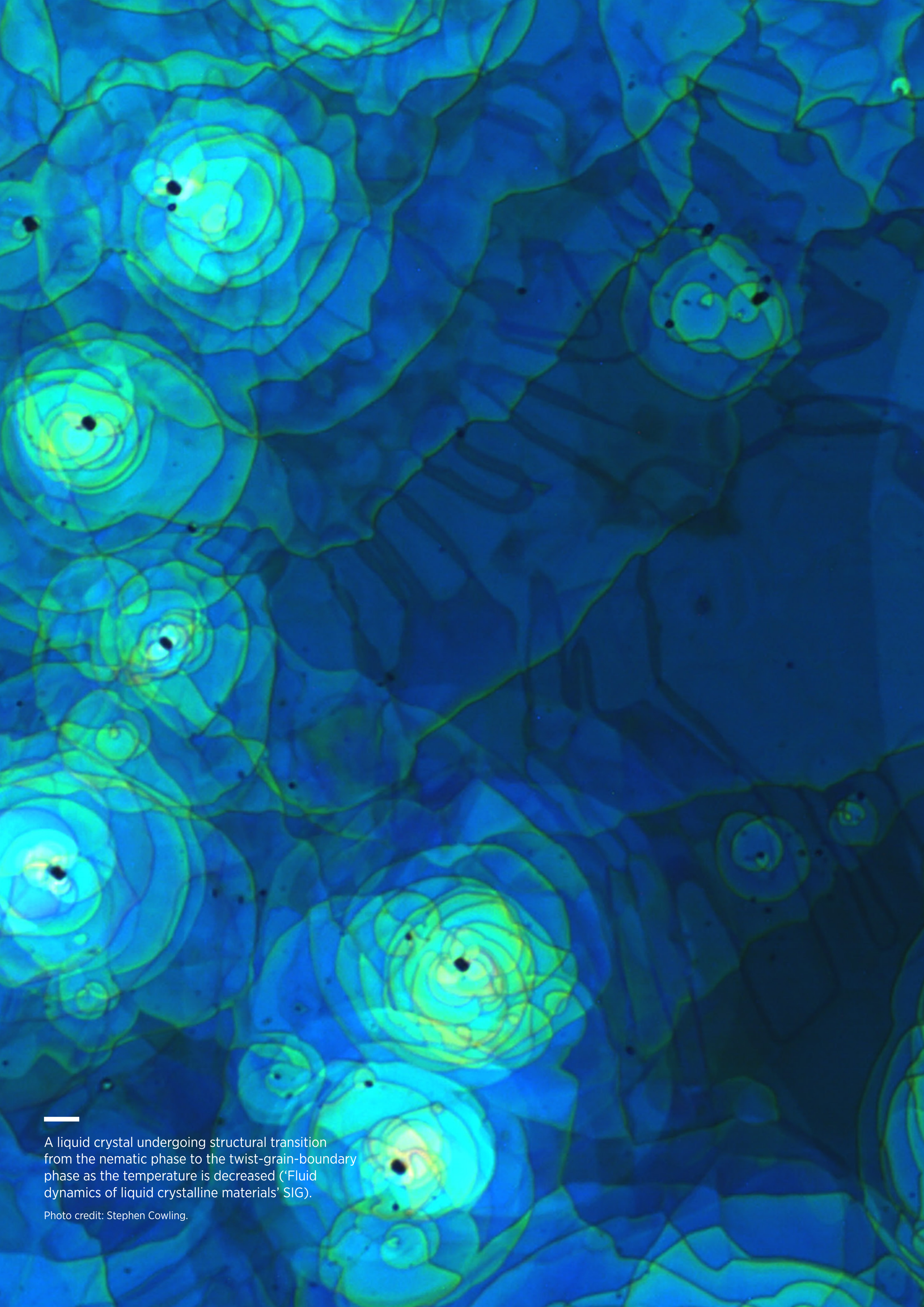
UK FLUIDS NETWORK

www.fluids.ac.uk



A liquid crystal undergoing structural transition from the nematic phase to the twist-grain-boundary phase as the temperature is decreased (‘Fluid dynamics of liquid crystalline materials’ SIG).

Photo credit: Stephen Cowling.

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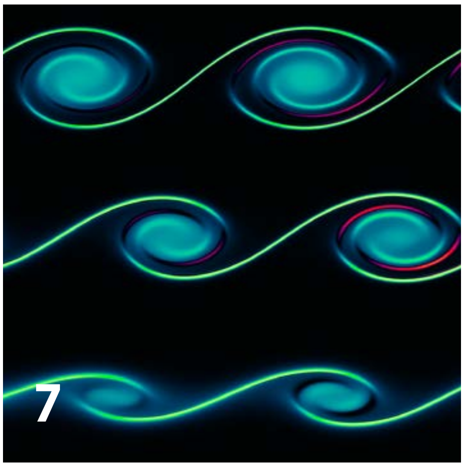
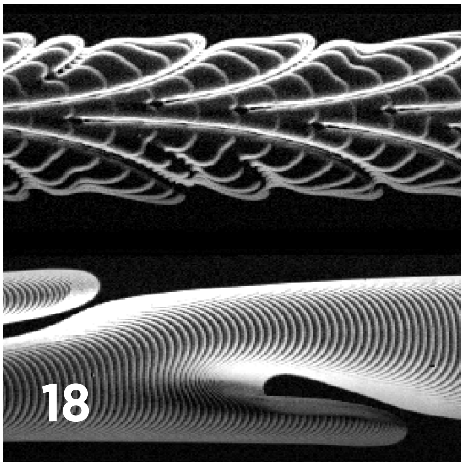
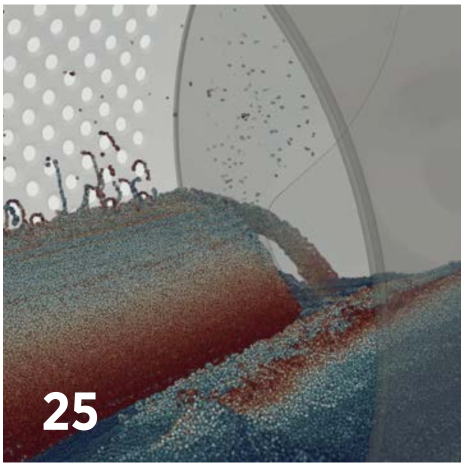


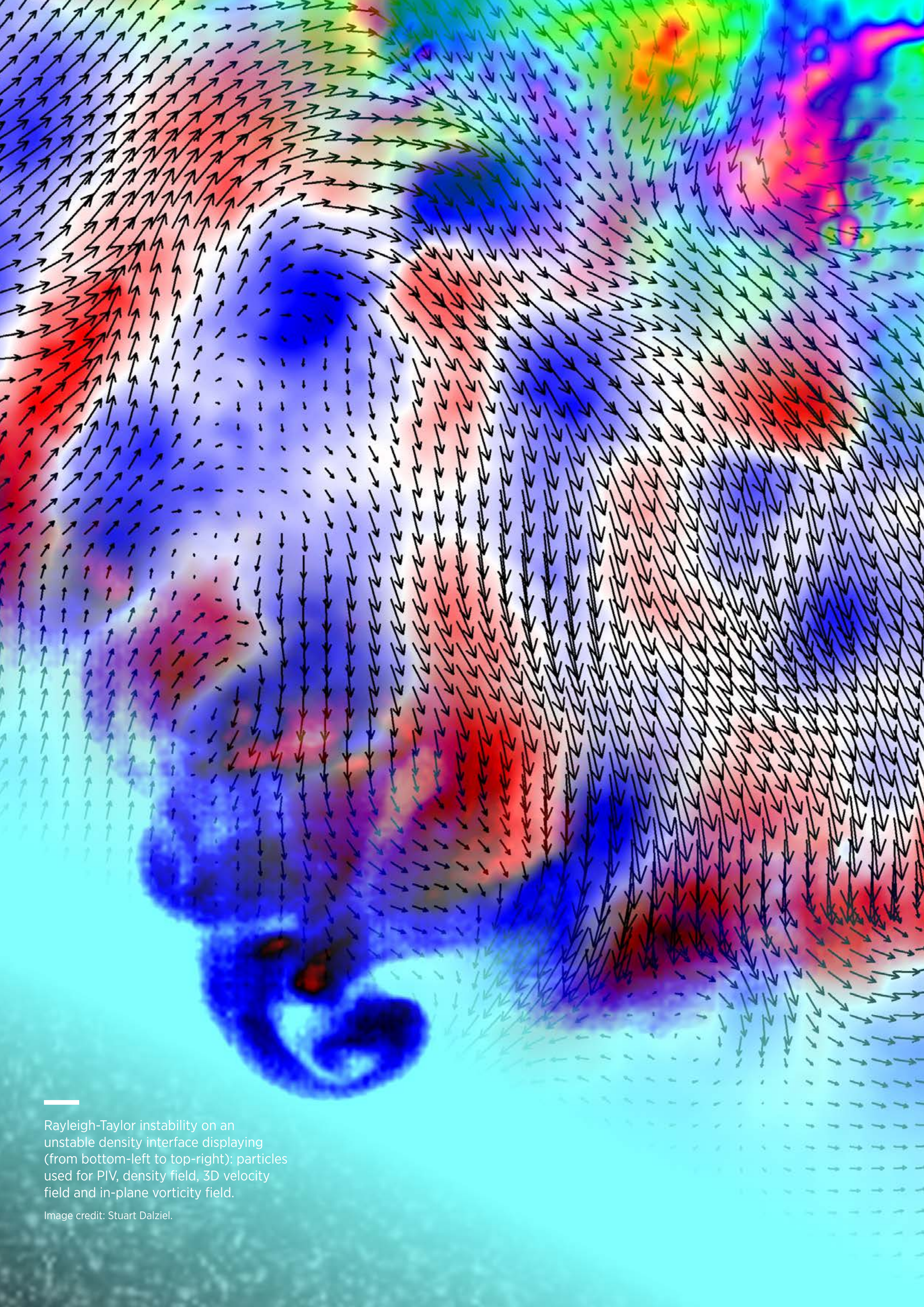




FRONT COVER

L.E.D. capsules are trapped in a chaotic flow around a rotating impeller.

Photo credit: Steven Wang & Ben Xu.



Rayleigh-Taylor instability on an unstable density interface displaying (from bottom-left to top-right): particles used for PIV, density field, 3D velocity field and in-plane vorticity field.

Image credit: Stuart Dalziel.

WELCOME FROM EXECUTIVE COMMITTEE

The Executive Committee would like to welcome you to this booklet on the latest activities and achievements of the UK Fluids Network (UKFN).

Fluid mechanics is an extraordinarily diverse subject, underpinning many areas of science, technology and engineering. The Executive Committee is no exception, with research interests in aerodynamics, astrophysics, environmental fluids, complex fluids and multiphase flows.

The UK is home to many internationally renowned fluids groups and researchers, spread across several dozen institutions. UKFN was set up to bring these together, ultimately to stimulate new research ideas and, practically, to facilitate putting together the necessary grant applications, and en route to increase coherence within the community.

From the outset, UKFN has aimed to be inclusive and to encompass the widest possible cross-section of the UK fluids community: academic, industrial and other research organisations; and both established and early-career researchers as well as graduate students.

Central to this aim has been the setting-up of 40 Special Interest Groups (SIGs) across topics in biological, environmental and industrial fluids, complex fluids, turbulent and multiphase flows and numerical techniques. SIGs are naturally diverse, attracting many different players within their specialist areas (in some cases for the first time), which has meant they form the active core of the network. As a result, around 1000 researchers have been brought together across more than 60 institutions.

The UKFN's Short Research Visits (SRVs), which run over anything from a few days to several months, have enabled more than 200 people and nearly 50 places to be connected through 86 visits. The range of researchers and topics has been surprisingly wide.

The website, newsletter and social media pages give everyone in the community the opportunity to connect and contribute to the network.

Graduate students and early career researchers are key to the continued good health of the UK fluids community, and they have been encouraged to participate fully in UKFN's activities. Furthermore, UKFN will continue to work alongside the now well-established UK Fluids Conference, which circulates around some of the major UK centres of fluid mechanics, as well as the Fluid Dynamics CDT and Institute for Fluid Dynamics at Leeds, to encourage their continued involvement in the network.

This booklet will serve as a reminder of what has been achieved so far, as an inspiration for the community to maintain the many connections established by UKFN, and to grow the network into the future.

ABOVE

(L to R) Anne Juel, Matthew Juniper, Steve Tobias, Neil Sandham, Nick Daish; not in photo: Paul Linden, Yannis Hardalupas.

Some 500 years ago, Leonardo da Vinci carefully drew the vortices around a partially-submerged body and the patterns of turbulent motion as water pours into a reservoir. As an early fluid mechanics researcher, Leonardo had only his eyes to observe and his hand to record.

Now, half a millennium on, researchers can map flows in exquisite detail using computers and advanced experimental techniques, including Direct Numerical Simulations, Particle Image Velocimetry and my own research area of Magnetic Resonance Imaging, with which even the flow inside an opaque medium can be observed and measured.

The UK has been at the forefront of fluid mechanics research since the birth of the field. This is witnessed by the number of equations and non-dimensional numbers that bear the names of UK scientists, such as the 'three Rs' – Reynolds, Rayleigh and Richardson.

Another giant in the field, G. I. Taylor, famously used fluid mechanics principles to estimate the energy released in the first atomic bomb test – classified at the time – from pictures published in Life magazine. His student, George Batchelor, founded the UK-based Journal of Fluid Mechanics, one of the premier journals in the field.

Today, fluid mechanics is a vast enterprise, involving well over 1000 PIs in the UK. It is a scientific discipline in its own right, yet thanks to the sheer ubiquity of fluids, it is pivotal to many others. By extension, it is a keystone in the UK economy.

I have followed the progress of the UK Fluids Network with interest and pleasure, as it connects the UK fluids community via its Special Interest Groups and Short Research Visits, and works with the EPSRC Centres for Doctoral Training in fluid mechanics to bring together researchers – in particular the all-important students, our PIs of tomorrow – from across institutions at the annual UK Fluids Conference.

While justifiably proud of the UK's fluid mechanics heritage, the UK Fluids Network looks very much to the future, with its efforts to foster an environment in which the UK is the place where world-leading research with genuine economic and societal impact happens – and from which a new 'R' may also one day emerge.

Lynn Gladden
EPSRC Executive Chair

Fluid Dynamics and Aerodynamics is one of the largest areas of research funded by EPSRC, with £81m invested in current projects, as of July 2019, although the underpinning science and engineering aspects of fluids cut across much of the research portfolio as it can be applied to many diverse areas across a range of length scales, such as microfluidics, drug delivery, process systems, carbon capture storage, biological systems such as bioreactors and water engineering.

Fundamental fluid dynamics research continues to be world-leading in many institutions across the UK and the UK Fluids Network initiative has been actively maximising the impact of EPSRC's recent investment in fluid mechanics through the sharing of expertise, facilities, equipment, and resources across the UK.

Since its announcement in 2016, the network has served to bring the community together and identify industrial needs for academic researchers to integrate fluid dynamics theory, experiments and numerics to solve challenging industrial, scientific, and societal problems.

Through its establishment of Special Interest Groups, it has enabled wider impact by accelerating the translation of knowledge into real-world disruptive technologies relevant to many sectors: process industries, aerospace, pharmaceutical, healthcare, water, construction, automotive, chemicals, oil and gas, as well as the emerging area of wind power.

UKFN continues to keep the UK at the forefront of fluid mechanics research for the benefit of the UK economy and also has helped to raise the profile of fluid mechanics through engagement with the media and public to communicate the important scientific and engineering challenges and how the understanding of fluids is vitally important in our daily lives.

We welcome the progress that has been made with UKFN and look forward to seeing further impact in the years to come.

Andrew Lawrence
EPSRC Head of Engineering

SPECIAL INTEREST GROUPS

The UK Fluids Network supports around 40 SIGs, which involve around 1000 researchers from the UK Fluids community. The SIGs provide an environment for academics, students, and industrial experts to collaborate on current problems and to identify future opportunities. In many cases, these have brought multiple disciplines together for the first time.

As wind flows over and around islands in the Aleutian chain, vortices at different scales are shed downstream ('Multi-scale processes in geophysical fluid dynamics' SIG).

Photo credit: NASA Earth Observatory.

LIST OF SPECIAL INTEREST GROUPS

AERODYNAMICS

- Ground vehicle aerodynamics
- High speed experimental aerodynamics
- User's forum for National Wind Tunnel Facility

BIOLOGICAL

- Biologically active fluids
- Challenges in cardiovascular flow modelling
- Fluid mechanics of the eye

COMPLEX

- Fluid dynamics of liquid crystalline materials
- Fluid mechanics of nanostructured materials
- Multi-scale and non-continuum flows
- Non-Newtonian fluid mechanics
- Quantum fluids

ENVIRONMENTAL

- Granular flows in the environment and industry
- Marine hydrodynamics
- Multi-scale processes in geophysical fluid dynamics
- Surface and internal waves
- Wave-structure interaction

EXPERIMENTAL

- Acoustofluidics
- Experimental flow diagnostics (xFD)

INDUSTRIAL

- Combustion science, technology and applications
- Fluid mechanics of cleaning and decontamination
- Nuclear thermal hydraulics – advanced modelling, simulation and experimentation
- Particulate matter filtration flows in automotive and marine applications
- Sprays in engineering applications: modelling and experimental studies

INSTABILITY & TURBULENCE

- Boundary layers in complex rotating systems
- Droplet and flow interactions with bio-inspired and smart surfaces
- Flow instability, modelling and control
- Non-equilibrium turbulence
- Turbulent skin-friction drag reduction
- Wave turbulence

MULTIPHASE

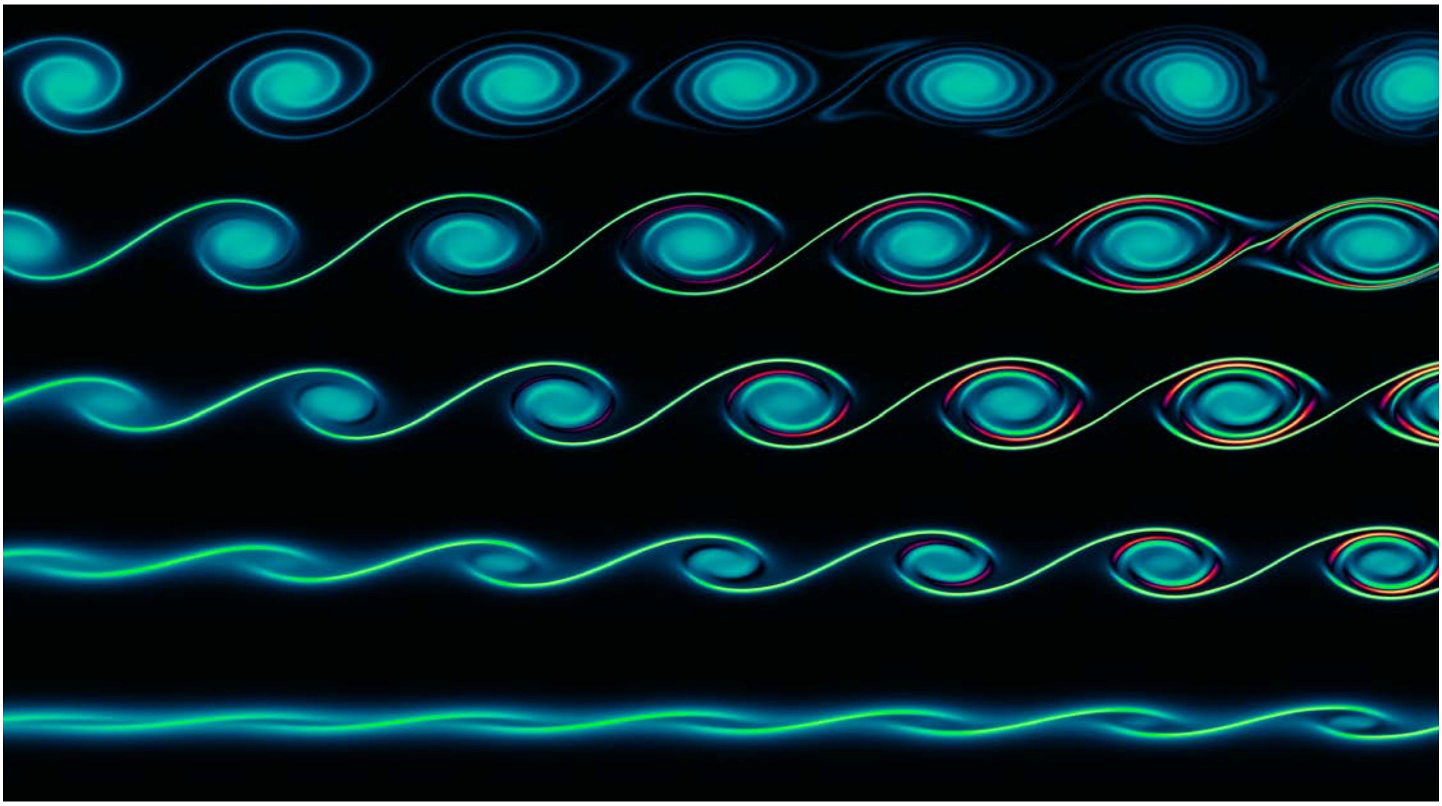
- Drop dynamics
- Mathematical challenges of nonlinear waves and interfacial dynamics
- Multiphase flows and transport phenomena

NUMERICAL

- Multicore and Manycore Algorithms to Tackle Turbulent flows (MUMATUR)
- Next generation time-stepping strategies for computer simulations of multi-scale fluid flows
- Numerical optimisation with fluids
- Smoothed particle hydrodynamics (SPH)

URBAN

- Low-energy ventilation
- Urban fluid mechanics



Flow instability, modelling and control

ABOVE
Computer simulations depict the evolution of density-stratified shear layers as the stratification becomes stronger (top to bottom).

Image credit: Chris Howland.

Transition to turbulence, coherent structure dynamics in turbulent flows, pattern formation in complex systems – these are the important and fascinating fluid dynamical phenomena in which the understanding and modelling of hydrodynamic instabilities play the central role. The study of these phenomena can be extended to their systematic control, which has an enormous range of industrial applications targeting drag reduction, mixing/heat transfer enhancement, noise mitigation and many others.

The SIG on flow instability, modelling and control in the UK Fluid Network specializes in these areas, where the UK has maintained world-class research for many years. The SIG facilitates communication and collaboration for emerging theoretical, computational and experimental challenges, training of next-generation researchers, and an increased international visibility of the UK's research activities.

The annual SIG meetings have provided a forum for discussing emerging themes, such as dynamical systems approach for flow instability, sensitivity for chaotic dynamical systems and deterministic turbulence. The SIG activities have also been scaled up to the international level to maximise the benefit to the UK community: the SIG has been involved in the organisation of Euromech Colloquium 598 on 'Coherent structures in wall turbulence' and the 11th International Symposium on Turbulence and Shear Flow Phenomena.

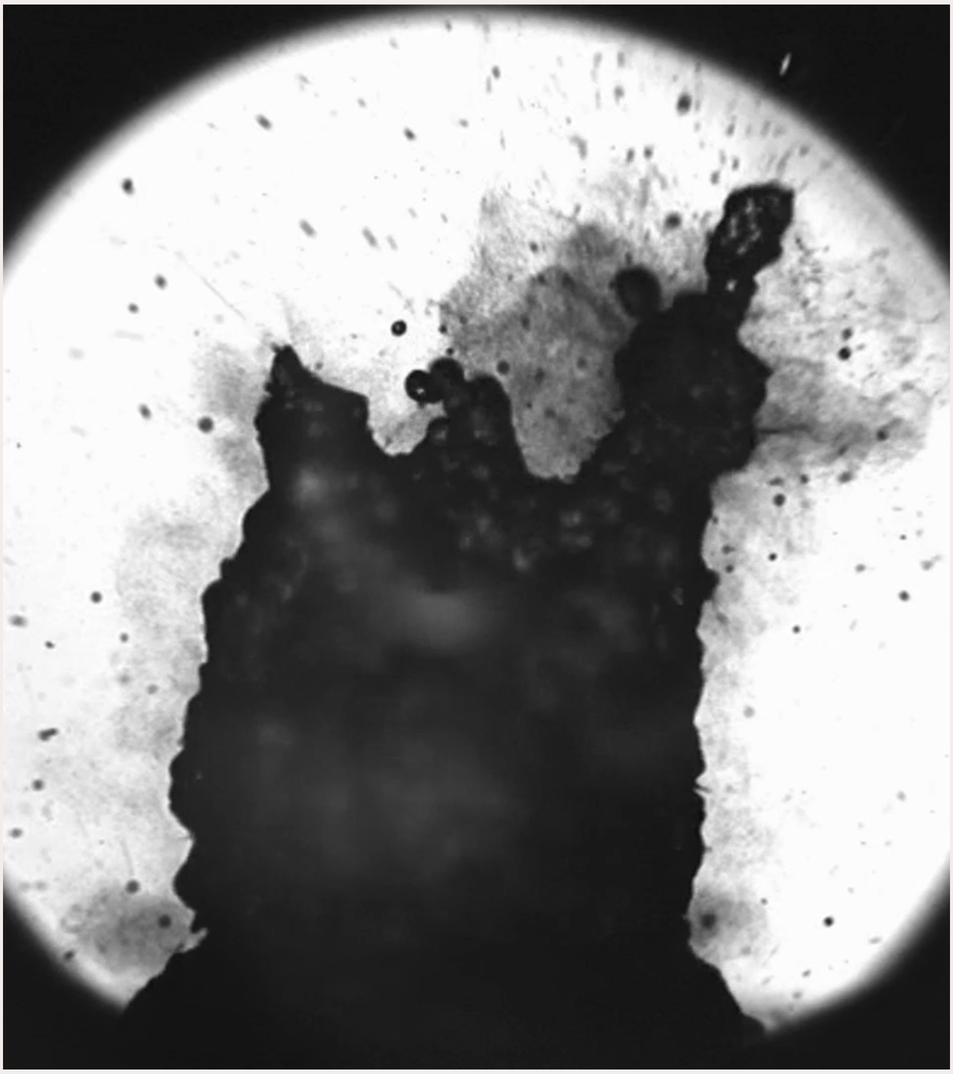
One of the core activities of the SIG is to train next-generation researchers. Towards this, a summer school on 'Modal Decompositions in Fluid Mechanics' has trained PhD students, postdocs and academics in the UK on the emerging analysis tools, such as POD, DMD, Koopman mode, model reduction, resolvent mode and dynamical systems analysis.

The annual SIG meetings have provided a forum for discussing emerging themes...and the SIG has trained next-generation researchers in the UK on the new analysis tools.

Yongyun Hwang

A Surface Acoustic Wave disrupts a droplet of water dropped onto its propagation path. The behaviour is used in medical nebulisers.

Image credit: Elijah Nazarzadeh.



Acoustofluidics

What happens when acoustic waves interact with liquid droplets or liquids in micro-channels? How do we make droplets jump or hover in space? How can these phenomena be exploited in diagnostic systems, biotechnology, and biomedicine? These are the questions asked by the Acoustofluidics SIG, which focuses on microfluidics induced by ultrasonic waves, surface acoustic waves, bulk acoustic waves and flexural waves.

To showcase acoustofluidics phenomena, the Acoustofluidics SIG recently organised the Acoustofluidics Olympics. Fifteen teams from the UK, Germany, Austria and France brought their acoustofluidics equipment and showed how objects can be levitated using ultrasound, how liquids can be continually atomised into a mist that can be used for drug inhalation, how particles or cells can be separated from other objects such as bacteria using acoustic standing waves, and how liquids can be pumped uphill or driven along a roller-coaster with acoustics.
As well as competing to have the fastest, largest, hottest, smallest, and weirdest acoustofluidics phenomenon, the teams taught spectators about the physical mechanisms at work in acoustofluidics systems. This created a forum for one-to-one exchange of ideas in ways that do not happen with oral or poster presentations. More than 20 local school children participated and interacted with the Acoustofluidics Olympics and demonstrations, aided by the STEM team at Northumbria University at Newcastle.

This type of event is inspiring, exciting and informative, and a different experience from a standard conference. Researchers can learn from each other's techniques and skills, and a general audience can physically watch the activities and easily understand the physics behind them.

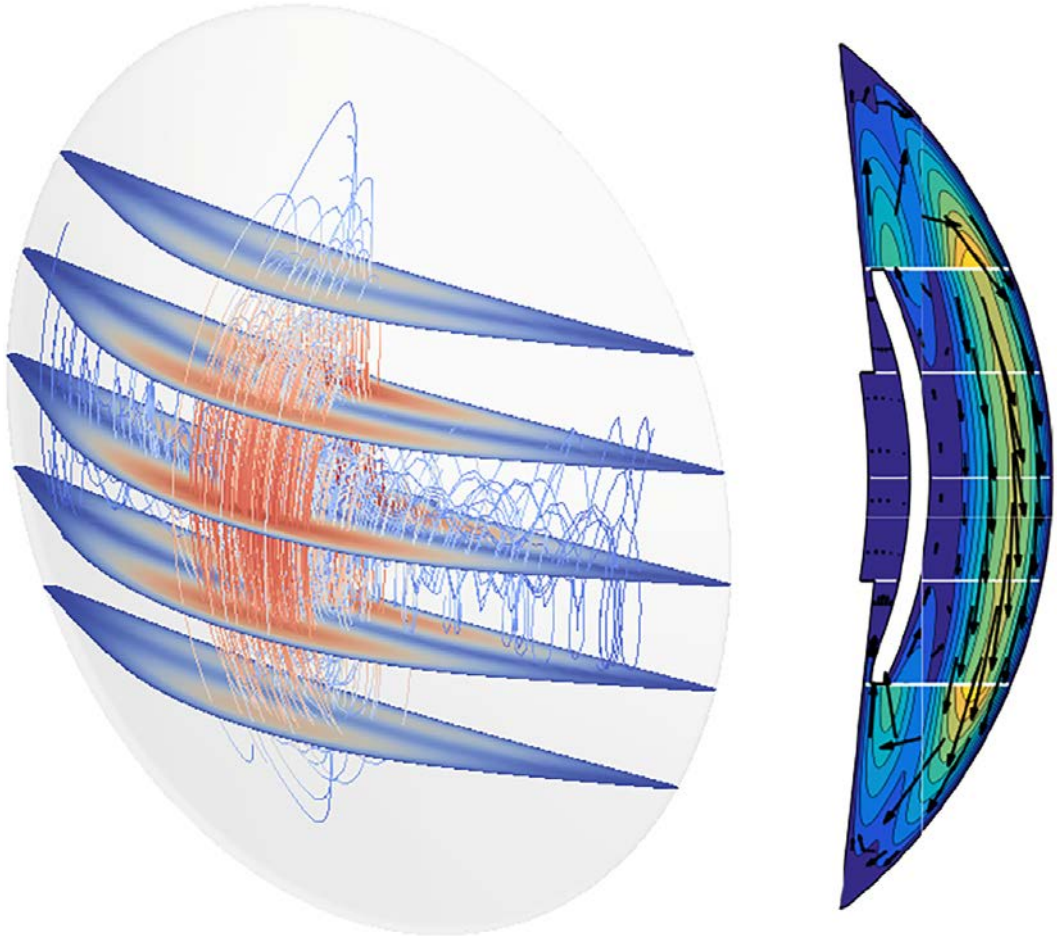
As well as hosting invited talks and oral/poster presentations, the Acoustofluidics SIG has industry engagement with several UK companies participating in events, and held a forum with discussions on potential commercialisation and funding applications.

This type of event is inspiring, exciting and informative, and a different experience from a standard conference. Researchers can learn from each other's techniques...and a general audience can physically watch...and easily understand the physics behind them.

Richard Fu

3D flow in the natural eye (left); flow in vertical plane of symmetry when a thermally-conducting lens has been inserted to correct vision (right). Shading represents velocity magnitude.

Image credit: Jennifer Tweedy.



Fluid mechanics of the eye

The eye offers a rich and complex environment in which to pursue fluid mechanical investigations. These can advance fundamental understanding of eye pathologies as well as potentially offering practical healthcare benefits.

The UKFN Special Interest Group in the Fluid Mechanics of the Eye has adopted a study group model to identify and pursue a variety of eye-related problems. Ophthalmologists with academic and research interests, together with biomedical engineers, spend a few days patiently explaining problems to assembled fluid mechanicians, who then work collaboratively, developing theoretical or computational models that seek to address the posed problem.

Suitable topics are identified prior to SIG meetings and brief descriptions are circulated to participants. The SIG meetings themselves (over a couple of days) are full of intense discussion and calculation, which are later written up as short reports. The most promising topics may develop into more substantial investigations that generate additional funding and ultimately yield publications.

The SIG meeting in September 2018, for example, was devoted to two problems: uveoscleral flow, which concerns an intricate flow pathway between the front and back of the eye that is regulated by osmotic and oncotic effects that may influence drug delivery; and the operation of a device used in a procedure called vitrectomy, which is strongly influenced by the viscoelastic properties of the vitreous fluid within the eye.

Given the complexity of the organ, fluid mechanics cannot be decoupled from numerous other processes that influence flow and transport processes: this is illustrated by a further recent problem, relevant to wet age-related macular degeneration (a major cause of impaired vision in older people), that concerned active membrane transport processes in retinal epithelial cells.

The SIG has demonstrated how productive multidisciplinary collaborations can be catalysed in a very cost-effective way, setting the stage for the strongest ideas to be pursued in detail in follow-on studies.

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Oliver Jensen

Sand dune migration is a granular flow that can have profound impacts on communities.

Photo credit: Nathalie Vriend.

The SIG is breaking down traditional silos in granular flow research (theoretical, numerical and experimental) and it is hoped to lead to a number of interdisciplinary collaborations.

Lis Bowman

Granular flows in the environment and industry

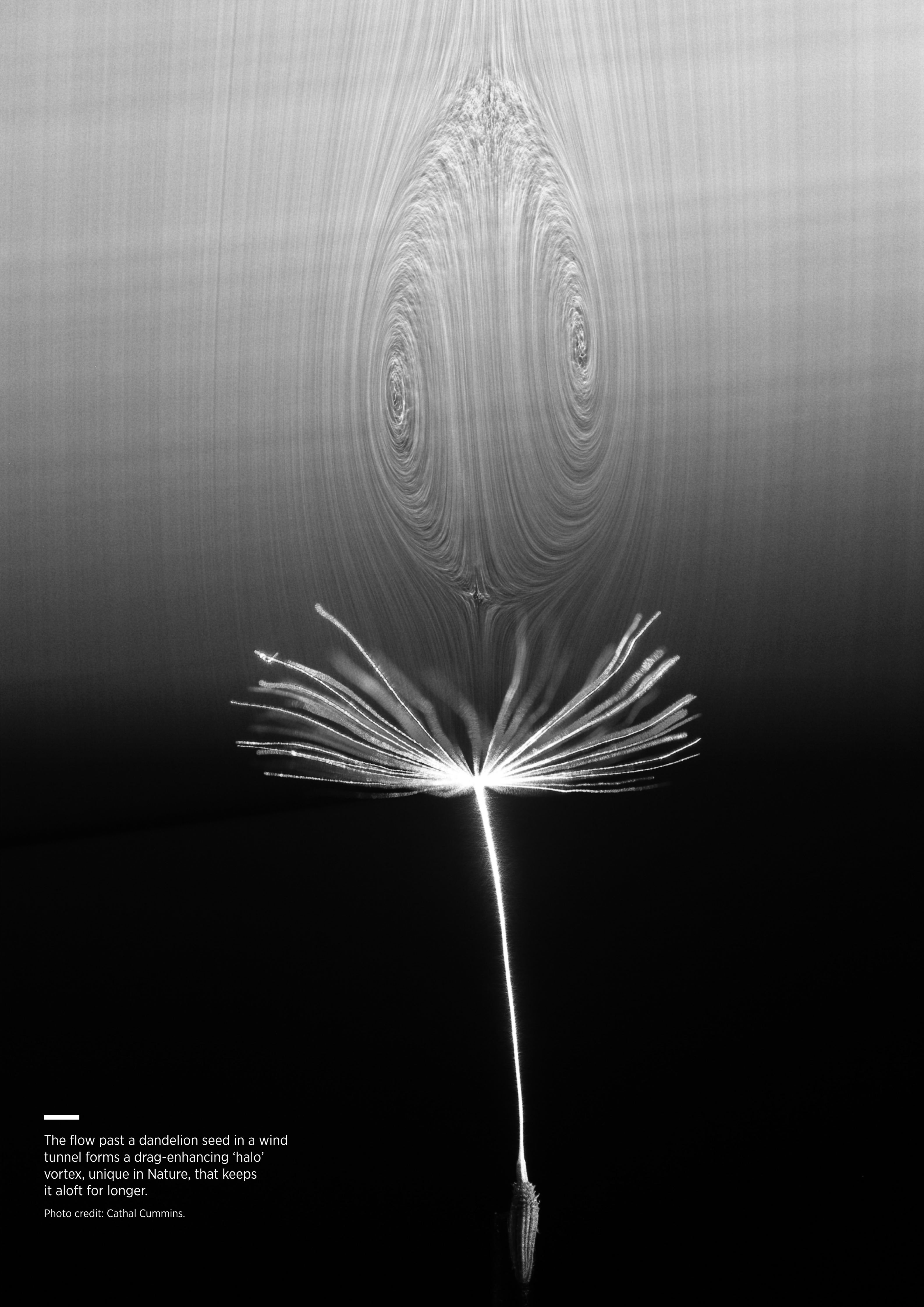
Granular flows span a huge range of disciplines and problems - from natural hazards, such as avalanches, to industrial applications, such as pharmaceutical manufacture. Furthermore, the physics of these flows, which can display behaviour akin to both fluids and solids, is still relatively poorly understood.

The Granular Flows SIG was set up to gather a cross-section of UK expertise. More than 40 academics and 20 PhDs have met at workshops in Cambridge, Sheffield and Edinburgh to discuss common problems and potential solutions to understanding granular flow, issues such as: segregation of different grain sizes within flows; consideration of particle shape and its measurement and influence on flow behaviour; and multiphase flow, including the influence of fluid content, viscosity, and grain size effects.

The three workshops covered

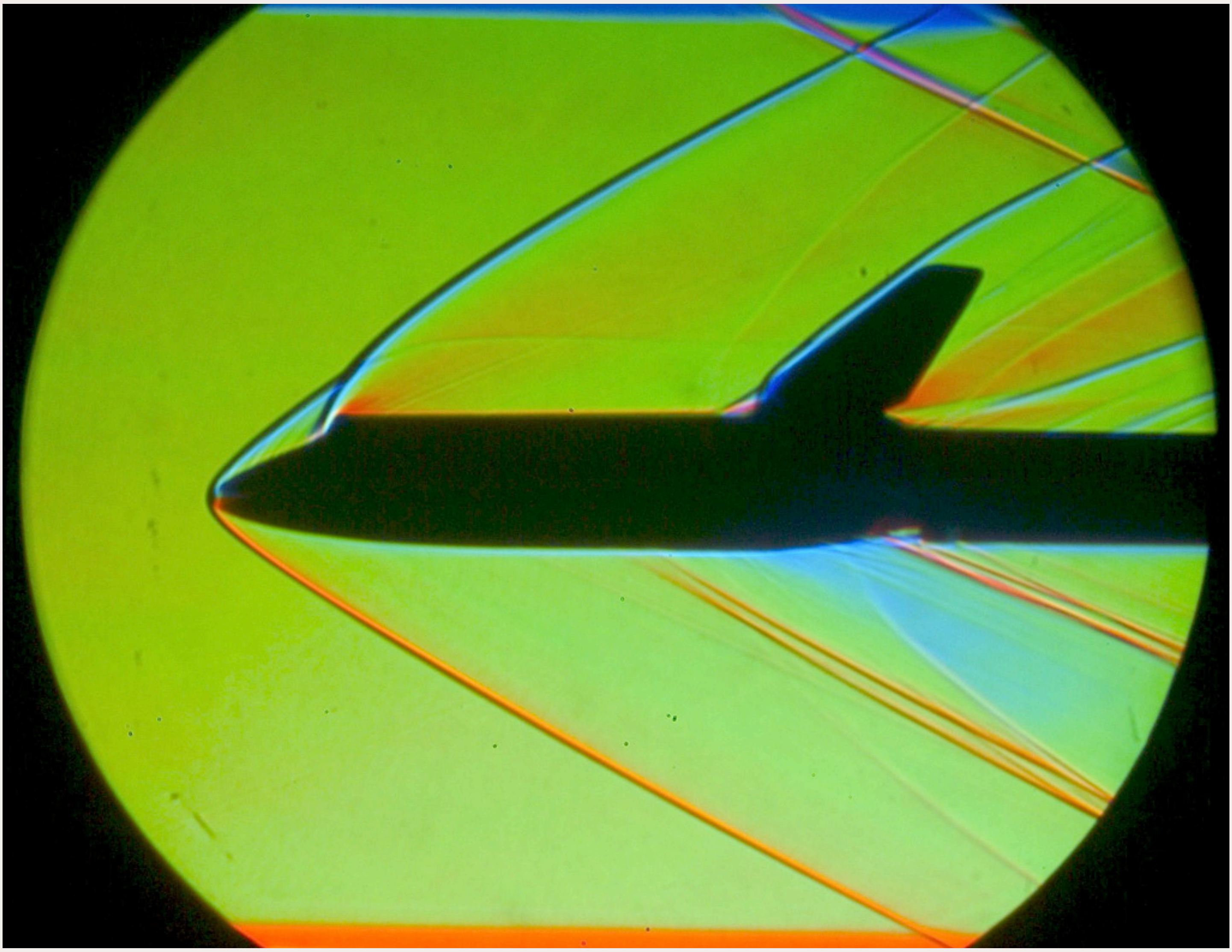
- in Cambridge, an initial introduction between disparate groups in applied maths, physics, engineering and geology and a visit to the photoelastic flow facility in Applied Maths;
- in Sheffield, industrial flows and industry connections, with input from four industry speakers spanning powder processing and civil engineering, and a visit to the experimental ‘transparent’ debris flow flume;
- in Edinburgh, environmental flows, such as volcanic flows, debris flows, sediment transport, rock avalanches and gravity currents, and discussions with mathematical colleagues on the potential for translating models from one field to another.

The SIG is breaking down traditional silos in granular flow research (theoretical, numerical and experimental) and it is hoped to lead to a number of interdisciplinary collaborations.



The flow past a dandelion seed in a wind tunnel forms a drag-enhancing 'halo' vortex, unique in Nature, that keeps it aloft for longer.

Photo credit: Cathal Cummins.



ABOVE
Schlieren visualisation of flow around the space shuttle.

Photo credit: Holger Babinsky.

During conferences we only see the bright side of things – it's great to have a chance to discuss what we are really struggling with and look for a solution together.

Michela Gramola, PhD student

High speed experimental aerodynamics

Problem-solving is at the heart of any PhD. Although PhD students have an overwhelming number of resources offering tools to tackle problems at their disposal (online courses, textbooks, research papers, ...), knowing how to interpret, filter, and use these tools is a challenge. PhD supervisors play an important role in this area but even they do not have all the expertise required.

The High Speed Experimental Aerodynamics SIG brings together academics and their PhD students from seven universities around the UK at regular workshops. These workshops include a dedicated session for PhD students to present a 1-slide problem related to their research. The group discusses possible approaches to tackle the problem; passing on the benefit of their collective skills, knowledge and experience.

The informal setting for this interaction is a big strength of the SIG that, uniquely, encourages open and honest exchanges of the type that seldom happen at more conventional conferences. PhD student Michela Gramola summed this up nicely: "During conferences we only see the bright side of things — it's great to have a chance to discuss what we are really struggling with and look for a solution together."

Multicore and Manycore Algorithms to Tackle Turbulent flows (MUMATUR)

ABOVE
Vortices coloured by velocity magnitude in the wake of single low-pressure turbine blade at Re = 80000.

Image credit: Sylvain Laizet.

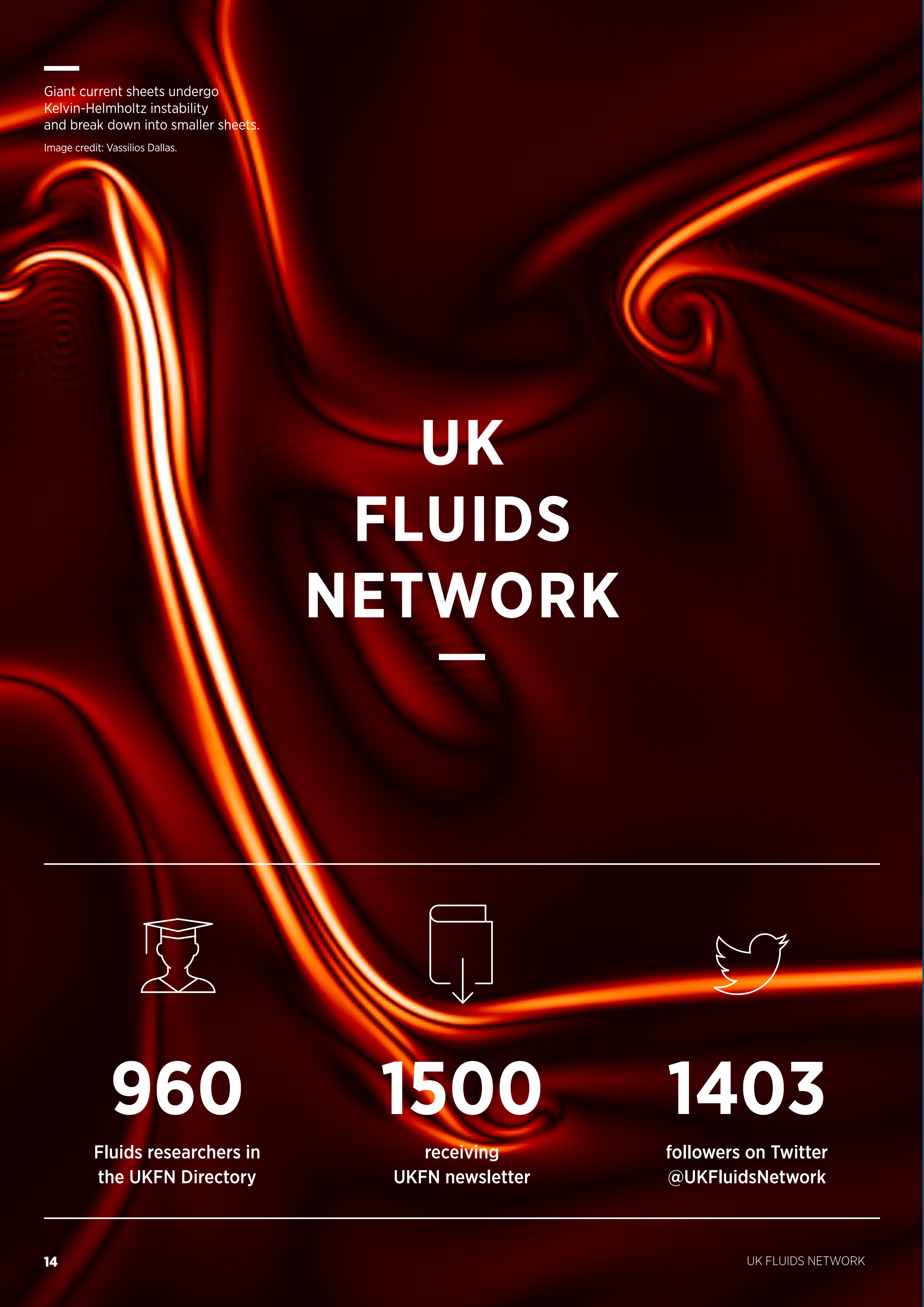
High Performance Computing (HPC) is currently a pervasive technology which strongly contributes to the excellence of the UK in a wide range of research areas including finance, meteorological predictions, transportation industries, physics, energy, material science and drug design. HPC has become indispensable for both scientific advancement and economic competitiveness. In particular, computational fluid dynamics (CFD) is now a critical complement to experiments and theories in order to understand turbulent flows and how to manipulate them for engineering applications.

The SIG has been crucial for the UK in order to coordinate, augment and unify the research efforts of its participants towards a better understanding of turbulent flows by exploiting modern HPC platforms ranging from multicore/manycore architectures to accelerators to graphics processing units.

By gathering together computational fluid dynamicists, mathematicians, HPC centre managers and software development experts, it has helped to foster strong collaborations between software developers and the turbulence community. It has provided opportunities for its members to meet colleagues from across various institutions in the UK, and to share technical knowledge with people from a wide range of scientific backgrounds.

The SIG has been crucial for UK research efforts...towards a better understanding of turbulent flows by exploiting modern HPC platforms.

Sylvain Laizet



Giant current sheets undergo Kelvin-Helmholtz instability and break down into smaller sheets.

Image credit: Vassilios Dallas.

UK FLUIDS NETWORK

960

Fluids researchers in the UKFN Directory

1500

receiving UKFN newsletter

1403

followers on Twitter @UKFluidsNetwork

SPECIAL INTEREST GROUPS

38 SIGs

934 members

66 institutions

216 meetings

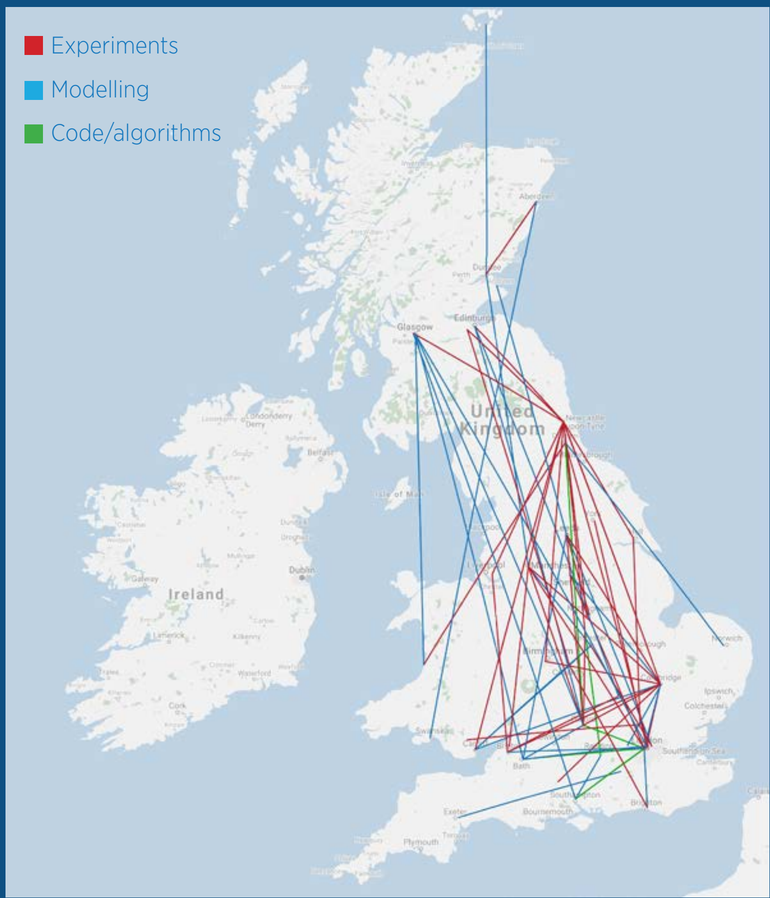
SHORT RESEARCH VISITS

86 visitors

48 places connected

800 days of visits

127 people visited

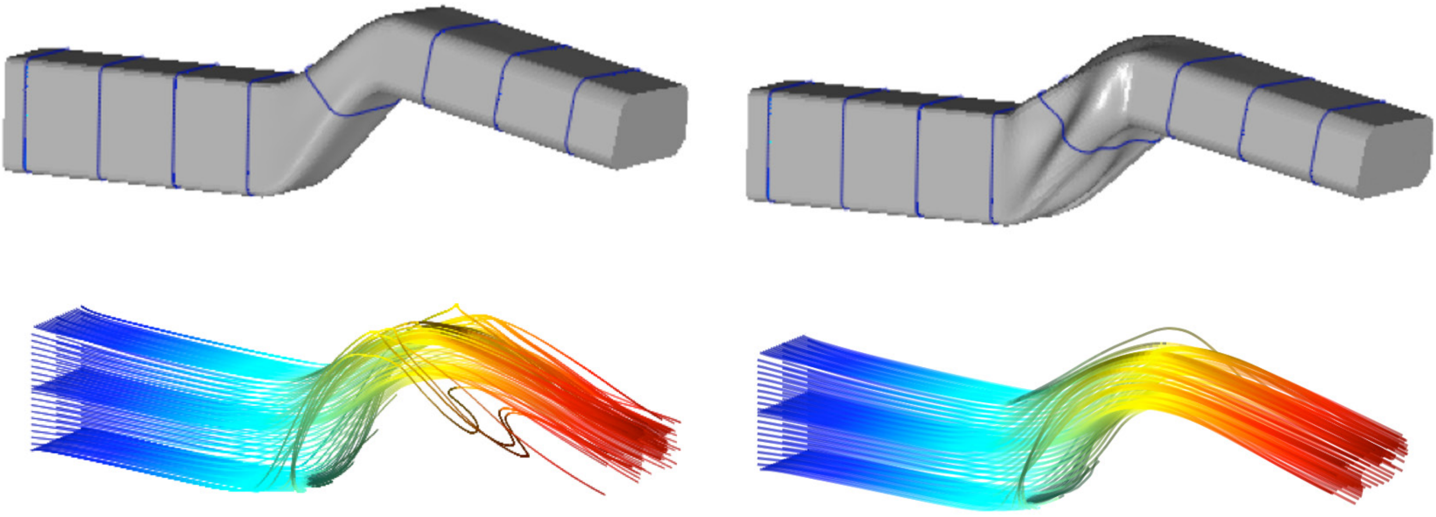


Droplet ‘gobbling’ leads to the formation of large terminal drops at the end of a thin jet of viscoelastic fluid.

Photo credit: Jian Hui Guan.

Shape optimisation for minimal pressure loss of an S-bend duct using a CAD-based surface parameterisation.

Image credit: Jens-Dominik Müller.



Numerical optimisation with fluids

The SIG has trained a new generation of PhD students and created materials that will be useful more broadly. The course notes, tutorials, and codes will be made available as an online resource through the UK Fluids Network website.

Jens-Dominik Müller

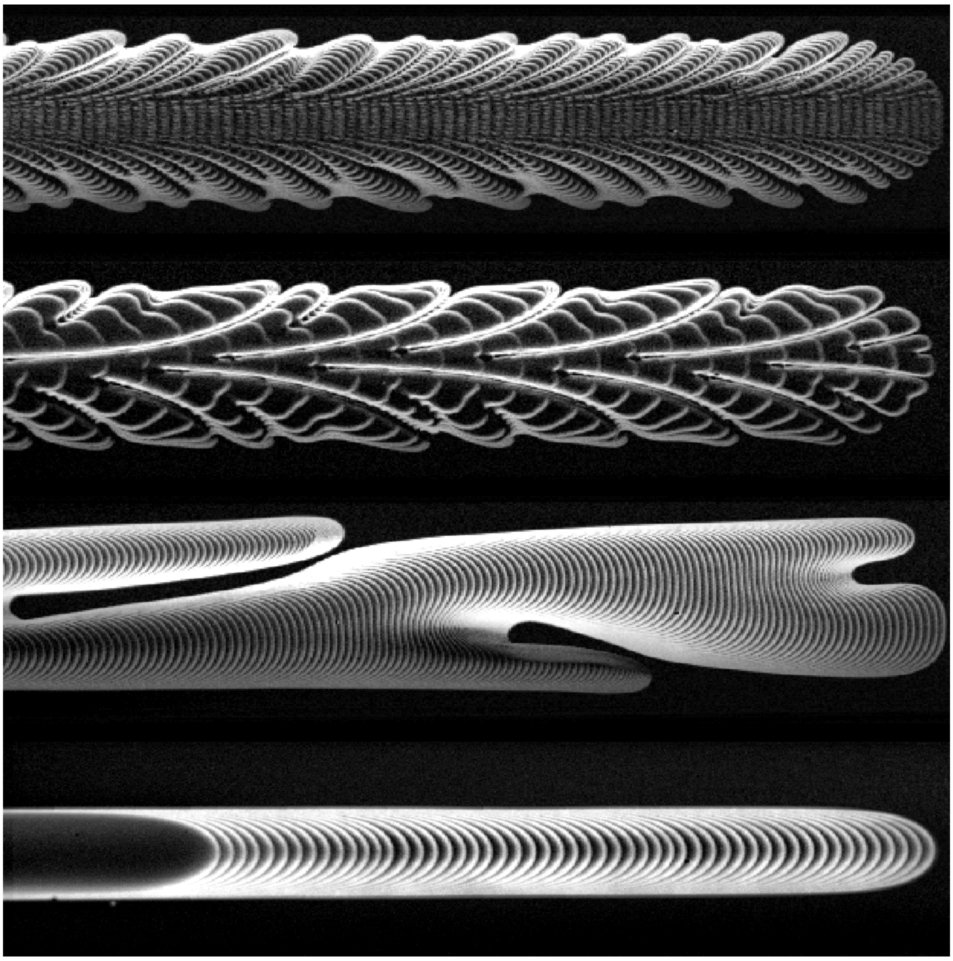
Numerical simulation of flow over 'planes, trains and automobiles' using Computational Fluid Dynamics (CFD) has reached a high degree of maturity and is an essential element of the industrial design process. CFD enables the designer to evaluate e.g. the lift or drag of a vehicle and minimise it by trying out a number of design changes. However, innovative modern designs often require looking beyond traditional design intuition, and are found using numerical optimization, which systematically explores the space of possible designs with a numerical algorithm to find an optimal design.

The Numerical Optimisation SIG has run two three-day long workshops. The first was on general Design Optimisation, ranging from Design of Experiments, which is widely used in industry, to Structural Topology Optimisation, which has great potential for design. The second was on gradient-based optimisation, adjoint methods and automatic differentiation. This harnesses the power of numerical methods by specifying a target before the simulations and then re-writing the codes to obtain the sensitivity of that target to all possible changes to the system. This gradient information can be used to converge quickly to an optimal solution.

The SIG has trained a new generation of PhD students and created materials that will be useful more broadly. Numerical code was provided at both workshops, which allowed students to understand the concepts by applying them to simple situations. The code could be adapted easily to more complex situations or could be used to understand what is happening under the bonnet in publicly-available optimisation toolboxes.

Spatio-temporal patterns formed when air displaces oil in a Hele-Shaw channel with an elastic upper boundary.

Photo credit: Callum Cuttle.



Multiphase flows and transport phenomena

Multiphase flows are ubiquitous in industry and in nature. They are inherently multiscale, as the bulk flow is influenced by the interfacial dynamics, such as the gas-liquid interface or a gas-liquid-solid contact line, on scales orders of magnitude smaller than the core flow. These interactions between scales and accompanying transport phenomena lead to complex behaviours, which are poorly understood and yet critical to engineering design.

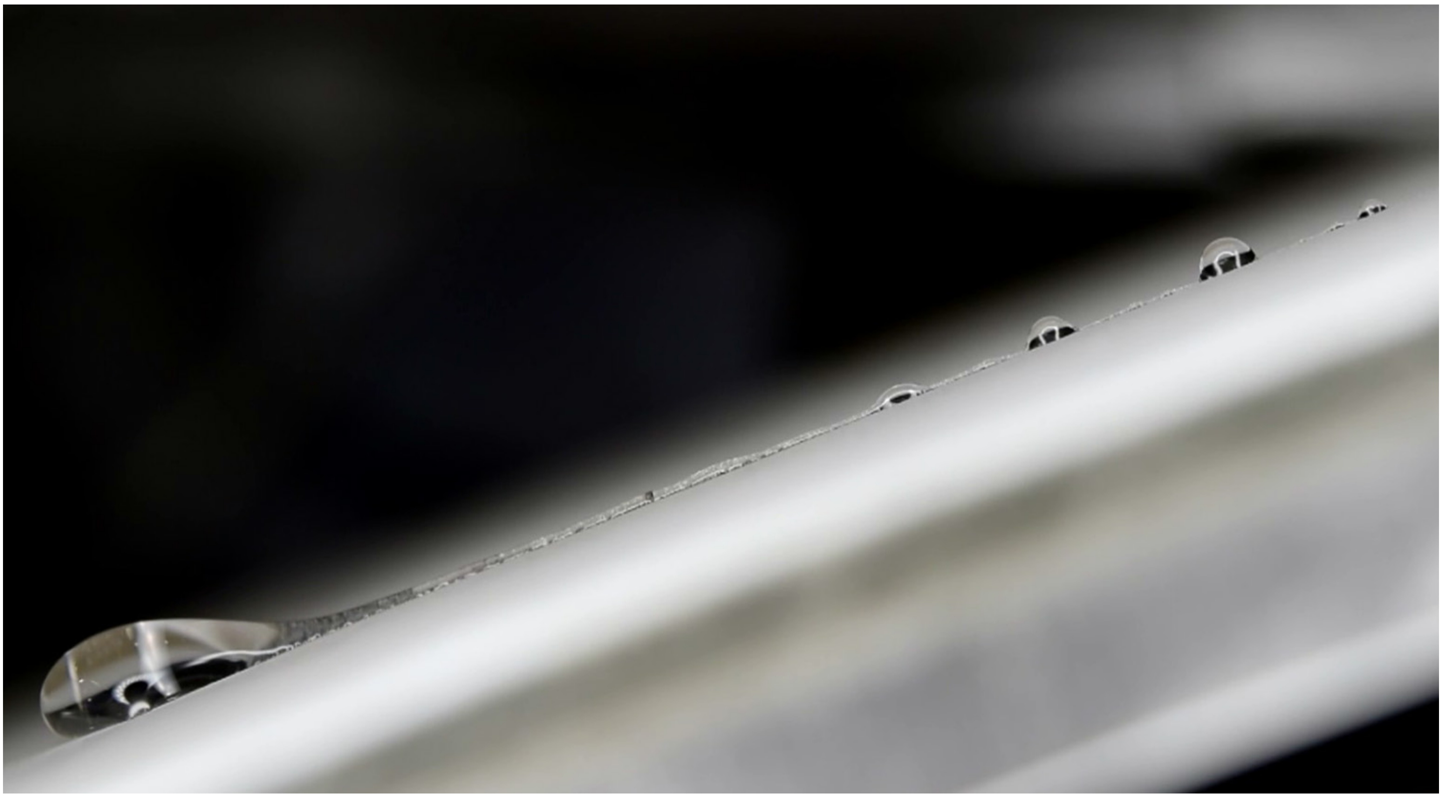
This SIG concerns all aspects of multiphase flows and related transport phenomena across different methodologies – experimental, theoretical and computational – and scales – from contact lines (μm) to interfacial waves (cm) to flow patterns (m). The group has more than 160 members and includes experts from academia and industry, spanning disciplines and applications, to strengthen and sustain the internationally-leading UK multiphase research community.

Our activities include a rich mix of day workshops, summer schools, ECR-focused cross-SIG events, ECR-driven career events, industry days and agenda-setting SIG meetings. A good example was the 'Barry Azzopardi Summer School on Experimental Methods and Data Analysis', held at the University of Nottingham in July 2018 in memory of Prof Barry Azzopardi (1947-2017). The Summer School was attended by around 50 members from academia and industry at all stages of their careers. This covered a wide range of topics from essential know-how, including basics of experimental methods, error analysis, design of experiments, and requirements for model validation, to the latest advances in experimental methods, such as 3D PIV/PTV, X-Ray tomography, concentration measurements and image analysis. These sessions were delivered by experts from industry and academia. A dedicated problem-solving and discussion session was also included, where participants exchanged ideas and discussed and resolved problems involving their experiments. The training material developed is available as a series of videos at bit.ly/2AbXLCC. The success of the Experimental Summer School has accelerated industrial interaction and led to a follow-up Modelling School.

The SIG offers an excellent platform for the multiphase flow community in the UK, and the success of its interactions has provided strong motivation to maintain it into the future.

This SIG concerns all aspects of multiphase flows...and our activities include a rich mix of events...the SIG offers an excellent platform for the multiphase flow community in the UK.

Prashant Valluri



Bead formation on a viscoelastic drop's tail.

Image credit: Haonan Xu.

Non-Newtonian fluid mechanics

Non-Newtonian Fluid Mechanics concerns the study of the flow of fluids with complex mechanical properties. This field is very broad, and our SIG is organised around three key themes: (i) Yield stress (so-called 'viscoplastic') fluids; (ii) Purely-elastic instabilities; and (iii) 'Flows of Suspensions', selected by the group at the opening meeting.

Non-Newtonian fluids, such as polymer and surfactant solutions, or suspensions of solid components in a liquid phase, are ubiquitous. Essentially all 'man-made' liquids are non-Newtonian in nature to varying degrees. As a consequence, we strive to combine academic and industrial expertise in our SIG and we made 'engaging with industry' a key aspect.

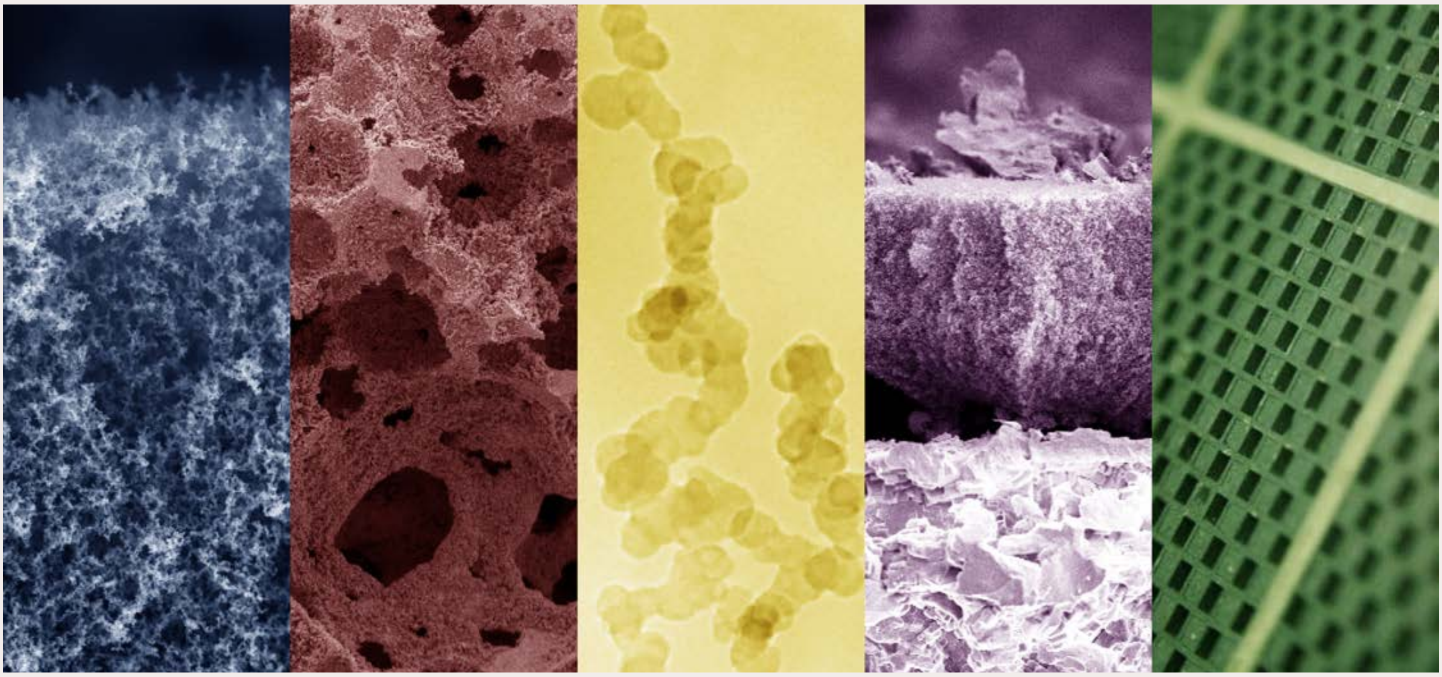
To engage industry from the outset we ensured that many non-academics / industrialists were invited to be members of the SIG. This led to 25% of the membership coming from companies such as ANSYS, Unilever, Procter & Gamble, CD Adapco-Siemens and Schlumberger.

Each SIG meeting has included invited 'Industrialist's viewpoint' talks to enable the practical challenges of dealing with such complex fluids to be better understood by the wider group. Examples have included Prof. Adam Kowalski (Unilever) and Dr. Nat Inkson (CD Adapco-Siemens) giving such talks at the opening meeting held at the University of Liverpool and Dr. Sean Lovett (Schlumberger) giving a detailed technical talk on 'Particles in yield stress fluids' at the second meeting held at The Higgs Centre at the University of Edinburgh. Sean also helped to co-organize that particular meeting on yield stress fluids. Our third meeting was Industrially-hosted by Schlumberger at their Cambridge-site.

Engagement with industry through invited talks, meeting co-organization and meeting hosting has proved successful in enabling good interactions between SIG members. Such interactions have also enabled reaffirmation to the academics involved – if any was needed – of the numerous practical applications of our area and the tremendous potential impact of better models and understanding of such complex fluid flows.

Non-Newtonian fluids, such as polymer and surfactant solutions, or suspensions of solid components in a liquid phase, are ubiquitous. Essentially all 'man-made' liquids are non-Newtonian to varying degrees. As a consequence, we made 'engaging with industry' a key aspect of our SIG.

Rob Poole



Left to right: particulate cake layer from automotive diesel engine; particulate-loaded ceramic foam filter; close-up of agglomerated particle; particulate cake layer on wall flow filter; automotive diesel particulate filter substrate.

Image credit: Svetlana Aleksandrova.

Particulate matter filtration flows in automotive and marine applications

While the environmental and health impacts of greenhouse gases and toxic air pollutants have been acknowledged for some time, the full extent of the harm caused by particulate matter (PM) emissions is only now becoming clear.

Transport emissions, which include brake and tyre wear and resuspension of road dust, are important and well-known, but the sources of PM are much more diverse: industry, power plants, off-road machinery and wood burning all make significant contributions, as well as secondary particles from reactions in the atmosphere and naturally-formed PM.

PM removal is relevant to many other areas, such as medical and cleaning applications. All of this has boosted studies of PM composition, transport and abatement technologies, with the result that particle filtration flows, and particle transport in particular, are important branches of fluid dynamics essential for successfully addressing the control of particulates.

The Special Interest Group in PM Filtration Flows brings together academics and industry to initiate a dialogue, identify challenges and outline solutions for future particulate filtration. From the start, industry interest and engagement have been overwhelming. OEMs, consultancies and suppliers from different sectors are taking an active part in group meetings, sharing their expertise in meeting presentations and in some cases even hosting meetings – one of the most successful group meetings was hosted by Johnson Matthey.

Excellent industry involvement in group activities means that much of the SIG's agenda focuses on applications (automotive particulate filters, marine emissions mitigation). Both mature technologies, such as wall-flow filtration, and novel developments, such as liquid adsorption, ultrasound and electric currents, have been covered. More fundamental topics cover filtration flow and kinetics modelling and experimental methods for filtration flow studies. The impact of the SIG is further enhanced by the involvement of regulators: Defra, the Department for Transport and the International Maritime Organization.

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Svetlana Aleksandrova

Faraday waves generated on the surface of a bath of silicone oil.

Photo credit: Naresh Sampara.

Mathematical challenges of nonlinear waves and interfacial dynamics

Behind any model or solution of fluid motion lies a wealth of mathematical questions. How do we derive suitable governing equations of fluids? How do we know how many boundary conditions to apply, and how to develop them? How can we exploit the size of physical parameters to reduce the complexity of our equations to make them readily solvable?

This SIG focuses on developing and sharing the mathematical techniques that are used by disparate groups in fluid dynamics. In particular, we combine two main areas that often are considered to be separate fields: nanoscale interfacial dynamics and global scale wave evolution. However, as has become apparent at our SIG meetings, we have much overlap and have learned a great deal from each other.

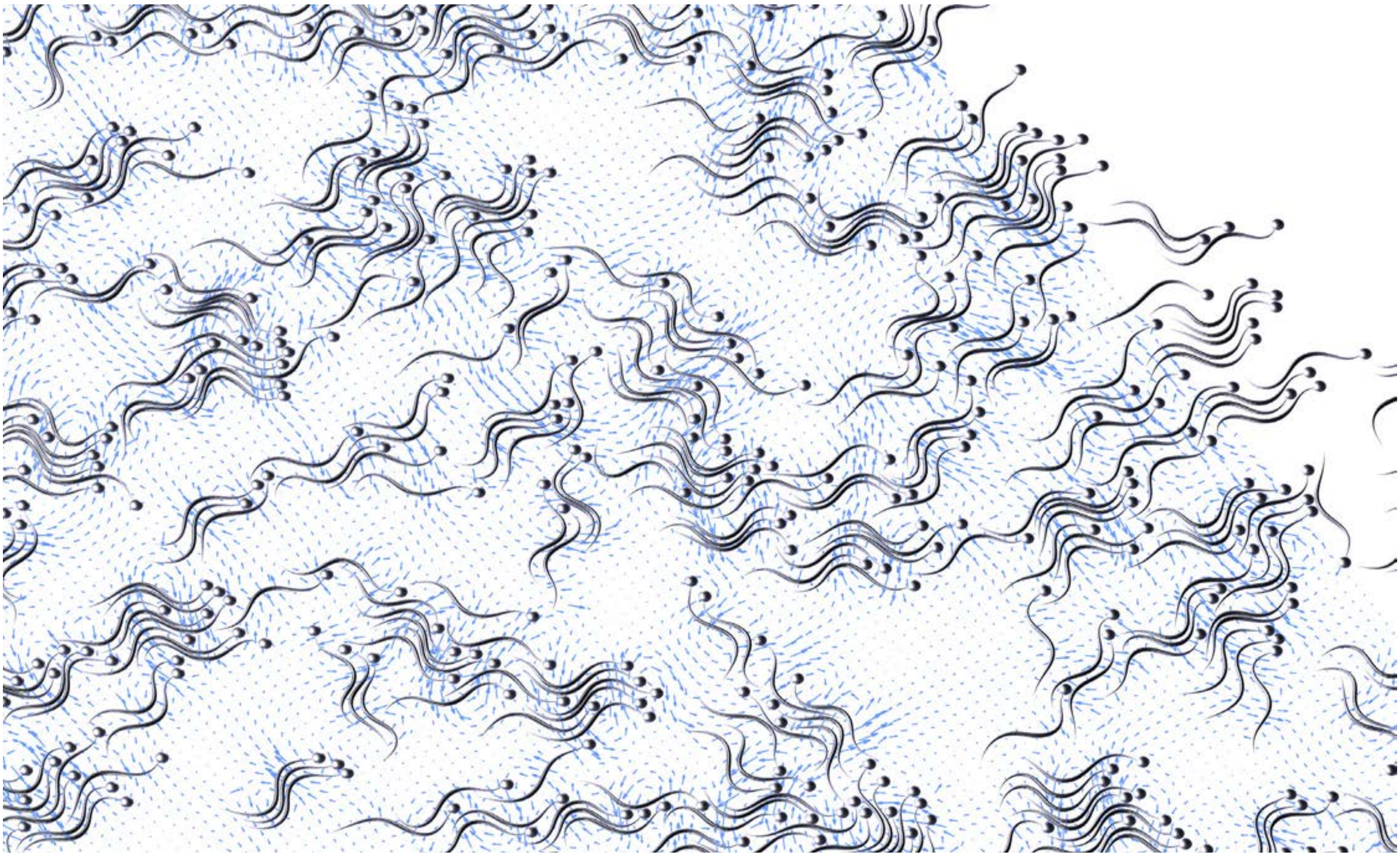
In our SIG we are mostly Mathematicians and Engineers from academia and industry, with especially strong leadership from Early Career academics, postdoctoral researchers and PhD students. The workshop style of our events is useful to students – with work in progress, preliminary results, and open questions being encouraged – and new lines of research and collaboration across disciplines have resulted. Numerous collaborative projects are now underway between academic and industrial researchers.

This SIG has enabled strong knowledge transfer between ostensibly separate fields of fluid dynamics through shared mathematical techniques. Knowledge e.g. from kilometre scale wave dynamics has led to surprising synergies in the analysis of nanoscale droplet motion and has also sparked new industrial links.

David Sibley

Rising warm salty fluid (dyed green) cools as heat diffuses away, forming narrow vertical plumes.

Photo credit: Megan Davies Wykes.



Biologically active fluids

Computer model of sperm cells in a viscous fluid, showing cluster formation and locally enhanced flows (arrows).

Image credit: Simon Schöller.

A 'biologically active fluid' is a fluid consisting of microscopic entities which generate stress, typically due to self-propulsion, and often cause pattern formation and turbulence-like states at very low Reynolds number. Famous examples include the 'zooming bionematic phase' exhibited by concentrated bacillus bacteria, convection plumes of upswimming algae and the swirling 'massal motility' of spermatozoa at high concentrations. The study of these beautiful and often clinically and industrially-relevant systems is inherently multiscale, linking the non-Newtonian mechanics at the continuum scale to microscopic models of the interaction of swimming cells with each other, through the suspending fluid.

The study of these systems is inherently multidisciplinary, bringing together microbiology, reproductive biology, ecology, botany, condensed matter physics and applied mathematics. Research techniques include computational modelling, microscopy, holography, micro-manipulation, microfluidics and genetics. It is therefore vital to bring experts in these different fields together to provide mutual training, both for the benefit of research trainees and also scientific peers.

In addition to talks on state-of-the-art (often unpublished) research by experts and graduate student poster sessions, we dedicate a day of each meeting to an early career workshop. These workshops each involve three 1-hour interactive masterclasses, from chalk-and-talk sessions on mathematical methods 'Biological Stokes Flow and Fundamental Solutions' and physical models 'Introduction to Complex Fluids', to immersive 360° cinema demonstrations of 3D digital holography of swimming microbes (complete with 3D glasses), to a hands-on coding workshop 'A quick-and-dirty guide to solving PDEs with regularised singularities'. A planned workshop session will involve hands-on microscopy with live cells. Workshop resources are being made available online at the SIG website along with more advanced material based on contributors' current research outputs. The SIG is thus generating much-needed training material and resources, vital for both graduate students and more experienced researchers working in this multidisciplinary area.

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David Smith

Low-energy ventilation

The urban environment creates myriad challenges – and research opportunities – in low-energy ventilation.

Image credit: Henry Burridge.

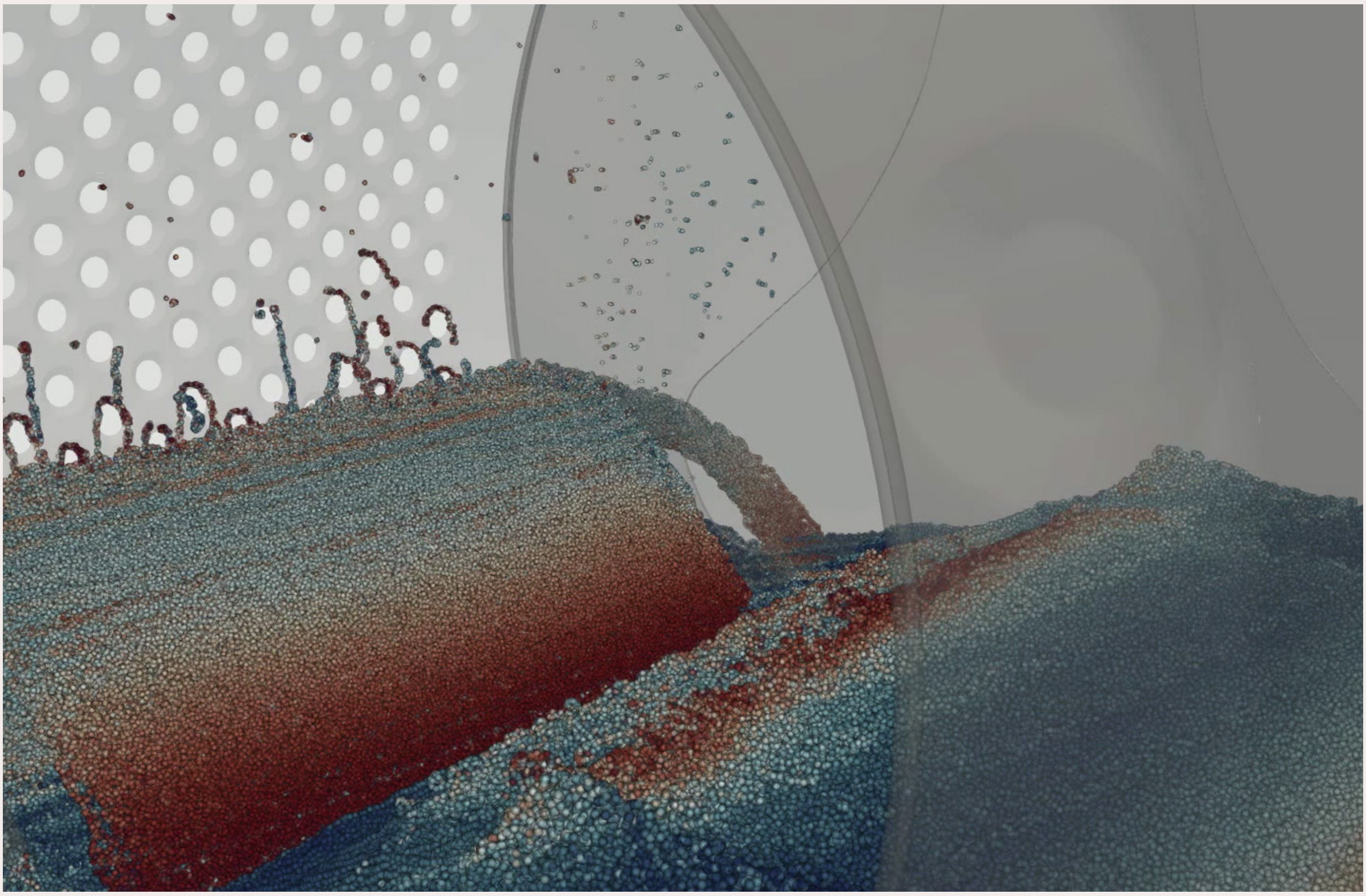
The Low-Energy Ventilation SIG (LEVSIG) aims to bridge the knowledge gap between optimal strategies for building ventilation and current industry practice. LEVSIG applies fundamental fluids mechanics and leads research to address simultaneously the demands of energy consumption and occupancy experience (thermal comfort, indoor air-quality).

The activities of LEVSIG have centred on developing a network of both researchers and practitioners who share the SIG's aims and wish to enable and promote cutting-edge research into building ventilation. To this end, LEVSIG has hosted six meeting symposia in a range of locations across the UK including Leeds, Cambridge, Nottingham, London and Loughborough. These events have enabled members of the network to share their research in an openly inclusive and collaborative environment. As a result of our activities the network now has over 130 members from around 25 UK research institutions and over a dozen different industrial partners. The network has further enhanced its reach through collaboration, for example by holding joint meetings with the Urban Fluid Mechanics SIG, the UK Indoor Environments Group (UKIEG), the Health Effects of Modern Airtight Construction (HEMAC) network and the CIBSE Natural Ventilation Group.

In addition, the network has sought to establish and support collaborative funding proposals by identifying key research needs and running proposal workshops, and its website www.lowenergyventilation.org is establishing a UK portal for building ventilation research, including an open-access repository of research and industry presentations, publications, design guidance and, in time, material from advanced level taught courses.

We are a network of over 130 researchers and practitioners whose aim is to bridge the gap between optimal strategies for building ventilation and current industry practice.

Henry Burridge



Capturing fluid sloshing inside a washing machine using SPH.

Image credit: Stephen Longshaw.

Smoothed particle hydrodynamics (SPH)

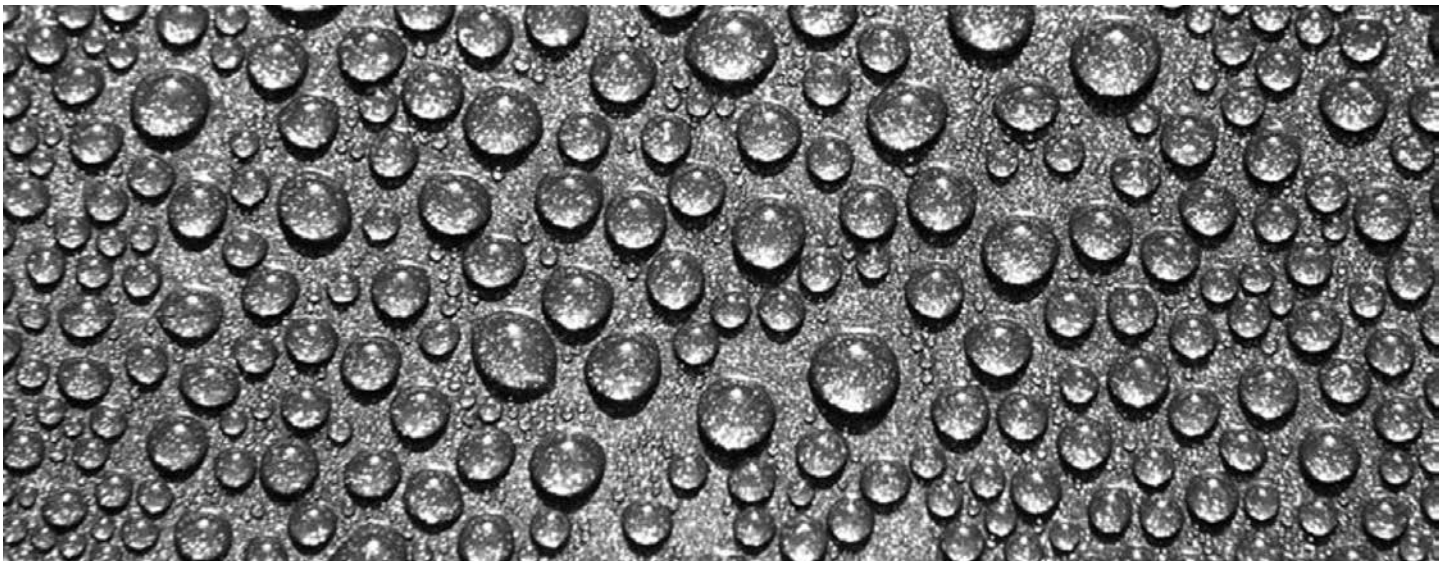
> The most valuable impact of the SIG for us has been in consolidating the open research questions from multiple academic disciplines to focus our attention on those questions that have the most impact to the widest number of sectors.
>
> **Richard Southern**

Many methods used to simulate physical problems rely on a computational mesh. Smoothed Particle Hydrodynamics (SPH) is an example of an approach that instead uses particles and is therefore meshless. This gives SPH advantages when tackling certain types of problem, especially those involving large deformation or a free surface.

There are a number of interpretations of the SPH method available, but fundamentally it involves discretising a problem into a set of particles and then calculating physical values at each of them by considering that of neighbouring particles using a short-range interpolation in a kernel around each.

The SPH SIG has two key goals: firstly, to bring together different scientific disciplines using the method, so advancements in each can be shared; and secondly, to bring industry into the conversation about SPH. The second goal is key to the future development of the method, since new, practical problems are needed to focus effort where it is required.

The SPH SIG has proved to be popular with existing UK-based academics and is beginning to draw attention from UK industry: feedback has shown this is down to the informal nature of the meetings and the fact that all discussions are focused on SPH with a wide variety of applications.



Fluid mechanics of cleaning and decontamination

Contaminant droplets can adhere to solid surfaces, and must be removed safely.

Photo credit: Adobe Stock.

Cleaning and decontamination are often perceived as annoying but necessary tasks which slow you down or distract you from your main goal, whether at home when doing the dishes or in manufacturing processes during product change-over phases. They are nevertheless essential to most human activities: for instance to maintain basic hygiene at home, prevent cross-contamination in drug preparation, avoid pipe blockages in engineering systems, or neutralise toxic substances after chemical spills.

This SIG's membership features a broad range of expertise, reflecting the complex and multidisciplinary challenges associated with cleaning and decontamination processes. Members come from academia, industry and government agencies with expertise in chemical engineering, mathematical modelling, chemistry, toxicology, mechanical engineering, and physics. During our meetings, which have seen more than 100 different participants over the last two years, we exchange knowledge and know-how, and have also discussed specific problems presented by industrial members of the SIG. For example, Dstl presented a case study on issues related to the spreading and re-absorption of contaminant by the decontamination procedure itself. This is a crucial challenge in the decontamination of toxic materials: how can we ensure that toxic materials have not simply been displaced but have been thoroughly neutralized to a safe level? After a 2 hour break-out group session in interdisciplinary teams mixing students with experienced researchers, each group presented their approach on how to tackle this problem. The wealth of ideas, exploiting numerical modelling, mathematical techniques and direct experimental testing, was not only useful to Dstl, but students also benefitted from discussing with experienced researchers how to approach complex real-life problems.

The SIG organised a two-day conference at the Isaac Newton Institute, Cambridge, in August 2018. It was attended by more than 45 academic and industrial researchers, as well as Master's and PhD students, from the UK and other EU countries. The conference had keynote speakers presenting in-depth topics, contributed talks and posters by members of both this and other related SIGs, as well as several breaks to promote discussion and exchange of ideas. From these informal conversations, one often realizes that challenges in very different applications can be addressed using similar principles, or conversely a particular model can have applications across many different disciplines. For instance, the technique of dye attenuation routinely used in experimental fluid mechanics inspired chemists at Dstl to develop coloured liquid simulants in order to improve testing of their decontamination procedure.

The wealth of ideas, exploiting numerical modelling, mathematical techniques and direct experimental testing, was not only useful to Dstl, but students also benefited from discussing with experienced researchers how to approach complex real-life problems.

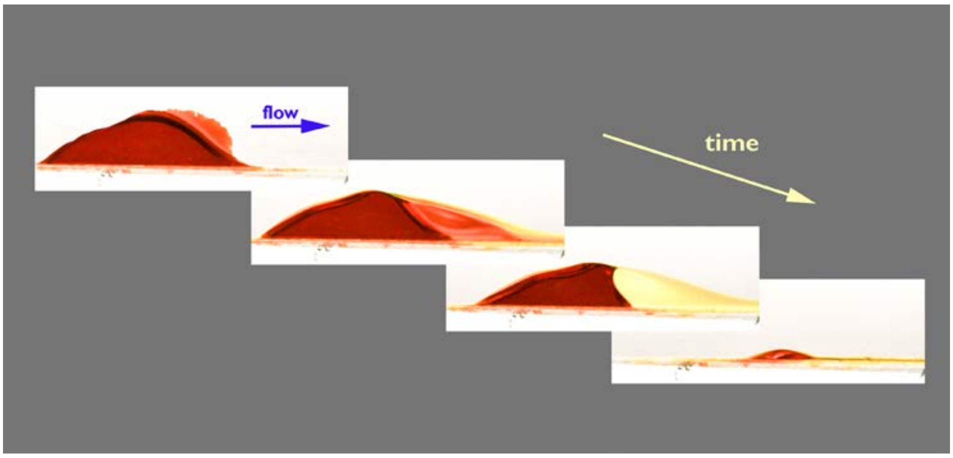
Julien Landel

SHORT RESEARCH VISITS

The UK Fluids Network has funded 86 visits of academics, ECRs and PhD students to work with other UK fluids researchers and groups. Typically lasting 1-2 weeks, these SRVs have developed new models and numerical techniques, used unique experimental set-ups in new applications and transferred knowledge via more than 120 connections.

The FloWave Ocean Energy Research Facility at the University of Edinburgh generating a spout.

Photo credit: Callum Bennetts.



Four snapshots in the evolution of a dye droplet showing corner flow behaviour.

Image credits: DAMTP, University of Cambridge & Dstl.

Novel ionic liquid dyes for fluid dynamics and decontamination studies

Dr Merlin Etzold (University of Cambridge) visited Dr Stephen Marriott (Defence Science and Technology Laboratory)

A liquid contaminant in a chemical attack will adhere to the surface of man-made structures. These are typically complex, with small gaps trapping droplets of the liquid, which are often sufficiently viscous and adhesive to prevent their immediate removal by the shear forces imposed by the decontaminant film. Common surface washing techniques induce a flow within gaps aligned with the dominant flow direction, aiding the dissolution and removal of the contaminant. Merlin examines this process through experiments with non-hazardous simulants, and this visit focused on conducting experiments to explore the suitability of a novel ionic liquid dye as a simulant in decontamination experiments on complex surfaces.

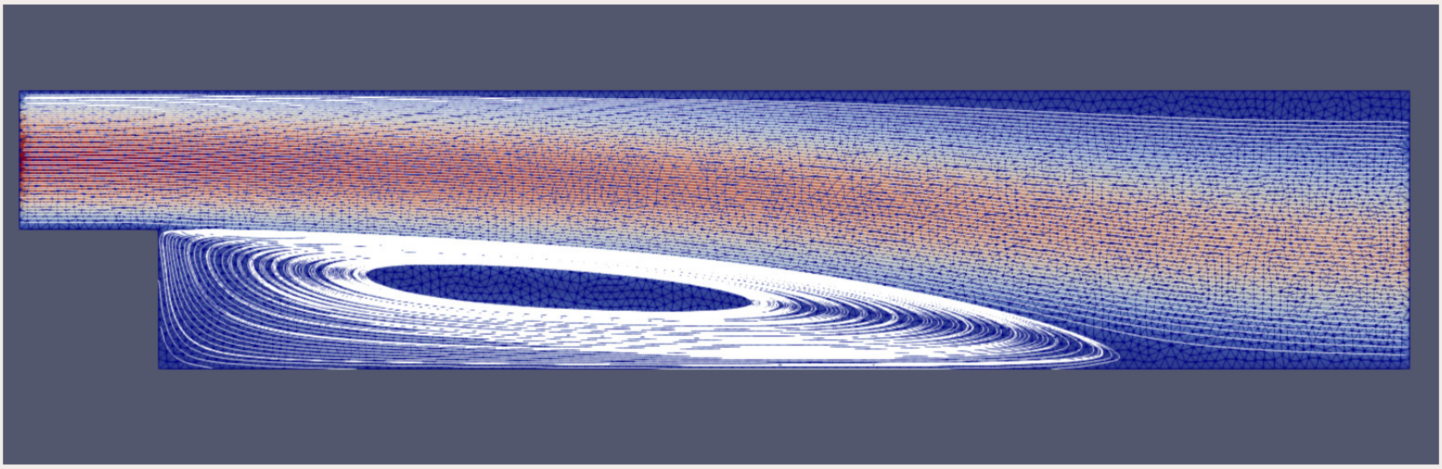
In the experiments the drop was removed by either fragmentation or removal in situ. In the latter case two regimes were identified: the first, in which the drop shrank by dissolution at the surface while maintaining a constant shape; and the second, in which the drop develops a corner flow, as illustrated in the above figure.

“The dye proved to be highly suitable as a model decontaminant. It adhered strongly to the glass surface and had a high viscosity (adjustable by changing the cation of this ionic liquid). The colour change of the dye during dissolution ensures easy distinction between dissolved dye and the remaining droplet. Since the dye turns essentially into fluorescein when dissolved, low concentrations can be detected. Thus, alternative strategies to track the decontamination progress by measuring the concentration of dye in the decontaminant as a function of time using UV-Vis spectroscopy can be used. Since fluorescein is detectable at very low concentrations, the dye also has potential for exploring secondary contamination (spreading of the contaminant by the decontamination efforts).”

Steve and Merlin are glad to see this work continued by a PhD student in Manchester, supervised by Julien Landel and Merlin. While the dye is currently not commercially available, Steve passed on the preparation technique to Merlin, enabling use of the dye in future experimental work at Cambridge.

The dye proved...highly suitable as a model decontaminant. It adhered strongly to the glass surface... low concentrations can be detected... [there is] easy distinction between dissolved dye and the remaining droplet...[it] also has potential for exploring secondary contamination.

Merlin Etzold



Two-dimensional flow over a backward-facing step, solved using the preconditioner developed in this SRV.

Image credit: Lawrence Mitchell.

Multigrid solvers for high Reynolds number stationary Navier-Stokes flow

Dr Lawrence Mitchell (Durham University) visited Dr Patrick Farrell and Mr Florian Wechsung (University of Oxford)

“In this short visit, we extended the Firedrake[1] finite element library to incorporate a number of features necessary for complex multigrid solvers in fluid dynamics. In addition to this, we made good progress implementing the augmented Lagrangian-based scheme of Benzi and Olshanskii.

“The core technology improvements made to Firedrake significantly extended the existing capabilities for implementing geometric multigrid solvers, and parallel Schwarz methods. These included:

- Grid transfer operators on all mesh types supported by Firedrake
- Ability for the model developer to provide per-solve custom grid transfer operators.
- Arbitrary configuration and selection of distributed mesh overlaps.

“The original aim of the visit was to develop effective preconditioners for the incompressible Navier-Stokes equations for high resolution problems. Initial results are promising: we have successfully implemented the scheme of Benzi and Olshanskii in 2D, and extended the setup to support problems in 3D. We have been able to solve problems of up to 1 billion degrees of freedom with only weak dependence of the solver on the Reynolds number. Once finalised, the solver itself will be made available as a tutorial in the Firedrake distribution.”

Patrick Farrell writes:

“I am delighted to report that the...SRV of Dr Lawrence Mitchell...was extremely successful. We have developed the world’s first Reynolds-robust preconditioner for the stationary incompressible Newtonian Navier-Stokes equations in three dimensions, enabling massive simulations (billions of degrees of freedom) on supercomputers that were previously impossible. The software developed via the SRV has been merged into PETSc, petsc4py, FIAT, PyOP2 and Firedrake, and a publication on our work is available on arXiv[2].”

1 www.firedrakeproject.org
2 arxiv.org/abs/1810.03315

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Patrick Farrell

Controlling nematic microfluidics: a merger of modelling, simulation and experiments

Dr Apala Majumdar (University of Bath) visited Dr Ian Griffiths (University of Oxford)

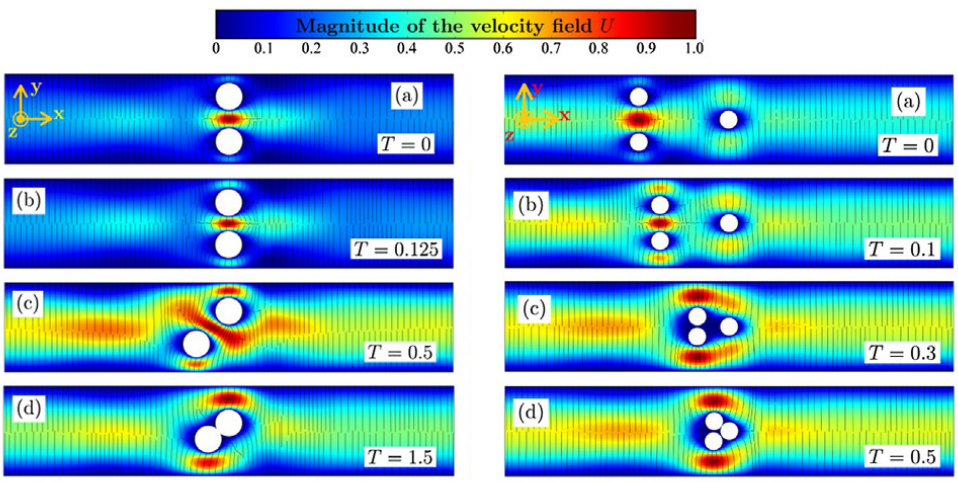
This project has led to three co-authored research articles, a joint PhD studentship in collaboration with Merck at InFoMM Oxford... and network funding applications to the London Mathematical Society.

Apala Majumdar

This research project focuses on hydrodynamics theories for nematic liquid crystals.

Nematic liquid crystals are classical examples of partially-ordered materials that combine the fluidity of liquids with the orientational order of crystalline solids. The hydrodynamic theory of nematic liquid crystals is very rich, offering new mechanical and rheological properties compared to isotropic Newtonian fluids. The essential mathematical framework comprises the continuity equation, an evolution equation for the nematic flow field and an evolution equation for the nematic order parameter, which describes the state of orientational ordering or material anisotropy. The evolution equations for the flow field and order parameter are intrinsically coupled, so that, informally speaking, the evolution equation for the flow field is the Navier-Stokes equations with an additional coupling stress between the flow field and nematic order parameter, which can introduce strikingly different flow profiles compared to solutions of the classical Navier-Stokes equations. Conversely, the flow field influences the nematic order parameter and can even create defects or locally disordered regions.

This project was based around two distinct hydrodynamic theories for nematic liquid crystals, namely the Ericksen-Leslie and Beris-Edwards theories for nematodynamics, in the context of a microfluidic problem. The emphasis was on spatio-temporal pattern formation in both frameworks and how the solution profiles depend on the pressure gradient, geometry, boundary conditions and material constants, including the effects of inclusions such as nanoparticles. This project has led to three co-authored research articles, a joint PhD studentship in collaboration with Merck at InFoMM Oxford, for which Ian Griffiths and Apala Majumdar are joint supervisors, and network funding applications to the London Mathematical Society.



Time evolution of 2 and 3 disc-like inclusions in a nematic microchannel (from [1], with permission).

[1] 'Nematohydrodynamics for colloidal self-assembly and transport phenomena' Mondal, S., Majumdar, A. & Griffiths, I.M. (2018) J. Colloid Interface Sci. 528, 431-442.

The soil removal mechanisms of liquid jets and sprays used in pharmaceutical batch cleaning

Mr Alistair Rodgers (University of Leeds) visited Prof Ian Wilson and Mr Rajesh Bhagat (University of Cambridge)

The visit to Cambridge was a very insightful and useful exercise that has enhanced the progression of the project greatly. The work using the CTS to detect the residual film...after spray cleaning was particularly useful in helping to understand the soil removal mechanisms of the spray.

Alistair Rodgers

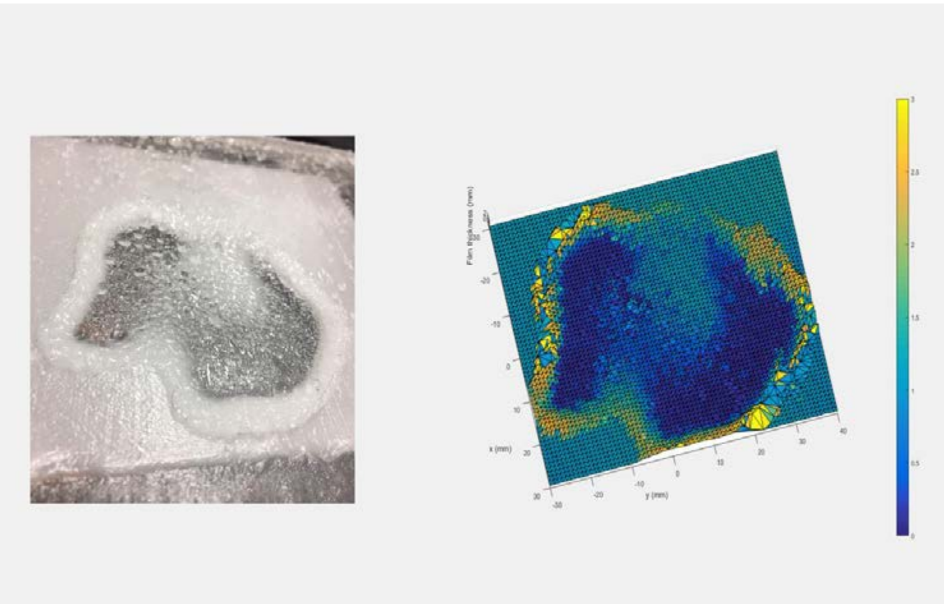
This visit was concerned with the cleaning of soiled surfaces using liquid sprays and jets, consisting of new experiments that utilised an experimental rig and measurement equipment at Cambridge not available in Leeds. Specifically, a confocal thickness sensor (CTS) was available, which was used to scan a surface that had been cleaned to show the distribution and size of the residual film – even for the very thin films left by sprays – on the surface. Also, the test rig included a mechanism to move the target plate relative to the jet, simulating a dynamic jet. This was of particular interest to Alistair, providing a useful comparison of the mechanisms of soil removal between a static and dynamic jet.

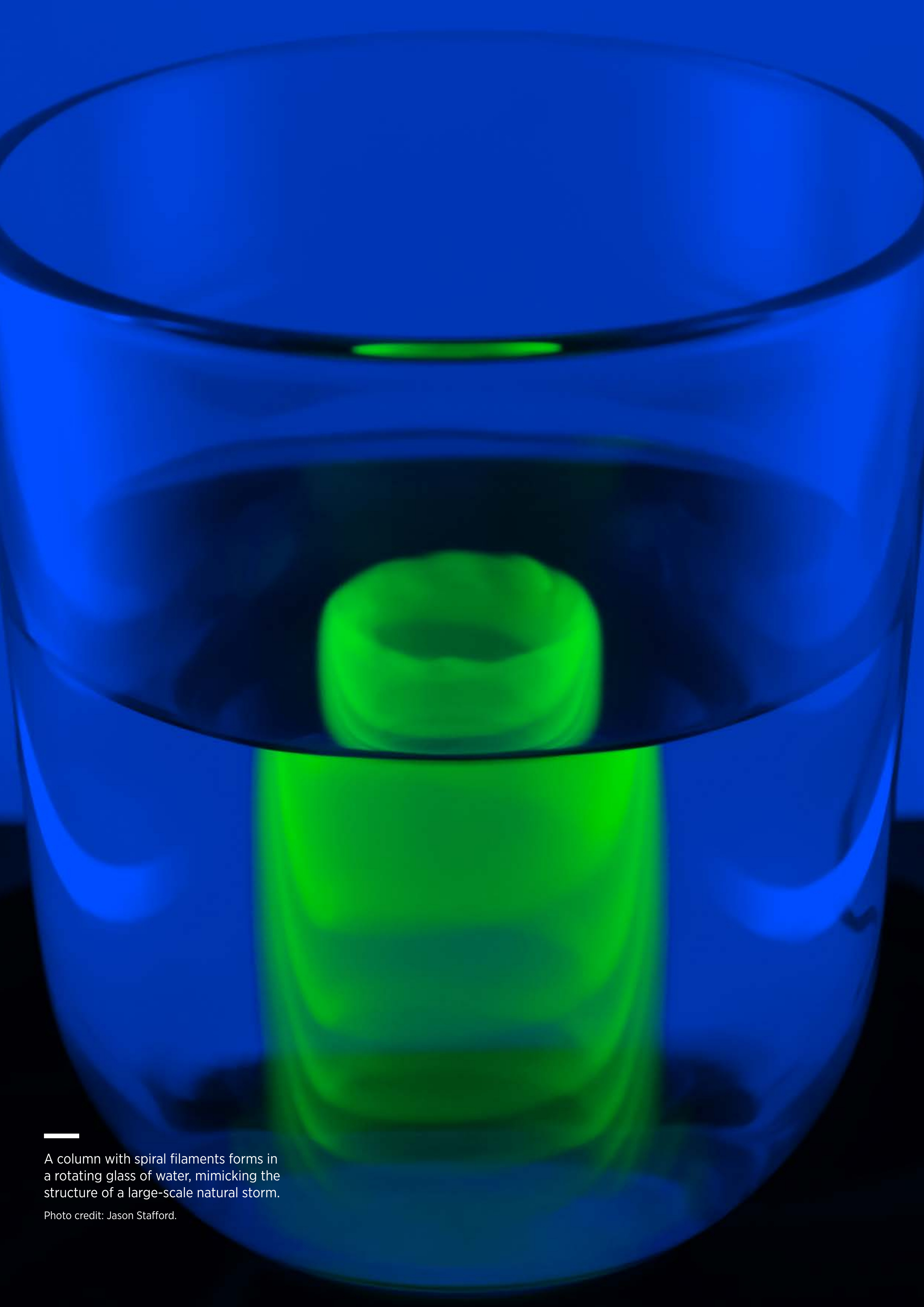
The materials used were Perspex as the target plate and white soft paraffin (WSP) as the soil, applied to the plate to the desired thickness. After cleaning, the CTS was used to measure film thickness by mounting the plate on an X-Y stepper motor table and comparing the distance to the cleaned surface with that to the target plate at a two-dimensional grid of points. One such example is shown in the figure below.

"The visit to Cambridge was a very insightful and useful exercise that has enhanced the progression of the project greatly. The work using the CTS to detect the residual film on the surface after spray cleaning was particularly useful in helping to understand the soil removal mechanisms of the spray in more detail. The extent of the residual film thickness was given whereas this was previously unobtainable without such equipment. This gives an insight into the volume of material transported by the spray, and knowing the power input for both the jet and the spray the respective cleaning efficiencies for both can be derived. The effectiveness of the CTS has been highlighted and is something that will be considered for use in Leeds. The dynamic jet experiments also provided an interesting perspective on what effect the motion of the jet has on cleaning. Since many industrial cleaning applications involve moving jets it was important to take this into consideration."

Soiled surface after spray cleaning alongside film thickness measurements obtained with CTS.

Image credits: Alistair Rodgers.





A column with spiral filaments forms in a rotating glass of water, mimicking the structure of a large-scale natural storm.

Photo credit: Jason Stafford.

Principal Investigator: Prof Matthew Juniper, University of Cambridge

Executive Committee: Prof Anne Juel, The University of Manchester
Prof Paul Linden, University of Cambridge
Prof Neil Sandham, University of Southampton
Prof Steven Tobias, University of Leeds
Prof Yannis Hardalupas, Imperial College London

Facilitator: Dr Nick Daish

BACK COVER
Vortices shed by tandem flapping flippers in experiments to study the efficiency of plesiosaur swimming.

Photo credit: Luke Muscutt.

Photo credit: Cathal Cummins.

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