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J. M. F. Tsang

Curriculum Vitae

Overview

I studied the Mathematical Tripos at Queens' College, Cambridge, graduating in 2015 with a MMath and a BA (Hons). My undergraduate syllabus focused on applied mathematics and fluid dynamics. Since 2015, I have been working towards a PhD on modelling granular flows, which is expected to finish in March 2019. Outside of research, I am very interested in teaching and outreach.

Education

2015–present (*expected March 2019*) **PhD candidate**, *DAMTP, University of Cambridge*.
Rheology of Dry Granular Flows. Funded by EPSRC and under the supervision of Nathalie Vriend and Stuart Dalziel. See 'Outline of research' below for details.

2014–15 **Master of Mathematics (Part III)**, *Queens' College, University of Cambridge*, Distinction (82%).
I took examinations in the following courses:
- Perturbation and Stability Methods
- Slow Viscous Flow
- Complex and Biological Fluids
- Fluid Dynamics of the Environment
- Fluid Dynamics of the Climate

My Part III Essay was titled *Global Modes in Shear Flow*. For this I was under the supervision of Nigel Peake.

2011–14 **BA (Hons) Mathematics**, *Queens' College, University of Cambridge*.
The University of Cambridge does not award an overall degree classification or percentage for undergraduate degrees, but instead awards a classification for each year.
- Part II: Class I (85%). Focus on applied mathematics.
- Part IB: Class I (92%)
- Part IA: Class I (95%)

2004–2011 **Secondary education**, *Colchester Royal Grammar School*.

Formal academic transcripts are available on request.

Experience

2016–present **Alpha tester, then developer**, *MercuryDPM*, Twente.
Developing features, documentation and bug-testing for *MercuryDPM*, an open-source package used for discrete particle simulations of granular materials.

2015–present **Supervisor**, *various colleges*, Cambridge.
I have supervised the following courses in the Mathematical Tripos:
- *Dynamical Systems*
- *Electromagnetism*
- *Fluid Dynamics I*
- *Integrable Systems*
- *Mathematical Biology*
- *Variational Principles* (calculus of variations)

2014 **Summer research student**, *Sainsbury Laboratory*, Cambridge.
Under the supervision of Jerzy Paszkowski and Radu Zabet, developing a method for detecting differentially methylated regions in genomes.

2014 **Statistical analyst**, *Admissions Office, Queens' College*, Cambridge.
Analysing the impact of outreach activity on applications, in collaboration with the Cambridge Admissions Office. Advising on improving data collection.

2013 **Summer research student**, *DAMTP*, Cambridge.
Under the supervision of Julia Gog and with Michael Leader, investigating models of influenza genomic packaging with numerical simulations and theoretical analysis.

Publications

Journal articles

- J. M. F. Tsang, S. B. Dalziel, N. M. Vriend. 'The granular Blasius problem', under consideration for publication in *Journal of Fluid Mechanics*.
- M. Catoni, J. M. F. Tsang, A. P. Greco and N. R. Zabet (2018). 'DMRcaller: a versatile R/Bioconductor package for detection and visualization of differentially methylated regions in CpG and non-CpG contexts', *Nucleic Acids Research*, gky602, doi:10.1093/nar/gky602.
- J. M. F. Tsang, S. B. Dalziel, N. M. Vriend (2018). 'Interaction between the Blasius boundary layer and a free surface', *JFM Rapids*, Volume 839, doi:10.1017/jfm.2018.2.

Other

- Weinhart, T., . . . , Tsang, J. M. F., . . . , Luding, S. and Thornton, A. R. (2017). 'MercuryDPM: Fast, flexible particle simulations in complex geometries – Part II: Applications'. V International Conference on Particle Based Methods, Fundamentals and Applications (Particles 2017), Hanover, Germany, September 2017.
- J. M. F. Tsang, S. B. Dalziel, N. M. Vriend (2016). 'Discrete particle modelling of granular roll waves', Annual Meeting of the APS Division of Fluid Dynamics, Portland OR USA, Nov 20–22, 2016.
- Zabet, N. and Tsang, J. (2015). DMRcaller: Differentially Methylated Regions caller. R package version 0.99.5. `http://bioconductor.org/packages/devel/bioc/html/DMRcaller.html`
- Zabet, N. R., Tsang, J. M. F., Catoni, M. & Paszkowski, J. (2014). 'A fast and versatile computational tool to identify differentially methylated regions in CG and non-CG context', In EpiGeneSys 4th Annual Meeting, 27–29 November, Centre of Genomic Regulation (CRG), Barcelona, Spain.

Academic and professional service

2018 Reviewer for International Journal of Multiphase Flow

2017 Reviewer for Physical Review E

Computing skills

Programming *Proficient:* C++, Mathematica, Matlab, PHP. *Functional:* Haskell.

Miscellaneous *Proficient:* MercuryDPM, HTML/CSS. *Functional:* Git, GNU/Linux, LaTeX.

Other skills

Languages *Native:* English. *Fluent:* Cantonese. *Basic:* French.

Prizes and awards

2017 Smith–Rayleigh and Knight–Rayleigh Prize essay, *Topographical effects on granular gravity currents.* Grade 3. Total £250.

2015 Queens' College: Foundation Scholarship. Total £300.

2014 Queens' College: President's Prize for Mathematics, and Foundation Scholarship. Total £400.

2013 Queens' College: Openshaw Prize, Prize on the results of University Examinations, and Foundation Scholarship. Total £450.

2012 Queens' College: Colton Prize, and Prize on the results of University Examinations. Total £300.

Non-academic interests

Societies
- **Queens' College MCR committee** Acting LGBT+ officer (Freshers' Week 2017).
- **Queens' Mathematics Society**
- **Cambridge SIAM–IMA Student Chapter** Junior treasurer (2016–17).
- **Emmy Noether Society** Secretary (2016–17).
- **Music**, including
  - Informal recitals
  - **St Clement's Church choir**
  - **Queens' College Graduate Choir**
  - **St Margaret Society of Queens' (MagSoc)** Librarian (2013–14).
- **Cambridge University Buddhist Society**: Junior treasurer (2013–15).

Education Access and outreach activities by Queens' or by the Faculty of Mathematics.

Personal Music (singing and piano), Chinese history.

Outline of research

Overview

My PhD thesis is titled 'Modelling dry granular flows over topography'. In my thesis, I study two prototypical examples of granular flows responding to changes in the shape or roughness of the surface that they flow over. I mathematically analyse continuum models of these flows, and compare these results to those of computer simulations.

Granular flows encompass a very wide range of industrial processes. Since classical times, the transportation of cereals has been a matter of food security. In modern times, sand is used extensively to make concrete and glass, and the global annual consumption of sand and gravel is estimated at 40 billion tons. In addition, granular currents also occur as devastating geophysical contexts such as avalanches, rockslides and debris flows, which kill thousands of people each year and cause economic and social devastation. Therefore, it is highly desirable that we should understand granular flows better, so that we can describe and predict their behaviours.

A common feature of all of these flows is that they are all driven by gravity down inclined surfaces, and resisted by friction, both internally from the base. (In addition, there may be other sources of drag, such as air resistance.) By 'topography', we mean any features of the base that change the inclination θ or the basal friction. For example, a curved chute has nonconstant θ, while a chute that is composed of different materials from one part to another will have a nonconstant basal friction. Modelling granular flows over topography can help us design systems of chutes that have improved flow rates or reduced stresses.

A granular material consists of many individual solid grains, but together they behave more like a liquid. Most industrial or environmental flows involve huge numbers of grains: for example, a 1 L beaker can hold millions of sand grains, all of which are irregular and unique in shape. The dynamics of each individual grain are governed by Newton's laws of motion, but given the large number of grains it would not be possible to solve all of these equations to find the trajectories of each individual grain. Instead, we are more interested in the collective or statistical properties of a flow. For example, within a flow down a chute, each individual grain may take a jagged path as it repeatedly collides with surrounding grains, but collectively they all steadily travel downwards. Models of granular flow try to describe these bulk properties, stripping away the details about individual grains.

Modelling granular flows

Models of granular materials can be divided into *continuum models* and *discrete particle models* (DPM). Under a continuum model, we treat the material as though it were homogeneous and completely occupied a given volume. We then describe the flow in terms of continuum fields, such as the velocity field $\boldsymbol{u}(\boldsymbol{x}, t)$. These fields represent local or ensemble averages of individual particles' velocities. A continuum model then specifies a set of partial differential equations that govern these fields. Continuum models are very useful because there are well-established methods for analysing p.d.e. and solving them numerically. However, the p.d.e. are based on observations about the bulk flow properties, and it is not known how they may be related to the 'microscopic' grain-to-grain dynamics. In my thesis, I study the '$\mu(I)$ rheology' (Jop *et al.* 2006), which is a commonly used continuum model of granular flows.

Discrete particle models start from a more 'first principles' approach. Instead of treating the material as a homogeneous continuum, a DPM retains the view that the matter is composed of individual particles, but simulates a flow by making simplifying assumptions about the shapes and sizes of these particles. For example, a common assumption is to consider the flow of two-dimensional circular discs down a slope, instead of sand grains, which are three-dimensional and irregularly shaped. DPM also use particles that are much larger than the physical grains that they represent, reducing the number of grains from the millions to the tens of thousands. When these simplifications have been made, it becomes much more computationally feasible to solve Newton's laws of motion for each grain. Although DPM simulations and lab experiments are both empirical, DPM allow us to gather information about the internal structure of a flow, which would not be possible from a lab experiment (in which one can only image the surface of a flow).

In my thesis, I describe some novel techniques to make a DPM represent more faithfully the bulk dynamics of a granular flow, despite these simplifications. For example, a two-dimensional system of discs has fewer grain-to-grain contacts than a three-dimensional system of spheres. With fewer contacts, too little energy is dissipated and the model predicts a flow that is too fast. This can be compensated for by taking a lower coefficient of restitution e. In my simulations, I take $e = 0.1$, which is much smmaller than the true value for glass-to-glass contacts, which is around 0.6.

My DPM simulations are conducted using the software MercuryDPM (Weinhart *et al.* 2017, Thornton *et al.* 2012, Weinhart *et al.* 2012). There are a number of important practical and computational (rather than modelling) issues that I have worked on, but these are outside the scope of my thesis.

Topography

Continuum models such as the $\mu(I)$ rheology have been extensively studied under certain conditions: one typically assumes that the flow varies in the streamwise direction over lengthscales $\mathcal{L}$ that are much longer than the characteristic depth $\mathcal{H}$. This 'shallowness' assumption greatly simplify the $\mu(I)$ equations, but are not valid for flows that experience abrupt topographical changes, such as a sudden increase in basal roughness.

One problem that I study in my thesis is a flow's response to a sudden increase in basal roughness. A flow over a smooth surface may slide freely against the bottom, but when the surface becomes rough then the velocity at the bottom drops towards zero. The effects of this no-slip condition are initially localised in a boundary layer at the bottom of the flow, but spreads upwards due to friction. The top of the flow initially carries on due to its inertia, until the boundary layer spreads throughout the current. We call this the 'granular Blasius problem', because it has many similarities to the classical problem. A major difference between the two problems is the presence of a free surface in the granular case. Tsang *et al.* (2018) describes the interaction between a boundary layer and a free surface for a classical fluid (rather than a granular flow).

In my thesis, I give an analysis of the $\mu(I)$ equations that is analogous to Prandtl's analysis of the Navier–Stokes equations for the Blasius boundary layer problem. I show that a suitably modified version of the $\mu(I)$ equations predicts a boundary layer structure that agrees qualitatively with results from DPM simulations. I also show that a model that uses the shallowness assumption incorrectly predicts the effects of this transition. This work has been submitted to *Journal of Fluid Mechanics* and is under consideration for publication.

I am also studying currents that are influenced by more 'macroscopic' topography, such as a curved surface or non-uniform time-dependent external forces (which might represent a changing wind, for example). In the case of a curved surface, the relevant streamwise lengthscale $\mathcal{L}$ is the radius of curvature. When $\mathcal{H}/\mathcal{L} \ll 1$, a leading-order approximation is to treat the surface as though it were locally flat. I am working on finding corrections to this approximation.

Outlook

In future work, I would like to study the effects of three-dimensionality and time-dependence. It is known, for example, that granular currents are susceptible to instabilities such as roll waves (Gray & Edwards 2014) and fingering (Pouliquen 1997), which are respectively analogous to the Kapitza instability (Dietze 2016) and viscous fingering (Saffman & Taylor 1958) in Newtonian fluids.

One further line of investigation is to explore the possible effects of topography on the formation and propagation of roll waves. Do slopes, barriers and changes in basal roughness amplify or dampen the magnitude of these waves? Can topographical features trigger these waves, if they have a periodicity close to the resonant wavelength? Understanding these instabilities can help us predict the variance in a current's depth and velocity. When modelling avalanches or debris flows, this would help us prepare for 'worst case' scenarios.