Bio-Physical Coupling in Predator-Prey Interactions

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LONG-TERM GOAL

Our goal is to understand the biological and physical processes involved in feeding in sufficient detail to quantitatively predict predator-prey contact rates.

OBJECTIVE

The objective of the present work is to explore the use of computational fluid dynamics to gain insights into quantitative features of typical feeding currents near copepods. In particular, we wish to study the shape and extent of the feeding current in three-dimensional space, and its relationship with how the feeding current is generated through forcing of the water by the copepod. Effects of various forcing distributions and copepod shapes will be studied, with particular emphasis on the feeding current, energetic efficiency, as well as far-field detectability by other predators or prey.

APPROACH

We examine some details of oceanic predator-prey interactions, by combining knowledge about plankton and the oceanic environment within a framework of three-dimensional, numerical simulations. For realistic shapes, Reynolds numbers, and force distributions, the equations of motion with proper boundary conditions can only be solved by using numerical methods. In this work, a commercially available, state-of-the-art, finite-volume, code FLUENT™ is used to calculate the feeding current.

Because the shape of copepod may be important in determining the configuration of the feeding currents, we employ curvilinear body-fitted coordinates to smoothly describe the body shape without the rough edges that would arise with Cartesian coordinates. In the simulations, the appendages that generate the feeding current are replaced by a distribution of forces acting on the water adjacent to and in front of the body. First, the accuracy of the code (FLUENT™) is verified by simulating two viscous, zero Reynolds number flows for which analytical solutions are available. Then, simulations with realistic body shape and Reynolds numbers are carried out. The entrainment region is visualized by tracking particles in the feeding current and by plotting the resulting streamtube. The result can be

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used to quantify how the copepod takes advantage of the feeding current to trap the algal particles into its capture area. The configuration of the feeding current close to the body surface of the copepod is controlled by how the copepod forces the feeding current and by the copepod morphology. In the numerical simulations, these parameters can be varied and their effects studied in a systematic manner. Our aim is to compare the numerical results for the feeding currents to the observational data and to show what is generic about shape, feeding strategy and feeding success.

WORK COMPLETED

In order to test the performance of the finite volume code FLUENT™ for viscous, low Reynolds number flow, two test cases for which analytical solutions are available were simulated. The first flow considered was Stokes flow in an infinite domain, with a point force located at the origin. The second flow considered was flow bounded internally by a solid sphere centered at the origin with a point force located outside the sphere. We chose a core computational region of $2 \times 2 \times 2\ cm^3$, contained in a $10 \times 10 \times 10\ cm^3$ cubical region. The boundary condition at the surface of this region is a constant relative static pressure. The no-slip solid sphere is centered at the midpoint of the cubical region. The radius of the sphere is 1.0 mm. A body-fitted coordinate grid is generated in which the sphere is divided into six equal-area regions and mapped into a cube. Strong grid stretching toward the solid sphere is employed. The grid system has $41 \times 41 \times 41$ cells.

Following the tests, calculations were performed for the flow generated by the feeding of a “copepod” in the shape of a sphere using the same grid as in the test cases. Then two antennae and a tail were added to the spherical “copepod” to make an artificial “copepod”. Software was developed for accurately tracking particles captured by the feeding current and thereby determining the effective range of the capture process. More realistic distributions of the force were also considered. Some preliminary calculations for the feeding currents of a more realistic shape were also performed.

RESULTS

1. The feeding current around a copepod was simulated numerically using a finite-volume code. The body shape of the copepod was represented with a curvilinear body-fitted coordinate system. In the simulations, the appendages that generate the feeding current were replaced by a distribution of forces exerted on the water adjacent to and in front of the copepod. The main features of the computed feeding current were shown to be comparable to the observations by Yen & Strickler (1996). The entrainment region of the feeding current was visualized by tracking particles in the feeding current and by plotting the resulting streamtube. The results quantitatively display the time and length scales of the feeding current which traps the algal particles into the copepod’s capture area.

2. The feeding current is a viscous shear flow which is controlled by two important factors. One is the body shape of the copepod. Since the surface of the body is the internal boundary of the feeding current, a no-slip condition must be satisfied on the surface. The other is the distribution of forces which, in the model, represents the copepod activities in generating the feeding current. The magnitude of the velocity and the normal and shear stress fields around the body surface of the copepod are strongly dependent on the spatial distribution of forces together with their distances from the surface of the body. In the numerical simulations, we varied the distribution of forces and the copepod’s morphology, and studied the effects on the configuration of the feeding current in a systematic manner.

3. By comparing various distributions of forces, it was shown that a distributed force dissipates less energy and results in a larger entrainment rate than a concentrated forces, and is thus energetically more desirable. This result may help to improve our understanding of the evolution of the feeding appendages.

4. Variations in the distribution of forces and in the body shape lead to the changes in the flow field very close to the copepod, and thus change the drag on the surface of the copepod. The viscous dissipation rate of the water volume very close to the copepod is also shown to be dependent on the distribution of forces and the body shape of the copepod. However, the feeding currents for different shapes of the main body or different force configuration showed little difference in the far-field. Consequently changes in the shape of the main body and in the activities for generating the feeding current may not affect the detectability by other motion sensing organisms several centimeters away. These results indicate that when the copepod generates a feeding current around itself, the configuration of the feeding current is shaped by the copepod's own activities and morphology. However, the specific details do not affect the far-field of the feeding current very much.

5. The net reaction force on the copepod from the feeding current is found to be of the same order of magnitude as the excess weight of the copepod, but is not sufficient to balance the excess weight completely.

REFERENCES

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