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Aquatic locomotion: New approaches to invertebrate and vertebrate biomechanics[1]

GEORGE V. LAUDER

Department of Ecology and Evolutionary Biology, University of California Irvine, Irvine, California 92697

AND

JOHN H. LONG, JR.

Department of Biology, Vassar College, Poughkeepsie, New York 12601

The study of how aquatic organisms locomote has a long and distinguished history, one that has been chronicled in numerous books and symposium volumes over the past thirty years (Clark, 1964; Gray, 1968; Lighthill, 1975; Webb, 1975; Wu *et al.*, 1975; Alexander and Goldspink, 1977; Pedley, 1977; Hoar and Randall, 1978; Blake, 1983; Webb and Weihs, 1983; Videler, 1993; Maddock *et al.*, 1994; Vogel, 1994; Ellington and Pedley, 1995). The volume of both secondary and primary literature reflects the intense interest in mechanisms of aquatic movement. And the breadth of this interest reflects the diversity of structural and functional principles of organismal design that are understood with particular clarity via the study of aquatic movement. As a consequence, researchers from diverse fields have focused on the problem of aquatic locomotion. For example, major contributions to our understanding of organismal design principles have been made by workers interested in the comparative physiology of aquatic movement, the biomechanical properties of locomotor structures, and the fluid dynamic principles involved in propulsion.

And yet, within the last five years, a number of new approaches have been developed that promise to extend considerably our understanding of how organisms move through water. We are embarking on a new phase of growth in the study of aquatic locomotion, a phase involving both different techniques and fresh conceptual approaches. These developments point toward both a revision of some current views, as well to entirely new discoveries about how organisms move.

Given the excitement about recent developments, we organized this symposium with the aim of illustrating a selection of novel ideas, results, and techniques. We structured the symposium around the two major modes by which propulsive forces are generated, appendage movement (the first eight papers) and axial deformation (the last seven papers), with the goal of providing examples of some of the most significant themes now becoming prominent in the study of aquatic locomotion.

In particular, we note the following new developments illustrated by one or more of the papers included in this symposium. (1) Much past interpretation of animal movement has been done within the context of steady-state fluid dynamic models. There is now good reason to suspect that such approaches do not reflect the unsteady nature of movement and may thus lead to incorrect interpretations of the physical principles underlying movement. (2) Patterns of animal movement have now been measured much more precisely both in two and three dimensions. Such quantitative measurements of both appendage and axial deformation are providing significant new insights into the nature of the physical interaction between the moving animal and the fluid me-

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dium. (3) Powerful new computational methods are being used to predict patterns of animal movement directly from hydrodynamic first principles. Such computer-based approaches have great promise for enabling us to understand the mechanistic basis of movement across a wide diversity of taxa, morphologies, and fluid environments. (4) Physiological and biomechanical studies of locomotor tissues both in isolated preparations and *in vivo* are providing new insights into where power is generated for thrust production and how work done in one portion of the movement cycle may be partially recovered during other phases. (5) The entire area of appendicular propulsion is undergoing a renaissance based on a wide diversity of approaches ranging from studies of underwater walking and running using jointed appendages, to investigation of appendage motions and energetics in fish and mammals.

This is a stimulating time. The new approaches highlighted in this symposium promise to contribute novel insights to the study of locomotion, and they presage an exciting future.

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