



IFPRI BRIEF TEMPLATE

Check One: **Project** **Review** **Collaboration**
 Workshop **Other**

Descriptive Title	Collaboration: Karen Daniels & Prabhu Nott on non-local rheology
Working Title¹	Non-local rheology of dry flows: from experiments to practical model
Technical Area²	Dry Systems
Date	June 22, 2021
Short Description	Collaboration between Daniels and Nott to compare experimental data and repair non-local rheology models with dilatancy and wall effects
Objectives	Repair models of non-local rheology with dilatancy and wall effects
Scope	<p>The past decade has seen multiple nonlocal rheological models proposed, all of which need to be tested against experimental data. As an IFPRI grantee, Karen Daniels (NCSU) has produced detailed data on the kinematics and internal stresses in sheared granular flows, and compared to two different models so far. Prabhu Nott (IISc) has recently published an alternative nonlocal rheological model that accounts for dilatancy (which the others do not). As an IFPRI grantee, he is currently working on experiments and model of screw feeders, but has not yet tested the model on simple experimental geometries such as the NCSU annular rheometer. This collaboration grant would facilitate the efforts of Daniels and Nott to elucidate (1) the effects of walls on the kinematics, and (2) the coupling between packing fraction and shear rate (dilatancy), and (3) internal stress fields.</p> <p>The key laboratory measurements needed to compare to the model are the stress profiles, velocity profiles, and packing fraction profiles. NCSU has an existing dataset from the main project (rheology as a function of wall roughness) which will be the starting point for our comparisons. It will likely be necessary to supplement that dataset with improved packing fraction and particle-tracking measurements in the vicinity of both walls. IISc has working code to make predictions from the model, and compare to experimental results. A particularly important variable to measure is the slip velocity at the wall (proportional to the angular velocity of the</p>

¹ Title used in meeting agendas and file archives

² One or more from the following list: W = wet systems; D = dry systems; F = particle formation; SR = size reduction; M = modeling; SE = systems engineering

	particles, which is important for identifying Cosserat effects). It may be possible to directly test these assumptions.
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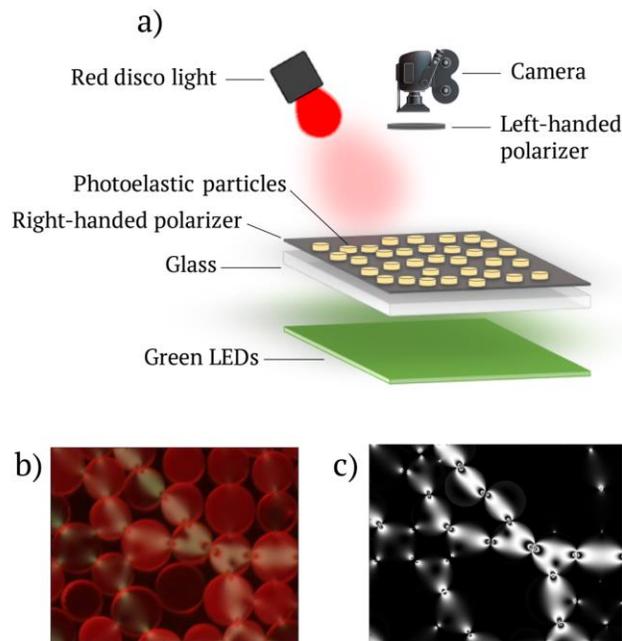
Recommended Contractors (2 or 3)		
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Detailed Research Description

The past decade has seen multiple nonlocal rheological models proposed, all of which need to be tested against experimental data. To date, two models (Kamrin, Andreotti) have been well-tested in experiments and perform equivalently; this work was funded by IFPRI during Years 1-6 of Karen Daniels' grant (1,2). As the Kamrin ("cooperative") model has one fewer free parameter, it is the preferred model and has been pursued in more detail. A key limitation of both of these nonlocal models is that they do not account for dilatancy explicitly, and therefore will always be limited in their ability to predict mass flux. In addition, questions remain about how to appropriately set the boundary conditions from first principles. Therefore, it is prudent to continue to examine other nonlocal models. Prabhu Nott (separately from his IFPRI funding) has recently published an alternative nonlocal rheological model that accounts for dilatancy inherently; the model has been validated by DEM simulations, but remains to be tested against experimental measurements (3).

Conveniently, the methods that Daniels has used for validating nonlocal models are quite general: particle-scale kinematics and internal stresses. Sample data collection and coarse-graining of a single image is shown at right (from ARR-12-05). These methods require movies of the dynamics to be taken until mixed lighting (unpolarized light in the red channel for particle-tracking and polarized light in the green channel for internal stress measurements), and the



required equipment is already present in her lab. The resulting images (panel b) can be fit to known photoelastic responses (panel c) to provide particle-scale contact force measurements. From this type of data, it is possible to coarse-grain the results to extract the packing fraction, velocity, strain rate fields, and stress fields (both shear and pressure). Nott's nonlocal model is similarly flexible: it can be written in cylindrical coordinates and solved for the annular rheometer geometry that currently exists in Daniels' lab (the same rheometer which has been used to test the other two models).

Therefore, we propose to complete the following aims:

- Aim 1: using realistic experimental conditions, determine the appropriate material parameters and solve Nott's nonlocal model. Make a comparison between

measurements from the experiments and predictions from the model, iterating to elucidate the conditions under which agreement is achievable for both strain rate and stress fields

- Aim 2: test the functional form of the coupling between packing fraction and shear rate, the behavior formally known as dilatancy
- Aim 3: use the experiments with different wall-roughness to test the effects of walls on the kinematics

The key laboratory measurements already exist (see ARR-12-06) – stress profiles, velocity profiles, and packing fraction profiles – for experimental runs with a variety of wall-roughnesses. It will likely be necessary to supplement that dataset with improved packing fraction and particle-tracking measurements in the vicinity of both walls, as these were not fully-resolved in previous experiments. A particularly important variable to measure is the slip velocity at the wall (proportional to the angular velocity of the particles, which is important for identifying Cosserat effects). In addition to the aims above, it may be possible to directly test these assumptions if the data is well-enough resolved.

IISc has working code to make predictions from the model and compare to experimental results. Apart from making predictions of the steady state, the model can also make predict the (unsteady) evolution of all the fields starting from a (roughly) uniform packing fraction – this will serve to validate the coupling between the shear rate and packing fraction fields.

This project will proceed by IISc graduate student Gautam making a monthlong visit to work NCSU to work closely with graduate student Fazelpour to establish the best parameters for the model. During this time, Fazelpour would take any additional data that is needed to establish the model and boundary conditions. The second two months would allow for analyzing any additional experimental runs, fine-tuning the model, and writing up the results. This work would need to begin approximately June 1 in order to align with Fazelpour's estimated completion of her PhD during May/June 2022.

Budget: \$25000

NCSU: \$19000

- 3 month NCSU postdoc: $1/4$ (\$60k annual salary + 9.05% fringe rate) = \$16500
- experimental supplies/machining = \$1000
- campus housing for visiting student @ \$50/night, 1 month = \$1500

IISc: \$6000

- Travel for 1 person, 1 month, from India: \$2000 transportation + \$50 per diem (\$1500) = \$3500
- 3 month IISc graduate student stipend: \$700/month = \$2100
- management fees = \$400

References:

- (1) Zhu Tang, Theodore A Brzinski, Michael Shearer, and Karen E Daniels. Nonlocal rheology of dense granular flow in annular shear experiments. *Soft Matter*. 14:3040-3048 (2018)
- (2) Farnaz Fazelpour, Zhu Tang, and Karen E. Daniels. The effect of grain shape and material on the nonlocal rheology of dense granular flows (2021)
<https://arxiv.org/abs/2108.11369>.
- (3) Peter Varun Dsouza and Prabhu R. Nott. A non-local constitutive model for slow granular flow that incorporates dilatancy. *Journal of Fluid Mechanics*. 888: R3 (2020)