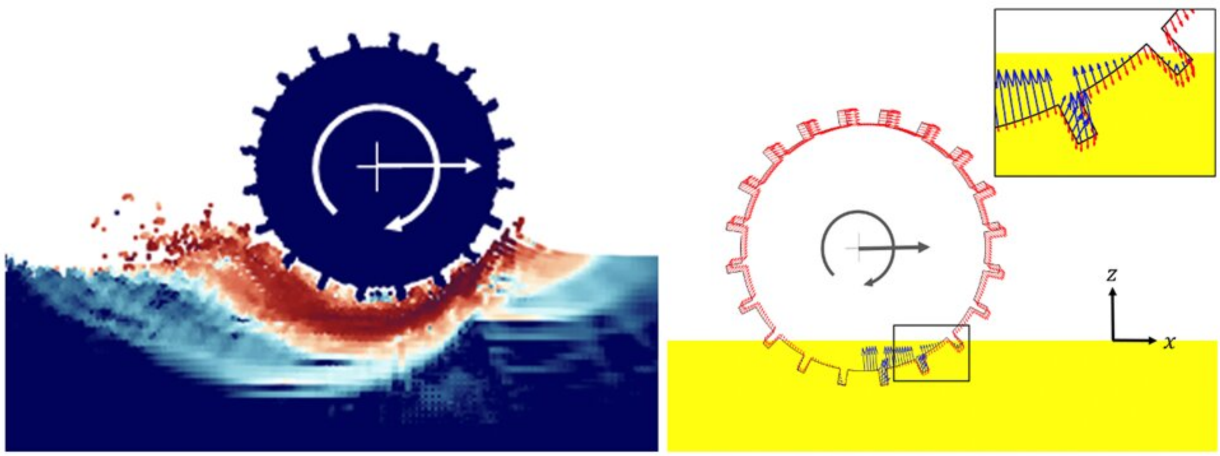
Rapid rovers, speedy sands: Fast-tracking terrain interaction modeling

May 5 2021, by John Toon



Scientists and engineers from MIT and Georgia Tech are enabling near real-time modeling of wheels, tank treads, and desert animals traveling at high speeds across sandy terrains. "Dynamic Resistive Force Theory," or DRFT modeling, illustrated here, provides a blueprint for speedier granular modeling -- and a path to help design better desert vehicles, and Mars and lunar rovers. Credit: Ken Kamrin and Shashank Agarwal, Massachusetts Institute of Technology; and Daniel Goldman and Andras Karsai, Georgia Tech

Granular materials, such as sand and gravel, are an interesting class of materials. They can display solid, liquid, and gas-like properties, depending on the scenario. But things can get complicated in cases of high-speed vehicle locomotion, which cause these materials to enter a "triple-phase" nature, acting like all three fundamental phases of matter at the same time.

As reported in the April 23, 2021 issue of the journal *Science Advances*, a team of engineers and physicists from the Massachusetts Institute of Technology (MIT) and Georgia Institute of Technology (GIT) have proposed a new model, Dynamic Resistive Force Theory, or DRFT, to enable near real-time modeling of high-speed motion for arbitrarily shaped objects moving through granular media.

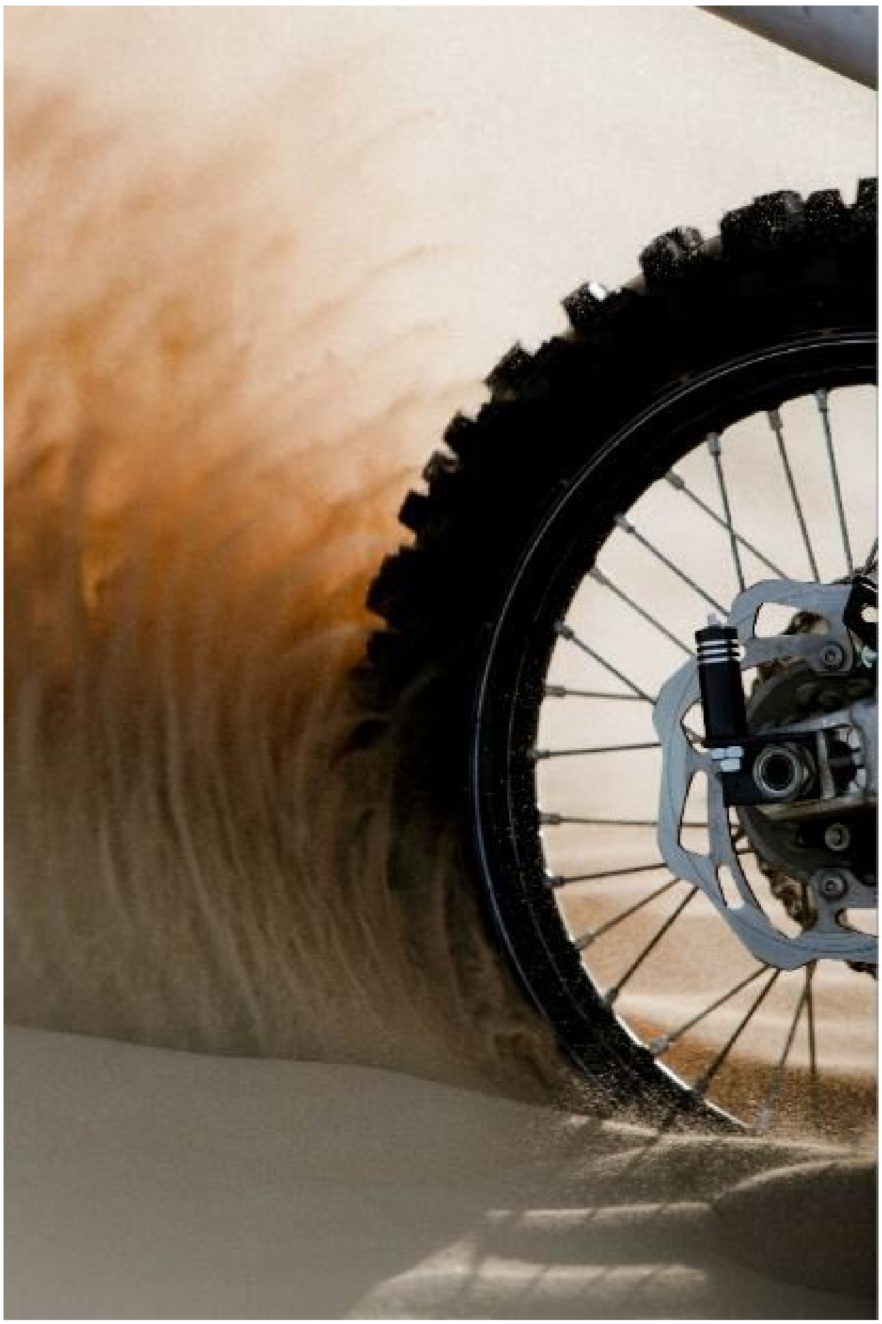
"Applications for this work include the predictive modeling of ground impacts, off-road vehicles, animal locomotion, and extraterrestrial rovers," notes Ken Kamrin, associate professor in the Department of Mechanical Engineering at MIT and the study's corresponding author.

Often, granular materials are modeled grain-by-grain, but this type of approach can be an expensive and slow affair. For instance, modeling one liter of beach sand for just a few seconds might take weeks to process on your average laptop computer.

Researchers have long sought faster ways to accurately model such materials—and often their overall interest is focused on understanding one piece in the overall modeling puzzle: the net force that a granular material like sand exerts on larger moving bodies.

"This is why, over the past century, scientists and engineers have developed the discipline of 'terramechanics,' which helps predict the locomotive performance of vehicles—mostly circular wheel and tanks treads—in granular terrains, like deserts," Kamrin explains. "The majority of the methods used in this discipline remain empirical in nature with little room for customization. DRFT fills this gap and allows for modeling the motion of arbitrary objects moving at various speeds in sands."

DRFT is a joint effort between Kamrin and graduate student Shashank Agarwal (also of Mechanical Engineering at MIT) in collaboration with Daniel Goldman, Dunn Family Professor of Physics and graduate student Andras Karsai (both of School of Physics at GIT).



Engineers and physicists from MIT and Georgia Tech are enabling near real-time modeling of wheels, treads, and desert animals traveling at high speeds across sandy terrains. "Dynamic Resistive Force Theory," or DRFT, provides a path to speedier granular modeling -- and help in designing optimal rough terrain vehicles, like Mars and lunar rovers. Credit: Jack Delulio on Unsplash

The research team unearthed the concept of DRFT after careful study of a continuum model of granular media, which—unlike the grain-by-grain approach—models the smooth flow of grains.

Their continuum analysis revealed an extended formula for the resistive forces that act on rapidly moving objects. While the static force response of granular media is already known as static RFT (Resistive Force Theory), DRFT's extended formulation includes two "key velocity-dependent effects" when calculating the force on each small piece of an object's surface. One contribution is due to the inertial effect of accelerating the granular media, and the other is, as Goldman explains, a "subtle structural modification," due to the changes in material strength that arise as the granular free-surface profile changes.

"Interestingly, when put together, DRFT captures diverse counterintuitive observations observed in granular locomotion, including the behaviors seen in circular and 'grousered' wheel locomotion, 'c-leg' robot locomotion, and possibly even the locomotion of desert animals like zebra-tailed lizards at high speeds," Goldman notes. "At the same time, DRFT illuminates the dominating physical phenomena occurring in rapid propulsion in grain beds."

"The research is of crucial importance for applications like path planning and optimal locomotor design for terrestrial, as well as extraterrestrial, applications, such as Mars and lunar rovers," adds Kamrin. "While this study specifically focuses on granular materials, it provides a blueprint for developing similar rapid, reduced-order models for other classes of materials like muds and slurries."

More information: Shashank Agarwal et al, Surprising simplicity in the modeling of dynamic granular intrusion, *Science Advances* (2021). DOI: 10.1126/sciadv.abe0631

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