Supporting information: Utilization of granular solidification during terrestrial locomotion of hatchling sea turtles

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Kinematic locomotion model

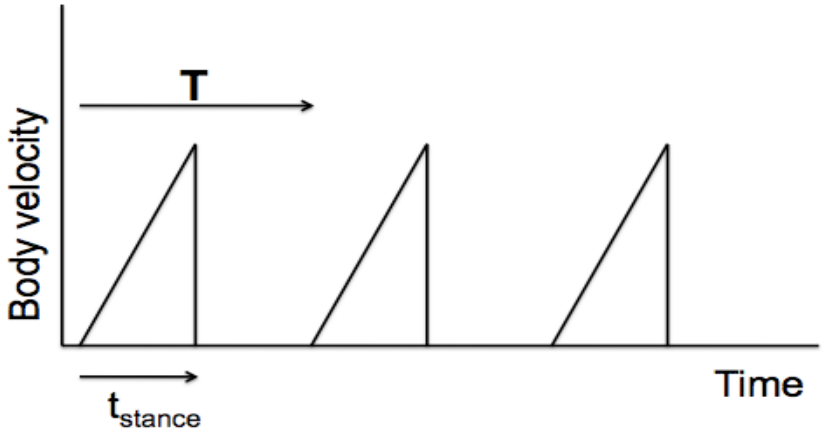

Figure S1: Idealized turtle body velocity vs time assuming a period of constant acceleration (during t_{stance}) during stride of period T.

From kinematic observations (Fig. 1) of turtles, we find that the instantaneous velocity during terrestrial locomotion starts from zero at the beginning of the stride and then increases linearly up to a peak velocity before falling back to zero and remaining at rest for some time before beginning the next step. The approximately linear increase in velocity during stance implies constant acceleration. We construct a model to determine how this inertial acceleration will vary with stride frequency. We model this velocity pattern as a sawtooth wave (Fig S1) with set frequency (f=1/T) and stance time (t_{stance}) which determine the duty factor $d_c = t_{stance}/T$, which in experiment has an average value of d_c=0.667±0.058 on sand and d_c=0.666±0.059 on sandpaper. The time average velocity is

$$\langle v \rangle = \frac{1}{T}\int_0^T v dt = \frac{1}{T}\int_0^{\Phi T} (at) dt = \frac{1}{2T} a (d_c T)^2 = \frac{d_c^{\,2}}{2} a \left(\frac{1}{f}\right)$$

and so for a given stride length S, <v> = Sf and the above equation yield

$$a = \frac{2 S_{eff}}{d_c^{\,2}} f^2$$

This model of locomotion based on kinematic observations of turtles predicts that the acceleration during stance should increase with the square of the stride frequency which is not inconsistent with experimental observations (Fig. 2c).

Field site: Jekyll Island, GA, USA

The field site is located on a barrier island off the coast of GA, offering 16 km of nesting beach for Loggerhead sea turtles. Approximately, 50 to 200 nests are laid each year, making it an important rookery for this species. Females return every 3 years to lay nests with up to 120 eggs. Incubation time is 60 days, at which time the hatchlings emerge and crawl towards the ocean (Hirth, 1980).

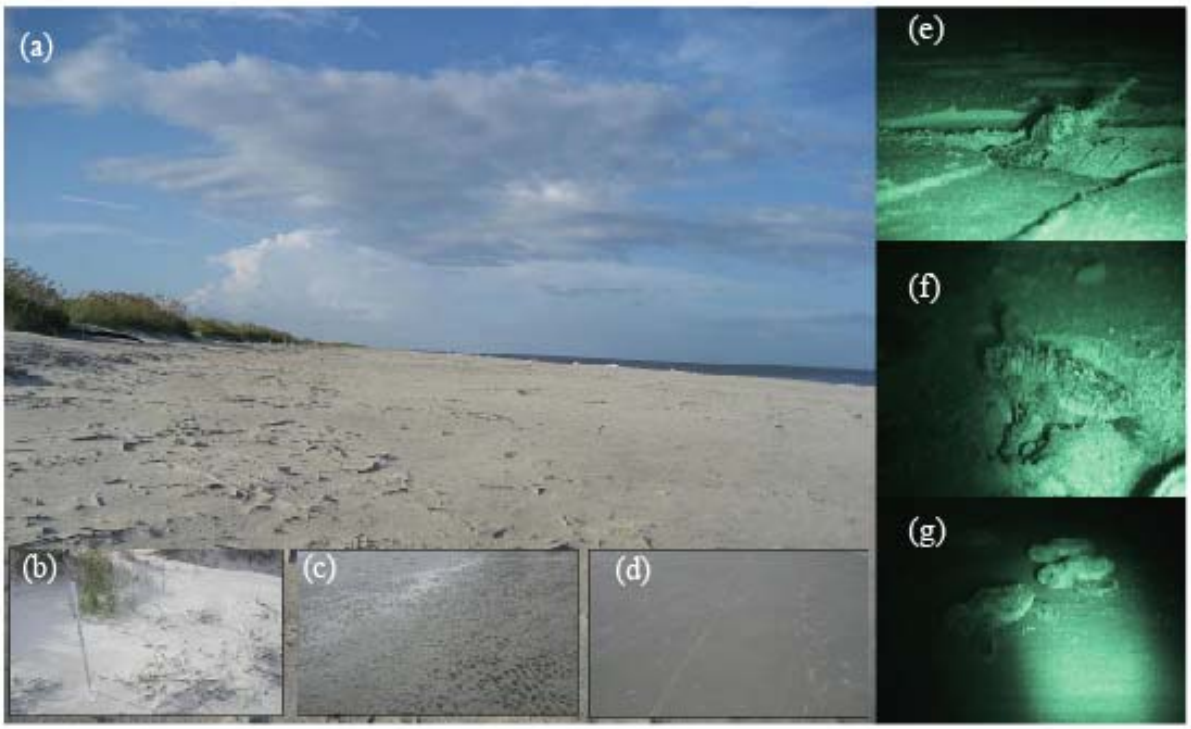

Figure S2: The field site on Jekyll Island, GA, USA: (a) overview of the beach, (b) loose packed sand and nesting site, (c) hard packed, wet and rippled sand during low tide (d) wet, hard sand close to the water. Panels (e)-(g) show examples of hatchling locomotion at night on their journey down the beach to the ocean.

Field-portable fluidized bed trackway

The fluidized bed (length 88cm) housed in the back of a truck is brought to the field site and is used to collect data in a controlled environment by creating repeatable initial conditions of states of dry sand found at the beach. Native Jekyll Island sand filled the bed to a depth of 6cm. A layer of aluminum honeycomb and a porous plastic plate create the flow distributor. The sidewalls are Plexiglas to allow visualization. A shop vacuum (5.0 HP) is used to blow air through the porous plate into the sand, fluidizing it (Li et al., 2009). After flow is turned off, the material settles into a loosely packed state. A board coated with sandpaper was placed in the trackway to study locomotion on hard ground.

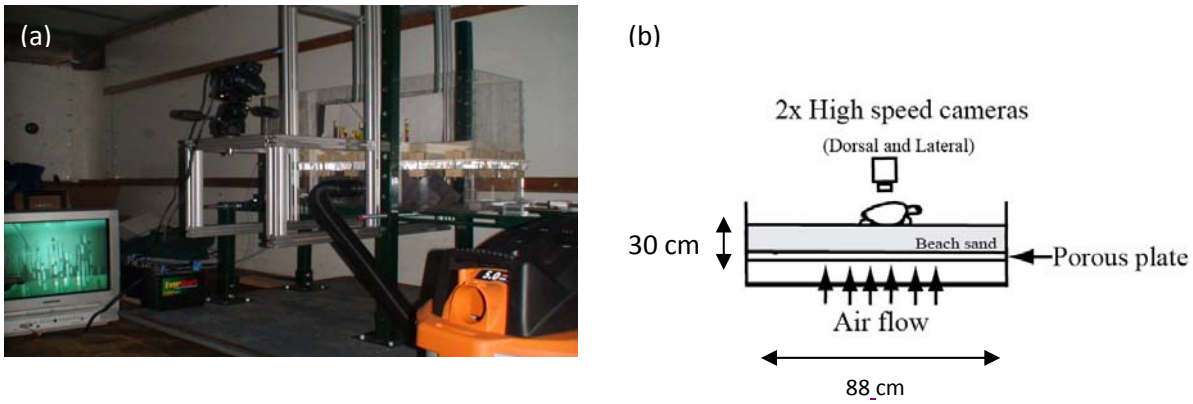

Figure S3: (a) Field apparatus including trackway, cameras and blowers was housed in a truck. (b) Fluidized bed trackway and high speed cameras.

References

Hirth, H. F. (1980) Some Aspects of the Nesting-Behavior and Reproductive-Biology of Sea Turtles. *American Zoologist,* **20,** 507-523.

Li, C., Umbanhowar, P. B., Komsuoglu, H., Koditschek, D. E. & Goldman, D. I. (2009) Sensitive dependence of the motion of a legged robot on granular media. *Proceedings of the National Academy of Sciences,* **106,** 3029-3034.

Supplementary videos

Video S1: Locomotion of Loggerhead sea turtles on the beach during run from the nest to the water.

Video S2: Dorsal and lateral videos (both slowed) of hatchling Loggerhead sea turtle locomotion on granular media.