Chapter 7
Locomotion in the Biological Realm

ABSTRACT

The interaction between shape, size, mechanics of motion, and energy makes the study of animal locomotion a very attractive topic from an engineering point of view. This is because the correlation of shape and form to the energetics of motion links animate and in-animate designs. One of the pressing needs in design is to develop efficient ways to combat the negative effects of friction on motion (i.e., friction-induced energy dissipation). Animals are subject to the same derogatory effects of friction. However, due to the interaction between their surface structure and their mechanics of locomotion, they are able to balance the energy invested in moving and the losses resulting from friction. This chapter explains the locomotory modes adopted by terrestrial animals.

INTRODUCTION

The essence of life is motion. Purposeful motion is an existential necessity of all microbial and animal life. Throughout millions of years, most non-plant life forms have developed variety of locomotion modes. Depending on the species, an adopted form of locomotion may vary from the simple or primitive, to the kinematically complex.

In the animal world, locomotion has many manifestations. Large terrestrial animals utilize limbs to support their weight therefore; they have to deal with gravitational forces upon movements. Other animals developed various means to minimize the gravitational influence and hence they stay close to the ground (and in some cases under the ground). Locomotory modes may include walking, running, crawling, flying, jumping, hoping and slithering to name a few. Motivations for animal movement are diverse, most however, originate from the necessity of performing tasks essential for survival. As such, finding food, evading predators, migration, and hunting are prime motivators for animal motion. A particular animal, however, does not confine itself to a single mode of locomotion. Rather, it is common in the animal kingdom for a particular species to switch between different modes. Monkeys can switch between bipedal and quadrupedal locomotion (Cohen and Jordan, 2010); salamanders may alternate walking and swimming (Arnold 1983); snakes use sidewinding, rectilinear, and concertina crawling (Damme, et al, 1998). Moreover, forward locomotion patterns may be modified to produce backward progression (Huey and Stevenson 1979).

DOI: 10.4018/978-1-6684-5638-5.ch007

A central question in the study of animal locomotion is what criteria govern the choice of a mode of motion by an animal given a set of external conditions? For example, what makes running favorable than walking or galloping favorable to trotting at a given instance? While the answer to this question is not yet clear, some argue that selective ecological pressures and survival requirements have shaped the locomotion methods and mechanisms of motion adopted by moving organisms. The supporting evidence for the survivability argument stem from observing the locomotory habits of species. Migratory animals adopt energy conserving locomotion mechanisms that cost minimal energy per unit distance. Frogs, on the other hand, have a very fast locomotion that allows timely escape from predators. Fast locomotion is costly, from an energy point of view, yet survival compensates for the high-energy cost. The notion of energetic cost poses interesting questions about the energetics of shape, size, and form of animals and whether these factors contribute to adoption of a particular locomotory mode. In all, the study of locomotion in animals leads to several intriguing questions about the build-up of species, their energy consumption profiles, and the engineering aspect of their design.

Animals, similar to humans, are subject to the constraints of universal physical laws. Consequently, their motion, regardless of the adopted mechanism, is subject to the same kinematic principles that govern other moving objects in the universe. To move, animals have to overcome resistances offered by the surrounding medium. Birds have to overcome the drag resulting from penetrating through air. In aqueous environments, swimming requires effort that overcomes fluid resistance. In terrestrial environments, meanwhile, gravitational effects manifest the main resistance to motion. Therefore, locomotion requires energy to overcome the effects of drag, inertia, friction, and gravity.

The physical environments occupied by animals fall into four broad categories: fossorial (underground), terrestrial (on the ground), aerial (in the air, which also includes arboreal or tree dwelling), and aquatic (in the water). For an animal to move through any of these environments it has to push through in order to make space for its body. The act of "pushing through" meets resistance from the medium. This resistance acts to impede the movement of the animal. In other words, the interaction of the form of the animal with the surrounding medium gives rise to a reaction that restricts motion. The nature and magnitude of the resulting impedance depends on the surrounding physical environment. It develops in the form of drag for aerial and aqueous mediums or in the form of friction for terrestrial and fossorial mediums. Additional restraints that result from the universal physical laws, e.g., gravity and inertia, act also to restrain locomotion.

To overcome the various resistances to motion, an animal has to perform work. The amount of work needed for each locomotion mode depends on various factors (such as form and size of the animal, surrounding medium and speed). In general, the energy needed to propel the animal has to exceed the sum of all impedances to motion (drag or friction) and the resistance to motion due to physical laws. However, the resistances acting on a given animal, due to adopting a particular mode of motion, need not be of equal magnitude, nor should they be of equal importance to motion. The degree of importance of each of the resistances depends on the medium surrounding the animal, and to some extent, on the shape of the animal. In terrestrial environments, gravity is the resistance to overcome. An elephant walking in the forest, for example, has at least to support its weight in order to move. Air resistance to the elephant motion is, for practical purposes, negligible. On the other hand, a duck swimming in a lake, has to contend with the drag resulting from viscous effects of water. The duck being naturally buoyant, need not expend much energy to maintain vertical position. However, if the duck attempts to fly, energy requirements will change. The duck, being considerably, heavier than air, have to resist the effects of gravity, and to combat aerodynamic drag. Body form in such a case works to reduce the total amount of