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Numerical Estimation and Validation of Drag Force for KCS Hull using STAR CCM+

Obaid Ullah Khan[1], Zeeshan Riaz[1], Asif Mansoor[1], Behzad Ahmed Zai[1], Najam us Saqib[2,*]

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ABSTRACT

Resistance prediction is mandatory for the optimal ship design and propulsion power requirement. This paper presents the resistance prediction of a container ship model, SVA KCS in calm water using Computational Fluid Dynamics (CFD) commercial software STARCCM+. It uses Reynolds Navier stokes equation for solving the numerical model. The numerical results of the KCS hull in calm water with the available experimental results are compared. A virtual towing tank experiment allowing all 3 DOF (heave pitch and surge) with the propeller propelling behind the ship at self-propulsion point is conducted. The result includes total drag force (shear & pressure), average sinkage and trim data. Rendered free surface visualization, pressure distribution and wake pattern has also been included. Furthermore, EHP (Estimated Hull performance) module of STARCCM+ has been used to predict the resistance of same hull. The obtained results demonstrate that the commercial CFD software STARCCM+ has the capability to predict the resistance, sinkage and trim of a ship hull. Subsequently, using EHP, automated module setup time and errors are greatly reduced.

1. Introduction.

Ship resistance predication is of much importance in the initial stage of ship design, although towing test experiments are commonly used to estimate the resistance of new hull. Furthermore, model tests take a lot of time and there is much possibility of error in constructing that model and placing the appendages at the right places. Towing tank tests with the propeller behind the ship predicts the flow field much better than the unappended towed hull. Self-propulsion tests are needed to be carried out to predict the self-propulsion point of ship. These towing tank experiments are very costly and the demand of solving this numerically has been increased enormously. CFD has gained much popularity for the prediction of resistance and other maneuverability characteristics due to its accuracy and economics. The computational time and cost for fully resolving the flow around a propeller is immensely high compared to Body force propeller method[1]. Studies showed that comparing the fully resolved propeller method and the body force method showed a good agreement for the predicated total force [2–3]. Benchmarking of the validation of Experimental and computational results are carried out in SIMMAN[4–5] Workshop for the resistance and maneuvering characteristics prediction. Three test models are selected for the benchmarking i.e. KCS, KVCC-L2 and DTMB 5415.

Simcenter STARCCM+ is used for numerically solving the resistance prediction. it has greatly advanced in marine industry for its easy process automation, various wave model from flat wave to 5th order wave, dynamic fluid body interaction (DFBI) for capturing different types of ship motions and high resolution interface capturing scheme has made this software most favorable for solving numerical grids of Ships. Simcenter STAR-CCM+ also comes up with an estimated hull performance module (EHP) which enables the users to setup marine simulation in few clicks, consequently, saving a lot of setup time. This paper

[1]Department of Engineering Sciences, PN Engineering College, National University of Sciences and Technology (NUST), Karachi, Pakistan.

[2]Department of Mechanical Engineering, NED University, Karachi, Pakistan.

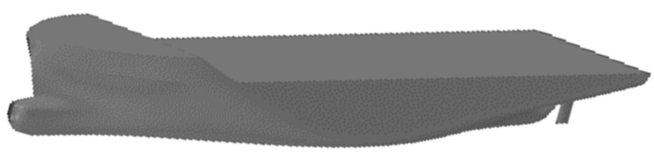
*Corresponding author: Najam us Saqib. E-mail Address: najamussaqib1987@gmail.com.

presents the virtual towing test of ships for resistance prediction using STARCCM+.

2. Model.

Resistance prediction is performed on a scaled KCS ship. This ship is especially designed for the verification and validation purpose and its model data and experimental results are available worldwide. These validations and experimental testing has been a part of different workshops like SIMMAN and Tokyo. Model ship data along with the hull files are obtained from SIMMAN [3]. Fig 1 shows the isometric view of the KCS Hull and the principal parameters of KCS are given in Table 1.

Figure 1: KCS Hull Isometric View.



Source: Authors.

Table 1: Dimensional Parameters of KCS Hull.

Component	Main Variables	Full scale	Model scale	Unit
Hull	Length between perpendiculars (Lpp)	230	4.3671	m
	Load waterline length (Lwl)	232.5	4.4141	m
	Beam waterline length (Bwl)	32.2	0.6114	m
	Depth (D)	19	0.450	m
	Draught (T)	10.8	0.2051	m
	Displacement (∇)	52030	0.3562	m^3
	Surface w/o rudder (S)	9530	3.4357	m^2
	Block coefficient (CB)	0.651	0.651	-
	Midship coefficient (CM)	0.985	0.984	-
Rudder	Surface area of rudder	115	0.0415	m^2
	Lateral Area of rudder	54.45	0.0196	m^2
	Turn rate	2.32	16.8	Deg/s
Propeller	No of blades	05	05	-
	Diameter (D)	7.9	0.150	m
	Rotation	Right handed	Right handed	-
	Hub ratio	0.180	0.227	-
	P/D	0.997	1.30	-

Source: Authors.

3. Numerical Modelling.

Mesh motion technique with rigid mesh motion model i.e. DFBI Rotation and Translation is applied to the computational domain. This technique updates the position of computational domain as the solver runs. It uses RANS formulation along with the continuity and momentum equation with a modification in the conservation equations for the mesh motion. VOF multiphase model is used with the High Resolution Interface Capturing scheme (HRIC) to capture the sharp interfaces of immiscible fluids (air and water). K-ε Turbulence model with all y+ layers treatment is used to capture the turbulence, the K-ε model has been extensively used in predicting the hydrodynamic performance of the ship and it is quite economical in simulation time compared with the k-w turbulence model [6]. Segregated flow solver is selected to solve the integral conservation of equation of mass and momentum.

Hexahedral mesh is used for the domain with volume refinements to capture the wake and accurate prediction of resistance. Mesh and time step sensitivity study is conducted using three different mesh sizes and the time step. Mesh sensitivity is conducted using the finest time step and time step sensitivity using the optimum mesh size, the details are shown in the Table 2 and Table 3. The connective time scale is the ration of LOA and Hull velocity. Final mesh size of 1.5M is selected to compare results with Experimental data which shows the details of mesh at different sections as shown in Fig 2.

Table 2: Total Resistance for different mesh cases.

Mesh Elements (M)	Drag (N)	Simulation Time (Hrs)	% Difference
0.6	20.35	5.13	-
1.5	20.32	13	0.63
2.5	20.31	23	0.049

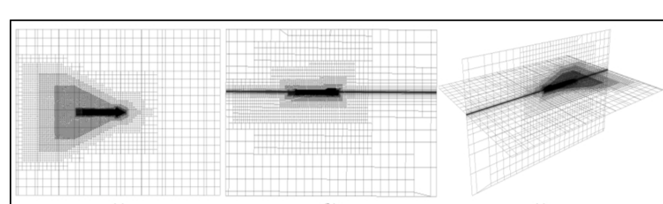
Source: Authors.

Table 3: Total Resistance for different time steps.

Time Step size	Drag (N)	Simulation Time (Hrs)	% Difference
Convective time scale/50	20.38	7	-
Convective time scale/100	20.33	13	0.24
Convective timescale/200	20.32	26	0.049

Source: Authors.

Figure 2: (a) Top view of the mesh showing wake region, (b) Side view of mesh showing the free surface, (c) Isometric view showing the mesh of whole domain.

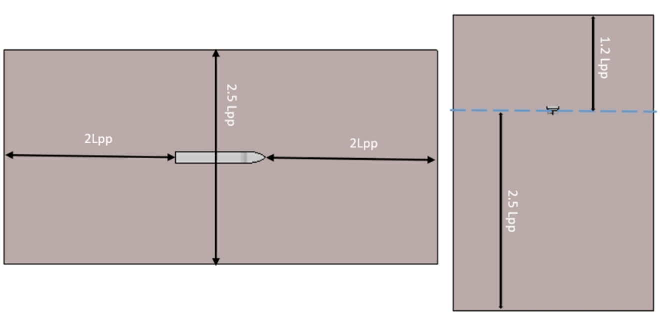


Source: Authors.

4. Computational domain and boundary condition.

The computational domain is made according to the ITTC standards[7] as shown in Fig. 3. The domain is made with a distance of 2Lpp in front and behind of the ship, 1.2Lpp above the free surface and 2.5Lpp below the free surface and 2.5Lpp in the lateral direction. Another setup with computational domain made automatically using the EHP module is also analyzed. Standard boundary conditions are applied using Simcenter STARCCM+ help files for calm water resistance predictions, the inlet, sides and top are treated as velocity inlet and the outlet is treated as the pressure outlet with a hydrostatic wave pressure specification. The ship boundary is treated as a no slip wall. Propeller is modelled using the body force propeller method, the advance coefficient, torque coefficient and the efficiency values are obtained from the SIMMAN 2008 website for KCS with propeller operating at the ship propulsion point i.e. 14rps [3]. The ship is free to move in 3DOF (two translations and one rotation) i.e. surge, heave and pitch and is constraint in the other 3DOF, these conditions are taken from the towing tank test [8] and replicated accordingly.

Figure 3: Computational Domain of KCS Hull.

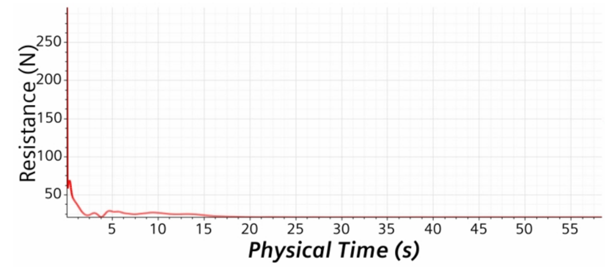


Source: Authors.

4.1. Results and discussion.

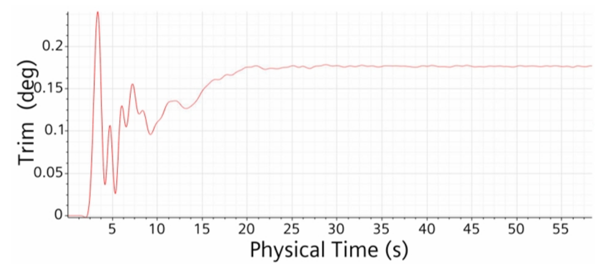
A ship moving in calm water experiences a force in the opposite direction of motion, this force is called the total resistance (R_T). This resistance is composed of mainly two components i.e. the Frictional resistance and the Pressure resistance. Friction of the water acting over the wetted surface area causes a force acting tangentially to the ship in the opposite direction of motion. This frictional force depends upon the surface roughness, viscosity and wetted surface area. In this study, surface roughness has not been taken into account. Pressure resistance is composed of the viscous wave making resistances. Simulation is performed on the optimum time step and the mesh size, convergence for resistance, sinkage and trim is obtained. An asymptotic convergence criterion of 0.0001 is selected for all three measured characteristics as shown in Fig 4-Fig 6.

Figure 4: Resistance Convergence.



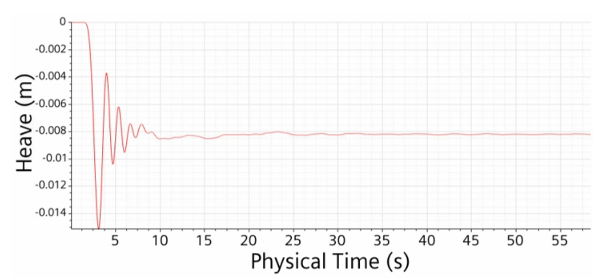
Source: Author.

Figure 5: Trim convergence.



Source: Author.

Figure 6: Heave convergence.



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A Kelvin wake pattern has been formed behind the ship depicting the accuracy of the simulation, the free surface elevation has been captured with HRIC model. Fig 7 - Fig 8 show the wake field contours and the rendered view of the wake in water. Fig 9 shows the pressure distribution of the hull indicating higher pressure on underwater hull and Fig 10 and Fig 11 show the captured free surface and its elevation.

Figure 7: Rendered Kelvin Wake Pattern.

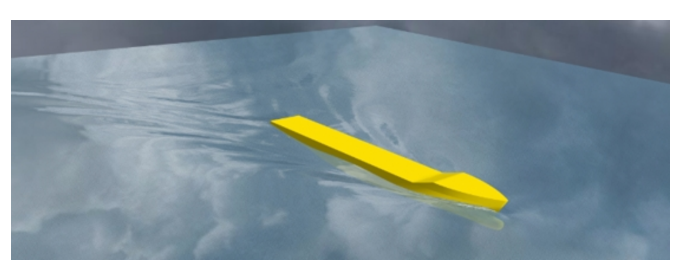

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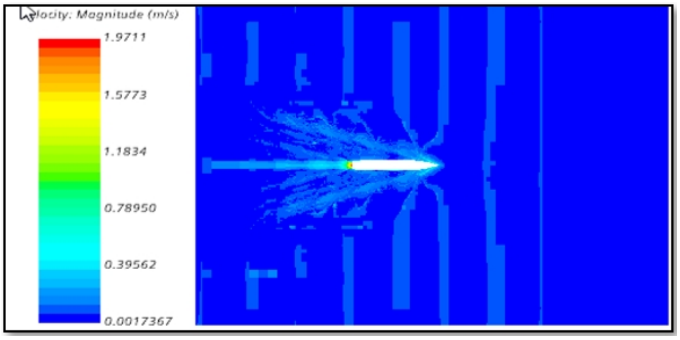
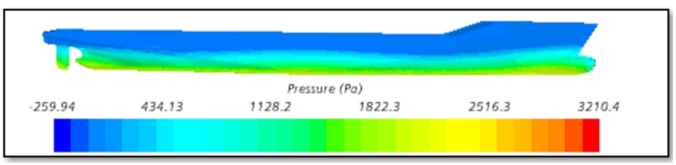
Figure 8: Kelvin wake pattern velocity contours.



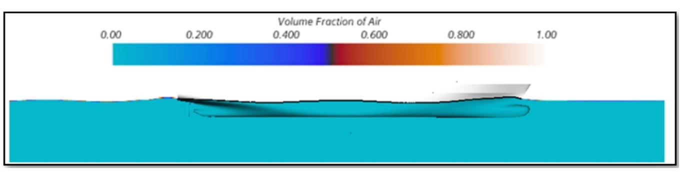
Source: Author.

Figure 9: Pressure Distribution around hull.



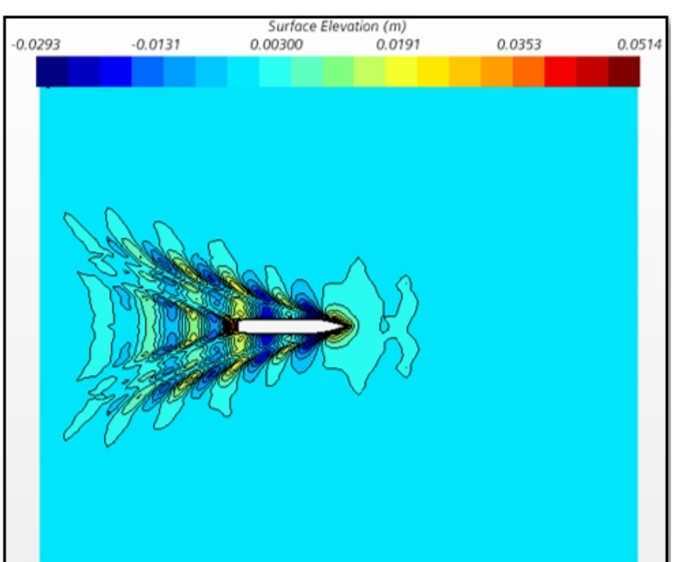
Source: Author.

Figure 10: Captured Free surface.



Source: Author.

Figure 11: Free surface Elevation.



Source: Author.

The resistance coefficient, sinkage and trim are shown in Eq. (1) to Eq. (8):

$$C_T = \frac{X}{1/2\rho S V^2} \tag{1}$$

$$C_F = \frac{0.075}{(log_{10}Re - 2)^2} \tag{2}$$

$$C_R = C_T - C_F \tag{3}$$

$$\frac{\sigma}{L_{PP}} = \frac{\Delta FP + \Delta AP}{L_{PP}} \tag{4}$$

$$\tau = \frac{(\Delta FP - \Delta AP)}{L_{PP}} \tag{5}$$

Where,
X is the total resistance
S is the wetted surface
ρ is the density of water

The total resistance coefficient, and the residuary resistance coefficient are calculated using the Eq. (1) to Eq. (5) and compared with the experimental values. The experimental results for this configuration of KCS model ship is only available for Froude number 0.26, the comparison of CFD and EFD results are tabulated in Table 4.

Table 4: Comparison between CFD and EFD Results.

Variables	Experimental values	Simulated results	% Difference
CT	$4.31*10^{-3}$	$4.106*10^{-3}$	4.71%
CR	$1.07*10^{-3}$	$1.0*10^{-3}$	6.54%
Heave (m)	0.2100	0.21319	1.43%
Trim (Deg)	0.185	0.176	4.86%

Source: Authors.

Conclusions

This paper shows the simulation of scaled model of KCS Hull. Virtual towing tank task has been performed for calculating the resistance, average sinkage and trim values. The method presented above using the mesh motion technique with dynamic fluid body interaction gives the ability to apply real life boundary conditions and constraints. The EHP modules offers quick setup from geometry to solution and post processing in just few clicks, it is designed to be used by non-expert users as well as experienced engineers. This paper recommends the use of EHP module of STARCCM+ for Virtual towing test simulations. The Experimental and the simulated results shows a good comparison. Overall it can be concluded that the STAR-CCM+ mesh motion technique can be adopted for performing fast virtual towing tests.

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