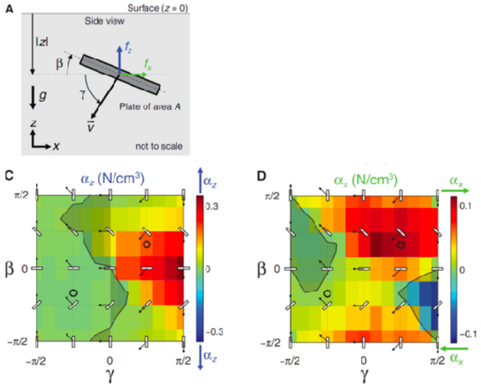
Extension of Resistive Force Theory to Anchoring Modes During Locomotion in Sand

- Resistive Force Theory (RFT) is simple empirical model of forces on an object moving through sand
  - Single terrain parameter
  - Velocity independent
  - Can be applied to arbitrary geometry

$$F_{z,x} = \int_S \xi \alpha_{z,x}(\beta, \gamma)\,|z|\,dA$$

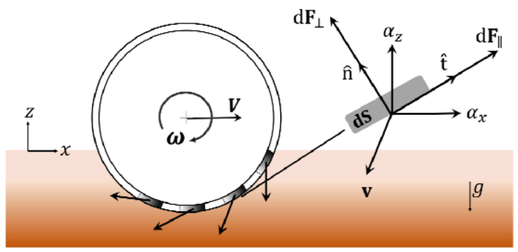
- Quick computation enables
  - Large design space exploration, both geometry & kinematics
  - Real-time control
  - Model corrections for changing terrain in situ

} Would benefit from a well-defined model



Li, 2013, Science

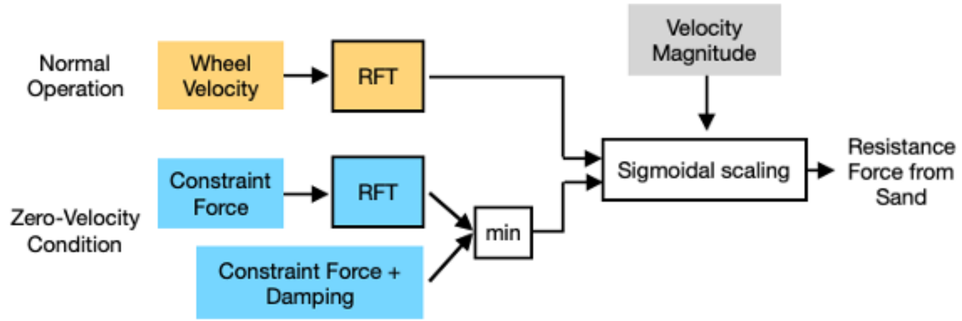
$$\mathbf{F}_d = \int [d\mathbf{F}_\parallel + d\mathbf{F}_\perp]\mathrm{d}S = \int [f_\parallel(\mathbf{v}\cdot\hat{\mathbf{t}})\hat{\mathbf{t}} + f_\perp(\mathbf{v}\cdot\hat{\mathbf{n}})\hat{\mathbf{n}}]\mathrm{d}S$$



Agarwal, 2019, Journal of Terramechanics

- RFT does not define forces on stationary objects
- Anchoring modes have been shown to be useful in rover locomotion design

Use constraint force vector as a proxy to the velocity vector at low velocities



- Challenges:
  - There is motion in 2 directions, unlike with rigid frictional contact
  - F = 0 when v = 0 is not an equilibrium
  - Constraint force vector can point in very different direction from velocity vector

- Future work:
  - Force-controlled plate penetration tests to observe sand's bearing capacity and displacement direction when viewed from RFT perspective
  - Experimental validation of multi-body simulation on full Scarab rover (has an inch-worming drive mode)