Biomimetically Inspired Vortex Ring Generators for Underwater Propulsion and Maneuvering

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There are many available Unmanned Underwater Vehicle (UUV) designs, most of them can be categorized in a few groups. Propeller thruster combined with control fins (or shrouded thrusters) to propel and steer the vehicle have traditionally been used in most Autonomous Underwater Vehicle (AUV) designs. Such designs are often streamlined (torpedo-like body shape) and optimized for low drag during forward motion. Maneuvering control forces are generated by lift or deflection forces created by fluid flow over the control surfaces. At cruising speeds, and for relatively uncluttered spaces, this paradigm is extremely efficient and effective. However, at low speeds and in tight spaces the magnitude of the available control forces drops significantly. Consequently, such vehicles are difficult to dock or operate at low speeds. As a result, much current effort is devoted to the development of docking mechanisms.

Remotely Operated Vehicles (ROVs) or AUVs, which are not designed for cruising, typically follow the so-called "Box Design". In Box designs better low speed maneuvering and control are achieved by sacrificing the low drag body-of-revolution design and adding multiple thrusters at different locations and directions. As a result of high drag, such vehicles require an escort ship or cable connection to reach the work zone.

In this presentation compact zero-mass pulsatile jet actuators are proposed for low speed maneuvering and station keeping of small underwater vehicles. The propulsion scheme suggested here is inspired by the propulsion of cephalopods (e.g. squid and octopi), salp, and jellyfish. Jet propulsion swimming of the squid is accomplished by drawing water into the mantle cavity, and then contracting the mantle muscles to force water out through the funnel.

The flow field of such zero-mass pulsatile jets are initially dominated by vortex ring formation. Pinched-off vortices characterize the extremum impulse accumulated by the leading vortex ring in a vortex ring formation process. Relevant parameters in this process are identified to design simple and low cost zero-mass pulsatile jet actuators. Direct thrust measurement experiments are conducted to measure the thrust generation for various input parameters. Thrust optimization of synthetic jets for maximal thrust generation is investigated for the proposed parameter space. Prototypes of such actuators are built and tested for underwater maneuvering and propulsion. The actuators could be used in two ways: (i) to improve the low speed maneuvering and station keeping capabilities of traditional propeller driven underwater vehicles, (ii) and as a synthetic jet for flow control and drag reduction at higher cruising speeds. A model for calculating the rotation rate of the underwater vehicle is also proposed and verified.

Keywords: jet propulsion, vortex ring, unmanned underwater vehicles, underwater maneuvering, cephalopods propulsion