Total resistance analysis on bow form model ulstein X-bow with various angle of flare and stem angle

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Abstract. The current bow form named X-Bow can face waves coming towards the ship by breaking waves more subtly. Based on the Ulstein X-bow design patent, there are provisions such as angle of flare bow and stem angle. Continue the previous research that investigates comparison of total ship resistance between conventional bow and x-bow on ship; this study aims to show the impact from various angle of flare bow and stem angle on total ship resistance by Computational Fluid Dynamic. Results are summarized in tables and graphs, showing that angle variations on the bow with 6° stem and 10° flare has the most optimal ship performance at 14 knots with a total resistance value 383,13 kN compared to the original model of 385,62 kN, which decreased by 0.64%.

1. Introduction

A main problem for the practicing naval architect is the prediction of the resistance of new ship building an early stage in the project. When a new ship is ordered, a contract containing a specification of the ship is signed between the owner and the shipyard. The shipbuilding company continues to develop hull forms to reduce the global warming effect. IMO MEPC’s latest regulation on Energy Efficiency Design Index (EEDI) has increased the interest of ship designers in estimating velocity losses based on actual sea conditions. Innovation in sea transportation especially ship with more optimal performance and maintain the existence of Indonesia as a maritime country in the eyes of the world. These efforts can be started from following the development of design innovation bow form. The bow of the ship is the most pressure and tension of the ocean waves because the bow serves to break the waves. Ships with a good bow will provide the efficiency of the resulting barriers so that ship operations and ship movements become better [1].

Therefore, the field of ship design should be open to innovation from other countries in order to compete. Ulstein group from Norway made an innovation in the ship's bow form called Ulstein X-Bow. With the X-bow form the waves coming towards the ship can be break more subtly and reduce the resistance than the conventional bow. The Ulstein X-bow concept needs to be studied more thoroughly to be implemented in Indonesia. One study has proven that the Ulstein X-bow is better at reducing the ship resistance than the bulbous bow [2]. Based on the Ulstein X-bow design patent there are several requirement such as the term flared bow and stem angle. These two angles will affect the diversity of shapes of the Ulstein X-bow.

In this study, the authors will investigate the effect of variations in the angle of the flared bow and stem on the X-bow to analyze the impact of the angular change on the resulting ship resistance.
2. Literature review

2.1 Ulstein X-bow definition

Overall the shape of the Ulstein X-bow is different from a conventional bow. The Ulstein X-bow is dominated by a high, rounded and expands slightly at the top of bow [3]. Ships with Ulstein X-bow have great buoyancy because of increasing volume of the bow shape. Ulstein X-bow was first introduced in 2005. Known as Inverted Bow because of the bow shape with the top flipped towards the rear. Ulstein X-bow was originally designed for offshore vessels. A vessel with a bow like this has better sea keeping than a conventional bow. In addition to sea keeping, this bow is also able to increase fuel efficiency and makes waves more subtly.

2.2 Ship Resistance

Ship resistance is the most important factor that determines the power of the ship needed [4]. Ship resistance is the study of fluid reactions due to the movement of the ship through the fluid. In terms of hydrodynamics, the ship is the amount of fluid force acting on the ship in such a way that it opposes the movement of the ship. The main and most significant factor is the hull geometry and the wet surface of the vessel [5]. The resistance is the same as the force component that works parallel to the axis of the ship's velocity. The total resistance on the vessel can be stated as follows.

\[ R_T = 0.5 \ C_t \ \rho \ V_s^2 \ S \quad (\text{kN}) \]  

Where :
- \( C_t \) = total resistance coefficient
- \( S \) = wet surface area on hull \( (m^2) \)
- \( \rho \) = density of sea water \( (kg/m^3) \)
- \( V_s \) = service velocity \( (m/s) \)

2.3 Flare bow and stem angle

The definition of Flare Bow Angle is the slope angle in the bow at the ship's body plan measured from the intersection of the high line with the waterline. The change of the flare angle will affect the shape of the fore area of the vessel. The design that reduces Bow Flare is claimed to eliminate slamming opportunities and reduce resistance [5]. The stem of angle is defined as the tilt angle the requirement 9° - 45°. For stem angle that is set with range 0° - 55° [6].

![Flare bow angle](image)

**Figure 1.** The angle of flare bow [7]

The flare bow angle is described in Figure 1 with the symbol \( \alpha \) which states the magnitude of the flare angle in the cross-section of the vessel. Figure 2. Illustrates the angle of the stem at the Ulstein X-bow direction in the longitudinal section of the ship.
3. Results and discussion

Table 1 shows the ship principal dimension which is used in the research.

| Principal dimension                  |          |
|-------------------------------------|----------|
| Length of Perpendicular (LPP)       | 102,12 m |
| Breadth (B)                         | 20,65 m  |
| Draft (T)                           | 4,00 m   |
| Height (H)                          | 11,52 m  |
| Displacement                        | 4500 ton |

Furthermore, the ship's resistance analyzes with the variation of the angle of flares bow and stem in X-bow form.

3.1 Modeling with delftship

From the main dimension, ship modeling as in Figure 3 with the Delftship software and export to AutoCAD to get better vision of linesplan.

Figure 2. Angle of stem

Figure 3. Linesplan of ship
3.2 Modeling with CAD software

Modeling is also done with the help of the Rhinoceros software in Figure 4 so that the model can be solid and run in CFD software.

![Figure 4. Modeling with CAD software](image)

3.3 Making of model variation

The modeling was originally designed using Autocad software to perform angle measurements. Then it was transferred to the Delfship software to form a smoother model and to the Rhinoceros software so that it could run in the CFD software. This research examines as many as 10 models of variation and 1 original model with bow shape X-bow which changes the angle of flare and stem. Figure 5 describes the variation of the flare angle. Taken by 5 corners so there are 5 models of variation of flare angle.

![Figure 5. The angle of flare model variation](image)

In table 2 is a breakdown of variations in the flare angle model. For this variation, the stem angle is not changed in order to see the effect of the flare angle clearly.
| Model | Angle variation (degree) |
|-------|-------------------------|
|       | Stem (°) | Flare (°) |
| Original | 6 | 21 |
| 1      | 6 | 10 |
| 2      | 6 | 15 |
| 3      | 6 | 25 |
| 4      | 6 | 35 |
| 5      | 6 | 45 |

Figure 6 illustrates the variation of the stem angle. Taken as many as 5 corners so there are 5 models of stem corner variations.

In Table 3 is a detailed variation of the stem corner model. For this variation, the angle of the flares is not changed in order to see the effect of the stem angle clearly.

| Model | Angle variation (degree) |
|-------|-------------------------|
|       | Stem (°) | Flare (°) |
| Original | 6 | 21 |
| 6      | 10 | 21 |
| 7      | 20 | 21 |
| 8      | 30 | 21 |
| 9      | 40 | 21 |
| 10     | 50 | 21 |

3.4 Model validation
Models obtained from modeling need to be validated first. Correction result on validation should not be more than 5%. If the analysis model is in accordance with the actual data it can be used in further
analysis. In table 4 the ship displacement value after becoming a model is 4499.9 tons while the original data of the vessel is 4500 tons, the validation correction results are 0.002%.

| Model | 8 (knot) | Percent | 10 (knot) | Percent | 12 (knot) | Percent | 14 (knot) | Percent |
|-------|----------|---------|-----------|---------|-----------|---------|-----------|---------|
| Original | 131.50 | - | 202.63 | - | 287.01 | - | 385.62 | - |
| 1 | 131.29 | -0.16% | 201.35 | -0.63% | 286.37 | -0.22% | 383.14 | 0.64% |
| 2 | 132.98 | 1.12% | 204.13 | 0.74% | 289.75 | 0.95% | 386.24 | 0.16% |
| 3 | 131.83 | 0.24% | 202.31 | 0.15% | 287.92 | 0.31% | 388.05 | 0.63% |
| 4 | 132.36 | 0.65% | 202.77 | 0.07% | 290.59 | 1.24% | 387.09 | 0.38% |
| 5 | 132.74 | 0.94% | 205.61 | 1.46% | 290.51 | 1.21% | 387.36 | 0.45% |

3.5 Total resistance analysis

Resistance analysis running on software Autodesk CFD. The eleventh Model tested in software is on 1:1 scale with each model tested 4 variations of speed ie 8 knots, 10 knots, 12 knots, and 14 knots. Below is presented the results of the test.

Table 5 describes the overall results of the value of the total resistance of each model at each speed. In the table shows that model 1 (stem 6°, flare 10°) the total resistance value always decreases compared to the original model at a speed of 8 knots the total resistance value of the original model is 131.50 kN, while in the variation model 1 the total resistance value becomes 131.29 kN, which is down by 0.16%. For the speed of 10 knots the total resistance value of the original model is 202.63 kN and has decreased in the variation model 1 to 201.35 kN so that it drops by 0.63%. At 12 knots the original model has a resistance value of 287.01 kN and dropped on the variation model 1 to 286.37 kN so that it decreased by 0.22% and at the maximum speed of 14 knots of model 1 also experienced a decrease in resistance from 385.62 kN to 383.14 kN which dropped by a percentage of 0.64%. From the results of the analysis on the variation model 1 to 5 with variables of the flare angle, then model 1 (stem 6°, flare 10°) the most constant at any speed always decreases in the value of resistance than the original model 1 (stem 6°, flare 21°). Thus flares with the smallest degree in the context of this research can produce a more optimal model in terms of the reduction in the value of total resistance.

Figure 7 illustrates the resistance graphic character for the original model to the variation of model 5 that the increasing speed increases the total resistance value, but model 1 is always at the bottom of the original model as well as other variation models. Furthermore, the analysis of the total resistance value was carried out in the second test, the ship model that experienced variations in the angle of the stem model 6 to model 10. Here are the results of the analysis of total resistance values.
Table 6 describes the overall results of the value of the total resistance of each model at each speed. But in this analysis states that the variation models 6 to 10 have a higher total resistance value than the original model at each speed. The original model (stem 6°, flare 21°) has a smaller total resistance value than any other variation model for any speed variation. In this analysis variation of model 6 (stem 10°, flare 21°) has increased the total resistance value but the result does not vary much with the original model results. Thus, in the original model and variation model 6 to 10 for variable angular variables that have a small degree of value can affect the small value of the total resistance.

Table 6. Total resistance result original to 6-10 stem variation models at 8-14 knot

| Model | 8 (knot) | 10 (knot) | 12 (knot) | 14 (knot) |
|-------|----------|----------|----------|----------|
|       | RT (kN)  | Percent  | RT (kN)  | Percent  | RT (kN)  | Percent  | RT (kN)  | Percent  |
| Original | 131.50  | 0.16%    | 202.63  | 0.49%    | 287.01  | 0.37%    | 385.62  | 0.30%    |
| 6      | 131.73  | 0.16%    | 203.64  | 0.49%    | 288.08  | 0.37%    | 386.8   | 0.30%    |
| 7      | 133.66  | 1.63%    | 205.76  | 1.54%    | 291.91  | 1.70%    | 390.97  | 1.38%    |
| 8      | 135.81  | 3.27%    | 208.00  | 2.64%    | 296.09  | 3.16%    | 398.6   | 3.36%    |
| 9      | 134.84  | 2.53%    | 207.65  | 2.47%    | 293.73  | 2.34%    | 395.06  | 2.59%    |
| 10     | 133.73  | 1.68%    | 206.66  | 1.97%    | 290.88  | 1.34%    | 394.31  | 2.25%    |

Figure 8 describes the character of the resistance graph for the original model up to the 6-10 models variation that the more speed increases the total resistance value increases. But with a small stem angle the resistance value also decreases in the context of this second test because the smallest angle of the stem is owned by the original model, the smallest resistance model is still owned by the original model.
3.6. Holtrop validation

To validate the results of the test model of CFD software, the manual calculation of the total resistance value in one model is carried out, namely the variation 1 model with the angular variation (stem 6°, flare 10°) compared to the total resistance value obtained from the software. The formula for calculating the total resistance value used is the general resistance formula.

\[ R_T = 0.5 \cdot C_t \cdot \rho \cdot V_s^2 \cdot S = 0.5 \times 0.007549208848 \times 1,025 \times 7.196^2 \times 1886.3 = 377.91 \text{ kN} \]

In CFD software the total resistance value of model 1 variation at 14 knots is 383.14 kN so based on the two values above there is an error difference of 1.36%.

4. Conclusions

From the results of the analysis of ship resistance obtained results for variations in flare angles the highest resistance of the variation model compared to the original model is that it occurs at a speed of 14 knots in the variation model 1 (stem 6°, flare 10°) with a percentage decrease of 0.64% from 385.62 kN in the original model to 383.14 kN in the variation model 1. Whereas for the variation of the angle of the stem there is no decrease in the total resistance value in the variation model compared to the original model. The most optimal variation model performance in terms of reduced resistance that is equal to 0.64% compared to the original model occurs in model 1 with variation (stem 6°, flare 10°).

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