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Comparison of physical, numerical and resistive force models of undulatory locomotion within granular media DANIEL I. GOLDMAN, RYAN D. MALADEN, YANG DING, Georgia Institute of Technology, PAUL UMBANHOWAR, Northwestern University — We integrate biological experiments, empirical theory, numerical simulation, and a physical robot model to reveal principles of undulatory locomotion in granular media. High speed x-ray imaging of the sandfish, *Scincus scincus,* in 3 mm glass particles reveals that it swims within the medium without limb use by propagating a single period traveling sinusoidal wave down its body, resulting in a wave efficiency, η, the ratio of its average forward speed to wave speed, of 0.54 ± 0.13. A resistive force theory (RFT) which balances granular thrust and drag forces along the body predicts η close to the observed value. We test this prediction against two other modeling approaches: a numerical model of the sandfish coupled to a Molecular Dynamics (MD) simulation of the granular medium, and an undulatory robot which swims within granular media. We use these models and analytic solutions of the RFT to vary the ratio of undulation amplitude to wavelength (A/λ) and demonstrate an optimal condition for sand-swimming that results from competition between η and λ. The RFT, in agreement with simulation and robot models, predicts that for a single period sinusoidal wave, maximal speed occurs for $A/\lambda \approx 0.2$, the same kinematics used by the sandfish.

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