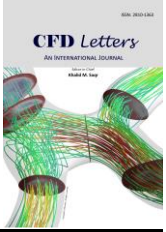
CFD Letters

Journal homepage:
https://semarakilmu.com.my/journals/index.php/CFD_Letters/index
ISSN: 2180-1363



Comparative Study of Ship Resistance and Fuel Consumption between Axe Bow and Moor Deep Ram Bow using CFD Method

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ARTICLE INFO

Article history:
Received 24 March 2022
Received in revised form 27 April 2022
Accepted 11 August 2022
Available online 31 August 2022

Keywords:
Axe Bow; Bulbous Bow; CFD; Moor Deep Ram Bow; Ship Resistance

ABSTRACT

Using a bulbous bow on the ship is the most common alternative way used to reduce resistance and fuel consumption. Some developments are created in terms of bow shapes to obtain the minimum shipping cost. The purpose of this study is to compare the total resistance (Rt) and specific fuel oil consumption (SFOC) in an 8000 DWT oil tanker by modifying the existing moor deep ram bow to axe bow using computational fluid dynamics (CFD) and empirical Holtrop method. Based on the results, the total resistance with a moor deep ram bow design at a service speed of 12 knots is 230,8 kN, while axe bow is 221,5 kN. This is directly proportional to the fuel consumption where by using axe bow, the ship will consume 83.64 tons in a trip of 1912 nautical miles. In contrast, with existing moor deep ram bow, the fuel consumption is just a slight 0.1 % higher than axe bow and still showing a competitive performance as it is generally used in cargo vessel.

1. Introduction

One of the main challenges in designing a ship is to create a well-designed hull so that it gets the minimum resistance and fuel consumption. This is very important because fuel consumption is the largest component of operating costs onboard. There are many ways which are created to reduce the resistance namely by improving the hull smoothness for large vessel [1] and by applying the stern foil on high-speed vessels [2]. However, generally, a bulbous bow is an alternative that is often used to reduce resistance and fuel consumption on ships. It is a construction located at the bow of the ship and serves to reduce ship resistance by up to 20% [3] especially wave-making resistance when operating at relatively large Froude numbers [4, 5]. The working principle of the bulbous bow is to generate a second bow wave that interfere with a divergent wave coming from the bow of the ship so that the wave is significantly reduced [6].

Besides having the advantage of reducing ship resistance, a bulbous bow is also good as a pitching damper [7]. In contrast, it also has drawbacks in terms of more complicated and expensive construction and greater chances of slamming [8]. At high speeds, the wave-making resistance

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https://doi.org/10.37934/cfdl.14.8.7180

component can be reduced significantly, while at low speeds the viscous resistance component is reduced in such a way [3]. Reducing ship resistance also means reducing engine power requirements at the same speed. It is stated that the engine power requirement of a ship without a bulbous bow is greater than that of a ship with a bulbous bow, especially at high speeds as shown in Figure 1 below [7].

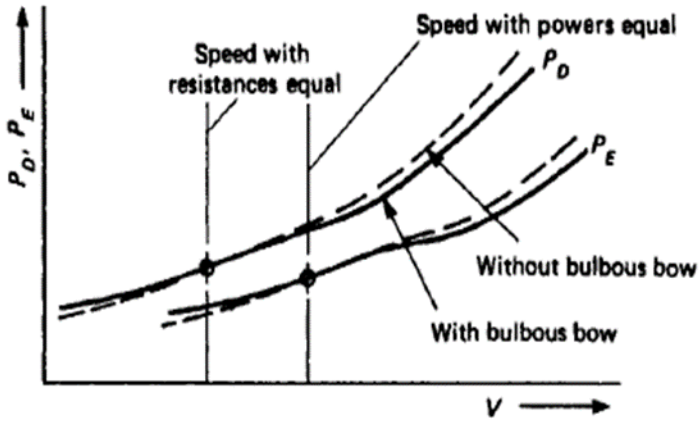


Fig. 1. Comparison of resistance between hull with and without bulbous bow [7]

The shapes of the bulbous bows are developed in such a way according to the needs and character of a particular ship. There are 8 conventional types of bulbous bows which are stated in the Practical Ship Design book. Besides they are used to reduce wave resistance, they are also designed by considering the ease of production mainly the added bulb with knuckle [8]. Nowadays, some modern bow shapes are introduced namely x-Bow and axe bow.

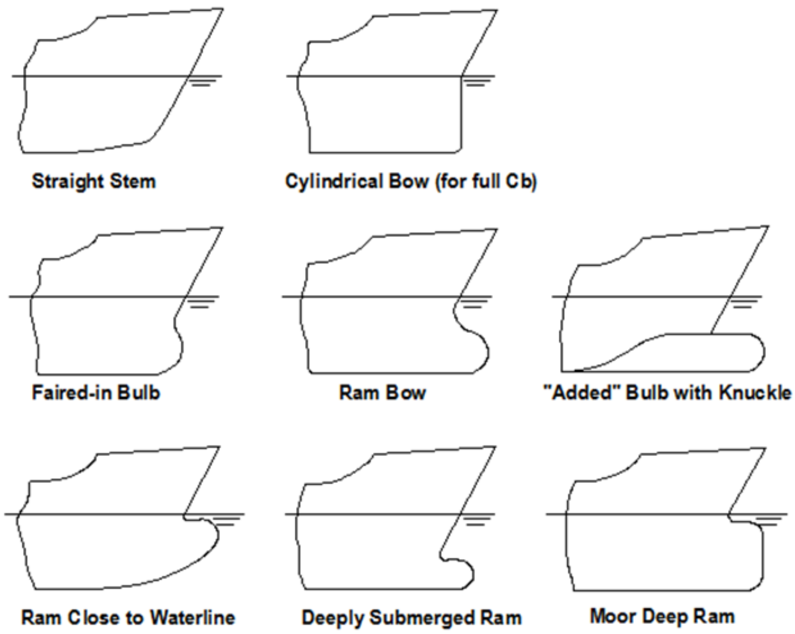


Fig. 2. Conventional Bulbous Bow Types [8]

An axe bow is a type of wave-piercing hull on the bow of a ship, characterized by a vertical bar and a relatively long and narrow entry (forehead hull) or shaped like an axe (see Figure 3). The forelegs are deep and the freeboard is relatively high, with a slight protruding downward, giving the bow profile resembling an axe. The advantages of using an axe bow type are that it relieves hull loads during slamming, provides smooth travel for crews, is easy to predict response to waves, and reduces pitch accelerations. Furthermore, the axe bow is able to reduce the resistance by 2.75% in research of bow redesign on fast missile boat 60 meter [9] and by 11.5% drag decrease of trimaran compared with conventional hulls [10]. Besides that, the axe bow also shows advantages in calm water resistance, especially in higher speed and good pitch response [11].

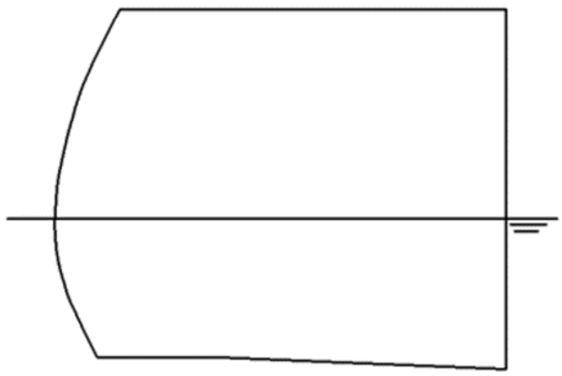


Fig. 3. Axe Bow

Based on the information above, it is interesting to investigate the performance of axe bow on a cargo ship in terms of resistance, the engine powering, and fuel consumption, as generally, this type is used only on special-purpose ships.

2. Methodology

An 8000 DWT Tanker is planned for a route of 1912.5 nautical at a speed of 12 knots. To overcome a higher need for engine power and fuel consumption, the existing moor deep ram bow will be compared to the axe bow without changing the dead weight tonnage of the ship. Bow and ship modeling are designed by using Maxsurf modeler while the resistance will be calculated by using computational fluid dynamics (CFD) Numeca. The CFD analysis is increasingly being used to analyze the optimal hull shape by various methods [12-16]. The result of this method is practically used in the preliminary design phase to predict the ship resistance and engine power requirement [17, 18]. The CFD result is also compared to the empirical Holtrop method as shown in Eq. (1) below.

$$R_{total} = R_F\,(1+k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \tag{1}$$

Total resistance consists of RF as the frictional resistance, 1+k1 is the hull form factor, RAPP is the added form resistance, RW is the wave resistance, RB is the bulbous bow resistance, RTR is the submerged transom resistance and RA is the correlation resistance between model and ship.

Table 1
Ship data

Dimension	Value
Lpp	102.3 m
Breadth	18.3 m
Depth	10.5 m
Draught	7.3 m
Vs	12 knots

The bow of the ship is simulated by using 2 types of bows as shown below.

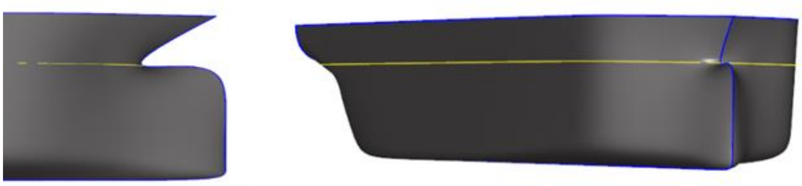


Fig. 4. Moor Deep Ram Bow

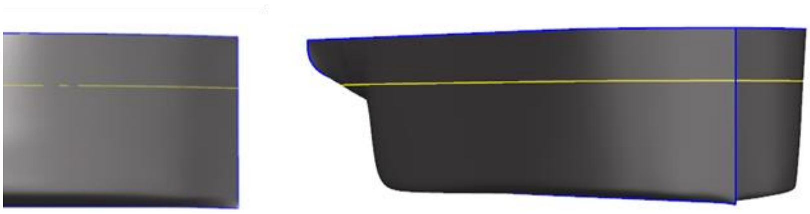


Fig. 5. Axe Bow

Engine power requirement is obtained by considering all efficiencies working in the propulsion system as equation below:

$$PB = \frac{V_S \ x \ R_T}{\eta_H \ x \ \eta_R \ x \ \eta_O \ x \ \eta_S \ x \ \eta_G} \tag{2}$$

where P_B is brake power in kW, V_s is ship speed in m/s, R_T is the total resistance in kN, while all efficiencies are non-dimensional units where η_H is hull efficiency, η_R is relative rotative efficiency, η_O is open water efficiency, η_S is shaft efficiency and η_G is gearbox efficiency. In calculating fuel consumption, equation 3 below is used to give information on how much fuel is used by the ship at the planned sea distance where PB_{mcr} is engine power in kW, *t* is voyage time in hour and SFOC is specific fuel consumption in g/kW hour.

$$W_{FO} = PB_{mcr} \ x \ t \ x \ SFOC \tag{3}$$

3. Results

Based on the simulation results by using Holtrop and CFD method at some speed variations ranging from 10 knots to 14 knots, the results are shown in Figure 6 below. At a design speed of 12 knots, the axe bow produces lower resistance than the moor deep ram bow namely 221.5 kN and

230.8 kN respectively. The CFD method results have a close gap with Holtrop method mainly in service speed of 12 knots as shown in Table 2 below.

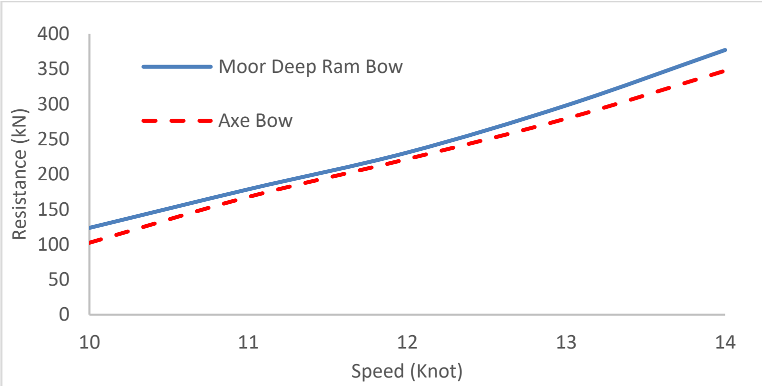
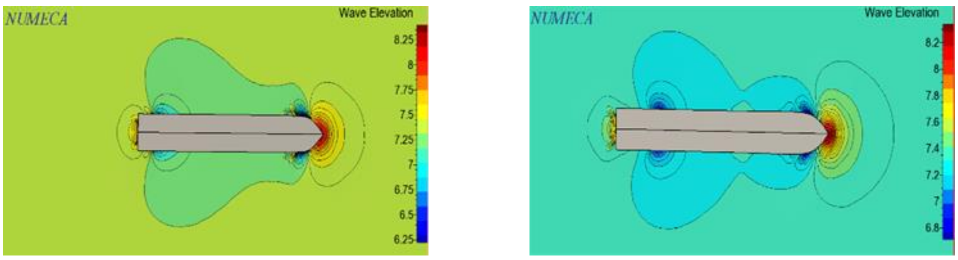


Fig. 6. Graph of resistance v speed on various bow types

Table 2
Ship resistance on variations in speed and shape of the bow

Bow types	Speed	Resistance (kN)	
		CFD	Holtrop
	Knot	kN	kN
Moor deep ram bow	10	123.5	143.9
	11	178.5	176.3
	12	230.8	215.4
	13	297.9	263.7
	14	376.9	324.1
Axe bow	10	102.3	120.0
	11	167.5	150.1
	12	221.5	189.1
	13	279.1	240.6
	14	347.3	309.1

The wave pattern visualization is important to see the phenomena that occur in hull-fluid interaction. The wave pattern is a secondary wave system consisting of transverse and divergent waves [19]. The pattern shows the wave elevation measured from the ship's draft. The higher the wave elevation, the greater the ship's wave resistance, which means that the total drag of the ship will also increase.



(a) (b)

Fig. 7. Wave Elevation in Various Bow Shapes by using CFD Numeca (a) Moor Deep Ram Bow, (b) Axe Bow

Based on Figures 7 and 8, it can be seen that by using CFD the ship with axe bow produces smaller wave elevation compared to moor deep ram bow. At a distance of about 101 m from the AP, the wave generated at a speed of 12 knots reach only 0.027 meters.

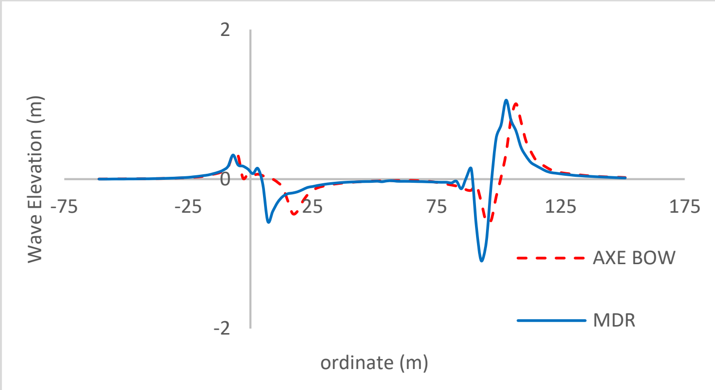
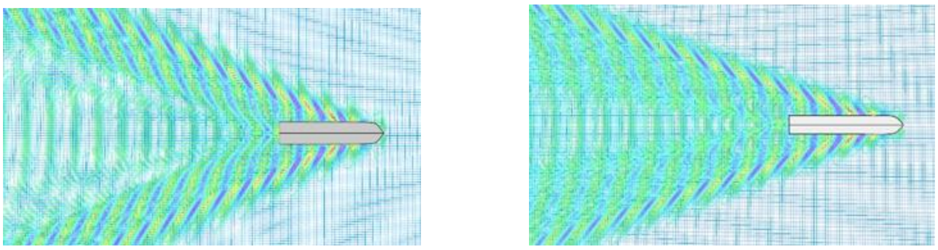


Fig. 8. Wave Elevation in Various Bow Shapes by CFD

The same result is also illustrated by maxsurf resistance-free surface wave patterns as shown in Figures 9 and 10. However it visualizes the wave elevation, not in the forepart, it shows that moor deep ram bow creates a higher wave elevation than axe bow.



(a) (b)

Fig. 9. Wave Patterns in Various Bow Shapes (a) Moor Deep Ram Bow, (b) Axe Bow

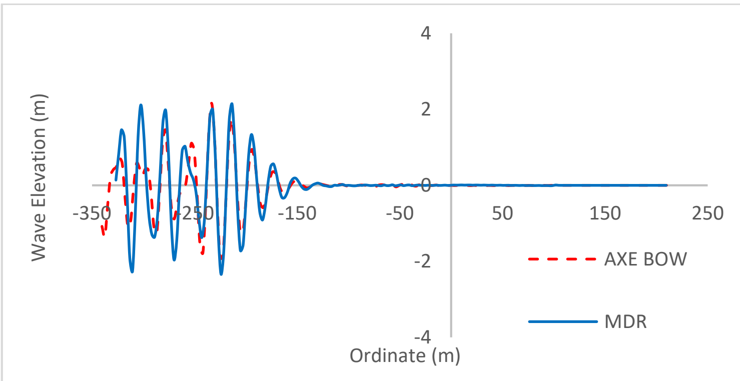


Fig. 10. Wave Elevation in Various Bow Shapes

The results of the wave elevation graph in Figures 8 and 10 show that there is a relationship between wave height and the resistance value at a speed of 12 knots in Table 2. The data show that the total ship resistance obtained from the CFD and Holtrop method is directly proportional to the wave height on the ship, here the greater the value of the wave height on the ship, the greater the total resistance obtained.

Wave resistance is the component that releases the energy causing the gravitational waves where for each point along the hull it is possible to have a pressure difference. The waves formed are the result of the interaction/resultant of several wave systems. Broadly speaking, there are four components of the wave system on the ship, namely: the bow wave system, the bow shoulder wave system, the stern shoulder wave system, and the stern wave system. In the bow area, the resulting wave has a relatively large height because the area is a point of pressure high, while at the fore and aft shoulders, the resulting waves will start from the wave trough because these areas tend to have low pressure.

The data are also supported by the results obtained from the simulation shown in Figure 11 where the results illustrate that the wave height caused by the bulbous bow as produced by the CFD is also in line with the Holtrop method simulation where the axe bow has the smallest wave resistance coefficient.

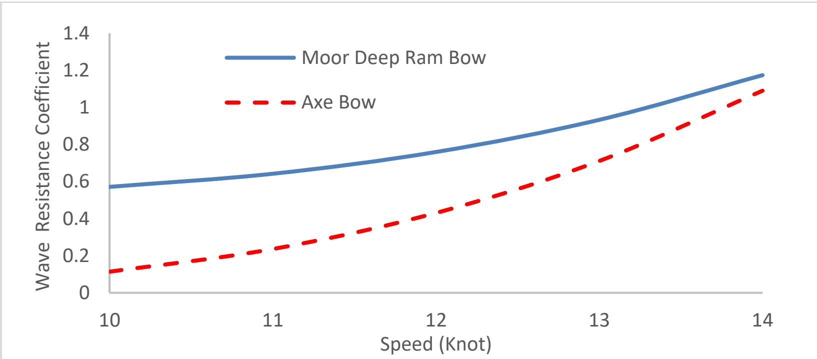


Fig. 11. Wave Resistance Coefficient v Speed

In line with the resistance, the engine power requirements of the axe bow at a speed of 12 knots is 2307 kW, while the moor deep ram is 2403 kW.

Table 3
Engine Power Requirements at Variations in Speed and Bow Shape

Speed (knot)	Engine power (kW)	
	Moor deep ram bow	Axe bow
10	1072	887
11	1703	1599
12	2403	2307
13	3360	3148
14	4578	4219

Engine power requirement is calculated by using Eq. (2) and the result is shown in Figure 12. To determine the type of engine used, the engine power at a speed of 12 knots is calculated at 85% to 90% MCR as the ideal range in the main engine operating conditions so that greater engine power is obtained as a backup when the ship is in rough hull condition

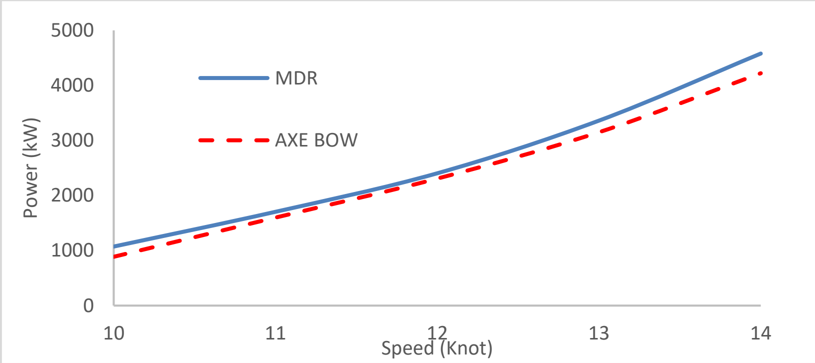


Fig. 12. Power v Speed Curves

Table 4 shows that to operate at 85% margin, the minimum engine power that is required for axe bow and moor deep ram bow are 2714 kW and 2827 kW respectively. So based on these results, the same type of engine can be used for the moor deep ram and axe bow.

Table 4
Engine Power Requirement Margin

% MCR	Engine Power (kW)	
	Moor Deep Ram bow	Axe bow
85	2827.33	2714.19
86	2794.45	2682.63
87	2762.33	2651.79
88	2730.94	2621.66
89	2700.25	2592.2
90	2670.25	2563.4

By using Eq. (3) and the data of SFOC in Table 5, it is confirmed that the shape of the axe bow requires a lower amount of fuel by 83.64 tons. This is because, at a speed of 12 knots, the engine power required is at 85% MCR where the SFOC is at the most efficient points. It proves that the shape of the axe bow with a lower resistance produces a lower fuel consumption value as well. Meanwhile, the shape of the existing moor deep ram bow with the same speed, fuel consumption will reach 83.73 tons. This value is 0.09 tons higher when compared to the axe bow.

Table 5
SFOC at Various Loads

Power Load (%)	SFOC (g/kWh)
100%	194.4
85%	193.4
75%	195.3
50%	207

Table 6
Fuel Requirements for Various Bulbous Bows

Bow Shape	Engine Power (KW)	MCR (%)	SFOC (g/kwh)	WFO (ton)
Moor Deep Ram Bow	2720	89%	193.6	83.73
Axe bow	2720	85%	193.4	83.64

4. Conclusions

The total resistance of axe bow shows a lower value accounting for 221.5 kN than the moor deep ram bow which obtain 230.8 kN. The results also show the relationship of the wave surface height created by hull-fluid interaction is in line with the wave resistance coefficient and the total resistance itself. Moreover, the fuel consumption for axe bow ship is just a slight advantage by 0.1% over the moor deep ram bow in one trip. This information gives an initial approach to the feasibility of axe bow to be used in cargo ships, although the existing moor deep ram bow still shows a competitive efficiency.

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