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Ship Motion in Viscous Flow under Irregular Waves

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Abstract— The important task of a ship designer is to develop the best possible shape of hull by considering fundamental factors like sufficient volume, adequate structural strength, ship's hydrodynamic performance like resistance and propulsion, seakeeping and satisfactory stability. The hydrodynamic characteristics of the ship is related to the resistance encountered by the ship and it is used in estimating the required propulsive power which helps the design of the propulsion system. And Prediction of ship motion in viscous flow under irregular waves (real sea conditions) is very important for sea keeping design of ship. The present project deals with the analysis of ship hull with forward speed in viscous flow to calculate the resistance coefficients, heave and pitch motions under irregular waves. A commercial CFD software SHIPFLOW 6.1 is used for hydrodynamic analysis of ship hull in viscous flow under irregular waves and results are published.

Index Terms— Resistance and propulsion, Seakeeping, Computational Fluid Dynamics, Viscous flow, Irregular waves.

1 INTRODUCTION

An accurate prediction of ship response in waves is very important for ship design and sea-keeping. Generally potential flow theory is used to compute the characteristic of fluid flow around a ship hull. But in practice, flow around the ship is viscous and sea conditions are rough in nature. In order to analyze the viscous flow, Reynolds Averaged Navier Stokes equation and Standard k-ω turbulence model have been used in the present work. Generally rough sea conditions like irregular incident waves which are not having uniform wave height and time period induce significant ship motions, which affect ship's resistance. Resulting change in resistance can compromise propulsive efficiency and can affect fuel consumption as well as economy of ship. So it is required to understand the performance of ship in viscous flow under irregular waves for optimum design of ship.

1.1 Computational Fluid Dynamics (CFD)

Fluid flows are governed by partial differential equations which represent the conservation laws for mass, momentum, and energy. Computational Fluid Dynamics (CFD) is the art of replacing such PDE systems by a set of algebraic equations which can be solved using digital computers. Computational Fluid Dynamics provides a qualitative and qualitative prediction of fluid flows by means of mathematical modeling, numerical methods and software tools. The solution of problems involving determination of resistances and ship motions using Computational Fluid Dynamics analysis is now becoming tractable due to enhanced accessibility to high performance computing. In the present study Computational Fluid Dynamics (CFD) is using for evaluating the resistant characteristics and ship motions.

1.2 Ship motion

Ship can experience motions that are defined by the six degrees of freedom as listed below and their notation represented as shown in the Fig 1.

Sway: linear lateral (side-to-side) motion.
Surge: linear longitudinal (front/back) motion.
Heave: linear vertical (up/down) motion.
Yaw: rotation of a vessel about its vertical axis.
Pitch: rotation of a vessel about its transverse axis.
Roll: rotation of a vessel about its longitudinal axis.

1.3 Resistance of ship

When a vessel moves forward through water at a constant velocity V, Its forward motion generates Dynamic pressure on the hull, producing a resultant force in the longitudinal direction and opposite to the advancing direction so called Wave making resistance and Tangential stresses on the wetted surface due to viscosity; the resultant force is also opposite to the ship's moving direction so called frictional resistance. Wave making resistance includes calm water wave resistance and added wave resistance. Neglecting eddy making resistance, appendage resistance and wind resistance the total resistance is equal to sum of frictional and wave making resistance.

Wave making resistance, $R_W = 0.5\ \rho\ C_W\ S\ V^2$
Frictional resistance, $R_F = 0.5\ \rho\ C_F\ S\ V^2$

Where, C_W = wave making drag coefficient, C_F = friction drag coefficient, ρ = density of fluid, S = wetted area of ship V = Relative velocity of ship

2 METHODOLOGY

Problem formulated with Governing equations and boundary conditions. Structural modelling was done using RHINO and offset file was generated in SHIPFLOW 6.1 and this was only used for the hydrodynamic analysis. Computational fluid domain was developed for viscous flows around a surface ship by volume of fluid (VOF) method. A mesh was generated for the ship body and also for fluid domain around the hull in SHIPFLOW 6.1. The analysis was carried out at selected Draft and for different Froude numbers. Resistance coefficients and response of ship motion under irregular waves are determined under different speed conditions of the ship hull using

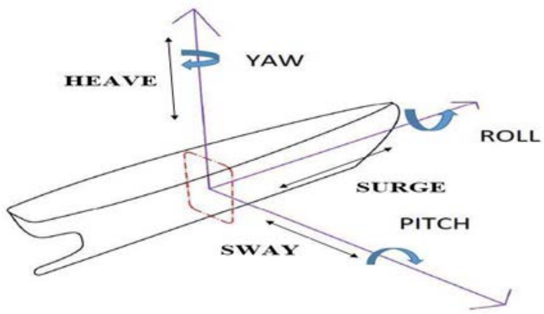

Fig 1 Translation and rotational motions of floating

SHIPFLOW 6.1.

3 STRUCTURAL MODELLING

The Ship is modelled as rigid body with six degrees of the freedom out of these three are displacement degrees of freedom Surge, Sway and Heave along the X, Y, Z axis and three rotational degrees of freedom Roll, Pitch, Yaw about X, Y and Z axis at its center of gravity as shown in Fig 1. A full scale KCS model is used in this study and the properties of hull are obtained from http://www.simman2008.dk and presented in the Table 1 (Tahsin et al., 2015). NURBS Surface of hull created using RHINO and it is shown in the Fig 2.

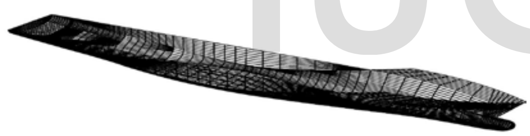

Fig. 2 Perspective view of KCS hull

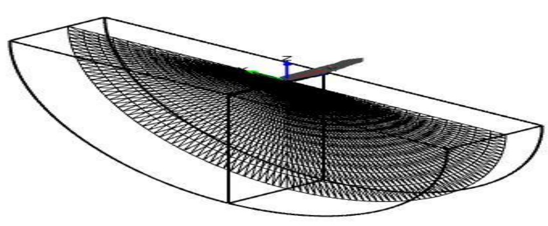

Fig. 3 Cut view of the computational fluid domain

3.1 Computational Fluid Domain and Boundary Conditions

A full scale KCS model is used in this study for analysis and a computational fluid domain has developed in SHIPFLOW 6.1 with the a size of 2 LPP from Forward Perpendicular (F.P), 3 LPP from Aft Perpendicular (A.P) and of radius of 3 LPP as shown in Fig 3 (ITTC, 2011b). The x-axis is horizontal, z-axis is vertical and the y-axis points to starboard (to the right when looking towards the bow of the ship). Analysis was performed with nonlinear boundary conditions. At the upstream or inlet boundary the values of the velocity (V) and the pressure (P) are known. ($V = V_O$ and $P=P_o$). The far field boundary conditions can be split into two parts: the boundary to the side of the ship and the boundary behind the ship. The disturbances to the side will disappear and the boundary conditions are the same as the upstream conditions. The disturbances behind the ship will not disappear and this leads to a different boundary condition. In practice Neumann boundary conditions are used at the downstream boundary i.e., $\partial V/\partial x = 0$ and $\partial P/\partial x=0$. The particles at the hull surface have the same speed as the ship, the so called the no-slip condition. This leads to the following boundary condition for the velocity at the solid surface (V=0). At the free surface there has to be kinematic equivalence between liquid and gas which means that the velocity of the flow at the free surface has to be tangent to the free surface.

TABLE 1

DETAILS OF THE KCS HULL

Length between perpendicular (LPP)	230 m
Length at waterline (LWL)	232.5 m
Beam at waterline (B)	32.2 m
Depth (D)	19 m
Draft (T)	10.8 m
Wetted surface area(S)	9539 m^2
Displacement (Δ)	52030 m^3
Block Coefficient (CB)	0.6505

4 HYDRODYNAMIC ANALYSIS

The 3D surface model of a full scale KCS hull is imported and an offset file was generated in SHIPFLOW 6.1 which is used for hydrodynamic analysis. XCHAP module in SHIPFLOW is used as viscous flow solver and uses several turbulence models. This solver can be used in a Zonal or a global approach and can handle overlapping grids. A CFD simulation was developed in viscous flow under irregular waves to predict the ship motion. Initially, simulation of viscous flows around the surface of ships by coupling the RANS equations with SST k- ω turbulent model was used for calm sea condition (venkata subbaiah et al., 2015) to find wave making resistance coefficients due to generated waves. Later, irregular waves are generated by defining significant wave height (Hs) and zero-crossing period (Tz) in head sea condition to find out added wave resistance as well as total resistance and ship response in heave and pitch. Stokes 5th order wave theory used inside the computational domain throughout all simulations. According to CD-Adapco (2014), this wave more resembles real wave. Hydrodynamic analysis was performed on a full scale KCS model in viscous flow under both regular and irregular waves in head sea conditions for the various incident waves as mentioned in the table 2 (Tahsin et al., 2015) and estimated the total resistance coefficients and ship responses in heave and pitch motions. The model used for validation is Hull series 60 (S_60), a standard ship is used for ship hydrodynamics research used by ITTC.

4.1 Data for the Numerical Investigation

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A full-scale model of the KCS was used for this study. The main properties of the KCS model are presented in Table 1. Hydrodynamic analysis was performed for the two speeds of the vessel, those are 19 and 24 knots and in both regular and irregular wave conditions. The input wave simulation cases are listed as shown in Table 2 for both regular and irregular wave conditions but regular waves are represented by the wave height and time period instead of significant wave height and zero crossing period. Irregular waves are not having uniform wave heights and time period and are generated based on ITTC spectrum. Reynold's number of 2.839×10^9 with density of water of 1025 kg/m^3 and kinematic viscosity of 0.0106 m^2/sec are considered and head sea conditions are simulated for present analysis.

TABLE 2

CASES FOR THE SIMULATION OF SHIP UNDER IRREGULAR WAVES

Case no.	Ship speed (knots)	Froude number	Significant wave height (m)	Zero crossing period (s)
	U	Fn	H_s	T_z
1	24	0.260	Calm water	
2			3.833	7.349
3			4.424	8.097
4			5.108	8.956
5			5.750	9.704
6	19	0.206	Calm water	
7			3.833	8.008
8			4.424	8.789
9			5.108	9.684
10			5.750	10.460

5 Results and Discussions

5.1 Resistance coefficients

The total wave resistance coefficients of the KCS hull for different cases (mentioned in Table 2) are tabulated in Table 3. The Kelvin wave pattern for Froude numbers 0.26 and 0.206 are shown respectively in Fig 4 for the ship hull under calm sea condition. It is observed the waves are clearly formed in Froude number Fn= 0.26 than compared to Froude number Fn= 0.206. The magnitude of the wave height is also higher at Froude number Fn=0.26 compared to 0.206. Also observed that the total resistance is increased with increase in speed of the ship and also with increase in incident Wave height in case of both regular and irregular waves but total resistance coefficient values are less for irregular waves compared to regular waves. Waves near the bow are high crested wave which is due to slamming of incident waves and deep trough immediate to the to the bow region along the hull. Actually total resistance increasing with the speed of the ship with some humps and hollows, because of resultant wave is interference of bow wave system, shoulder wave system and stern wave systems. In case of irregular waves because of non-uniform wave height, the total resistance is less compared to regular waves

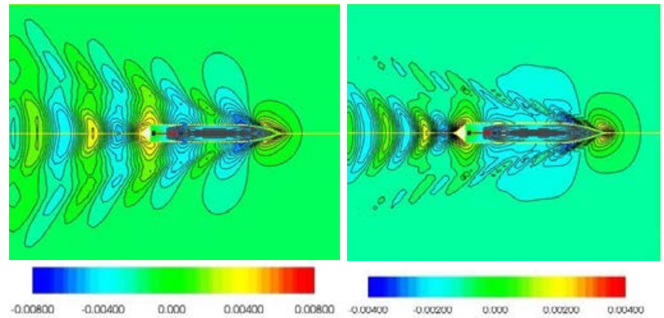

Fig. 4 Free surface elevation for Froude number 0.26 and 0.206 respectively

TABLE 3

TOTAL RESISTANCE COEFFICIENTS UNDER REGULAR AND IRREGULAR WAVES

Case no.	Total resistance coefficients in regular waves	Total resistance coefficients Irregular waves
1	0.002147	0.002147
2	0.003515	0.002694
3	0.004894	0.003021
4	0.003934	0.002751
5	0.004665	0.002834
6	0.002062	0.002062
7	0.003166	0.002522
8	0.003738	0.003084
9	0.003399	0.003402
10	0.003560	0.003239

5.2 Ship motion responses in head sea

Setting of ship under irregular wave conditions are same as of that ship under regular wave except for the wave motion of ship under irregular wave. Motions of waves are generated by means of superposition of wave components defined by an ITTC spectrum for irregular waves. Irregular waves are generated by defining significant wave height (Hs) and zero-crossing period (Tz). Table 2 represents the wave data taken for simulation of ship in irregular wave. Hydrodynamic analysis was performed to find out the heave and pitch motions in head sea conditions. If the ship is symmetric about its center plane the sway, roll and yaw motion can be decoupled from the surge, heave and pitch motion. Supposing the ship is a slender body, the surge motion is negligible in the head sea condition,

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therefore, the heave-pitch coupled motion is considered. Fig 5 and 6 shows the heave and pitch response over the time period and its spectral density respectively. Analysis was performed for different incident wave cases both in regular and irregular waves. It is observed that the heave amplitude of 0.631m and peak frequency of 3.75 rad/sec is obtained for case 2 (Hs = 3.833m; Tz = 7.349s) in irregular waves. Heave energy resides over a frequency range of 2.31 Hz to 4.88Hz. And also observed that the pitch displacement of 1.278^0 and peak frequency of 3.72 rad/sec is obtained for case 2 (Hs = 3.833m; T_z = 7.349s) in irregular waves. Similarly heave and pitch responses are calculated for the different incident wave cases as mentioned in the Table 2 for both regular and irregular waves and corresponding results are published in the Table 4 and Table 5.

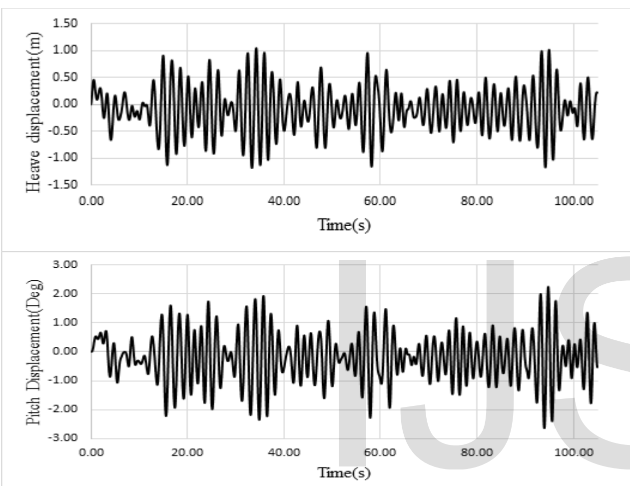

Fig. 5 Time histories of heave and pitch for case 2

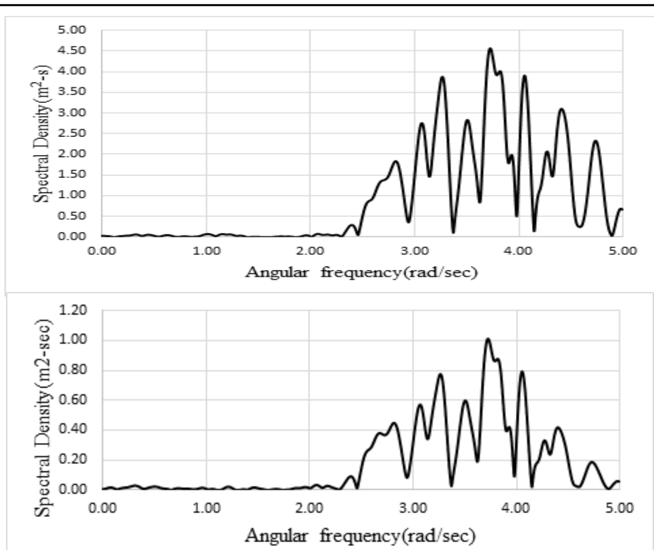

Fig. 6 Spectral density of Heave and Pitch for case 2

TABLE 4

PEAK HEAVE AND PITCH RESPONSE FOR DIFFERENT CASES UNDER REGULAR WAVES

Case no.	Heave		pitch	
	peak frequency (Radians)	significant amplitude (m)	peak frequency (Radians)	significant amplitude (Degree)
1	-	-	-	-
2	1.360	1.450	3.000	1.540
3	2.170	1.690	4.700	1.660
4	2.530	1.840	5.720	1.860
5	3.010	2.000	5.960	2.000
6	-	-	-	-
7	1.500	1.650	3.470	1.680
8	1.870	1.830	3.870	1.790
9	2.120	2.010	4.350	1.960
10	2.590	2.200	4.470	2.150

TABLE 5

PEAK HEAVE AND PITCH RESPONSE FOR DIFFERENT CASES UNDER IRREGULAR WAVES

Case no.	Heave		pitch	
	peak frequency (Radians)	significant amplitude (m)	peak frequency (Radians)	significant amplitude (Degree)
1	-	-	-	-
2	3.75	0.631	3.72	1.278
3	3.73	0.726	3.73	1.478
4	3.71	1.064	3.70	2.137
5	3.72	1.366	3.72	2.656
6	-	-	-	-
7	3.51	0.567	3.50	1.317
8	3.75	0.817	3.44	1.870

9	2.48	1.166	3.43	2.462
10	2.45	1.451	3.40	2.862

5 VALIDATION

Venakta subbaiah (2015) performed simulations on S_60 and determined wave-elevation contours and resistance coefficients at various Froude numbers (Fn = 0.16, 0.20, 0.24, 0.28, 0.30 and 0.316). Details pertaining to the S_60 hull which is used for validation are presented in Table 6. A comparison of the wave making resistance coefficients obtained from the literature and that from the present simulations using SHIPFLOW 6.1 in this study are presented in Fig 7 and these values are in close agreement with one another.

TABLE 6
DETAILS OF THE S_60 HULL

Length Between Perpendicular [LPP]	121.92 m
Breadth [B]	16.26 m
Draft [T]	6.502 m
Block Coefficient [CB]	0.60
Wetted surface area [S]	2526.4 m^2

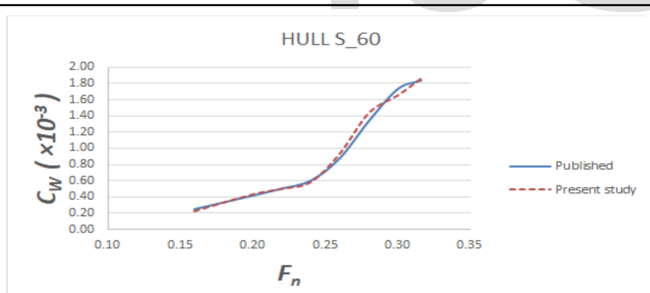

Fig. 7 Comparison of CW values

CONCLUSION

A nonlinear steady RANS simulations was carried on a full scale KCS model in regular and irregular wave conditions using a commercial CFD software SHIPFLOW at two different speeds in head sea condition and corresponding results are compared. It is observed that total resistance coefficient of irregular waves decreases by 24-40% compared to regular for a ship forward speed of 24 knots. The reduction in resistance coefficient is found to be 10-20% for ship speed of 19 knots. Heave displacement decreases by 40-55% and pitch displacement decreases by 55-65% for the ship forward speed of 24 knots in irregular waves compared to regular waves. Total resistance coefficient of ship motion in calm sea for ship forward speed of 24 knots is 6% higher than the ship forward speed of 19 knots.

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REFERENCES

[1] Tahsin Tezdogann, Yigit Kemal Demirel ,Paula Kellett, Mahdi Khorasanchi, Atilla Incecik, Osman Turan, 2015, Full-scale unsteady RANS CFD simulations of ship behavior and performance in head seas due to slow steaming, University of Strathclyde, UK, Ocean Engineering, 97(2015)186–206

[2] Claus D. Simonsen, Janne F. Otzen, Soizic Joncquez and Frederick Stern, 2013, EFD and CFD for KCS heaving and pitching in regular head waves, Journal Marine Science Technology (2013) 18:435–459

[3] Chen Jing-pu, 2010, Numerical simulations of wave-induced ship motions in Time domain by a rankine panel method, China Ship Scientific Research Center, Shanghai, Journal of Hydrodynamics 2010,22(3):373-380

[4] Cheng-Wen Lin, 1995, Viscous Drag Calculations For Ship Hull Geometry, Naval Surface Warfare Center, Bethesda, Viscous Drag Calculations For Ship Hull Geometry

[5] D. X. Zhu and M. Katory, 1997, A Time-Domain Prediction Method Of Ship Motions, Department of Civil & Structural Engineering, The Hong Kong Polytechnic University, Ocean Engng, Vol. 25, No. 9, pp. 781–791

[6] De-cheng Wan, Zhi-rong Shen, Juan Ma, 2010, Numerical simulations of viscous flows around surface ship by level set method, Shanghai Jiao Tong University, Shanghai, China, Journal of Hydrodynamics, 2010, 22(5), supplement :271-277

[7] Ernst Heinrich Hirschel, Jean Cousteix, Wilhelm Kordulla, 2014, Three-Dimensional Attached Viscous Flow, Springer Heidelberg New York

[8] Irkal Mohsin A.R, S. Nallayarasu , S.K. Bhattacharyya, 2014, Experimental And Cfd Simulation Of Roll Motion Of Ship With Bilge Keel, International Conference on Computational and Experimental Marine Hydrodynamics

[9] B.Venkata Subbaiaha, Santosh.G.Thampia, V.Mustafaa, 2015, Modelling and CFD Analysis of Traditional Snake Boats of Kerala, International conference on water resources, coastal and ocean engineering (ICWRCOE 2015).

[10] Zhang Zhi-rong., Liu Hui., Shu Song-ping., ZHAO Feng., 2006. Application of CFD in Ship Engineering Design Practice and Ship Hydrodynamics. Conference of Global Chinese Scholars on Hydrodynamics. 315-322.

[11] Zhang Zhi-rong, Liu Hui, Zhu Song-ping, Zhao Feng, 2006, Application of CFD in ship engineering design practice and ship hydrodynamics, University of Wollongong, NSW, Global Chinese Scholars on Hydrodynamics

[12] Koichi Kitagawa, Boundary Element Analysis of Viscous Flow, Toshiba Corporation , Springer-Verlag Berlin Heidelberg New York

[13] Muniyandy Elangovan, 2011, Simulation of Irregular Waves by CFD, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:5, No:7, 2011

[14] Aiguo Shia., Ming Wu., Bo Yang., Xiao Wang., Zuochao Wang., 2012. Resistance Calculation and Motions Simulation for Free Surface Ship Based on CFD. Journal of Procedia Engineering 30, 68-74.

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