Midlands Fluid Mechanics Meeting 2023

It is our pleasure to welcome you all to Aston University for the very first Midlands Fluid Mechanics Meeting (MFMM 2023). MFMM aims to bring together academics from across the midlands who are interested in, and are working on, fluid mechanics problems. There is a vast wealth of pioneering fluids research being conducted in the Midlands and this meeting will hopefully serve as a platform for us to share research insights from our respective institutions and, importantly, provide an informal setting for the generation of new academic collaborations.

In our own experience, at least, it would appear that UK Fluids Network activities have dropped off in recent times. Additionally, with this year's UK Fluids Conference now taking place in the middle of October, as opposed to the traditional early September window, it seems like a prudent time to be coming together on a more local scale. Today's meeting will consist of a series of 15 minute presentations with 5 minutes allocated for questions and transition to the next speaker. An ample number of breaks have been scheduled throughout the day so if you find there is no time for your question(s) please do go and introduce yourself to the speaker over coffee or lunch.

Perhaps this will transpire to simply be a one-off event. However, we're hopeful that there will be sufficient interest for this to be an event that continues in to the future, moving annually from one Midlands institution to the next. We note that such meetings have run continuously and successfully in Scotland for the last 36 years!

Lastly, thanks must go out to the Engineering and Physical Sciences Academic and Research Team here at Aston who have helped with administrative tasks and room bookings, the EPSRC who a providing partial support for this meeting via grant number (EP/V006614/2) and to all of you as participants for contributing to what we're sure will prove to be a interesting and inspiring meeting.

With very best wishes,
MFMM 2023 Organising Committee

(Paul Griffiths, Abhishek Kumar, Patrick Geoghegan, Liam Escott, Jason Ferguson & Niall Hanevy)

Engineering and Physical Sciences Research Council

Aston University BIRMINGHAM UK

Meeting Room, Lunch, Drinks & Dinner

Note that all activities, less lunch, will take place in room G63 of the Main Building. The room will be clearly sign-posted from the foyer. Lunch will be held in Conference Aston, just a short walk away. All participants are very much welcome to attend post-MFMM drinks at The Wellington, before those who have indicated an interest (by paying in advance - many thanks indeed!) will retire to Purecraft Bar & Kitchen for dinner at approximately 18:30.

Schedule

Timing	Activity
08:45-09:10	Arrival - tea & coffee
09:10-09:20	Welcome - Prof. Tony Dodd EPS Deputy Dean Research
09:20-10:40	Morning Session 1 - Chair Dr. Paul Griffiths
10:40-11:00	Mid-morning break - tea & coffee
11:00-12:40	Morning Session 2 - Chair Dr. Abhishek Kumar
12:40-14:00	Lunch - Conference Aston
14:00-15:20	Afternoon Session 1 - Chair Dr. Chandan Bose
15:20-15:40	Mid-afternoon break - tea & coffee
15:40-16:40	Afternoon Session 2 - Chair Prof. Peter J Thomas

Overview of Talks

Morning Session 1	
09:20-09:40	Dr. James Jewkes (University of Leicester)
09:40-10:00	Dr. Abhishek Kumar (Coventry University)
10:00-10:20	Ms. Eleanor Barton (Aston University)
10:20-10:40	Mr. Larry Godwin (Aston University)
Morning Session 2	
11:00-11:20	Dr. Chandan Bose (University of Birmingham)
11:20-11:40	Dr. Ran Holtzman (Coventry University)
11:40-12:00	Dr. Benjamin Smith (University of Leicester)
12:00-12:20	Ms. Aleena Urooj (Aston University)
12:20-12:40	Mr. Niall Hanevy (Aston University)
Afternoon Session 1	
14:00-14:20	Dr. Liam Escott (Aston University)
14:20-14:40	Prof. Jonathan Healey (Keele University)
14:40-15:00	Prof. Peter J Thomas (University of Warwick)
15:00-15:20	Mr. Jason Ferguson (Aston University)
Afternoon Session 2	
15:40-16:00	Dr. Philip Trevelyan (Aston University)
16:00-16:20	Dr. Mykyta Chubynsky (Coventry University)
16:20-16:40	Dr. Amit Chattopadhyay (Aston University)

Morning Session 1 - Chair Dr. Paul Griffiths

Talk 1 – 09:20-09:40: Dr. James Jewkes (*University of Leicester*) - **Better Bubblers**

J. W. Jewkes & J. Mifsud

In the high pressure aluminium die casting (HPADC) and injection moulding (IM) industries, a unique flow field is used to cool slender mould protrusions: a jet impingement confined within a dead-end channel, known in industry as a 'bubbler'. These devices are used ubiquitously, however their implementation within a mould has been constrained by the limitations of 2D machining; recent advances in Additive Manufacturing (AM) now offer timely and novel opportunities to improve their design. Our challenge is that the heat- and flow-regime associated with a bubbler has received limited attention in the literature, so an improved understanding is required to access the optimum cooling performance that the AM of these devices can enable. The goal of this project is therefore to establish, via experimental and numerical methods, the heat and flow phenomenology associated with bubblers, and to develop novel methods that will enable their design to be optimised for AM.

Talk 2 – 09:40-10:00: Dr. Abhishek Kumar (*Coventry University*) - **Suppressing Buoyant Instability Using Forcing Based on Receptivity**

A. Kumar & A. Potherat

By using receptivity as an external force, this study seeks to suppress the buoyant instability that arises in mixed baroclinic convection in a cavity. We consider a nearly semi-cylindrical cavity with an upper free surface, where fluid can be fed in, and porous lower boundaries, where fluid can escape. This cavity comprises a semicircular lower boundary, two adiabatic sidewalls and is infinitely extended in the third direction. This configuration describes problems involving melted solid materials, for example, in metallurgical casting processes. Our earlier linear stability analysis and direct numerical simulations show that the unstable modes are three-dimensional [1]. Next, we propose a mechanism to suppress these unstable modes. Our results demonstrate how the adjoint modes (receptivity) can be used as an external force to suppress the instability. There is a crucial role played by the amplitude and phase of the adjoint modes. We implement this time-dependent receptivity forcing in the spectral-element code NEKTAR++ [2].

References:

[1] Kumar and Pothérat, J. Fluid Mech. 885, A40 (2020).
[2] Moxey *et al.*, Comput. Phys. Commun. 249, 107110 (2020).

Talk 3 – 10:00-10:20: Ms. Eleanor Barton (*Aston University*) - **Physiologically Realistic Models of the Aorta for Fluid Dynamic Experimentation**

E. P. F. Barton, P. H. Geoghegan, J-B. R. G. Souppez, J. Simms, J. A. Lowe & L. J. Leslie

Fluid dynamics provides insights into flow variations between healthy and diseased aortic arteries. Key markers like wall shear stress are known to influence arterial disease progression. However, there remains a lack of experimental validation for arterial flows. The purpose of this study is to develop a physiologically realistic aortic phantom for particle image velocimetry (PIV) analysis. An idealised aortic geometry was developed from the literature and manufactured from a mix of two transparent silicones, using the lost core casting method with 3D printed moulds. A flow circuit was devised, featuring flow meters and pressure transducers for monitoring the inlet and outlet boundary conditions. A pulsatile pump delivers a physiological flow by matching the in vivo Reynolds and Womersley numbers. The present work identifies the challenges of manufacturing a phantom for PIV and demonstrates that this silicone mix can achieve the desired Young's modulus of the aortic wall (1.6 MPa), and target refractive index (1.41) required for PIV optical access. These findings may provide a method for constructing future phantoms that match in vivo conditions, for fluid dynamic experimentation.

Talk 4 – 10:20-10:40: Mr. Larry Godwin (*Aston University*) - **Non-Modal Analysis in Stratified Counter Rotating Taylor-Couette Flow**

L. E. Godwin, P. M. J. Trevelyan, T. Akinaga & S. C. Generalis

This study explores the application of non-normal analysis to investigate the behaviour of Stratified counter rotating Taylor-Couette Flow (STCF), a topic that has received relatively less attention compared to wall bounded flows like shear flows. The study examines the behaviour of perturbations under varying temperature conditions, emphasising their amplification patterns and correlations between different configurations. The research sheds light on the sub-critical effects of thermal stratification on disturbance dynamics and how the interplay of viscous, buoyancy, and centrifugal forces influences the decay phases of the amplification factor. As temperature increases, buoyancy forces dominate, leading to a transient thermal instability and triggering asymptotic growth in the amplification factor. The findings reveal that incorporating temperature significantly alters the anticipated outcome, deviating from results obtained by previous studies. The analysis uncovers complex dynamical phenomena unique to transient dynamics that cannot be captured solely by focusing on the growth rate of the eigenvalue.

Morning Session 2 - Chair Dr. Abhishek Kumar

Talk 1 – 11:00-11:20: Dr. Chandan Bose (*University of Birmingham*) - **Gust Response of Free-Falling Porous Plates and Discs**

C. Bose & I. M. Viola

Some natural plant seeds, such as dandelions, exhibit long-distance dispersal by enabling the formation of vortical flow structures associated with a lowered terminal velocity. Furthermore, the underlying fluid-structure interaction often exploits the wind gusts to augment their flight characteristics. To that end, we model the flight behaviour of free-falling porous plates and discs using high-fidelity fluid-structure interaction simulations and study their response dynamics when subjected to transverse discrete gusts. We show that the transverse gust results in a transient reduction of the terminal velocity. The gust effect is quantitatively measured through the difference in altitude after the transient between a plate that experiences a gust and one that falls in quiescent flow. The gain in altitude increases with the gust acceleration, as well as with the Galilei number and the non-dimensional mass. We also show that a sufficiently large and sustained gust can result in a temporary uplift of the plate. These results will inform the design of insect-scale flyers transported and distributed by the wind.

Talk 2 – 11:20-11:40: Dr. Ran Holtzman (*Coventry University*) - **Nonequilibrium Flows in Porous Materials**

R. Holtzman

We examine the nonequilibrium nature of fluid displacement in heterogeneous media from a theoretical, numerical and experimental standpoint, using an imperfect Hele-Shaw cell featuring a localized extended constriction. We focus on the configurational energy dissipated in imbibition and drainage, and how it relates to the capillary pressure-saturation hysteresis cycle. Individual constrictions can be classified as weak (reversible) or strong (dissipative), depending on their cross-section gradient. We show however that cooperative effects can make displacements through a pair of weak defects dissipative, through spatial interactions mediated by interfacial tension; we identify the critical distance between the weak constrictions, below which irreversibility, dissipation, and hysteresis emerges.

Talk 3 – 11:40-12:00: Dr. Benjamin Smith (*University of Leicester*) - **The Steady Flow Around a Rotating Sphere**

B. J. Smith, Z. Hussain, S. J. Garrett & S. A. W. Calabretto

A new model of the steady flow around the rotating sphere is developed including the widely observed boundary layer collision and subsequent radial jet at the equator. The current models of the equatorial flow are discussed, but the presence of a large recirculation region not seen in experimental or numerical studies suggests that these models are not sufficiently accurate. By incorporating azimuthal curvature, due to the cylindrical-like geometry of the sphere at the equator, results are in excellent agreement with state of the art simulations and the physical mechanisms of the equatorial flow can finally be determined.

Talk 4 – 12:00-12:20: Ms. Aleena Urooj (*Aston University*) - **Viscous Instabilities in a Porous Medium of an Initially Linear Viscosity Profile in the Presence of a Jump**

A. Urooj, S. C. Generalis & P. M. J. Trevelyan

In this study we investigate a viscous instability in which a fluid containing a species is injected into a porous medium in two dimensions. The initial concentration of the species is linearly decreasing except for an isolated jump where the concentration increases. The linear stability analysis is obtained using the quasi-steady state approximation. The initial stability of the system can be obtained analytically. As the species diffuses in time the instantaneous growth rates evolve in time. For later time the stability of the system is obtained numerically. Various combinations of the density gradient above and below the jump are considered. Although the jump initially destabilises the system, eventually, after a finite amount of time, the system becomes stable.

Talk 5 – 12:20-12:40: Mr. Niall Hanevy (*Aston University*) - **Boundary Layer Flows on Stretching Surfaces**

N. Hanevy, S. O. Stephen, P. M. J. Trevelyan, A. Kumar & P. T. Griffiths

Boundary layer flows induced by the extrusion of a surface have received considerable attention since they were first described by Sakiadis [1]. These so-called 'stretching flows' are of practical importance to chemical and metallurgy industries where extrusion processes are commonplace. Most previous studies in this area consider the stretching sheet to be solid and free from deformation. Until very recently these types of flows were thought to be linearly stable. However, recent work [2] has shown that these flows are, in fact, linearly unstable to disturbances in the form of Tollmien-Schlichting waves. Our current analysis validates the linear stability theory via direct numerical simulations using the spectral element software Nektar++ [3]. In addition to this, we will also consider the dynamics of a sheet that thins as it is stretched. Our work is motivated by Al-Housseiny & Stone [4] who were the first to consider the isothermal problem. The coupling of the dynamics of the sheet and the induced boundary layer flow imposes restrictions on the validity of self-similar base flow solutions. We will report on the linear stability characteristics of these flows and will draw comparisons with previous investigations.

References:

[1] Sakiadis, AIChE J. 7, 221 (1961).
[2] Griffiths *et al.*, Phys. Fluids. 33, 084106 (2021).
[3] Cantwell *et al.*, Comput. Phys. Commun. 192 (2015).
[4] Al-Housseiny and Stone, J. Fluid Mech. 706, 597 (2012).

Afternoon Session 1 - Chair Dr. Chandan Bose

Talk 1 – 14:00-14:20: Dr. Liam Escott (*Aston University*) - **Investigation of the Flow and Stability of an Injected Shear-Thinning Boundary Layer into Background Newtonian Fluid**

L. J. Escott & P. T. Griffiths

Research into fluid systems which are inspired by a natural phenomenon have been of interest to the mathematical community for many years. One case study considers the secretion of complex fluid onto the skin of certain varieties of fish, colloquially known as 'fish slime'. This can have many benefits for the fish, such as a reduction in drag coefficient. We provide an analysis of a similar model, which involves the injection of a shear-thinning fluid through lower wall into pre-existent Newtonian boundary layer. This injection can vary in angle and injection rate to better capture what might be observed on the fish. The injected phase is captured by the Carreau-Yasuda model and allow a variation in power law index to investigate viscosity variation. We present base flow solutions for a variety of parameters, given both a self-similar and two-dimensional framework, in which the interfacial location is determined by the flow, and provide a linear stability analysis. It has been shown in previous studies, that for a specific choice of shear-thinning parameter space, one can delay the onset of instability given no injection, and we show that the same is possible within our model.

Talk 2 – 14:20-14:40: Prof. Jonathan Healey (*Keele University*) - **Global Instability Produced by Infinitesimal Roughness Terms**

J. J. Healey & M. R. Turner

Amplitude equations can model dispersion relations for waves in a variety of media. We are interested in unstable waves in fluid flows. Small amplitude disturbances can be represented as a superposition of waves, which usually requires assuming that the flow is homogeneous in the streamwise direction. However, even a nominally 'parallel' flow will have small amplitude roughness at solid boundaries. We use amplitude equations with small random spatially inhomogeneous terms to model the effect of rough boundaries. In a parallel flow, 'absolute instability theory' describes whether or not wavepackets propagate away from their source. 'Global instability theory' is the corresponding theory for a spatially inhomogeneous flow. We use Floquet theory to study the effect of small roughness terms on global stability in amplitude equations. We show there are cases where the homogeneous problem has an $O(1)$ global decay rate, but the inclusion of infinitesimal roughness creates a global instability with $O(1)$ global growth rate. Therefore even small roughness can not be ignored!

Talk 3 – 14:40-15:00: Prof. Peter J Thomas (*University of Warwick*) - **Concept for an Experimental Study Investigating Effects of Coriolis Forces on Cavitation-Bubble Collapse in an Ultra-High-Speed Rotating System**

P. J. Thomas, I. Tzanakis, P. Prentice, M. Hočevar & M. Dular

Coriolis effects, induced by system rotation result in counter-intuitive effects on fluid flows. Cavitation occurs frequently in rotary flows (e.g. ship propellers). However, due to the time and spatial scales of cavitation-bubble dynamics, in comparison to the time scale relevant to the rotary flow, Coriolis effects are not relevant in currently existing technological contexts. Nevertheless, it is possible to design a laboratory experiment where Coriolis effects should exist. These could, potentially, be exploited for new cavitation-based technologies. The concept for the experimental configuration required to induce strong Coriolis effects on cavitation bubbles will be outlined. The relevant parameters governing the process are addressed. It is speculated as regards what Coriolis effects might arise and in which contexts one could, potentially, beneficially exploit them. The long-term goal is to design, build and test a rig that enables performing experiments investigating the effects induced by Coriolis forces on cavitation bubbles under the extreme conditions at ultra-high-speed background rotation.

Talk 4 – 15:00-15:20: Mr. Jason Ferguson (*Aston University*) - **Boundary Layers Flows on Rough Surfaces**

J. Ferguson, P. M. J. Trevelyan, A. Kumar & P. T. Griffiths

Studies have shown that surface roughness can delay the onset of instability for the rough rotating disc boundary layer. This is of benefit for many reasons, not the least energetically beneficial, drag reducing effects. We consider high Reynolds number boundary layer flows over a rough moving surface. The effect of a sinusoidal surface is considered as a model for our roughness and a range of different amplitudes are considered. The purpose of the research is to investigate whether such a surface can be used as a drag reduction technique. For many boundary layer flows such as the Blasius boundary layer over a smooth flat plate, self-similar solutions exist. The challenge when modelling a rough surface is that self-similar solutions do not exist. We formulate the problem by appropriately transforming the Navier-Stokes equations to account for the roughness and solve the governing equations utilising the Keller-box scheme. We examine the basic flow profiles for a range of amplitudes. We also analyse the linear stability of the flow by considering the mean flow profiles and conducting a normal mode analysis. We solve the resulting eigenvalue problem and present out findings.

Afternoon Session 2 - Chair Prof. Peter J Thomas

Talk 1 – 15:40-16:00: Dr. Philip Trevelyan (*Aston University*) - **A Falling Fluid Droplet in an Oscillating Flow Field**

P. M. J. Trevelyan, I. T. Williams, S. Kalliadasis & S. C. Generalis

In this work we examine the fluid flow in and around a falling fluid droplet in a vertically oscillating fluid flow. In our study we assume axisymmetric Stokes flow and additionally for small deformations to the droplet the governing equations can be linearised. This mathematical procedure leads to an infinite system of equations. In the small-capillary limit this system can be simplified further. We present the results of our investigations and we also show that the resulting solution breaks down with singularities along the vertical axis of the droplet.

Talk 2 – 16:00-16:20: Dr. Mykyta Chubynsky (*Coventry University*) - **Rolling and Sliding in a Continuum Model of a Spreading Nanodroplet**

M. V. Chubynsky, S. Perumanath, R. Pillai, M. K. Borg & J. E. Sprittles

For nanoscale flows, a question of both theoretical and practical importance is to what extent such flows can be described by continuum models. With this question in mind, we compare molecular dynamics (MD) simulations of spreading of a quasi-2D water nanodroplet on a solid surface to a continuum model in which the flow inside the droplet obeys the usual Navier-Stokes equations and the interaction with the surface is modelled via normal and shear stress boundary conditions on the droplet surface. We find excellent agreement between the droplet shape profiles obtained in MD and our continuum simulations. An effect present in both our model and MD, but absent in classical simulations of wetting, is acceleration of the free surface of the droplet towards the solid surface both before and after contact, which leads to “rolling” motion in the early stages of spreading. The continuum approach is then used to study the crossover between rolling and classical sliding for 3D droplets of up to several hundred nm in size, which would be computationally intractable using MD.

Talk 3 – 16:20-17:40: Dr. Amit Chattopadhyay (*Aston University*) - **Magneto-Rotational Instability in Accretion Flows**

A. K. Chattopadhyay & B. Mukhopadhyay

In this talk, I will propose a new approach to understand the origin of magneto-rotational instability (MRI) in stochastically driven accretion flows. These sheared flows are Rayleigh stable but see unexpected rise in the angular momenta of rotating accretion discs notwithstanding decreasing angular velocities. These strong instabilities have earned the nickname of ’linear instability’, a technical misnomer but also a pointer to the irregular nature of such transport properties. The basis of Landau stability and scaling properties of such jet flows will also be highlighted from a study of the relevant Orr-Sommerfeld-Squire model.

MFMM 2023 Participants

Name	Institution
Dr. Abhishek Kumar	Coventry University
Ms. Aleena Urooj	Aston University
Mr. Ali Saei Behrouzi	University of Warwick
Dr. Ali Haghiri	University of Leicester
Dr. Amit Chattopadhyay	Aston University
Dr. Andrew McMullan	University of Leicester
Dr. Benjamin Smith	University of Leicester
Dr. Chandan Bose	University of Birmingham
Dr. Chris Pringle	Coventry University
Prof. Christopher Davies	University of Leicester
Ms. Eleanor Barton	Aston University
Ms. Hibah Saddal	Coventry University
Dr. Jacopo Gianfrani	Coventry University
Dr. Jacqueline Mifsud	University of Leicester
Mr. Jake Pattison	University of Warwick
Dr. James Jewkes	University of Leicester
Mr. Jason Ferguson	Aston University
Mr. Jean-Baptiste Souppez	Aston University
Dr. Jialin Su	Loughborough University
Mr. Jo Samuel	University of Leeds
Prof. Jonathan Healey	Keele University
Dr. Junho Park	Coventry University
Dr. Kawa Manmi	University of Warwick
Mr. Larry Godwin	Aston University
Dr. Liam Escott	Aston University
Dr. Mykyta Chubynsky	Coventry University
Mr. Niall Hanevy	Aston University
Dr. Noura Bettaieb	Coventry University
Dr. Nwabueze Emekwuru	Coventry University
Dr. Patrick Geoghegan	Aston University
Dr. Paul Griffiths	Aston University
Prof. Peter J Thomas	University of Warwick
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