PARTICLE IMAGE VELOCIMETRY SYSTEMS FOR QUANTITATIVE FLOW MEASUREMENTS OF BIO-LOCOMOTION

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APPLICATION NOTE PIV-024 (US)

Particle Image Velocimetry (PIV) is an excellent diagnostic tool that can be used to obtain instantaneous fluid velocity data relevant to your biological flows. PIV provides insight into the fluid mechanics at work and their interplay with relevant subjects of interest in biology including locomotion, propulsive mechanisms and efficiency, agility, and formation flying/swimming. Due to its non-invasive optical nature, PIV can be used in both water and air environments, without disturbing or influencing the subject of interest. As a technique already long in use within engineering and mechanics communities, PIV is an established diagnostic providing high-quality and precise measurements within fluid flows.

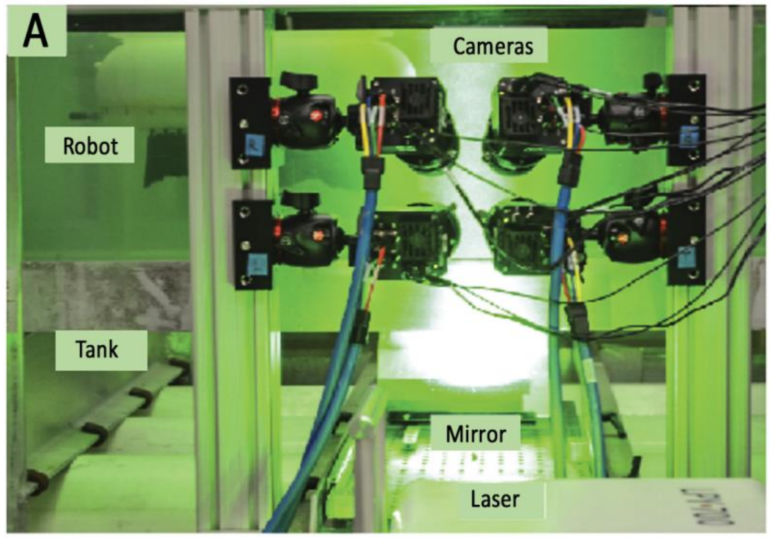
By customizing the configuration of your PIV system, the results required for your research can be easily obtained: including two-component or three-component measurements on a plane, and three-component measurements in volumes. Variations of each of these systems allow for both low-repetition and time-resolved data acquisition rates. All PIV systems provide instantaneous vector maps of flowfield velocity, and access to resulting derived measurements and parameters such as turbulence characteristics, vorticity, and coherent structure identification and tracking.

For instance, time-resolved PIV systems commonly allow for data capture rates in excess of 1000 Hz, providing detailed insight into the temporal and spatial evolution of fluid structures. This opens PIV users to investigation of the temporal fluid mechanics in biological phenomena like vortex formation and tracking in the wake of a bird flying with a wind tunnel, or a swimming fish, cephalopod, or jelly fish. The motion of the surrounding air or water can be tracked precisely, providing total understanding of the mechanics, and with a high temporal resolution.

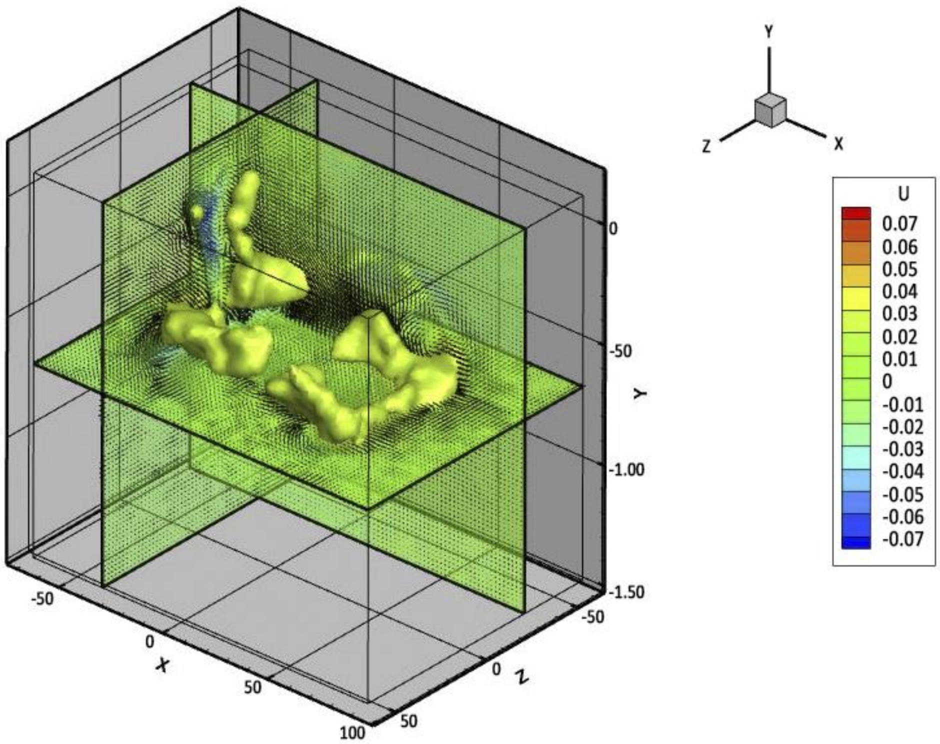
A volumetric PIV system further extends the usefulness of the diagnostic, as data for all three velocity components everywhere within a three-dimensional space are measured directly and simultaneously. This allows the user to visualize and quantify the instantaneous flow structure, such as the linked-chain vortex structure generated by a shark. Further, volumetric PIV systems operating at time-resolved rates provide even more complete spatial and temporal understanding fluid dynamics at work within a biological flow.

PIV diagnostics provide the biologist with access to quantitative data pertaining to the fluid motion in their subjects of interest. This is an avenue for increased understanding of both the biological subject itself, the surrounding fluid mechanics, and the dynamic relationship and interplay between them. A number of application examples are given in the subsequent pages to illustrative the power and capability of PIV systems.

(1) A Volumetric PIV system at Florida Atlantic University.



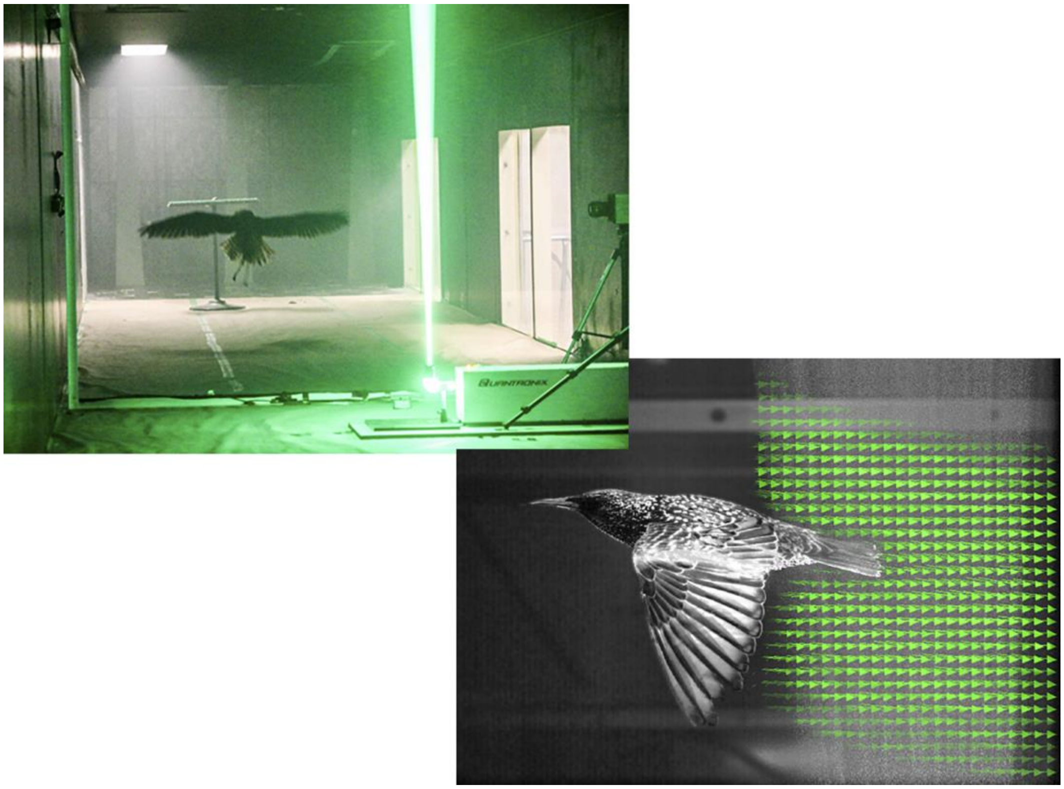
Four-camera volumetric PIV arrangement for the investigation of robotic fish.

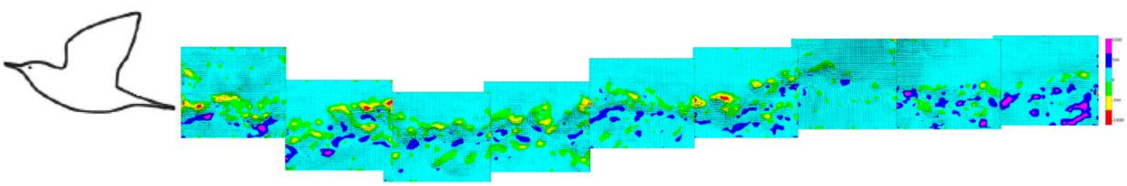


Vortex rings and planar velocity profiles generated from the robotic fish

Reference: Hanlin L, Troolin D, Hortensius R, Pothos S, Curet O (2017) "Volumetric PIV of multiple free-swimming maneuvers generated by the KnifeBot: a biomimetic vessel propelled by an undulating fin," *70th Annual Meeting of the APS Division of Fluid Dynamics*, Denver, CO, November 19–21, 2017.

(2) Wake flows behind various birds, including raptors and starlings, obtained with a time-resolved planar PIV system at Western University.

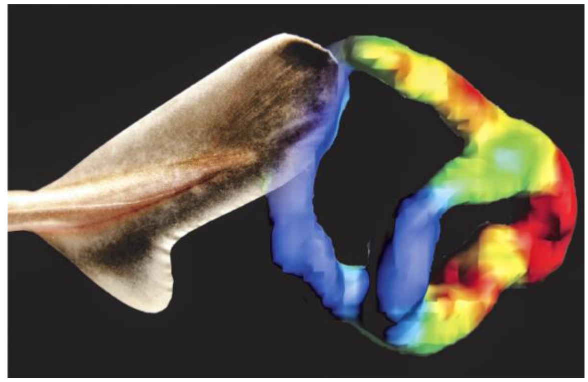


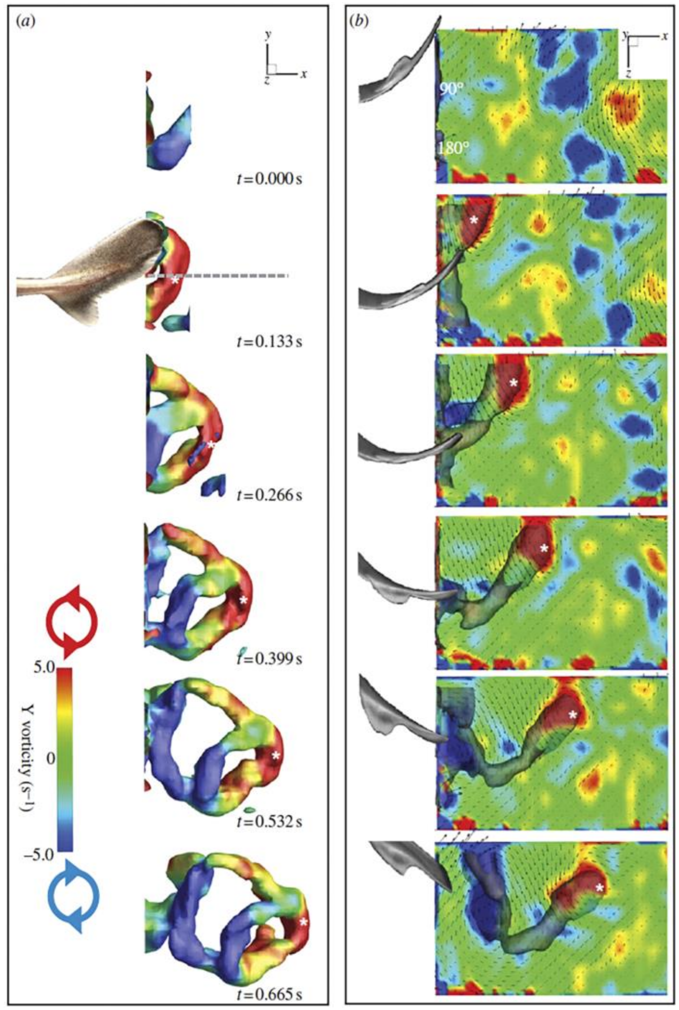


Reference: Western University, ON, Canada—Adam Kirchhefer, Gregory Kopp and Roi Gurka.

(3) Shark tail wake flow with volumetric PIV system at Harvard University.

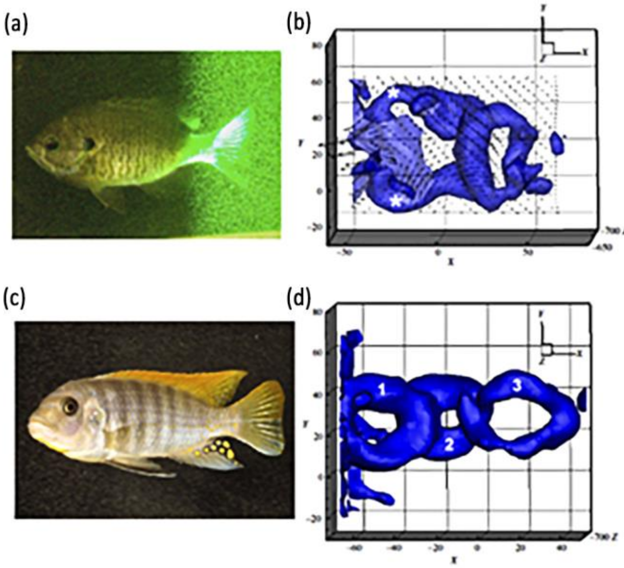
Sharks are unique swimmers in that, unlike other fish, they possess speed and maneuverability, making them of interest for research in the area of underwater propulsion. The novel “linked chain” structure of the downstream wake works to combine forces in multiple directions to efficiently achieve the desired propulsive result, with virtually constant thrust.

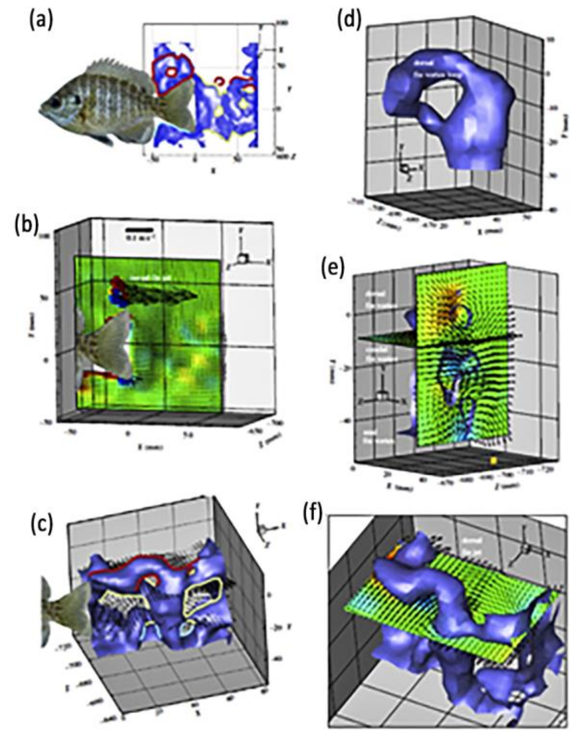




Reference: Flammang, B.E., Lauder, G.V., Troolin, D.R., Strand, T.E. (2011) Volumetric imaging of shark tail hydrodynamics reveals a three-dimensional dual-ring vortex wake structure. *Proceedings of the Royal Society of London B*. **278**, pp. 3670 –3678, doi:10.1098/rspb.2011.0489.

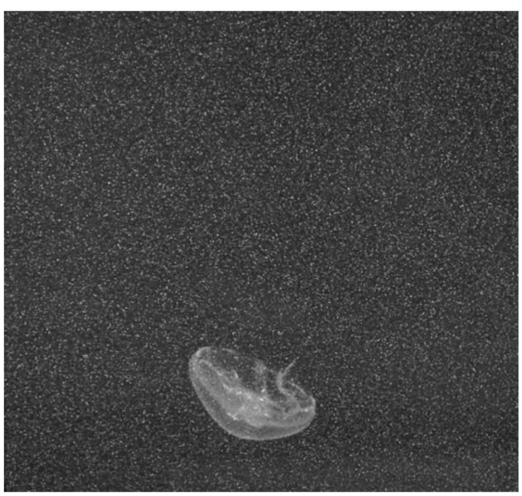
(4) Investigation of fish locomotion with volumetric PIV system at Harvard University.

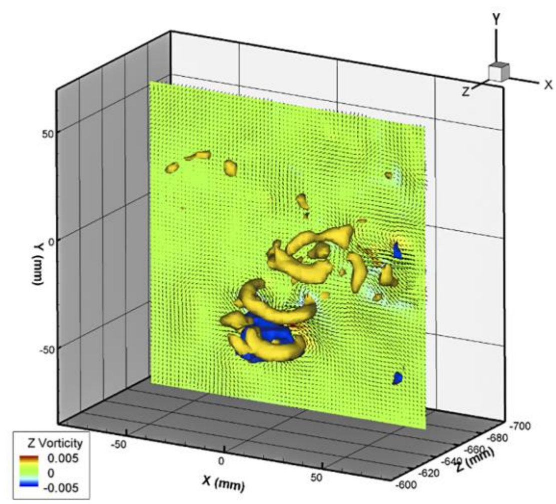




Reference: Flammang, B.E., Lauder, G.V., Troolin, D.R., Strand, T.E. (2011), “Volumetric imaging of fish locomotion.” *Biology Letters* **7**, pp. 695–698, doi: 10.1098/rsbl.2011.0282.

(5) Flow mechanism of jelly fish using volumetric PIV system at Woods Hole Institute.

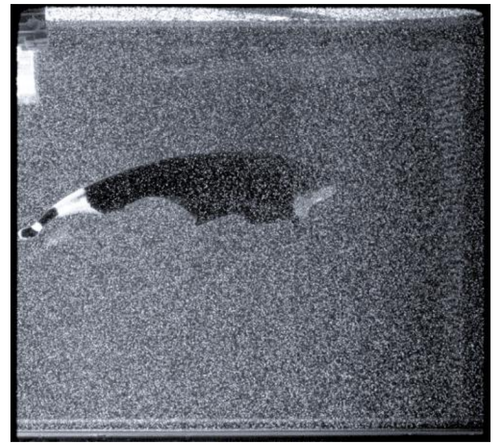


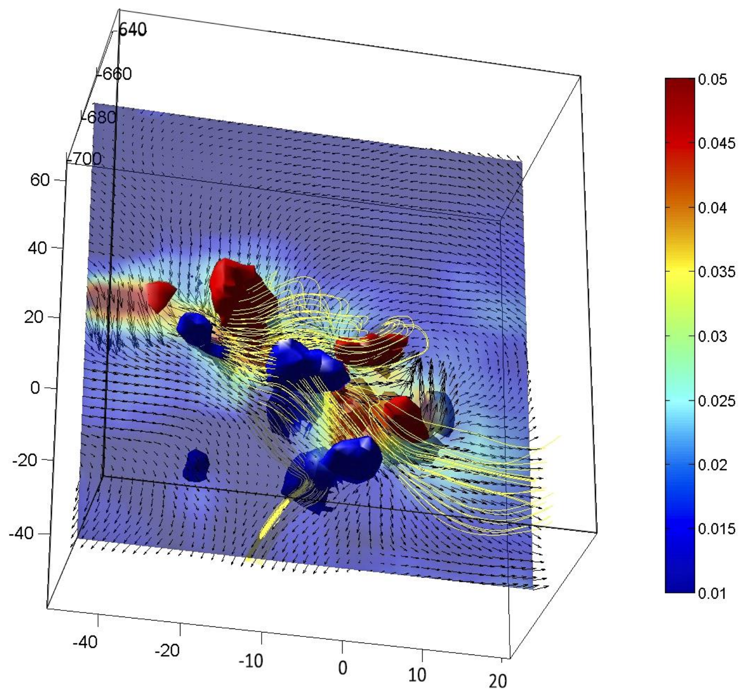


Reference: Gemmell BJ; Costello J; Colin S; Dabiri J; Adhikari D; Troolin D; Sheng J; Longmire E (2012), “Position Control in Jellyfish: Abandoning radial symmetry to create inclined, asymmetric vortex rings,” *2012 Ocean Sciences Meeting*, Salt Lake City, UT, February 20-24, 2012.

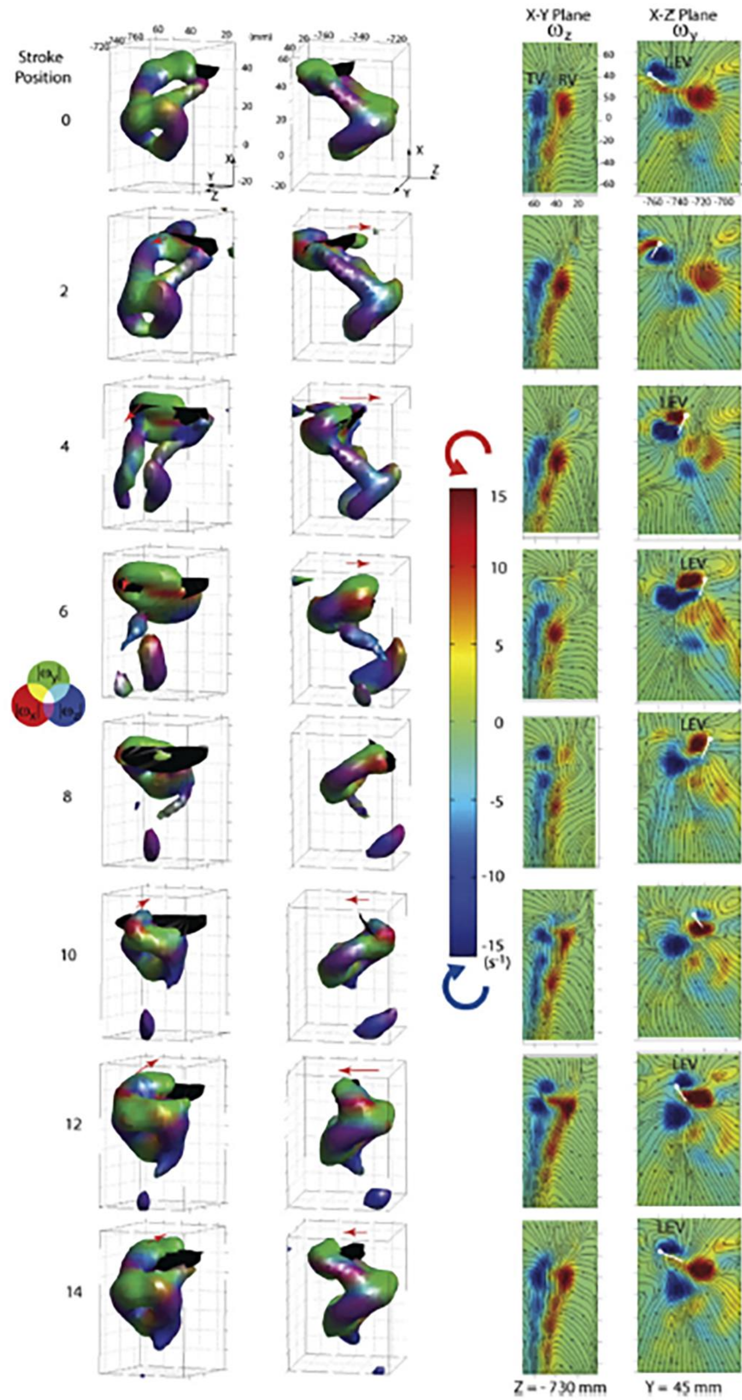
(6) Investigation of fish fin with volumetric PIV at Old Dominion University.

The caudal fish has a pair of pectoral fins near the front that are used primarily for maneuvering. The bulk of the motion is produced by the ribbon-like fin extending the length of its body on the bottom. This fish is unique in its extreme agility, and its abilities in stopping and starting, and reversing direction almost instantly.



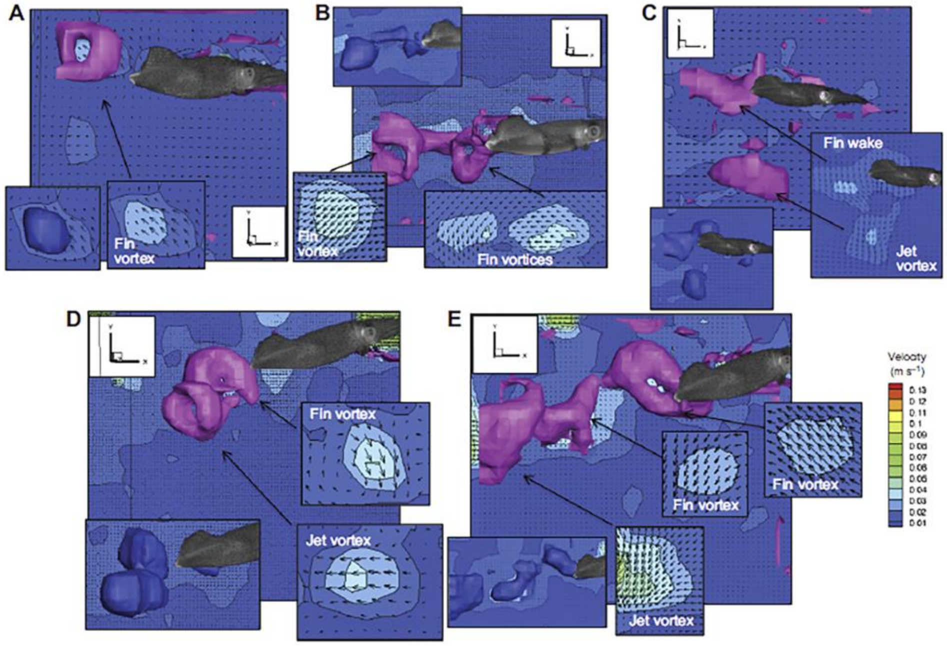


(7) Investigation of hover dynamics of flapping wing flight using volumetric PIV at Purdue University.



Reference: Cheng B, Roll J, Liu Y, Troolin D R, Deng X (2013), “Three Dimensional Vortex Wake Structure of Flapping Wings in Hovering Flight,” *Journal of the Royal Society Interface,* doi: 10.1098/rsif.2013.0984.

(8) An investigation of cephalopod vortex ring formation in tail-first and arm-first swimming directions using volumetric PIV at Old Dominion University.



Reference: Ian K Bartol, Paul S Krueger, Rachel A Jastrebsky, Sheila Williams, Joseph T Thompson, "Volumetric Flow Imaging Reveals the Importance of Vortex Ring Formation in Squid Swimming Tail-First and Arms-First," (2016), *Biological Sciences.*

