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Numerical simulation of an amphibious vehicle sailing resistance

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Abstract

In order to evaluate the waterborne performance of amphibious vehicle, based on Fluid Dynamics and principle of marine mechanics related knowledge, the resistances and viscous flow field of amphibious vehicle in different headway were numericaly simulated by solving Navier-Stokes equatlons with the $k-\varepsilon$ turbulence model. we obtained the result of frictiona resistance coefficient 、 residual resistance coefficient and running resistance coefficient,thus we can calculate its total resistances. the reliability of computing methed was validated by comparing the calculation results with the test data.

Keywords: *Numerical Simulation, Amphibious Vehicle, Sailing Resistance, Viscous Flow Field.*

1. Introduction

The speediness of the amphibious vehicle is one of the most important qualities, for the amphibious vehicle, the speediness is closely connected to improve the combat effectiveness and survivability. So, forecasting and optimizing design the speediness of the weapons is one of the critical technology for the amphibious vehicle's design. The speediness of the amphibious vehicle contains two sides, resistance and propulsion, then, researching on the resistance during the vehicle running plays an important role in ameliorating the speediness.

The determination of the resistance of the amphibious vehicle has been mostly a perpetual remain on pool model resistance test, not only wasted a lot of manpower and material resources but also the flow filed around the vehicle can't be accurately described. Therefore, in the vehicle design stage ,there is no doubt that the CFD method is the ideal choice.

The amphibious vehicle are different obviously from ship structure, its features contain short length, small surface and shape change highlights, the vehicle road wheel, track and other transmission devices becomes the part of the body. Therefore, it's not applicable for the amphibious vehicle to analysis the theory of ship sailing resistance, in the amphibious vehicle's total resistance, sailing resistance component ratio and value are different from ship's[1].

The sailing resistance of the amphibious vehicle consist of friction drag, form drag and wave drag, the friction drag is relate to the viscosity of water, the form drag is relate to the pressure of water and the wave drag is relate to the speed of car[2]. For the towing tank test, it can't achieve that let it and real vehicle satisfy the Reynolds number and Froude number at the same time. So, tissue the test when the Froude number is equal to each other. In order to get the real resistance from the towing tank test, Froude get the following assumption, the sailing resistance of the amphibious vehicle have two parts, one part is friction drag which can be calculated according to the 1957 ITTC fairly flat formula and only associated with Reynolds number; The other part is called the residual resistance coefficient(form drag and wave drag included) consistent with the Froude similarity criterion ,that's to say, the corresponding dimensionless resistance coefficient and Froude number are equal, only about[3].

The amphibious vehicle using Froude two dimensional method conversion of the total resistance can be in the following form :

Residual resistance coefficient $C_r = C_{tm} - C_{fm}$

Real vehicle total resistance coefficient

$C_{ts} = C_{fs} + C_r + \Delta C_F$

Total resistance $R_{ts} = C_{ts} \times (\rho S V^2 /2)$

Where C_{ts} is the real vehicle total resistance coefficient; C_{fs} is vehicle friction coefficient; C_r is the residual resistance coefficient; ΔC_F for model and real vehicle conversion of resistance between the compensation value, generally take 0.004; C_{tm} is towing total resistance coefficient; C_{fm} for towing friction coefficient; Rts is the real vehicle total resistance; ρ is the density of water, while S and V are wet surface area and speed. So through CFD numerical simulation we can calculate the model of residual resistance, thereby obtaining the residual resistance coefficient C_r, through the corresponding experience formula can be derived C_{fs}, then obtains total resistance coefficient C_{ts}, the resistance coefficient and resistance relationship can calculate the total resistance.

2. Mathematical model

2.1 Incompressible fluid continuity equation and N-S equation[4]

$$\frac{\partial u_i}{\partial x_i}=0$$

$$\rho\frac{\partial(u_iu_j)}{\partial x_j}=-\frac{\partial P}{\partial x_i}+\rho g_i+\rho\frac{\partial}{\partial x_j}\left[v\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]-\frac{\partial\left(\rho\overline{u_i'u_j'}\right)}{\partial x_j}$$

where $u_i=(u,v,w)$ is the velocity component in $x_i=(x,y,z)$ direction, while P, ρ, v, g_i, $-\rho\overline{u_i'u_j'}$ are the static pressure,fluid density, fluid viscosity, gravitational acceleration weight and Reynolds stresses, respectively.

Free surface fluctuation is tracked by the use of VOF, the equation can be written as:

$$\frac{\partial a_q}{\partial t}+\frac{\partial(u_ia_q)}{\partial x_i}=0,(q=1,2)$$

$$a_1+a_2=1$$

Where a_1 、 a_2 are the air phase, phase volume fraction.

2.2 Turbulence models

In the article ,the sailing resistance of the amphibious vehicle is calculated by turbulence models. The turbulence kinetic energy equation is [5~6]:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k$$

The turbulent dissipation rate equation:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon$$

where G_k and G_b are turbulence kinetic energy by average speed grads, turbulence kinetic energy by buoyancy, respectively,and Y_M is the condensability turbulence pulsant expanding to total dissipation ration,and μ_t is the turbulence viscosity constance,and $C_{1\varepsilon}$ (=1.44), $C_{2\varepsilon}$ (=1.92),and $C_{3\varepsilon}$ (=0.09) are the turbulence model constants.

2.3 Boundary conditions

This is a gas, liquid two-phase flow problems, because the amphibious vehicle's higher part is air, the lower part is water,during the sailing, it must cause the interaction between water and air, and generate waves.Wave theory can be divided into liner wave and nonlinear wave.In the specific conditions, the wave height relative to the wave length(or relative to the depth of water) is generally limited, in this wave of finite amplitude,fluctuations of the free water surface caused by nonlinear effects must be taken into consideration, thus the actual ocean waves are studied based on the nonlinear wave theory. In this article ,using two order Stokes wave, incident boundary speed to satisfy the following conditions:

x direction speed

$$u=\frac{\pi H}{T}\frac{\cosh ks}{\sinh ks}\cos\theta+\frac{3}{4}\frac{\pi H}{T}\left(\frac{\pi H}{L}\right)\frac{\cosh 2ks}{\sinh^4 kd}\cos 2\theta$$

y direction speed

$$v=\frac{\pi H}{T}\frac{\sinh ks}{\sinh kd}\sin\theta+\frac{3}{4}\frac{\pi H}{T}\left(\frac{\pi H}{L}\right)\frac{\sinh 2ks}{\sinh^4 kd}\sinh 2\theta$$

Where H is the height of wave; θ is the phase angle ;L is the wavelength ;k is the wave number ;d is the height of wave which does not consider the wave surface; s is height with wave surface considered; T is the period. This article uses UDF technology as the incident boundary conditions coupled to the calculation equation, in order to achieve the unsteady wave simulation.

The computational domain boundary conditions consist of entrance,exit and wall,in the flow direction of the entrance boundary given the flow velocity, the air and water volume fraction; exit boundary is far from the amphibious vehicle and the flow had reached a steady state; then,flow direction parallel to the distant boundary set free outflow boundary; considering the viscous effects,the vehicle surface defined as not slip wall; the calculation region at the bottom of fixed boundary.

2.4 Numerical methods

The finite volume method is adopted to discrete momentum equation. Convection using two order upwind difference scheme, diffusion using a central difference scheme, the pressure velocity coupling using SIMPLE algorithm.

3.The calculation model and results analysis

3.1 The amphibious vehicle towing test

The experiment was done in Dalian science and engineering university ship mold pond.The pond's total lenth is 160 ms and breadth is 7 ms, water's deep is 3.7 ms;The trailer is the empty beam structure, speed scope is 0.01~8 ms/s.

The Principal particulars about model list on Table 1, the model adopted steel quality model that is jointed with the high-quality cold armor plate of 2 mms.The model reduced scale is 1:4. Model test data as shown Fig 1.

Table1: Principal performance about model

serial number	item	unit	value
1	total lenth	m	1.994
2	total high	m	0.40
3	total breadth	m	0.73
4	water line	m	0.299
5	tonnage	kg	328

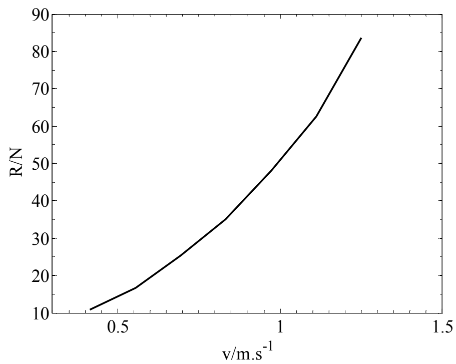

Fig. 1 Model test of the resistance curve

3.2 Establishment of calculation model

Practice has proved that, compared with structured grids,unstructured grids is more suitable for complex areas grid, its random data structure is more easy to be adaptive,so as to capture the physical characteristics of flow field,therefore,this calculation model averaging using unstructured grid.Calculated using the model are consistent with the model, numerical calculation flow field length,width and depth were 160m,7.m,3.7m(reference model experiment where the pool size).

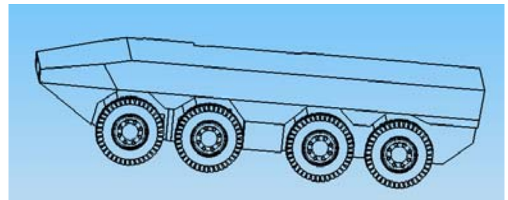

Fig. 2 Computed model

Fig 2 is an amphibious vehicle model diagram, In order to simplify the problem,tire using approximate cylinders instead,computational domain for the front 5 times vehicle length, 2 times body top commander .

Table.2: Computed resistance of the real vehicle

Number	V(m/s)	$C_r X10^{-2}$	$C_{fs} X10^{-3}$	$C_{ts} X10^{-2}$	R_{ts} (KN)
1	0.833	3.005	3.315	3.737	0.714
2	1.111	2.589	3.148	3.304	1.122
3	1.389	2.398	3.026	3.101	1.645
4	1.667	2.226	2.932	2.953	2.256
5	1.944	2.228	2.856	2.966	3.083
6	2.222	2.231	2.793	2.989	4.059
7	2.500	2.500	2.738	3.094	5.318

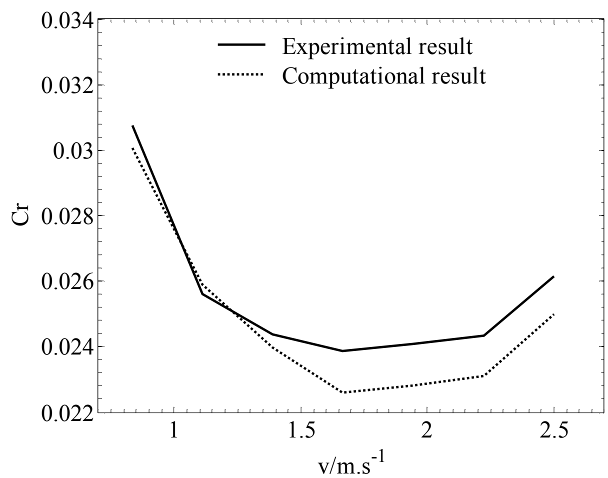

Fig. 3 Relationship between residual resistance coefficient and speed of the amphibious vehicle

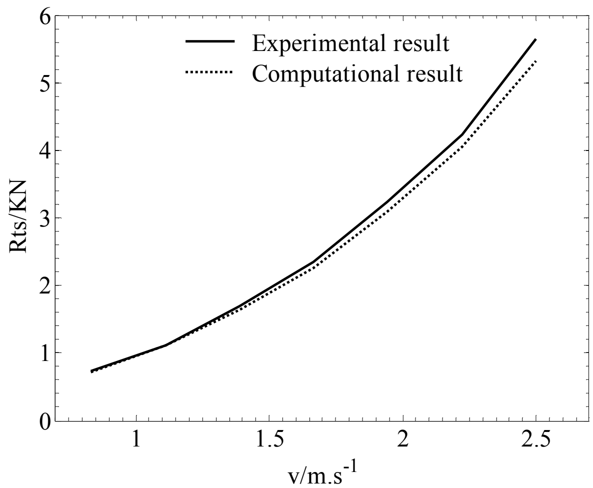

Fig. 4 Relationship between running resistance and speed of the total amphibious vehicle

3.3 Results of the computation

Through a series of the amphibious vehicle turbulent viscous flow theory and Froude two time method results of the computation shown in Table2, whereΔCF is 0.004, friction resistance curve, Fig 3 is the amphibious vehicle residual resistance coefficient with the sailing speed curve.Fig 4 is the amphibious vehicle total resistance with the sailing speed curve.

4 Conclusions

In this article ,using the theory of fluid mechanics for amphibious vehicle navigation performance was studied by numerical simulation,from the final results can be obtained the following conclusions:

1) In the turbulent viscosity theory,to the residual resistance coefficient comparison,numerical simulation of calculation and model experimental results are basically the same.In particular when the vehicle's speed is more than $1.667m/s$ the residual resistance coefficient varied little with the sailing speed changes, at the same time, when the vehicle's speed is less than $1.667m/s$ the rate of change is quick.

2) We can see from Figure 4 that the real vehicle resistance is more and more big along with speed increases, this is accorded with the resistance characteristic of the ships.At the same time it can be seen by comparison the calculated resistance curve and test curve is more consistent, especially at low speed,the calculation results are in good agreement with experimental results.It shows thatflow field numerical calculation of adapting turbulent model, calculation method and the boundary condition is reasonable.

3） In the current numerical calculation technology more mature circumstances,recommend the use of numerical calculation technique and test technology means combining forecasting of resistance for the amphibious vehicles.

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