Analysis Of Resistance And Effective Wake Friction Due To Addition Of Stern Tunnels On Passenger Ship Using Cfd

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Abstract. In this study, the stern tunnel to improve the efficiency of ship propulsion system is analysed. Stern tunnels installed on the two sides of the ship stern. Analysis of ship resistance and wake friction of the ship using CFD are carried out. The stern tunnel height (Hw) and length (L) are implemented to find the better stern tunnel form of the ship. The result of analysis showed that model has a high stern tunnels (Hw) of 1,444 m or additional high stern tunnels ratio of 16% and stern long tunnels (L) about 7 m is a model that has the smallest resistance about 1.1137 N or able to make reduction of resistance amount 11.2582%. While, the model with the addition of height of 0.2 m and a length of 9 m of stern tunnel is a model that has the better advanced speed about 4,927% in increase, and better wake friction about 30.4% in reduce.

1. Introduction

This research was carried out on the passenger ship of MV Tropical Princess Cruises that has V hullform using two propulsor. In this passenger ship will be added stern tunnels on both sides of the ship stern.

Stern tunnels are one of hullform modification that aims to centralize the flow of water towards the propeller which improves speed advanced tunnels stern of the ship so it can add thrust and propeller efficiency as well as reducing the wake value of ship. The study is conducted to modify the shape of the stern tunnel on passenger ships. The parameters of stern tunnel is considerd to be modified, that is the height of stern tunnel (Hw) and the length of stern tunnel (L).

Some of the studies CAD-integrated CFD and optimization method can be used simultaneously to solve any problems, including the optimization of hull shape. Deddy, C [2, 3] has developed the parametric bulbous bow design and submarine design are constructed using the cubic Bezier curve method and the curve-plane intersection method, then it can be used to generate a parametric bulbous bow shape automatically using solid modeling for the optimization calculation in the effort to minimize the ship's resistance.

For ship stern tunnel form that have been done in which the secondary parameter is varied to modify the ship stern tunnels by height stern tunnels (Hw) using 3(three) variations of 1.1 m - 1.5 m on a cargo ship of BM-Duisburg to analyze the ship's performance. The result showed that the improvement of Hw tends to reduce wake friction and increase the thrust deduction factor [1].

Refer to this fact, beside the height of stern tunnel (Hw), it is also essential to do the assessment on the parameter of the length of stern tunnels (L) on passenger vessels with various variations in order to get the larger advanced speed value, the largest and the smaller wake friction value.

2. Stern Tunnel Parameters

Stern Tunnels is a modified form of the stern of the ship to make a convex curve so allowing the installation of larger diameter of propeller. The advantage of this one is a higher efficiency of the wake friction due to the combination of the decline of the shaft angle and increase the propeller dimension. Figure 1 shows the dimensions of stern tunnel is used in this study.
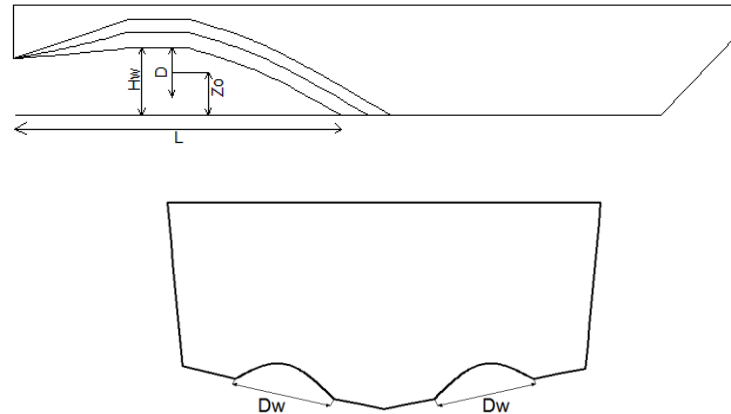
Figure 1. Stern Tunnel Parameters

where:
L   : The length of stern tunnel
Hw   : The height of stern tunnel
D   : Propeller diameter
Dw   : Stern tunnel diameter
Zo   : Distance of hub propeller to baseline.

3. Resistance And Wake Calculation Using Cfd

3D Modeling of ship is created to analyze ship resistance and effective wake friction using CFD (Computational Fluid Dynamic) method then it will be validated with empirical method.

This research is focused to obtain a hullform has a small resistance and wake of ship comparing with original hullform of ship after changing of stern form using adding of stern tunnel. Stern tunnel lenght (L) and stern tunnel height (Hw) as parameters are applied to create stern form of models.

Ship model uses a scale of 1:40. This model is used to a CFD simulation process acccording with total number of mesh elements (Table 1).

Table 1. Ship principle dimensions (original and CFD model scale)

No.	Items	Original Scale	CFD Model Scale	Unit
1	*Length Over All (LOA)*	30.66	0.7665	m
2	*Length of Waterline (Lwl)*	28.655	0.7164	m
3	*Breadth (B)*	6.08	0.152	m
4	*Depth (H)*	3.3	0.0825	m
5	*Draft (T)*	1.52	0.038	m
6	*Wetted Surface Area (WSA)*	170.953	0.10676	m^2
7	*Speed (Vs)*	7.716	1.2188	m/s
8	*Froude Number (Fn)*	0.46	0.46	
9	*Coefficient Block (Cb)*	0.415	0.415	

3.1. Ship Model Variations

Table 2 shows variation of stern form based on 2(two) parameters, such as: stern tunnel lenght (L) and stern tunnel height (Hw). Correspondence one to one is implemented to obtain Model B to Model M.

Table 2. Variation of models based on stern tunnel height (Hw) and Lenght (L)

| Models	Hw	Ratio of Hw added (%)	L	Ratio of L added (%)
Model A	1,244 m	-	-	
Model B	1,344 m	8	7 m	23 %
Model C	1,344 m	8	8 m	26 %
Model D	1,344 m	8	9 m	30%
Model E	1,394 m	12	7 m	23 %
Model F	1,394 m	12	8 m	26 %
Model G	1,394 m	12	9 m	30%
Model H	1,444 m	16	7 m	23 %
Model I	1,444 m	16	8 m	26 %
Model J	1,444 m	16	9 m	30%
Model K	1,494 m	20	7 m	23 %
Model L	1,494 m	20	8 m	26 %
Model M	1,494 m	20	9 m	30%

Table 3 shows value of wetted surface area after adding the stern tunnel on the ship stern. The Percentage of WSA difference on the model M is 0,925% larger than original model.

Table 3. Wetted Surface Area on each model

Model	WSA (m^2)	WSA Difference to Model A (%)
Model A	0.106760	0.000
Model B	0.107125	0.342
Model C	0.107199	0.412
Model D	0.107252	0.461
Model E	0.107331	0.535
Model F	0.107378	0.579
Model G	0.107392	0.592
Model H	0.107398	0.598
Model I	0.107430	0.628
Model J	0.107563	0.752
Model K	0.107582	0.771
Model L	0.107679	0.861
Model M	0.107748	0.925

3.2. CFD Process

Phase mesh is the most complicated stage. When an error is occured in the process working, so mesh production will be stoped and failed. Then the mesh step must be repeated, or if the error due to the form of the model then needs to be fixed before the new model do mesh process again. So, it is advisable to be careful and meticulous. The greater of the number of mesh elements, so the mesh results will be more delicate and can get more accurate of results. If the number of elements is too much, the numerical simulation process will be more severe and more consumable time. Figure 2 shows the result of mesh elements for ship model.
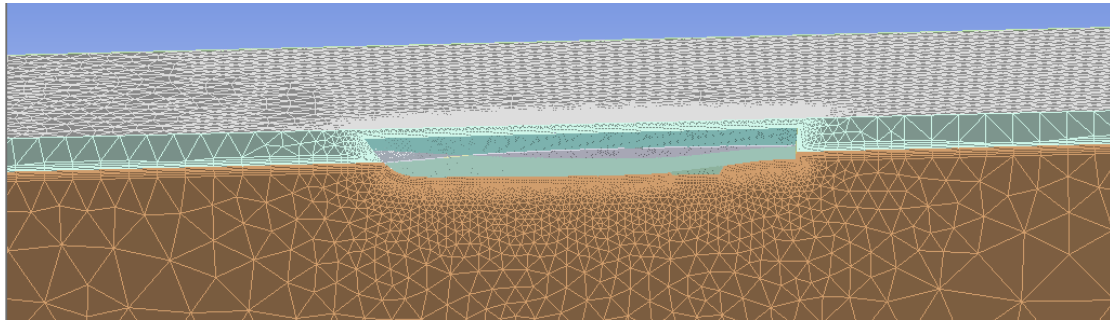
Figure 2. Mesh process and total number of elements

Meshing process time depends on total number of elements. In this research, total number of mesh elements about 600,000 elements for each models. Consumable time of mesh production abou 5 minutes. Table 4 and 5 show the result of mesh statistics for each models.

Table 4. Mesh statistics for each models

Mesh Statistics	Model A	Model B	Model C	Model D	Model E	Model F	Model G
Total number of nodes	137131	142196	136908	153808	156063	153617	149487
Total number of tetrahedra	387984	404299	425586	446661	450143	481215	474254
Total number of pyramids	3295	2301	3658	3423	3775	4304	4460
Total number of prisms	119819	125116	105975	131891	134623	118185	112737
Total number of elements	511098	531716	535219	581975	588541	603704	591451

Table 5. The Remaining mesh statistics models

Mesh Statistics	Model H	Model I	Model J	Model K	Model L	Model M
Total number of nodes	153617	151140	169472	172532	165995	176283
Total number of tetrahedra	481215	479633	496213	501138	528640	525142
Total number of pyramids	4304	4601	3835	4342	5779	4542
Total number of prisms	118185	114450	144537	147967	124482	147110
Total number of elements	598684	603704	644585	653447	658901	676794

Model setup stage is a important step in numerical simulation based on Computational Fluid Dynamic (CFD) because choice of boundary condition has any effects into the good result. The wrong input of boundary condition value will cause an error of simulation process.

In this simulation process, boundary condition of bottom uses wall type and free slip wall, it means fluid motion did not occure any slip. Boundary condition of the hull uses the wall type, the same as the bottom. Mass and momentum use the free slip wall which means that the fluid moves no slip. While the wall roughness applies a smooth wall. For inlet boundary condition, the mass and momentum uses Cartesian velocity components. This inlet fluid will move and the inlet fluid velocity is also determined. Determination of velocity at the inlet is filled using three coordinates, namely speed U, V, W (X, Y, Z). Turbulence in the inlet is 1% (low). The boundary condition of the oulet isoutlet type which its function as a discharge of the fluid. The flow is a subsonic at the outlet. Side boundary is set up as a wall because of its function as a closed wall. Then the mass and momentum uses free slip wall like as the bottom. The boundary condition of symmetry is located on the ship hull. The boundary type uses symmetry. Then the boundary condition of top uses an opening because its function is as an open field and subsonic fluid flow. Mass and momentum use an entrainment with relative pressure of 0 (zero).

Calculation of total resistance of ship is performed by simulating stern form using CFD analysis. CFD simulation results are validated with empirical calculations to determine the level of calculation error about ± 5%. Table 6 shows comparison of empirical and numerical calculations.

Table 6. Comparison of empirical and numerical calculations

Metode	Rf (N)	Rv (N)	Rw (N)	Rt (N)
Empiris	0.398	0,5065	0.739	1,2463
Numerik	0.406	0.517	0.738	1.255
Different (%)	2,01	2,07	0,13	0,7

Table 6 shows that the error value of empirical and numerical calculations is less than 5%. This result proves that the numerical calculations based CFD is very closed with empirical calculation.

3.2.1. Ship resistance calculation
Total ship resistance value is obtained from magnitude of force on the ship hull. In the Table 7 are presented the value of total ship resistance in the each models.

Table 7. Total resistance calculation for each models

Models	Coeff. of total resistance (Ct)	Total Resistance (N)	Difference with Model A (%)
Model A	0.01544	1.2550	-
Model B	0.0150829	1.2306	-1.9124
Model C	0.01434	1.1709	-6.2948
Model D	0.01401	1.1426	-7.7230
Model E	0.01417	1.1581	-8.8606
Model F	0.01388	1.1335	-9.7052

Models	Coeff. of total resistance (Ct)	Total Resistance (N)	Difference with Model A (%)
Model G	0.01377	1.1265	-10.6454
Model H	0.01362	1.1137	-11.2582
Model I	0.0136725	1.1182	-10.8980
Model J	0.01404	1.1510	-6.5006
Model K	0.01472	1.2075	-5.3778
Model L	0.0145	1.1875	-3.7624
Model M	0.01489	1.2220	-2.6265

Table 7 shows that the addition of stern tunnels on all of variation models tend to reduce the total ship resistance (Rt) with a range between 1.91 -11.26%. Model H has a high stern tunnels (Hw) of 1,444 m or additional high stern tunnels ratio of 16% and stern long tunnels (L) about 7 m is a model that has the smallest resistance = 1.1137 N with a difference with the model A of 0,1413 N or a reduction of resistance amount 11.2582%.

Figure 3 shows a comparison between the resistance value of each ship models that are: friction resistance (Rf), viscous resistance(Rv), wave resistance (Rw) and total resistance (Rt).
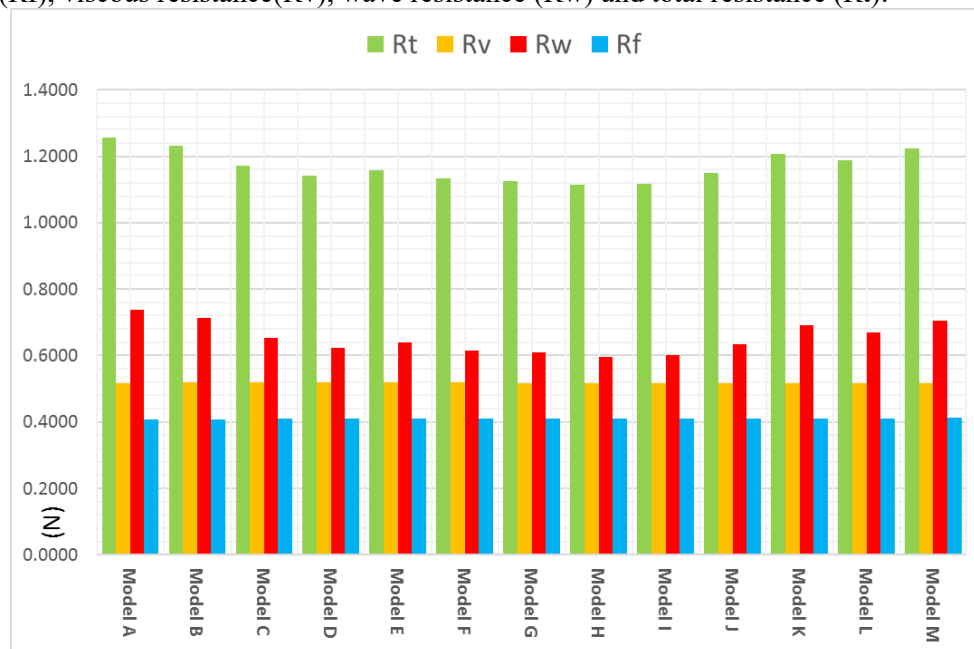

Figure 3. Components of resistance for each models

Based on the results are shown in Figure 3 can be conclude that the addition of stern tunnels on a Froude number of 0.46 is obtained that wave resistance (Rw) is greater than the friction resistance and viscous resistance. The wave resistance has a significant effect in reducing total resistance with addition of the stern tunnels comparing with other resistance components such as friction resistance and viscous

resistance that tends to stay constant due to the value of original model resistance. In Figure 4 and Figure 5 presents a wave countour on side of the Model A and Model H.
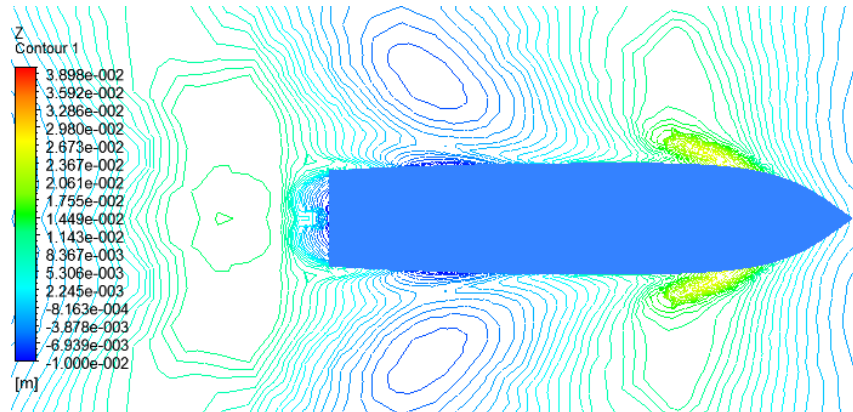
Figure 4. Wave pattern model A
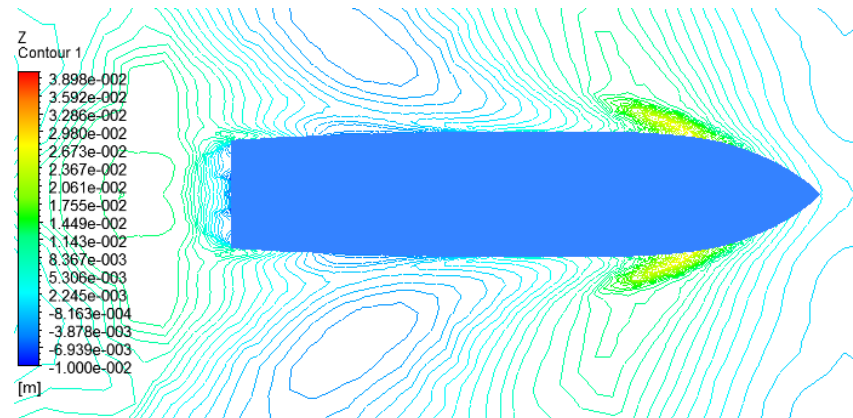
Figure 5. Wave pattern model H

3.2.2. Wake Calculation

In calculating the value of a wake, in this study the average value Va scale model obtained from Ansys CFD-Post is converted into an average Va original model by using the calculation of the Froude number. Here are the results of calculations wake of thirteen models such variations.

Table 8. Comparison advance velocity (Va) and wake for each models

Model	Va [M/S]	Wake	Difference (%)
Model A	6.6407	0.13936	
Model B	6.6913	0.13281	-4.69891
Model C	6.7194	0.12916	-7.31773
Model D	6.7928	0.11965	-14.14364
Model E	6.8413	0.11337	-18.64840
Model F	6.8860	0.10756	-22.81302
Model G	6.8512	0.11207	-19.57719

Model	Va [M/S]	Wake	Difference (%)
Model H	6.8769	0.10875	-21.96265
Model I	6.8951	0.10639	-23.65843
Model J	6.9364	0.10104	-27.49690
Model K	6.8773	0.10870	-22.00055
Model L	6.9155	0.10374	-25.55509
Model M	6.9679	0.09695	-30.43011

From the all variation models are analyzed based on CFD can be stated that the addition of stern tunnels can concentrate the flow of water leading to the propeller that cause advanced speed (Va) is increased or with another word the value of Va is increases and the value of ship wake-friction becomes decrease. From the results is obtained that the model M with high stern tunnels 1,494 m (stern tunnels add rate of 20%) and long stern tunnels 9 m is a model that has the smallest value that is equal to 0.09695 wake with a percentage of the difference in value wake the original model was reduced by 30.4%.

4. Conclusions

In this study, Model H has a high stern tunnels (Hw) of 1,444 m or additional high stern tunnels ratio of 16% and stern long tunnels (L) about 7 m is a model that has the smallest resistance = 1.1137 N with a difference with the model A of 0,1413 N or a reduction of resistance amount 11.2582%.

While Model M has a stern tunnel height about 1,494 m (increase by 20%) and stern tunnel length about 9 m are model that have an advanced speed value is larger than other model is equal to 6.9679 m/s with the difference in Va value comparing the original model increased by 0,3272 m/s or 4,927%.

Model M has a stern tunnel height about 1,494 m (increase by 20%) and stern tunnel length about 9 m are model that have an effective wake friction value is smaller than other model is equal to 0.0969 by the difference in wake value comparing the original model reduced by 0.0424 or 30.4%. The addition of stern tunnels can increase the advanced speed of ship and reduce the effective wake-friction ship.

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