the hull as inputs to the equation. The offsets were automatically generated from the external IGES file.

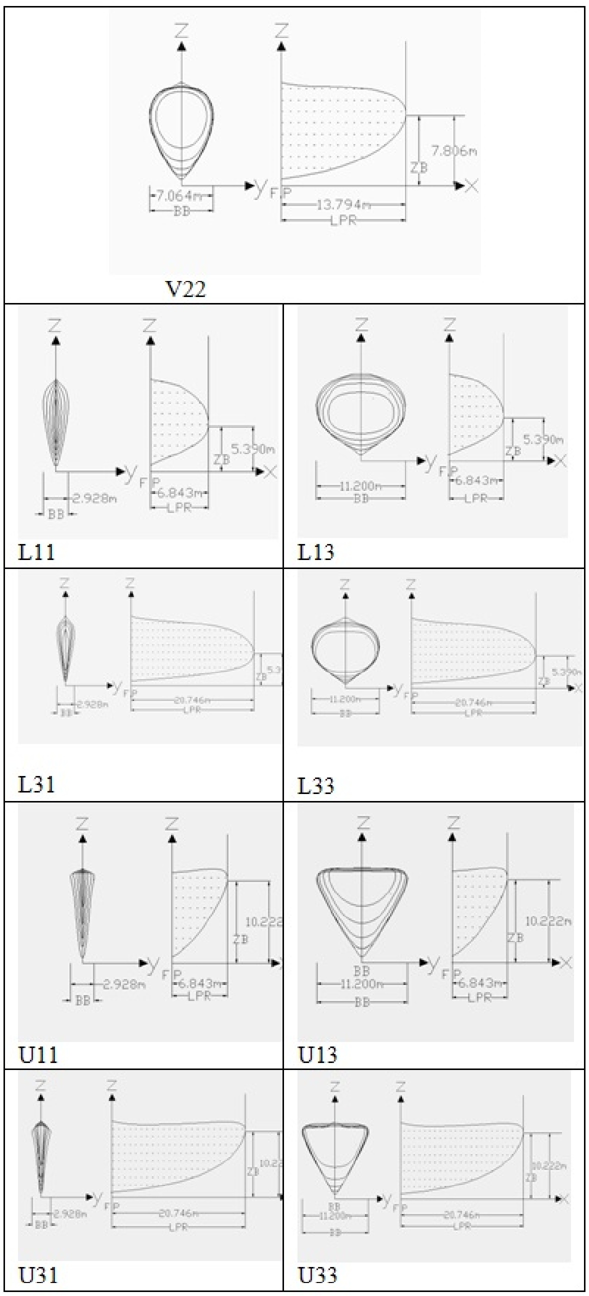


Figure-3. Profile and cross sectional view of 9 different configurations of bulbous bow.

XPAN itself is the potential flow solver within the Shipflow® code. Even though within the Shipflow® there is a RANS solver, XCHAP which using a finite-volume CFD approach, the XPAN solver is believe to be adequate enough for the computation as they are capable to fulfil the expected outcome of the study by sufficiently providing values of the wave-making resistance coefficients. The overall flow of the methodology can be referred to Figure-4.

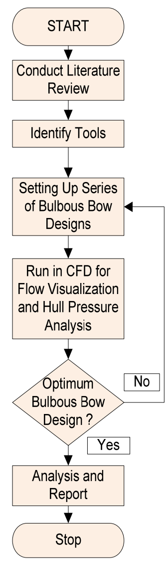


Figure-4. The flow of methodology.

RESULT AND DISCUSSION

The results from the CFD computations are plotted in terms of wave- making resistance coefficient of transverse wave cut method (C_{WTWC}) with respect to Froude number, Fn. The wave cut analysis technique determines the wave resistance by calculating the energy flux from the wave pattern. It is a much preferable technique as it puts fewer requirements on the size of the free surface. The method determines the wave elevation in a number of transverse wave cuts behind the ship. The wave cut method approximates the wave elevation in each wave cut by the sum of a series of elemental waves. The wave resistance was determined with the result of this approximation. The advantage of the wave cut analysis is that it is less dependent on the number of panels on the hull. This make the wave cut method more robust than the pressure integration method for hulls with a complicated geometry (high curvature areas) [5].

In general, Figure-5 shows that the hull U33 significantly has the lowest value of wave-making resistance coefficient using the transverse wave cut method at Froude number of 0.2135 whilst L13 is the opposite having the highest value of wave-making resistance coefficient.

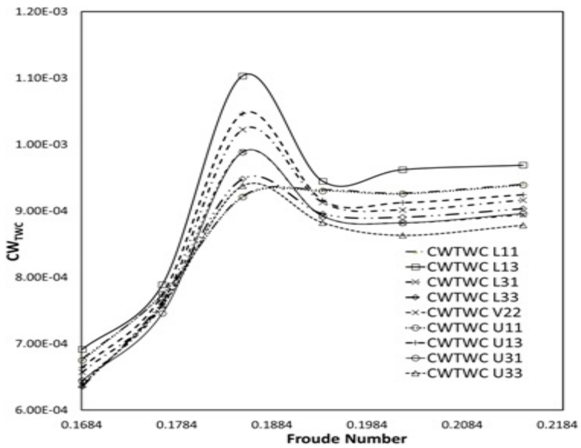


Figure-5. C_{WTWC} with respect to Froude number.

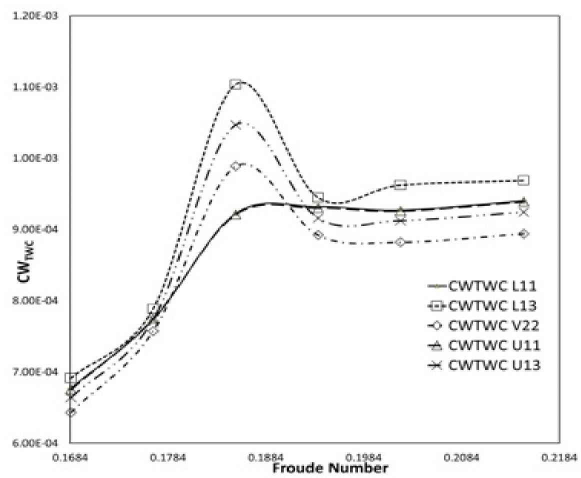


Figure-6. C_{WTWC} of shortened bulb with respect to Froude number.

Figure-6 shows that by shortening the bulb protruding length L_{PR}, the wave-making resistance is increased. L11 and U11 have similar pattern as they were overlapping on each other and this indicates that there is no difference if the height Z_B is varied at shortened bulb breadth B_B. The parent hull of V22 still has the lowest values of wave-making resistance C_W, but U13 shows that a bulb prefer to have lengthened bulb protruding length L_{PR}, widened bulb breadth B_B and increased height Z_B in order to reduce the wave-making resistance.

Figure-7 shows that by lengthening the bulb protruding length L_{PR} the wave-making resistance is reduced. U31 and V22 have similar pattern as they were overlapping on each other and this indicates that there is little or no improvements in wave-making resistance if the height Z_B is increased at shortened bulb breadth B_B. Moreover, lowering the height Z_B will increase wave resistance as both L31 and L33 have highest values of C_W among the lengthened bulbs. U33 confirms the indication by U13 by having the lowest values of C_W. Generally, optimisation of a bulb can be done by lengthening bulb protruding length L_{PR}, widening bulb breadth B_B and increasing height Z_B.

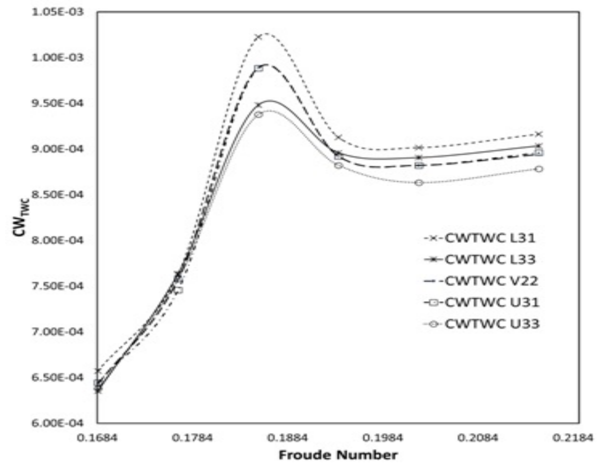
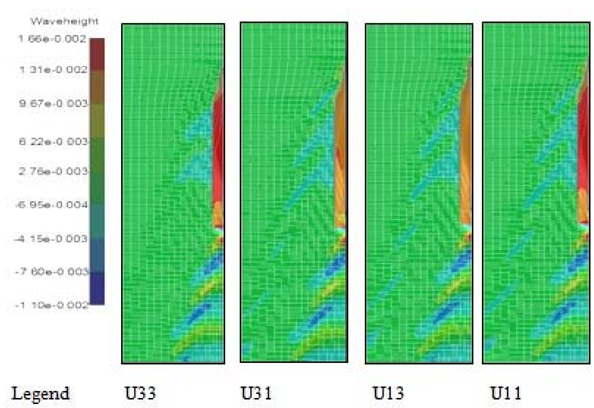


Figure-7. C_{WTWC} of lengthened bulb with respect to Froude number.

Figure-8 shows the wave patterns for all nine hulls. The wave pattern of U33 has distinctly fewer diagonal waves and less extensive than the other wave patterns generated by the other eight hulls. As the generated waves represent the energy loss, only U33 and L33 have less extensive waves than the parent hull V22 and these two hulls can be chosen as the optimised bulbous bow designs. The less extensive wave pattern of L33 proves that a bulb can be optimised by lengthening bulb protruding length L_{PR} and widening bulb breadth B_B Moreover by comparing L33 and U33, it is remarked that the waves can be reduced by increasing the bulb height Z_B.



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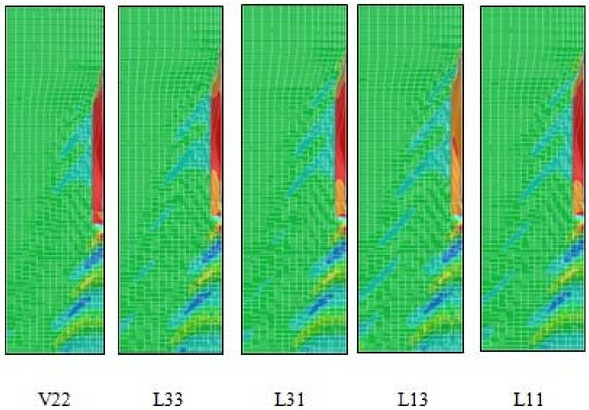

Figure-8. Wave pattern at 25.5 knots with the changes of Z_B bulbs.

Figure-9. shows the percentage difference of the wave-making resistance coefficient relative to the wake-making resistance coefficient of the parent hull V22. It is clear that from the plot that the wave-making resistance of the hull U33 was the lowest, in fact lower than the parent hull itself.

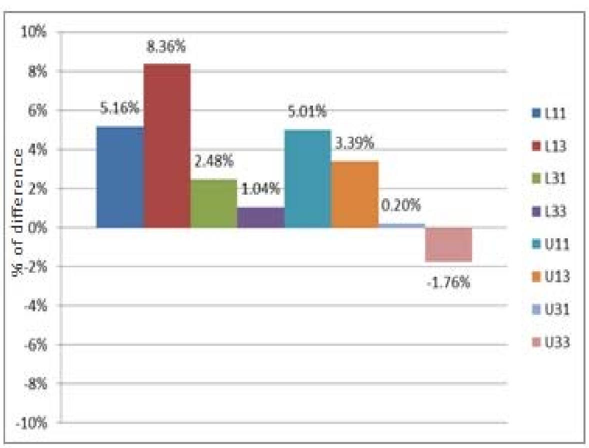

Figure-9. Percentage of difference on C_{WTWC} between nine different bow design at 25.5 knots.

There was not much improvement in terms of wave-making resistance reduction when the height Z_B was varied at configuration of reduced bulb breadth B_B and shortened bulb protruding length L_{PR}. This has been shown in Table-2, as the percentage of difference of L11 and U11 comparing to the parent hull were almost similar (the design can be referred to Figure-4 earlier). However, increasing the bulb breadth B_B will generally decrease the wave resistance and the trend is indicated in most of the cases of the design; as shown by pairs of L31 and L33; U11 and U13; U31 and U33 in Table-2. By fixing the other main parameters (L_{PR} and Z_B), the pairs clearly show that the C_{WTWC} slightly reduced with increase of bulb breadth B_B.

Table-2. Comparison of C_{WTWC} between nine different bow design at 25.5 knot.

No.	Hull	V_S (knot)	CW_{TWC}	Difference %
1	V22	25.5	0.0008941	-
2	L11	25.5	0.0009403	5.16%
3	L13	25.5	0.0009688	8.36%
4	L31	25.5	0.0009162	2.48%
5	L33	25.5	0.0009034	1.04%
6	U11	25.5	0.0009389	5.01%
7	U13	25.5	0.0009244	3.39%
8	U31	25.5	0.0008959	0.20%
9	U33	25.5	0.0008784	-1.76%

CONCLUSIONS

The study on the effect of the ship's fore-body shape on wave making resistance of an Ultra Large Container Carrier (ULCC) was conducted using nine hulls of varied bulb parameters. The results showed that the wave resistance coefficient can be reduced by lengthening the bulb protruding length L_{PR}, widening bulb breadth B_B and increasing height Z_B. Ultimately *U33* was chosen as the optimised hull. The selection of *U33* as the optimised bulb were based on the result of wave resistance of transverse wavecut and wave pattern.

It recommended that further development to be carried out in analysing the effect of the ship's fore-body shape on wave making resistance. The following are the recommendations that the author strongly emphasised on:

- To validate the result from this investigation with towing tank experiment.
- To investigate the wave making resistance under the influence of draft or waterline.

It is hope that the outcomes from the investigation can be made as a guidance in designing a bulbous bow, in particular for an ULCC. The results from this investigation are not meant to replace the usage of a towing tank altogether but rather to complement on each other as a powerful tool for the ship designer and naval architect alike.

ACKNOWLEDGEMENTS

The author acknowledges the support from Universiti Kuala Lumpur through the funding of a short term research grant under the project "Investigation of the Effect of Ship's Fore-Body Shape and half Angle of Entrance on Wake-Making Resistance of an Ultra-Large Container Carrier (ULCC)", Project ID: STR10054.

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