Unrecognized Passive Controls of Posture and Trajectory in Many Actively Swimming Aquatic Animals

Malcolm S. Gordon, Dean V. Lauritzen, and Alexis M. Wiktorowicz
Department of Ecology and Evolutionary Biology, University of California
Los Angeles, CA, USA

ABSTRACT
Greater control of movements gives actively swimming aquatic animals greater abilities to move as necessary. Control mechanisms affect posture, swimming trajectory, static and dynamic stability, and maneuverability. Control mechanisms are both passive and powered. This paper focuses on an unrecognized set of passive mechanisms of control of posture and trajectory that occur in a wide variety of actively swimming aquatic animals. We discuss insights concerning passive mechanisms of control deriving from our earlier work with tetraodontiform fishes that we think also apply much more widely. Detailed consideration is given to possible roles of lateral keels and rows of scutes located on and near the caudal peduncles in many different elasmobranchs (sharks) and bony fishes, also to the peduncular keels found in all cetaceans. Similar structures in some fossil aquatic forms are also discussed.

KEY WORDS: Fishes; cetaceans; swimming; passive control; posture; trajectory

INTRODUCTION
The purpose of this paper is to bring to the attention of the engineering community interested in biomimetics and bioinspired design some hitherto unrecognized potentially interesting features of many kinds of actively swimming fishes (both sharks and bony fishes), also of all cetaceans (whales, porpoises, dolphins), We believe that these features produce specific kinds of hydrodynamic effects that can play significant passive roles in increasing the stability and agility of the animals having them while they swim and maneuver. Incorporating similar features into the designs of engineered underwater or aerial vehicles might have beneficial effects (Bar-Cohen, 2006).

BACKGROUND
Robust mechanisms for both posture and trajectory control are essential for actively swimming aquatic animals moving and maneuvering at varying speeds through variably turbulent waters. The better these animals can control their body postures, trajectories, stability and maneuverability the more easily they can move as they need to.

Mechanisms contributing to posture and trajectory control are either passive or powered. All animals use varying combinations of both types of mechanisms while swimming, their relative importance changing continuously as types and levels of activity vary in response to changing motivational and environmental conditions. Passive mechanisms operate automatically and continuously, requiring neither work nor attention by the animal. Powered mechanisms require coordination and control. The relative quantitative importance of these two categories of control mechanisms is unknown for all animals under all conditions.

The diversity of ways available for aquatic animals to achieve high levels of posture and trajectory control while swimming is so great that analytically manageable levels of understanding of the patterns and processes used by them as they move about in their own environments often elude us. Contributing to this diversity is the fact that most, if not all, of the anatomical (morphological) and surface (integumentary) features participating in these control processes are actually multifunctional. Many of these features also play roles in the generation of other flow-related phenomena, including directing flows and producing lift, drag, and thrust (Fish, 1998; Fish and Lauder, 2006).

Considering separately the passive and powered mechanisms of these controls can reduce this complexity. Aquatic animal locomotion generally is an active area of research; the relevant literature is increasing rapidly. This discussion is not a comprehensive survey of the broader field. Recent useful review articles include Weihs (1993, 2002), Webb (1997, 2002, 2006), Lauder and Drucker (2002, 2004), Drucker et al. (2006), Lauder (2006), Lauder and Tytell (2006), and Fish and Lauder (2006).

This paper focuses on passive mechanisms for posture and trajectory control. Passive mechanisms are either internal and static or external and hydrodynamic. A widespread internal/static mechanism is the metacentric height difference between the positions of the centers of mass and centers of buoyancy within fish bodies (Weihs, 1993, 2002; Webb, 1997, 2002, 2006). Many, if not most, fishes are hydrostatically unstable because their centers of buoyancy are below their centers of mass. This may be the case for both neutrally buoyant and denser than water species. Reasons for this situation are not well understood, but