The Energetics of River Fish in Gusty Environments

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After millions of years of evolution, river fish have become highly adept at navigating their gusty and unsteady aquatic environments. Beal et al. demonstrated the trout's natural ability to extract energy from the flow and propel itself forward by placing a specimen in the periodic wake of a half-cylinder. Further, this energy extraction technique, called Kármán gaiting, was not only observed when the trout was alive, but also when it was deceased [1]. Kármán gaiting is therefore of notable interest from an ecological standpoint as it could alter the consumption and feeding habits of river fish. For instance, Liao et al. showed that an approximate 47% energy savings was measured for live Kármán gaiting fish. As climate change continues to affect aquatic environments, the reduction in flow rate of a river could drastically alter the feeding requirements and food chain of the surrounding ecosystem [2, 3]. Despite the importance of this phenomenon, the energetics of river fish have yet to be fully understood, raising the question of whether this is a tunable behaviour. Namely, the extent of which this energy saving technique is affected by the flow parameters must be studied [1, 2]. As such, the gust resilience of Albertan fish (e.g. rainbow trout, *Oncorhynchus mykiss*) is to be evaluated. This abstract thus outlines the proposed experimental Particle Image Velocimetry (PIV) setup that will be used to quantify the effect of Reynold's number, Strouhal number, and reduced frequency on the energetics of free-swimming trout.

A fish treadmill will be used to simulate the trout's free-stream swimming conditions. The velocity of the free-stream can be altered, allowing for sustained testing or "burst" measurements. At the inlet of the test section, a pitchable aluminum plate will be used to generate flow perturbations (e.g. aperiodically or as gusts). The chord of the plate and the pitching frequency can both be varied, directly affecting the reduced frequency and Strouhal number of the flow. Stereo PIV will be used to evaluate the resulting hydrodynamic forces produced by the trout under these altered conditions. By comparing between these perturbed swimming tests, the extent of which the river fish can adapt to the flow and apply their gaiting technique will be evaluated. Notably, the wake amplitude to flapping amplitude ratio and wake wavelength to body length ratio are of interest.

Typically, when studying biological flows, a whole field measurement is preferred to understand the large-scale shedding of vortex structures. However, the use of lasers to illuminate a flow volume presents several issues. The shadows cast by the biological specimen can block critical regions of the flow. There is also a component of "luck" when using PIV on live specimens: without physically interfering with the fish's swimming, one must wait for it to pass through the analysis region (e.g. laser sheet) [4, 5]. Finally, when considering three-dimensional analysis, traditional methods rely on the illumination of the entire volume of interest. With the measured trout being around 20 cm in length, the illumination of the control volume by laser light is problematic for multiple reasons, many of which are listed above [5, 6, 7, 8]. To overcome these drawbacks, a Trefftz plane measurement technique is to be applied. Assuming incompressible flow and a fixed control volume in an orthogonal coordinate system, the following reformulation of the Reynold's Transport Theorem is obtained [6]:

$$\vec{F}(t) = \underbrace{-\rho\frac{\partial}{\partial t}\iint_{CS}\vec{x}(\vec{u}(t)\cdot\vec{n})\,\mathrm{dS}}_{\text{unsteady}} \underbrace{-\,\rho\iint_{CS}\vec{u}(t)(\vec{u}(t)\cdot\vec{n})\,\mathrm{dS}}_{\text{convective}} \underbrace{-\iint_{CS}p(t)\vec{n}\,\mathrm{dS}}_{\text{pressure}} + \underbrace{\iint_{CS}\vec{\tau}(t)\cdot\vec{n}\,\mathrm{dS}}_{\text{shear}}$$

Where, $\vec{F}(t)$ represents the net forces acting on the control surfaces, ρ is the fluid density, $\vec{x}$ is the position vector measured from a fixed frame of reference, $\vec{u}(t)$ is fluid velocity, dS is the integration surface, $\vec{n}$ is the vector normal to a given surface, $p(t)$ is pressure, and $\vec{\tau}$ is the shear stress tensor [6, 9]. From here, the flow inlet and outlet can be directly measured using PIV, allowing for the extraction of volume integral terms through surface measurements. Overall, hydrodynamic force measurements for a gaiting trout can be taken using well established Stereo PIV methods, allowing for the study of river fish energetics for a variety of flows.

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References

[1] D. N. Beal, F. S. Hover, M. S. Triantafyllou, J. C. Liao, and G. V. Lauder, "Passive propulsion in vortex wakes," *Journal of Fluid Mechanics*, vol. 549, pp. 385–402, 2006.

[2] J. C. Liao and O. Akanyeti, "Fish swimming in a kármán vortex street: Kinematics, sensory biology and energetics," *Marine Technology Society Journal*, vol. 51, pp. 48–55, 9 2017.

[3] H. O. Pörtner and M. A. Peck, "Climate change effects on fishes and fisheries: Towards a cause-and-effect understanding," *Journal of Fish Biology*, vol. 77, pp. 1745–1779, 11 2010.

[4] J. O. Dabiri, "Optimal vortex formation as a unifying principle in biological propulsion," *Annual Review of Fluid Mechanics*, vol. 41, pp. 17–33, 1 2009.

[5] E. J. Stamhuis, J. J. Videler, L. A. V. Duren, and U. K. Müller, "Applying digital particle image velocimetry to animal-generated flows: Traps, hurdles and cures in mapping steady and unsteady flows in re regimes between 10-2 and 10-5," *Experiments in Fluids*, vol. 33, pp. 801–813, 2002.

[6] A. Mohebbian and D. E. Rival, "Assessment of the derivative-moment transformation method for unsteady-load estimation," *Experiments in Fluids*, vol. 53, pp. 319–330, Mar. 2012.

[7] U. K. Müller, J. Smit, E. J. Stamhuis, and J. J. Videler, "How the body contributes to the wake in undulatory fish swimming: flow fields of a swimming eel (anguilla anguilla)," *Experimental Biology*, vol. 204, 2001.

[8] E. J. Anderson, W. R. Mcgillis, and M. A. Grosenbaugh, "The boundary layer of swimming fish," *Journal of Experimental Biology*, vol. 204, pp. 81–102, 1 2001.

[9] D. Lentink, A. F. Haselsteiner, and R. Ingersoll, "In vivo recording of aerodynamic force with an aerodynamic force platform: from drones to birds," *Journal of The Royal Society Interface*, vol. 12, p. 20141283, Mar. 2015.

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