PhD PROJECT PROPOSAL

## **PhD Project Title**

Topology in transient and turbulent multi-phase fluid flows

## **PhD Supervisory Team**

## Principal Supervisor: Dr. Jason Stafford, [j.stafford@bham.ac.uk](mailto:j.stafford@bham.ac.uk), School of Engineering

## Co-Supervisor: Prof. Iseult Lynch, [I.Lynch@bham.ac.uk](mailto:I.Lynch@bham.ac.uk), School of Geography, Earth and Environmental Sciences

## **Project Abstract**

## Research into topology and topological optimisation for fluid systems has grown over the past decade, with applications extending to numerous multi-physics problems including conjugate heat transfer, fluid-structure interaction and species transport. Despite this growth in research, a limiting factor is the predominant focus on steady-state and laminar flow problems. A significant portion of real fluid systems comprise of transient, turbulent, and often multi-phase flow conditions. This project will perform high fidelity computational models (e.g. LES/DNS) and topological analysis methods, to study these complex phenomena. Predictions will be validated with laboratory experiments. The project will specifically focus on solving key challenges that involve multi-phase particle-flow systems. In these systems, liquid fluid flows can alter the structure and transport of micro- and nano-scale solid particles. The structure-flow relationships will be investigated by combining hydrodynamic experiments with particle characterisation techniques. These insights will support advances in a broad range fields, such as intensification of industrial processes and mitigation strategies for harmful pollutants in the environment.

## **Detailed Project Description**

From the synthesis of new nanomaterials for advanced technologies, to the transport of microscale particle pollutants in environmental compartments, transient and turbulent multi-phase flows play a central role. The mixing dynamics of chemical reactors influence particle morphologies and reaction kinetics, directly affecting the product quality and waste generated from many industrial processes [1]. In natural environments, air and water compartments are being exposed to excessive levels of fine particles from transport, industrialisation and unsustainable living habits [2]. Fluid dynamics are at the core of these processes, transporting and eroding waste particles into finer materials that harm natural processes, easily pass into biological systems and ultimately lead to a growing strain on the global ecology.

This project will focus on revealing the dynamics and topology of these ubiquitous turbulent multi-phase flows. To achieve this, fluid flows will be described by invariants that are useful for characterising flow features, regimes and quantifying the level of deformation and mixing in fluid elements. These invariants, such as velocity gradient, rate-of-strain and rate-of-rotation tensors, provide this information through analysis of their local and global topology. An example of this is shown in Figure 1 A below. Here, a snapshot of a direct numerical simulation is presented for a liquid film flowing over a rapidly rotating disc [1]. Waves are produced by interfacial flow instabilities. The corresponding high-speed experiments on this system are also shown in Figure 1 B. These instabilities lead to nonlinearities and alter the rate-of-strain topology within the thin liquid film (shown as green). If systems like this are used to manufacture nanomaterials, such as two-dimensional graphene sheets shown in Figure 1 C for example, the material quantity and quality is connected to these dynamic topological features. There is, therefore, a structure-flow relationship that links fluid dynamics with the particle shape and size and this is poorly understood at present.

This project will implement high fidelity direct numerical simulations (DNS) and large eddy simulations (LES) to capture this detailed information about the flow topology of systems containing dispersed particles. The intention will be to use this data to probe how the structure of turbulence changes with proximity to microparticle surfaces, and identify the local topological features categorized by stable/unstable nodes present in the invariants [3]. This will be supplemented by hydrodynamic and micro-/nano-material characterisation experiments (e.g. High speed imagery and electron microscopy, Figure 1 B and C) to determine the structure-flow relationships that are universal to transient and turbulent flows. A comprehensive parameter space will be considered, from dilute to dense particle dispersions, which will also capture the agglomeration and breakup of particle clouds. Indeed, it is expected that these clouds will feature interesting global topologies, depending on the turbulent behaviour, particle Stokes number and concentration.

The research is therefore very relevant for the CDT in Topological Design, given the opportunity to collaborate with a diverse cross-college team working on other areas of topology that could be applied within this field (e.g. Soft Matter and Chemistry, Thermal Engineering, and Mathematical, Computational and Data Sciences).

Fig. 1

***Figure 1:*** *Direct numerical simulations* ***(A)*** *and corresponding high speed imagery* ***(B)*** *of flow over a rapidly rotating disc used to produce two-dimensional particles* ***(C)*** [1].

*References*

[1] **J. Stafford** et al. (2021) Real-time monitoring and hydrodynamic scaling of shear exfoliated graphene, *2D Materials*, 8, 025029, <https://doi.org/10.1088/2053-1583/abdf2f>

[2] T. Wu, K. Lo and **J. Stafford** (2021) Vehicle non-exhaust emissions – Revealing the pathways from source to environmental exposure, *Environmental Pollution*, 268:A, 115654, <https://doi.org/10.1016/j.envpol.2020.115654>

[3] M. S. Dodd and L. Jofre (2019) Small-scale flow topologies in decaying isotropic turbulence laden with finite-size droplets, *Phys. Rev. Fluids,* 4, 064303, <https://doi.org/10.1103/PhysRevFluids.4.064303>

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