Integrated Hydrodynamic Investigation on an I-AUV Manipulation State

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I INTRODUCTION

With the development of I-AUV, small sized AUV and manipulator system has been developed and researched. Generally, when the weight of manipulator is less than one fiftieth of the vehicle, the coupled interactions between the vehicle and its manipulator cannot be ignored [1]. For underwater vehicles, hydrodynamics effects significantly on cruising and operation performance. Therefore, it is necessary to consider hydrodynamics performance in the vehicle design [2], control [3], motion plan and operation [4]. I-AUV should not only maintain adequate endurance for operation range, but also be easily maneuverable for flexible floating operation [5]. In the literacies of hydrodynamic analysis, experimental investigation with planar motion mechanism (PMM) [6] and numerical simulations [7, 8] are the two most important methods. For the hydrodynamics [9] and maneuverability [10] prediction of streamlined AUVs, both experiments and simulations are at their maturity stage. But when considering with multibody mutually interactions, problems and uncertainties still remain. Although one can investigate hydrodynamic performances on each body, for example to treat the vehicle and manipulator separately [11], the prediction results are still inaccurate because their dynamic coupling and interaction in process. In order to obtain more complete hydrodynamics and maneuverability knowledge on I-AUV floating operation, water channel experiments and computation fluid dynamics (CFD) have been made on various operation postures.

II DESIGN PROCESS OF THE HEU-TRIS_I-AUV

Fig.1 describes the mechanical design and cruising state of HEU-TRIS_I-AUV. The vehicle is 2.38m long, 0.536m wide and 0.382m high. It includes a 170kg vehicle carrier and a 4-DOF manipulator with the designed maximum operation depth at 100m. The 4-DOF-manipulator includes the shoulder swing, upper arm rotation, elbow swing and wrist rotation with full spread length at 0.78m and 18kg in weight. Since the wrist rotation involves little configuration change, its hydrodynamic effects can be neglected in the analysis. This article mainly researches on the hydrodynamic effects from the manipulator DOF of shoulder swing, upper arm rotation and elbow swing. The combined nonlinear equation of horizontal motion of the AUV is shown as [12]:

$$(m - X_{\dot{u}})\dot{u} - m y_g \dot{r} = X_{HS} + X_{prop} + X_{u|u|}u|u| + (X_{vr} + m)vr + (X_{rr} + m x_g)r^2 \tag{1}$$

$$(m - Y_{\dot{v}})\dot{v} + (m x_g - Y_{\dot{r}})\dot{r} = Y_{HS} + Y_{prop} + Y_{v|v|}v|v| + Y_{r|r|}r|r| + m y_g r^2 + (Y_r - m)ur + Y_v uv \tag{2}$$

$$-m y_g \dot{u} + (m x_g - N_{\dot{v}})\dot{v} + (I_{zz} - N_{\dot{r}})\dot{r} = N_{HS} + N_{prop} + N_{v|v|}v|v| + N_{r|r|}r|r| + (N_r - m x_g)ur - m y_g vr + N_v uv \tag{3}$$

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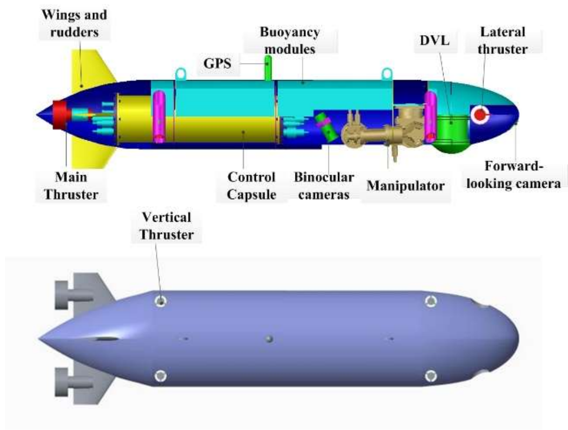

Fig.1. The general layout and design of HEU-TRIS_I-AUV

III EXPERIMENTS AND CFD ANALYSIS ON HEU-TRIS_I-AUV

The floating manipulation hydrodynamic performance of the HEU-TRIS_I-AUV is investigated through CFD and PMM experiment work. From Fig.2, the manipulator posture is fixed in the water channel due to limited depth while a series of PMM experiments are carried out for each manipulator posture. Moreover, the variation trend of hydrodynamic coefficients of the HEU-TRIS_I-AUV, including $X'_{u|u|}$, Y'_v , $Y'_{v|v|}$, Z'_w, M'_w, N'_v and $N'_{v|v|}$, is investigated through PMM experiments. The result presents that the change of the manipulator posture will cause a large change in the force and moment of the HEU-TRIS_I-AUV. By analyzing the corresponding curves of the manipulator posture and hydrodynamic coefficients, more detailed hydrodynamic coupling effects are obtained.

CFD reproduces PMM experiments and further studies the change of forces and moments of the HEU-TRIS_I-AUV during the movement of the manipulator. As shown in Fig.3, since the manipulator broke the streamline and symmetry of the HEU-TRIS_I-AUV, there are a lot of vortexes under the vehicle body in CFD simulation, and these vortexes cause the viscous pressure resistance to rise rapidly. The results show that the manipulation process generates the changes of axial drag X, sway force Y and yaw moment N of the HEU-TRIS_I-AUV. Furthermore, simulations and analysis on HEU-TRIS_I-AUV static and dynamic manipulation can not only obtain the variation tendencies of hydrodynamic coefficients during manipulation, but also provide references for the motion plan and control of floating manipulation.

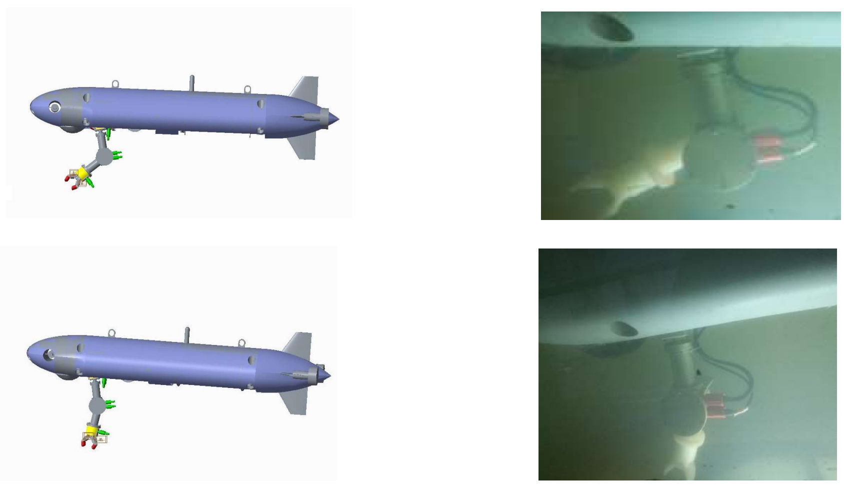

Fig.2 The PMM experiment of the HEU-TRIS_I-AUV

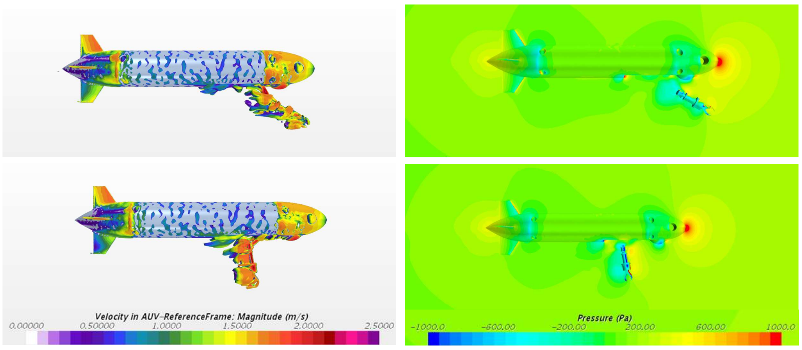

Fig.3 Vortices and pressure contour of manipulation in the status state ($Q - criterion = 50$)

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