“Study of Trim Dependence for Ship performance in the Actual Sea Conditions by Computational Fluid Dynamics (CFD) Simulations"

Final Report

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Abstract

Nowadays, Computational Fluid Dynamics (CFD) simulation techniques are widely used in ship hydrodynamics applications and resistance analysis based on CFD simulations plays a decisive role in the development of new, eco-friendly ship hull forms. The purpose of this study is to analyze the trim effect on resistance and performance of ship by employing CFD simulation methodology. In the present study, the free surface flow around the Kriso Container Ship (KCS) model without rudder is simulated first in even keel condition using the RANS solver Fluent. The mesh, boundary conditions, and solution techniques are validated by comparing the computed resistance value to experimental value in even keel condition. As a result, a reasonable agreement is found. Afterwards, the validated mesh, boundary conditions, solution techniques are employed to estimate the resistance of KCS hull in different trim conditions at Fn=0.26 and the results are compared with the even condition.

1. Ship Model

In the present study, Kriso Container Ship (KCS) hull is selected as a model case for CFD validation because the extensive model test data of this KCS hull are available for resistance at different Froude numbers (CFD Tokyo Workshop 2005). The profile of the KRISO Container Ship (KCS) is shown in Figure 1 and the main particulars of the model used in the present study are listed in Table 1.

Figure 1 KRISO Container Ship (KCS)

Table 1 Main particulars of ship model

Parameters			Dimensions
Length of overall	L_{WL}	[m]	7.3570
Length between perpendiculars	L_{PP}	[m]	7.2786
Beam	B	[m]	1.0190
Draft	T	[m]	0.3418
Wetted surface area w/o rudder	S	[m^2]	9.4379
Block coefficient	C_b		0.6510
Displacement	∇	[m^3]	1.6490
Scale ratio	λ		31.599

2. Numerical method

In the present study, the commercial CFD software FLUENT is used to simulate the free surface flow of a container ship at a model scale. It solves the RANS equations using a cell-centered finite-volume method. The governing equations are the three-dimensional Reynolds Averaged Navier-Stokes equations (RANS) for incompressible flow. For the analysis of high Reynolds number flows, the Shear Stress Transport $k-\omega-SST$ two-equation turbulence model by Menter is employed with a wall function approach for turbulence closure. Computational grids are generated using GAMBIT, pre-processor of FLUENT. The unstructured tetrahedral and structured hexahedral meshes are generated around the model scale KCS hull geometry without rudder. The Reynolds number based on ship length (L_{WL}) and ship velocity is 1.26 x 10^7 and the Froude number is 0.26.

3. Simulation Results

In the present study, the double model flow and free surface flow computations of KCS model without rudder in even keel condition at *Fn*= 0.26 is carried out first to validate mesh, boundary conditions, and solution techniques since the model test data is available for resistance of KCS hull in even keel condition(CFD Tokyo Workshop 2005). The validated mesh, boundary conditions, and solution techniques are later used to calculate resistance in different trim conditions.

3.1 Double Model Flow Computations in Even Keel and Different Trim Conditions

As a first step of present study, Double Model flow computations for KCS hull form without rudder are performed at different Froude numbers in even keel condition to validate mesh, boundary conditions, and solution techniques. The computed results for Double Model flow are compared with model test results of case 2.1 proposed in the CFD Workshop 2015 and found reasonable agreement. Same mesh, boundary conditions and solution techniques are used to calculate the KCS hull resistance at *Fn* = 0.26 in different trim conditions shown in Table 2. A positive (+) trim value is defined bow up. Comparing with even keel condition, significant increase in total resistance coefficient is observed when ship was trimmed by stern. It is noted that trim effect cannot be clearly seen in Double Model computation because viscous resistance change slightly with change in trim. The fact that there are slight changes in wetted surface area with change in trim and the effect of trim is dominant on wave making resistance part.

3.2 Free Surface Flow Computations in Even Keel and Different Trim Conditions

The free surface flow computation around the KCS model without rudder in even keel condition at *Fn*= 0.26 is carried out first to validate mesh, boundary conditions, and solution techniques. Computational domain for free surface flow is defined by $-L \le x \le 2.5L$, $0 \le y \le -L$ and, $-L \le z \le 0.06\,L$, for all cases. Only the port side is computed due to symmetry. The computational domain consists of two blocks and 1.7 M cells. The partial views of computational grid shown in Figure 3 are the magnified views of bow and stern region for KCS hull model. Transient state computations are performed. The converged solutions for free surface flow computation with engineering accuracy are obtained with over 10,000 time steps (110 s).

The comparison of the computed resistance coefficient result with corresponding model test result in even keel condition at *Fn*=0.26 is shown in Table 2. It is noted that the difference is not much since the comparison error (%) is about 5.4 % and thus resistance result is found as a reasonable agreement. The free surface pattern near the hull is also well captured since the grid resolution is fine enough.

Afterwards, the same mesh, boundary conditions and solution techniques are employed to estimate the resistance values of KCS hull at design draft in different trim conditions shown in Table 3. Grids for KCS hull in even keel and trim conditions are generated to be the same as much as possible in order to reduce the effect of grid difference.

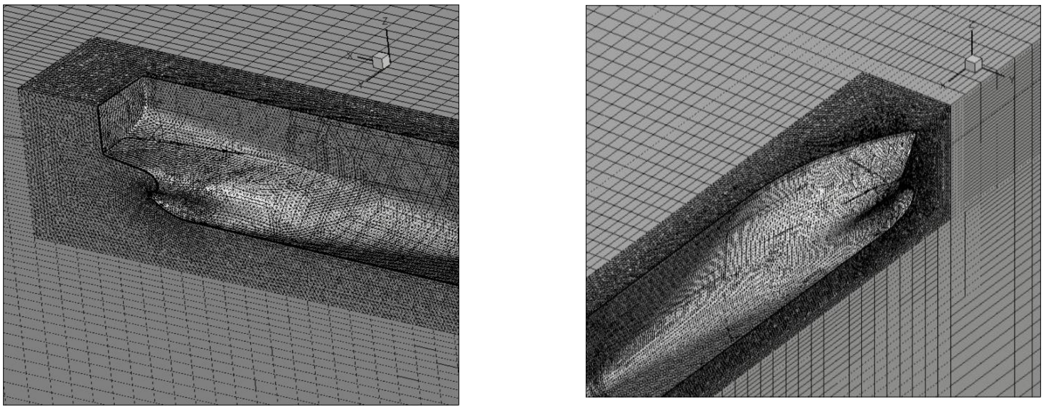

Figure 3 The partial views of computational grid of KCS hull.

Table 2 Comparison of computed and experimental total resistance coefficient results in even keel condition at *Fn*=0.26

KCS hull	Total Drag coefficient $C_T = \frac{D}{1/2\rho V^2 S}$	Comparison Error (%)
Computed	3.910×10^{-3}	5.4%
Experiment	3.711×10^{-3}	

Table 3 Trim Conditions

Trim Conditions	Trim by bow		Even keel	Trim by stern	
Trim [m] % LWL	-0.75%	-1.5%	0	+0.75%	+1.5%
Trim Angle [Degree]	-0.43	-0.859	0	+0.43	+0.859
Wetted surface area (S) [m^2]	4.756	4.744	4.785	4.827	4.825

The computed resistance coefficients results of KCS in even keel and different trim conditions at *Fn*=0.26 are listed in Table 4. The resistance coefficients are nondimensionalized with $0.5\rho V^2 L^2$ where ρ is a density of water and *V* and *L* are speed and a length of a ship model KCS. Table 5 shows the computed resistance results where the total resistance is decomposed into viscous resistance and wave making resistance in order to analyze the trim effect on each resistance component.

Table 4 Computed resistance coefficients for the KCS hull in even keel and different trim conditions

Trim conditions	Trim Angle (deg)	$C_p = \frac{R_p}{\frac{1}{2}\rho L^2 V^2}$	$C_F = \frac{R_F}{\frac{1}{2}\rho L^2 V^2}$	$C_T = \frac{R_T}{\frac{1}{2}\rho L^2 V^2}$
Even Keel	0	2.235E-04	4.588E-04	6.824E-04
Trim by bow	-0.43	2.270E-04	4.580E-04	6.850E-04
Trim stern	+0.43	2.454E-04	4.578E-04	7.032E-04
Trim by bow	-0.859	2.444E-04	4.542E-04	6.987E-04
Trim by stern	+0.859	2.849E-04	4.453E-04	7.302E-04

The wave making resistance R_w (R_T - R_v) are calculated by using the corresponding form factors which are estimated by the double model flow computation. The results show that viscous resistance changes slightly with change in trim and the effect of trim is dominant on wave making resistance. The viscous, wave making and total resistance versus trim plots for the KCS hull are shown in Figure 4, 5 and 6. The computed wave profiles along the hull and the longitudinal wave cut at y/L_{pp}=0.15 in even keel condition and different trim conditions are compared in Figure 7. The difference in bow and stern waves generated by trim by bow and stern are clearly observed.

Table 5 Computed resistance results in even keel and different trim conditions

Trim conditions	Trim Angle (deg)	R_w(N)	R_v (N)	R_T (N)
Even Keel	0	19.164	70.91	90.074
Trim by bow	-0.43	21.160	70.19	90.424
Trim stern	+0.43	22.916	69.91	92.823
Trim by bow	-0.859	22.608	69.81	92.226
Trim by stern	+0.859	26.375	69.95	96.392

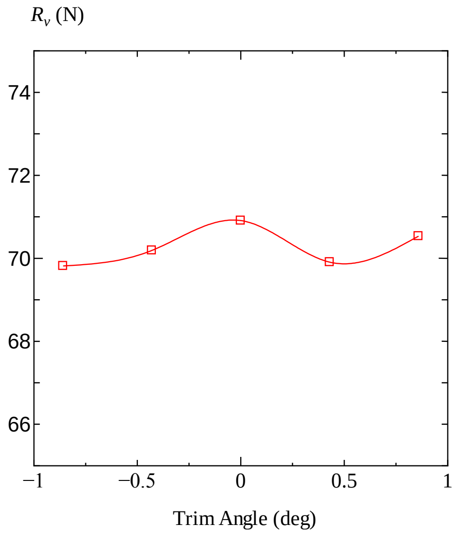

Figure 4 Viscous resistance as a function of Trim

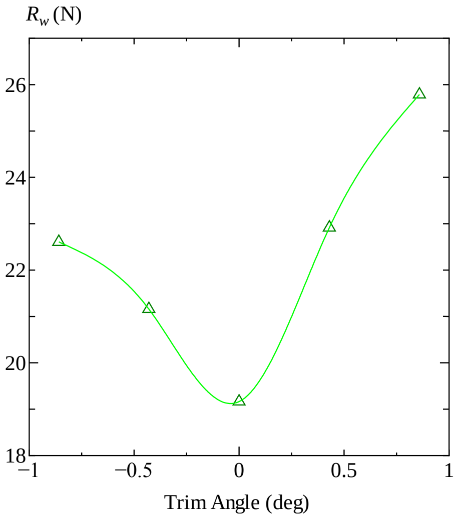

Figure 5 Wave making resistance as a function of Trim

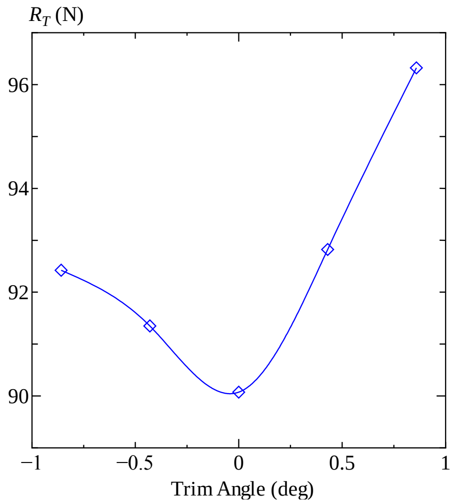

Figure 6 Total resistance as a function of trim (positive (+) trim value is defined bow up)

Comparing with the even keel condition, the trend of the increased total resistance in trim conditions is observed. The significant increase in total resistance is about 3 % and 7% when the ship was trimmed by stern 0.43 deg and 0.859deg. However, on trimming the ship by bow, total resistance of the hull increases about 0.4% by 0.43 deg and 2 % by 0.859deg.

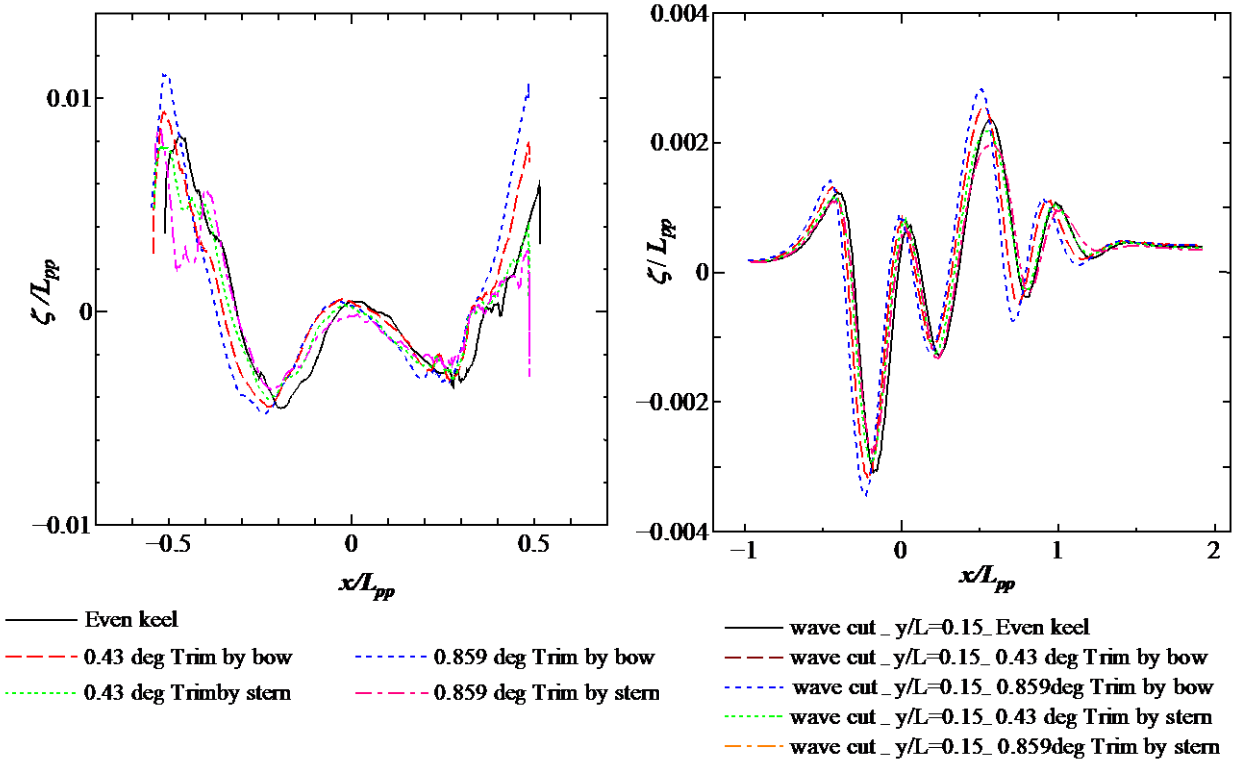

Figure 7 Computed wave profiles on the hull and longitudinal wave cut at y/L_{pp}=0.15 in even keel and different trim conditions at Fn=0.26

4. Conclusions and Future works

In the present study, CFD simulation techniques have been employed for MOERI container ship (KCS) hull to analyze the effect of trim on resistance. The method presented for free surface flow computation around the KCS model is carried out in even keel and four different trim conditions in calm water at design speed and draft. The computed resistance result in even keel condition is compared with experiment result and found in reasonable agreement since the comparison error is about 5.4%.

Comparing with the even keel condition, the trend of the increased total resistance in trim conditions is observed. The significant increase in total resistance is observed when the ship is trimmed by stern. Among four different trim conditions, the resistance of KCS model in trim by bow 0.43 (deg) condition is lower than the rest of three trim conditions. The results showed that the even keel condition gives minimum drag compared with the different trim conditions in the design speed and design displacement because a ship is designed to be most efficient in the design speed and in the design draft.

In future works, CFD simulations in the lower speeds shall be carried for KCS hull since trim optimization of container ship is needed in the off-design and conditions such as slowing steaming or light weight conditions. It is expected that the characteristics of resistance components due to trim can be confirmed by the experiments.