Jumping on water: Drag based propulsion in *E. cyanophlyctis* and *Acris spp.*

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Motivation

Many animals move on or interact with the surface of the water. This behavior near or on the liquid-air interface often involves impacting the water surface (water entry) and moving normal to the interface and exiting in air (water exit). The problem of water entry and exit is not only applicable to animal behavior, such as basilisk lizards (*Basiliscus plumifrons*) running on water (see Figure 1) or cats and dogs lapping fluid, but also to several engineering problems, such as submarine surfacing and hydroplane landing.

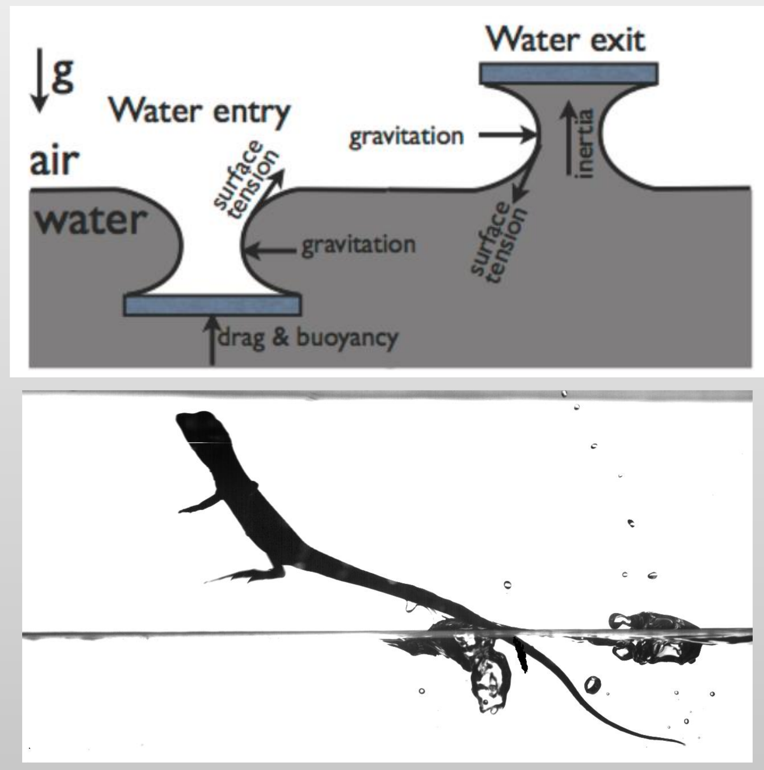


Figure 1: (top) Various forces dictating the fluid dynamics of water entry/exit (below) A shadow-graph of a basilisk lizard running on water

Surprisingly little is known about the reported 'skittering' behavior in some species of frogs [4]. While *Euphlyctis cyanophlyctis,* the Indian Skitter Frog, is named for its ability to jump multiple successive times on the surface of the water (see Figure 1), its impressive jumping behavior has only been the subject of one previous study [3]. Cricket frogs (*Acris spp.*) are an abundant species native to the United States that have also been reported to perform this skittering behavior [4], and yet there is no scientific literature mentioning or studying this fact more recent than 1980.

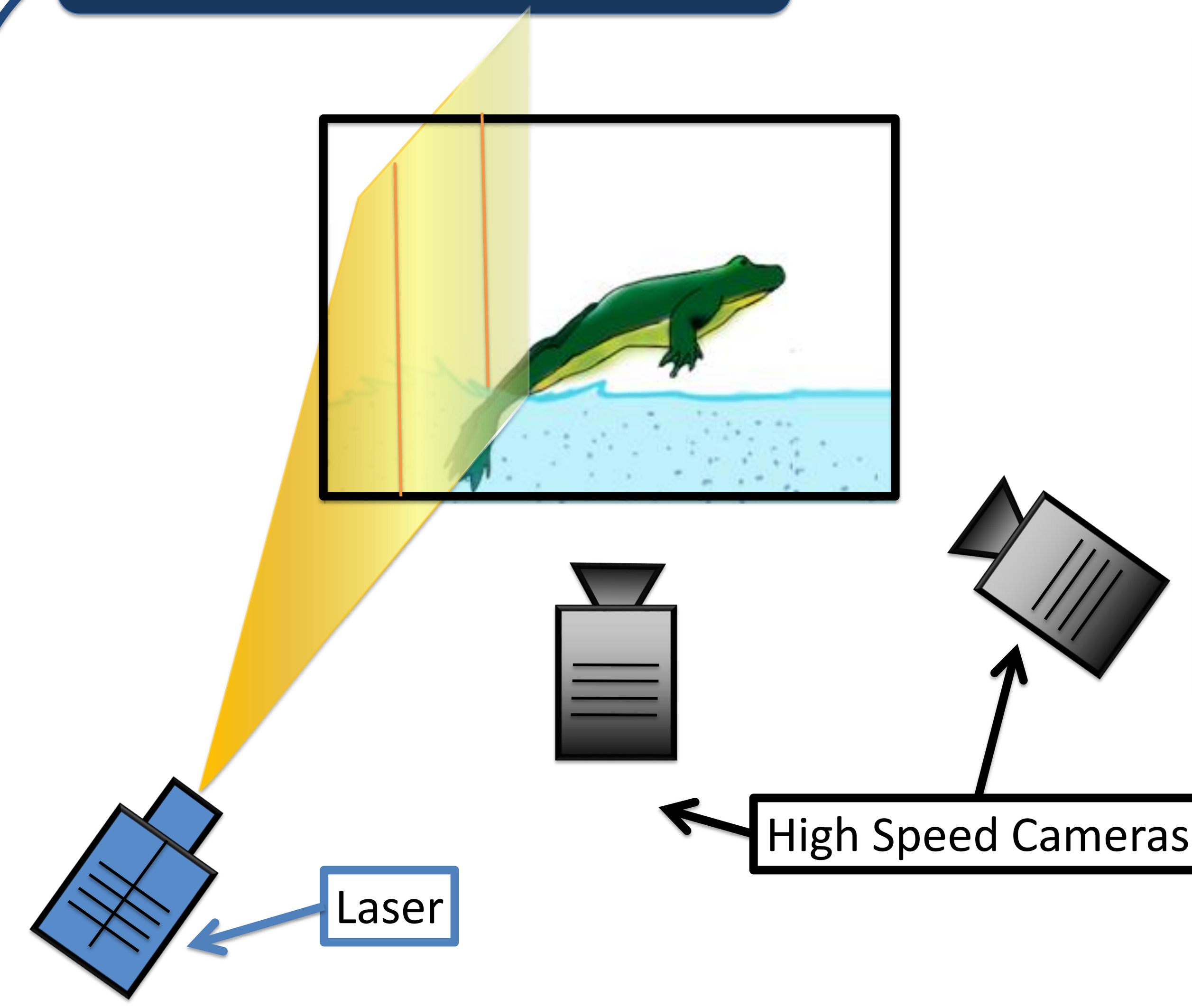
Figure 2: Five superimposed frames of *E. cyanophlyctis* jumping on water. Each frame is 50 ms apart. Adapted from [2]

Despite the similar behavior of these basilisk lizards and skittering frogs, the mechanisms and physics behind this mode of locomotion may be quite different in these two vertebrates.

The goal of this project is thus to study the kinematics and forces involved in *Acris spp.* and *E. cyanophlyctis* skittering on water to determine if and how they differ from *Basiliscus plumifrons* lizards running on water.

Figure 3: A. *creptians* (left) and *A. gryllus* (right) both have been reported to `skip' or `skitter' on the water. [4, private correspondence] Pictures © John White

Methods



Experimental Design

- The frog is released into a tank seeded with neutrally buoyant reflective particles and is startled to encourage the frog to jump across the water
- A laser plane is situated to illuminate the particles in a ~1 mm plane
- Multiple high speed cameras (two shown here) are focused on either the frog's limbs (in order to capture **kinematic** data) or the illuminated particles (for use in estimating the fluid velocity with **Digital Particle Image Velocimetry**)
  - Having at least 2 cameras film the particle field allows for **DPIV** to calculate 3 dimensional velocity vectors in the 2D plane illuminated
  - The velocity fields calculated with **DPIV** can then be used to estimate the force the frog impacts on the water

We predict that unlike the basilisk lizard, these frogs support their body weight mostly through drag instead of impact forces

Force Analysis

Assuming that the frog's feet have a `slap' and `stroke' phase similar to the basilisk lizard, we can calculate the slap force by modeling the volume of water displaced by the foot as a bolus cylinder [6]. In that case, the time averaged slap force can be given by:

$$F_{slap} = \frac{mU}{t}$$

where U is the total mean velocity of cylinder expansion away from the foot and t is the time from foot-water contact to the frame being analyzed. The time averaged stroke velocity generated in the fluid can be estimated with:

$$F = \frac{\rho \Gamma A}{t}$$

where ρ is the density of water, Γ is the average circulation around the centers of vorticity, A is the projected area of the vortex ring on the light sheet, and t is the time from the start of the stroke to the frame being analyzed.

Kinematic Analysis

- Joint locations and other morphological landmarks cannot be painted on to the frog's porous skin
- **Marker-less tracking** must be used to track the angles and speed of joints and limbs
  - Feature descriptors such as SIFT can be used to track corner-like pixels throughout a video (see Figure 3)
  - By modeling limbs as rigid bodies, additional constraints can be added to improve tracking results [5]

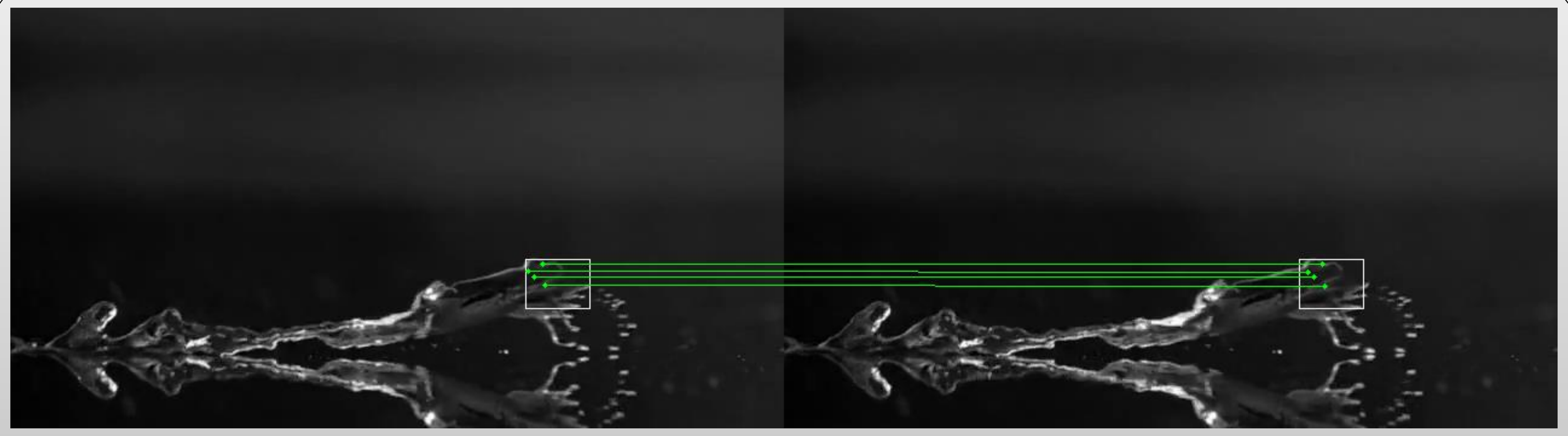
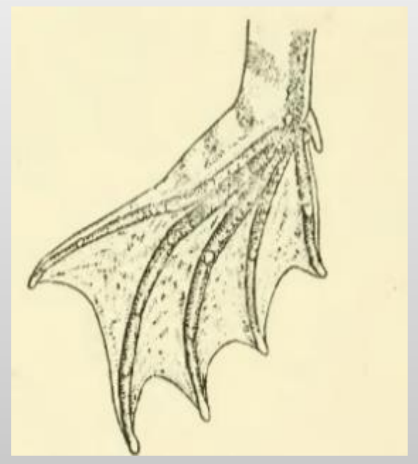


Figure 4: A frog's head being tracked between two successive frames in the video from [2] using SIFT features. Green lines connect matched features, and the white box is the region being tracked.

Future Work



Drawing of *E. cyanophlyctis* foot from [7]

A large factor in the jumping performance of these frogs is likely due to the morphology of their feet. We plan to collect morphological data for a large number of preserved specimens of both skittering frogs and non-skittering frogs. Using this data we can determine if the foot morphology is likely to play a critical role in allowing these frogs to skitter on the surface. Such data will also allow for the creation of foot models, with which we can determine theoretical drag coefficients and effective radii of the frogs feet.

References

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