Vortobots

Vortex-generating microscopic robots would move in swarms.

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The term "vortobots" denotes proposed swimming robots that would have dimensions as small as micrometers or even nanometers and that would move in swarms through fluids by generating and exploiting vortices in a cooperative manner. Vortobots were conceived as means of exploring confined or otherwise inaccessible fluid environments: they are expected to be especially attractive for biomedical uses like examining the interiors of blood vessels.

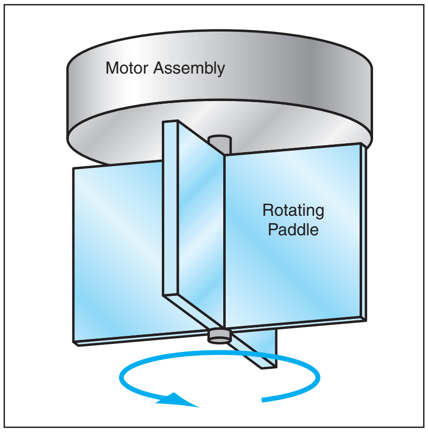

Figure 1. A **Spinning Paddle** on a floating microrobot would generate a vortex in the surrounding fluid.

The main advantage of the vortobot concept, relative to other concepts for swimming microscopic robots, is that the mechanisms for locomotion would be relatively simple and, therefore, could be miniaturized more easily. For example, only a simple spinning paddle would be required to generate a vortex around a vortobot (see Figure 1). The difficulty is that a smart swarming and cooperative control algorithm would be necessary for purposeful locomotion. This necessity arises because, as a consequence of basic principles of vortex dynamics, an isolated single vortex cannot move by itself because its induced flow at the center is zero; however, a vortex can move other vortices by the induced flow. By cleverly adjusting the strength and sign of each member in a group of vortices, the group can achieve net translational motion in the preferred direction through cooperation.

Figure 2 presents two simple examples that serve to illustrate the principle of cooperative motion of vortobots. For the sake of simplicity, these examples are based on an idealized two-dimensional potential flow of an inviscid, incompressible liquid. The example of the upper part of the figure is of two vortices of equal magnitude and opposite sign. The centers of the vortices would move along parallel paths. The example of the lower part of the figure is of two vortices of the same magnitude and sign. In this case, both vortices would move in a circle in diametrically opposite positions. More complex motions can be obtained by introducing more vortices (or pairs of vortices) and choosing different vortex strengths and orientations.

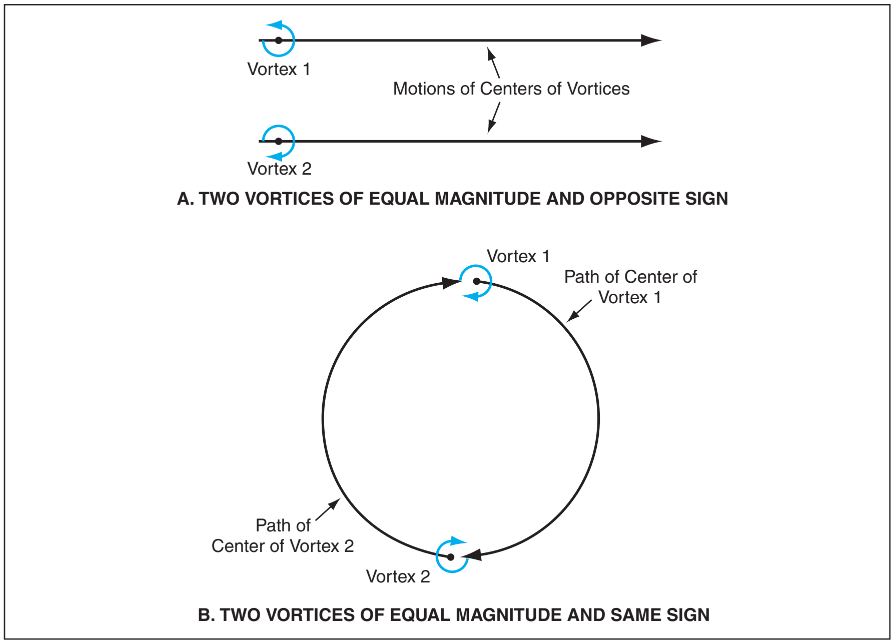

Figure 2. **Two Vortices of Equal Magnitude** would move along parallel lines or around a common center, depending on whether they were of opposite sign or the same sign, respectively.

Alternatively or in addition to what has been described thus far, vortobots could be equipped with simple oscillating source/sink mechanisms. Like a vortex, an oscillating source/sink generated by a single floating object would result in little or no net translational motion, whereas multiple oscillating source/sinks could produce net translational motion.

Of course, it would be necessary to control the vortobots in a swarm to obtain the cooperative action needed for locomotion. Both global and local control algorithms are under investigation. A global algorithm would be based on knowledge of the position of every vortobot and would strive to control the overall motion of the swarm. A local algorithm would not depend on explicit knowledge of the positions of the vortobots, but rather the local influence of nearby vortobots. This type of algorithm would be implemented independently in each vortobot, and would be formulated so that the combined effect of the independent actions of the vortobots would be the desired collective behavior. For the purpose of a local control algorithm, vortobots could communicate with neighboring vortobots indirectly through such sensed fluid parameters as shear, pressure, and concentration. For longer-range communication (which would be necessary for a global control algorithm), sound waves could be used.

This work was done by Han Park and Flavio Noca of Caltech and Petros Koumoutsakos of ETH Zurich, Switzerland, for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
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