# Bouncing, flouncing, jouncing sea stars: characterizing the oscillatory gait of *Asterias forbesi*

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Sea stars locomote using numerous fluid-filled tube feet on their undersides called podia. Like how humans walk and run, sea stars exhibit two gaits: a slower crawling gait in which their podia are uncoordinated, and a faster oscillatory gait where their podia move together to create a bouncing motion (Figs. 1, 2a). A common tool for analyzing gaits of terrestrial organisms is the Froude number, defined as the ratio of kinetic energy to potential energy of a moving organism. Humans transition from walking to running at a Froude number of approximately 0.5, but sea star Froude numbers are on the order of $10^{-2}$ to $10^{-3}$. A consistent Froude number for sea star gait transitions may indicate a mechanical reason for the difference in gaits. Our project investigated whether sea stars tend to transition at a consistent Froude number by temporally pinpointing the transitions using kinematic data from videos of locomoting sea stars and calculating the Froude number at that moment. We also developed a model to characterize the action of each podium engaged in a bounce during the oscillatory gait.

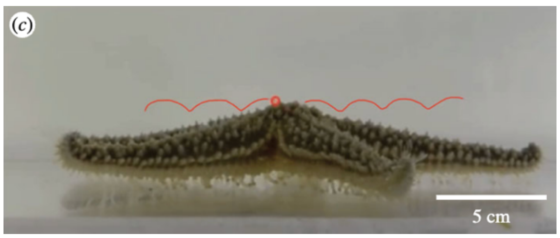


**Figure 1.** Vertical displacement of an *Asterias forbesi* individual during its oscillatory gait from Ellers et al. (2021).

First, we collected 30 *Asterias forbesi* individuals of various sizes at Rockland Breakwater in Rockland, Maine. The sea stars were acclimated to 55$^o$F and filmed in a custom-built plexiglass flow tank with cameras capturing side-view and bottom-view videos. To initiate the transition from the crawling to bouncing gait, sea stars were placed in the filming tank upside-down so that they would right themselves and begin to move across the tank, being gently adjusted if they moved off-track. Videos were processed in Deep Lab Cut (DLC) to extract kinematic data.

To choose the moment of transition, we used a Fourier transform to find the dominant frequency of the signal of velocity parallel to the tank floor, which identifies the frequency of the sea star's oscillatory gait. We also used the signal-to-noise ratio (SNR) to quantify how strong the oscillatory signal of the velocity data was compared to signals of other frequencies to determine when a transition occurred (Fig. 2b). The end goal is Froude number calculations drawing from Ellers et al. (2021) conducted at these points of transition to investigate the consistency of the transitional Froude number.

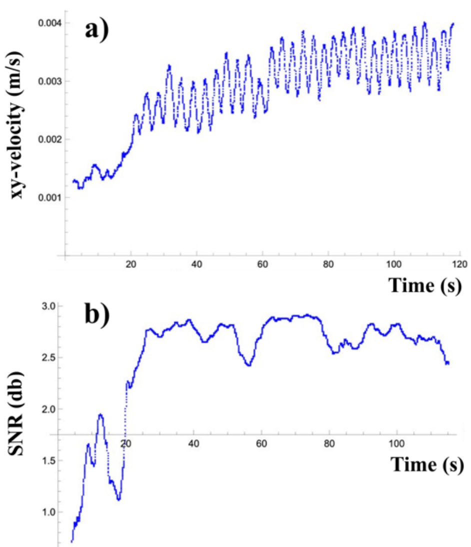


**Figure 2**. a) xy-velocity (m/s) and b) signal-to-noise ratio (dB) over time for an *Asterias forbesi* transition film.

We built upon the torque-stabilized inverted pendulum model created by Ellers et al. (2021) to further investigate podial action within the oscillatory gait by treating each podium as a compressed spring that decompresses as it is drawn towards its vertical by the torque force (Fig. 3). This mimics how water rushes into a podium causing it to inflate and extend (slow rise), vaulting the sea star over the podia (fast fall). Through simulating this model in Julia, we recreated a slow rise and fast fall from the top of the podia. Future improvements to this model include incorporating a joint to represent the bend of the podia and adding the stopping force of the set of podia involved more realistically in the next bounce.

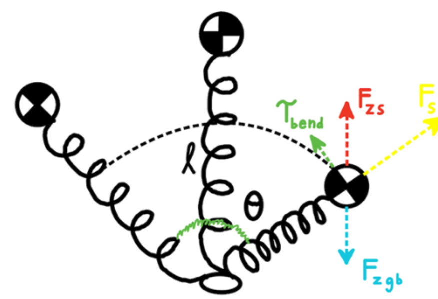


**Figure 3.** Diagram of our torque-stabilized spring-loaded inverted pendulum (TS-SLIP) model for a podium during the oscillatory gait.

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## References

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