INSTANTANEOUS VOLUMETRIC WAKE ANALYSIS OF LOCOMOTION IN TELEOST FISHES

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ABSTRACT: Previous studies of the wake hydrodynamics of fishes have been restricted to two-dimensional digital particle image velocimetry (DPIV) slices by available technology. By comparing multiple slices, previous researchers hypothesized the three-dimensional structure of the vortex wakes produced by swimming fishes. In teleost fishes, such as the bluegill sunfish, the homocercal tail produces a single jet with each lateral pass. Using conventional two-dimensional DPIV, vorticity shed by the homocercal tail was visualized as two counter-rotating vortices which were hypothesized to be part of a three-dimensional rotating ring through which a jet of fluid passed. Now, using a volumetric DPIV system, we have confirmed that the three-dimensional structure of the vortex ring produced by the homocercal tail fin is indeed as predicted. In addition, multiple lateral passes of the tail produced a linked chain of vortex rings. Using this volumetric DPIV system we were also able to instantaneously capture the three-dimensional wake interactions of the dorsal and anal fins with the caudal fin in both live fishes and robotic analogs.

METHODS:

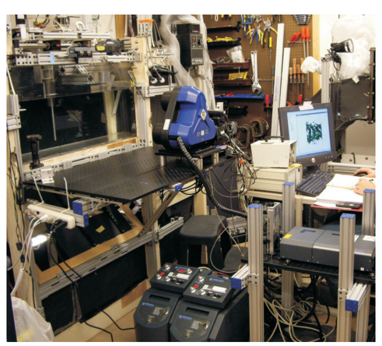


Fig. 1

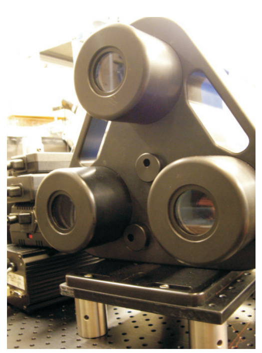


Fig. 2

Fig. 1. Experimental arrangement of the flow tank, lasers, and volumetric imaging system for capturing the instantaneous volumetric wake behind freely swimming fishes and robotic tail models. Total volume imaged was 14*14*10 cm.

Fig. 2. Volumetric 3-component velocimetry (V3V) volumetric flow imaging tripod camera probe captured image pairs at 7.25 Hz with a time of 3500 us between each image pair at 12 bit resolution.

Fig. 3. Schematic representation of 3D particle identification. Particle images from the *left* image (L) are represented by *white*, particle images from the *right* image (R) are represented by *red*, and particle images from the *top* image (T) are represented by *blue*. The centroid of the triplet represents the *x* and *y* location, the and the size gives the *z* location. (Figure from Troolin and Longmire, 2009).

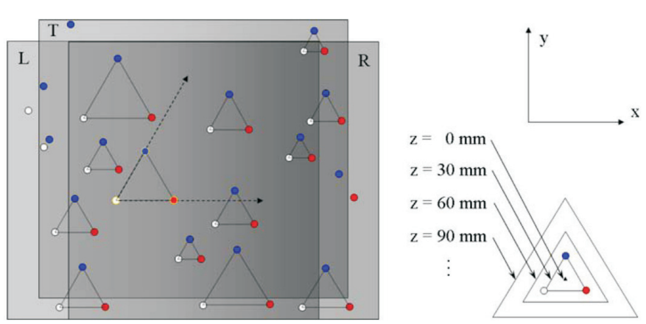
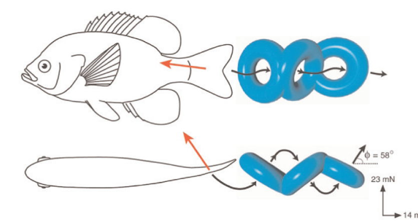


Fig. 3

HYPOTHESIS 1: Each lateral pass of the homocercal tail produces a single jet of fluid, which passes through a vortex ring. Multiple lateral passes performed during swimming produce a series of linked vortex rings. (Figure from Lauder and Drucker, 2002)



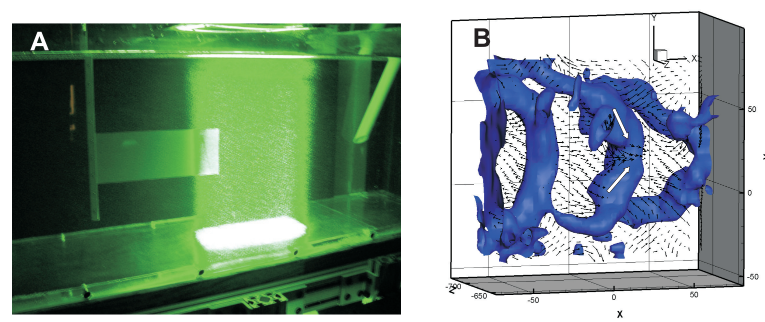


Fig. 4. (A) Robotic simplified homocercal tail model in laser volume and (B) volumetric reconstruction of wake produced. Note how downstream edge constricts jet (white arrows).

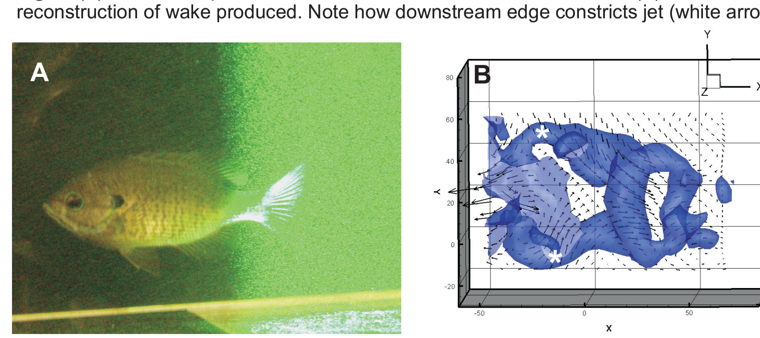


Fig. 5. (A) Live bluegill sunfish swimming in laser volume and (B) volumetric reconstruction of wake produced (at 40% translucency). * = trailing edge vortices separating from tail fin.

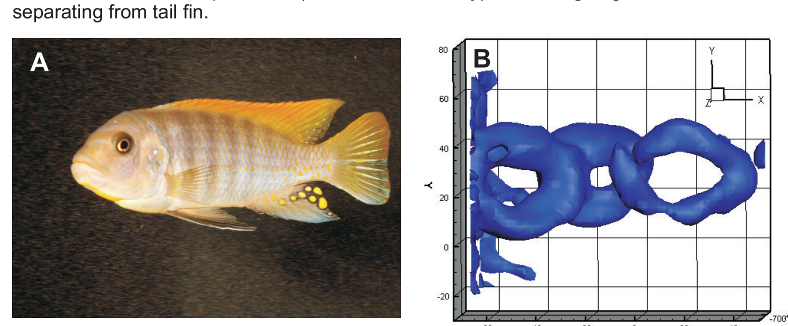
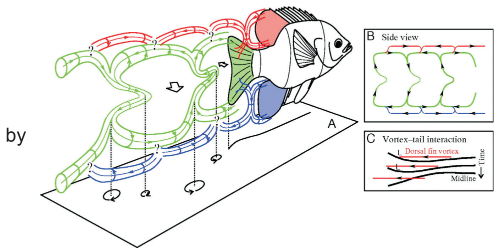


Fig. 6. (A) Live cichlid swimming in laser volume and (B) volumetric reconstruction of wake produced.

HYPOTHESIS 2: Vorticity produced by the dorsal and anal fins of a swimming fish interacts with that produced by the caudal fin. (Figure from Tytell, 2006)



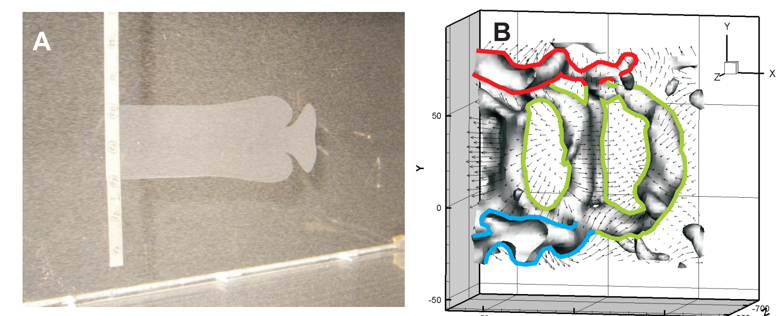


Fig. 7. (A) Robotic bluegill homocercal tail model in laser volume and (B) volumetric reconstruction of wake produced by the dorsal (red), anal (blue) and caudal (green) fins.

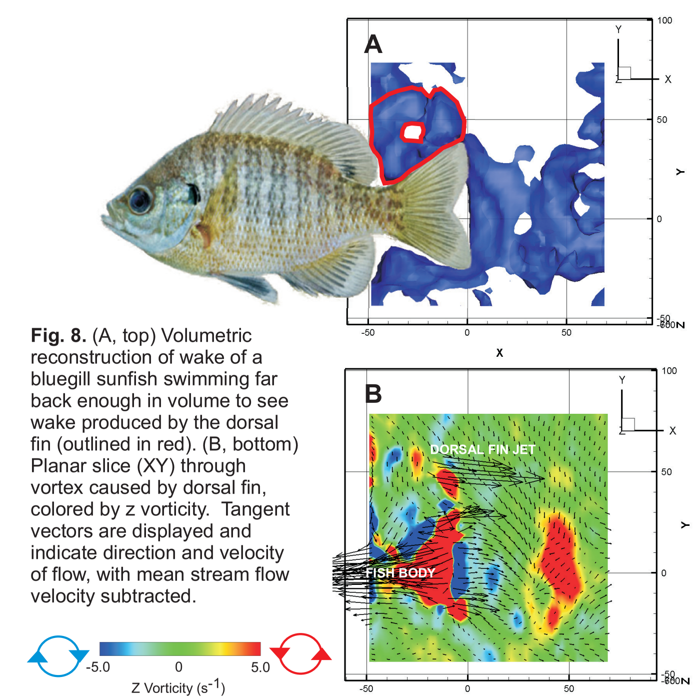
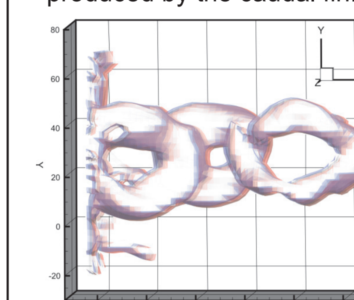


Fig. 8. (A, top) Volumetric reconstruction of wake of a bluegill sunfish swimming far back enough in volume to see wake produced by the dorsal fin (outlined in red). (B, bottom) Planar slice (XY) through vortex caused by dorsal fin, colored by z vorticity. Tangent vectors are displayed and indicate direction and velocity of flow, with mean stream flow velocity subtracted.

CONCLUSIONS:

The ability to capture an instantaneous snapshot of the complete wake structure produced by a swimming fish removes the potential error involved with previous technologies, where researchers had to integrate multiple data sets to produce a 3D structure. Using this new technology, we have confirmed that homocercal tails produce a series of linked ring vortices during steady swimming. We have also been able to identify dorsal and anal fin wake structures and are beginning to build a better understanding of how they interact with the wake produced by the caudal fin.



Anaglyph of Fig. 6B, view with 3D glasses.

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