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CFD-based hydrodynamic analysis of bionic fish

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Abstract: *Underwater robots are now widely used in marine exploration. Traditional underwater robots are large, less maneuverable, have high resistance to underwater operation and are also not conducive to close observation of fish behavioral habits. Bionic fish robots can compensate for some of these disadvantages very well. At the same time, there is still relatively little work on the shape design and analysis of bionic fish robots, so it is important to study the shape of bionic fish and perform hydrodynamic analysis on them. Based on the theory of fluid mechanics, this paper systematically applies the dynamic properties of fluid and designs an underwater robot imitating a carp using SOLIDWORKS 3D modelling software. Numerical simulations using CFD software show that this fish-like form structure has a low drag coefficient and a reasonable design, and can also provide guidance for form design optimization work. It is clear from the literature that the analysis of the shape of bionic fish is still focused on certain specific structures and that there is a lack of work on the overall analysis and evaluation of the shape. The proposed research method is not only applicable to the overall analysis of the bionic fish shape, but also to most of the bionic fish shape analysis scenarios, which is highly applicable.*

Keywords: *Bionic Fish; Hydrodynamic Analysis; CFD; Shape Design*

1. Introduction

With the development of science and technology, the demand for marine exploration is increasing. Bionic fish as underwater robots are favored by most scientists due to their low drag and high mobility. The Bionic Fish has a wide range of applications. In underwater exploration, bionic fish can search for remains and explore divers on the seabed [1]; in aquaculture, bionic fish can monitor water quality and detect germs [2]; in underwater operations, bionic fish can inspect underwater pipes and repair underwater facilities [3]. As can be seen, bionic fish are playing an increasingly important role. While the results of shape and dynamics analysis of transport machinery such as cars have been increasingly improved, there are still few results on the shape design and hydrodynamic analysis of new underwater robots such as bionic fish. Bian Zewu et al. designed a flutter gliding underwater robot and performed CFD analysis [7]; Zhao Hualin made a detailed analysis of the drag reduction performance of the bionic surface by setting different parameters such as jet aperture, direction and velocity [4]; therefore, this paper also proposes a bionic carp model for shallow water aquaculture and uses CFD software to perform hydrodynamic analysis on it.

2. Model building and solving.

2.1 3D modeling of the imitation carp

This paper designs an underwater robot that imitates the swimming of a carp, a freshwater fish creature. The main reason for using a Wiley surface is that it guarantees a streamlined construction of the overall fish surface and the freedom of modification without strong dimensional constraints. Our modelling work was divided into three steps.

2.1.1 Drawing of the fish body

The fish body was constructed on the basis of a sketch of an adult crucian carp, as shown in Fig. 1. We selected a length of 230 mm and a maximum width of about 38 mm. this length is the length of a typical adult crucian carp and corresponds to the actual situation.

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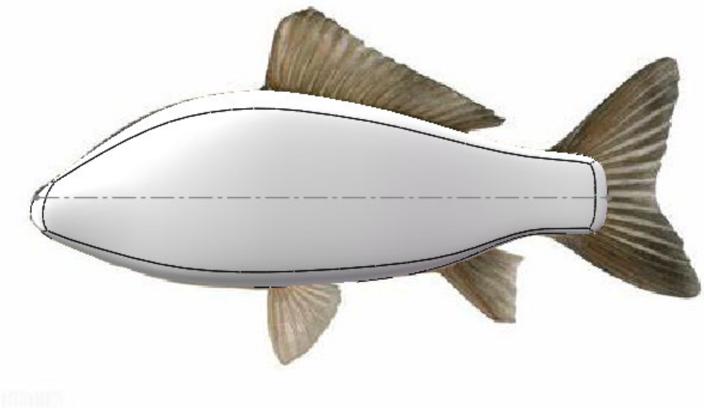

Figure 1: Fish body structure

2.1.2 Fin drawing

The fins not only maintain the fish's swimming posture but also reduce surface drag during the swim. We have therefore designed a model of a carp with the same caudal, lateral, pectoral and dorsal fins, as shown in Figure 2.

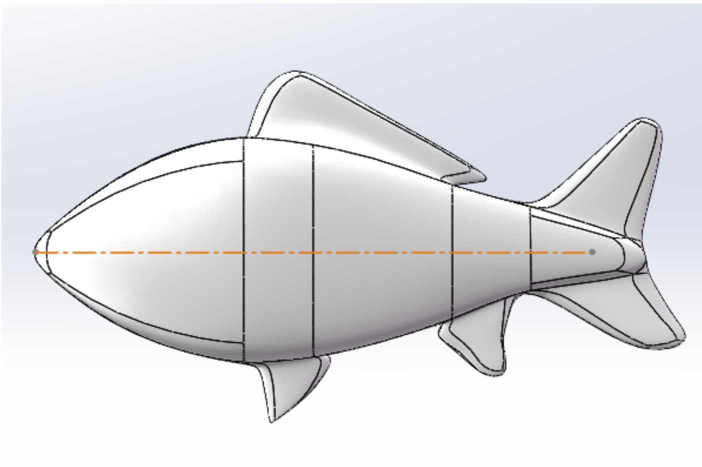

Figure 2: Fin structure

2.1.3 Model evaluation and error analysis

The model of the bionic fish was evaluated using the geometric evaluation and error analysis functions of SOLIDWORKS. The results of the evaluation show that the model has no interrupted surfaces, interrupted edges and thin surfaces, indicating that the design of the shape is reasonable and can greatly improve the resistance reduction performance of the model.

2.2 Hydrodynamic analysis of bionic fish

The current requirements for the hydrodynamic performance of bionic fish are large lift-to-drag ratios and low drag. As this paper focuses on the bionic fish swimming underwater. Therefore, we focus on four parameters - pressure, velocity, drag and drag coefficient - when performing hydrodynamic analysis. The analysis steps are divided into two main steps.

2.2.1 Meshing

In order to improve the efficiency of the analysis, half of the 3D model can be imported into the analysis. The set basin length is 5 times the length of the model, the height is about 1.4 times the length of the model, the width is about 3 times the maximum width of the model and the meshing type is polyhedral. In order to improve the efficiency of the analysis, the maximum and minimum mesh sizes were expanded to 5 times the system recommended values, and important areas were also divided and encrypted with smaller mesh sizes. The model after the meshing process is shown in Figure 3.

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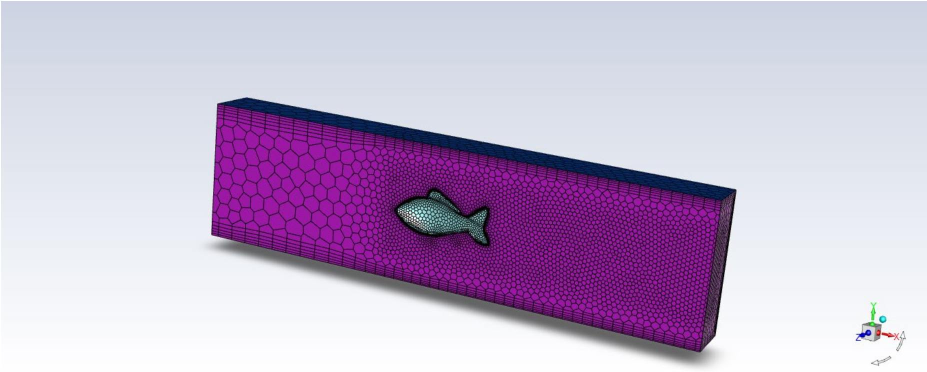

Figure 3: Grid structure

2.2.2 Solving conditions

We mainly used FLUENT software for the hydrodynamic analysis of the imitation carp model. The crucian carp has reached the critical Reynolds number at normal swimming speed, so we chose the turbulence model for the analysis. The initialization settings are as follows.

1) The use of a double precision 3d explicit uncoupled steady state solver.

2) Turbulence equation: the K -omega equation, with the SST wall function chosen for the wall function.

3) Fluid material: water with a density of 998.2 kg/m³ and a viscosity of 0.00101 Pa-s.

4) Boundary conditions: inlet flow velocities set to 2.5m/s, 3m/s, 3.5m/s, 4m/s and outlet free flow.

5) Numerical calculation method for the flow field: COUPLE method is used.

3. Results

3.1 Resistance coefficient and horizontal resistance

Through fluid simulation, we measured four sets of data, as shown in Table 1. From the resulting data we can see that as the velocity of the flow field increases, the resistance coefficient of the water is increasing, and the horizontal resistance of the fluid is also increasing, in line with the regular values of the test. Since only four sets of fluid velocities were set, no conclusions can yet be drawn about this phenomenon. However, it is certain that the flowline profile of the bionic fish possesses superior drag reduction performance than the average underwater robot.

Table 1: Drag coefficient and Drag

Flow field velocity	Horizontal resistance coefficient	Horizontal resistance	Vertical resistance coefficient	Vertical resistance
2.5m/s	111.24536	3.86299	0.69528	0.021436
3.0m/s	156.18686	5.11231	0.97616	0.031952
3.5m/s	208.33607	6.45979	1.30210	0.040373
4.0m/s	267.59174	8.03215	1.67244	0.050201

3.2 Velocity vector diagram for longitudinal sections

As can be seen in Figure 4, the flow of water across the surface of the fish did not produce any large eddies or separation, and basically flowed smoothly along the surface of the fish. However, there was a small amount of separation followed by reattachment at the top and pectoral fins. There was a trace of swirling at the end of the caudal fin[6]. This indicates that there are still design flaws in these two sections and subsequent improvements can be focused on these areas.

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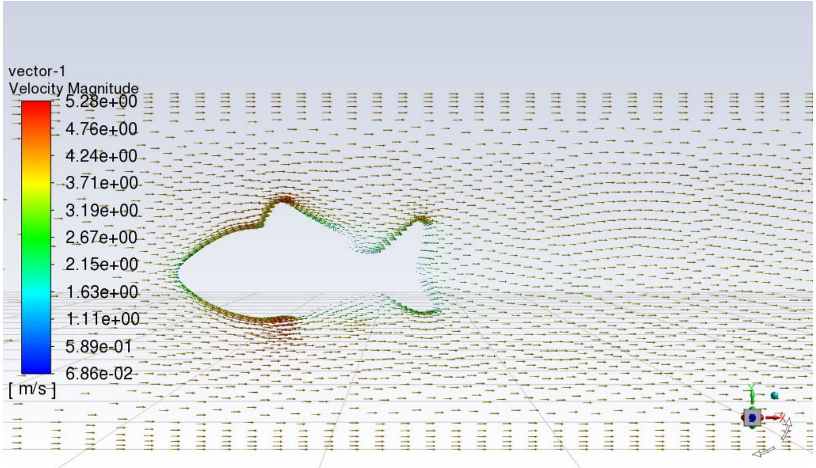

Figure 4: Velocity vector diagram

3.3 Pressure distribution between the surface of the fish and the longitudinal centrally symmetrical surface

The shape of the bionic fish affects the pressure on different parts of the fish, so it is important to analyze the pressure distribution map of the bionic fish. As can be seen in Figure 5, a positive pressure zone is generated at the head of the fish, indicating that this is where the greatest pressure is applied and that this is the main source of resistance to the fish. Negative pressure zones are generated at the top and pectoral fins, where the special shape of the fins results in high fluid velocities and therefore negative pressure[5]. [The pressure can then be reduced by optimizing the line and curvature of the head area and reducing its projected area.

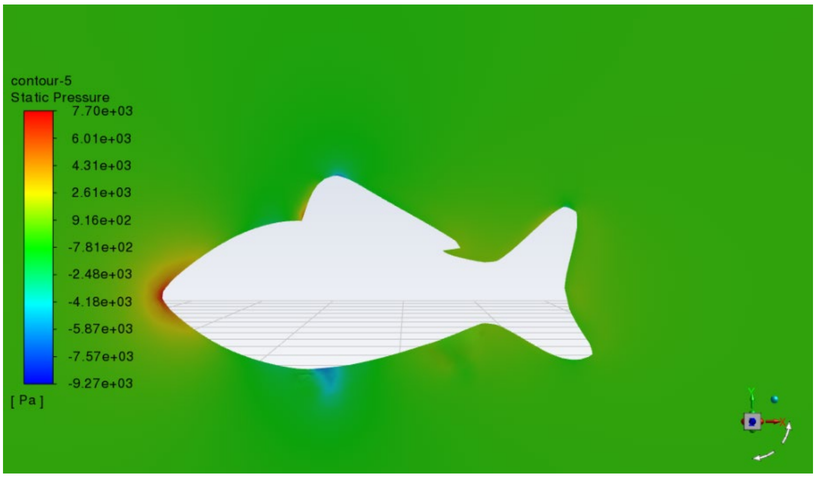

Figure 5: Pressure cloud map

4. Conclusions

This paper presents the idea of using CFD software for hydrodynamic analysis of underwater robots and using the analysis data for optimization of the shape design. From the hydrodynamic analysis data, it can be seen that our bionic fish robot is designed to have less resistance when sailing underwater. This demonstrates that this approach not only reduces our experimental cycle time and costs, but also allows for a more rational and standardized model design.

In the future, we can continue to analyze the shape of various types of fins in depth to investigate the mechanism of propulsion and to find the optimal shape parameters to further reduce drag and improve navigation speed. As there is still a paucity of literature on the design and hydrodynamic analysis of bionic fish, we believe that this research method is a useful reference and guide for the design and analysis of bionic fish underwater robots.

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