Midlands Fluid Mechanics Meeting (MFMM) 2024

Dear MFMM delegates,

It is our pleasure to welcome you to the University of Leicester for the 2nd edition of the Midlands Fluid Mechanics Meeting (MFMM 2024) on Monday 2nd September 2024.

The 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.

Last year's inaugural meeting hosted by Aston University was a great success, and we endeavour to continue this tradition of organising an annual Midlands Fluids Mechanics Group meeting for years to come. We are hopeful that there will be sufficient and sustained 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 similar meetings (in particular, the Scottish Fluid Mechanics Meetings) have run continuously and successfully in Scotland for the last 37 years!

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) after a presentation, please do go and introduce yourself to the speaker over coffee or lunch.

Lastly, thanks must go out to the EPSRC who are providing support for this meeting via grant number EP/V02695X/1 and to all of you as participants for contributing to what we are sure will prove to be another interesting and inspiring meeting.

With very best wishes,
MFMM 2024 Organising Committee

(Jacqueline Mifsud, James Jewkes, Paul Griffiths, Andrew McMullan, & Chandan Bose).

Engineering and Physical Sciences Research Council

UNIVERSITY OF LEICESTER

Meeting Room, Lunch, Drinks & Dinner

Meeting presentations will take place in the Oak room in College Court, the University of Leicester's conference centre. Upon arrival, there will be a registration desk in the Dannatt Foyer (just by the stairs that lead up to the Oak Room). Lunch will be on-site in the restaurant at College Court. All participants are very much welcome to attend post-MFMM drinks (around 17:00) at The Cradock Arms (across the road from College Court), before those who have registered an interest will meet for dinner at Heritage India (on Welford Road) at 18:30.

Schedule

08:45-09:10	Arrival - tea & coffee
09:10-09:20	Welcome - Prof. Simon Gill, Dean of Research, College of Science and Engineering
09:20-10:40	Morning Session 1 - Chair Prof. Stephen Garrett
10:40-11:00	Mid-morning break - tea & coffee
11:00-12:20	Morning Session 2 - Chair Dr. James Jewkes
12:20-12:30	MFMM Group Photo
12:30-14:00	Lunch - Conference Aston
14:00-15:20	Afternoon Session 1 - Chair Prof. Andrew McMullan
15:20-15:40	Mid-afternoon break - tea & coffee
15:40-16:40	Afternoon Session 2 - Chair Dr. Chandan Bose
16:40-16:45	Closing Remarks

Overview of Talks

Morning Session 1	
09:20-09:40	Dr. Benjamin Bugeat (University of Leicester)
09:40-10:00	Dr. Dongdong Xu (Aston University)
10:00-10:20	Mr. Niall Hanevy (Aston University)
10:20-10:40	Dr. Ali Haghiri (University of Leicester)
Morning Session 2	
11:00-11:20	Prof. Andrew McMullan (Aston University)
11:20-11:40	Dr. Sotos Generalis (Aston University)
11:40-12:00	Dr. Chandan Bose (University of Birmingham)
12:00-12:20	Mr. Larry Godwin (Aston University)
Afternoon Session 1	
14:00-14:20	Dr. Shailesh Naire (Keele University)
14:20-14:40	Dr. Patrick Geoghegan (Aston University)
14:40-15:00	Ms. Hibah Saddal (University of Birmingham)
15:00-15:20	Dr. Philip Trevelyan (Aston University)
Afternoon Session 2	
15:40-16:00	Dr. Mykyta Chubynsky (Coventry University)
16:00-16:20	Ms. Eleanor Barton (Aston University)
16:20-16:40	Mr. Michael Okolo (Loughborough University)

Morning Session 1 - Chair Prof. Stephen Garrett

Talk 1 – 09:20-09:40: Dr. Benjamin Bugeat (*University of Leicester*) - **A mechanism for the hydrodynamic instability in supercritical fluids**

B. Bugeat; P. C. Boldini; A. M. Hasan; R. Pecnik

A new hydrodynamic instability has recently been observed in supercritical fluids using numerical calculation based on linear stability theory (Ren et al. JFM 2019). In the presence of heat transfer, supercritical fluids can exhibit large variations of density and viscosity, resulting in shear flows that are strongly stratified. In this talk, a physical mechanism of this instability is proposed, based on the self-amplifying interaction of two vorticity waves. These two waves are themselves generated by two distinct mechanisms: one by shear effects – relying on the advection of the mean vorticity, and one by baroclinic effects, stemming from the large mean density variations of supercritical fluids that are misaligned with the disturbance pressure gradient.

Talk 2 – 09:40-10:00: Dr. Dongdong Xu (*Aston University*) - **Instability of streaky hypersonic boundary layers over cooled walls**

D. Xu; P. Ricco

We investigate the instability of streaks induced by free-stream vortical disturbances in cooled-wall hypersonic boundary layers. Three distinct types of instability modes are identified: modified Mack second modes, newly discovered secondary instability modes, and sinuous or varicose modes akin to those in incompressible boundary layers. A unique characteristic of the newly discovered secondary-instability modes is that they distort the streaks in the high-speed regions. The flow distortion caused by the hypersonic streaks destabilise the three-dimensional secondary streaks but attenuates the growth of the radiating Mack modes, which may effectively reduce the two-dimensional noise produced by the boundary layer. The numerical results indicate that the secondary instability of streaks happens in low and high speed regions.

Talk 3 – 10:00-10:20: Mr. Niall Hanevy (*Aston University*) - **Non Modal Instabilities on Stretching Sheets**

N. Hanevy; P. 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. 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, with critical Reynolds numbers reported which are orders of magnitude larger than for other boundary layer flows. Hence our current analysis looks for alternative energy growth mechanisms which may be more prominent in flow regimes of interest. We further investigate the role of additional, higher order stretching terms which arise through parallelisation of the base flow. In the modal analysis these terms were found to have modest quantitative effect. However, the non-modal mechanism is applicable at Reynolds numbers which are orders of magnitude smaller, justifying their inclusion compared to the standard Orr-Sommerfeld Squire squire formulation adopted in [3] for the Falkner-Skan boundary layer.

References:
[1] Sakiadis, AIChE J 7, 221 (1961).
[2] Griffiths et al., Phys. Fluids 33, 084106 (2021).
[3] Corbett and Bottaro, Phys. Fluids 12.1, 120-130 (2000).

Talk 4 – 10:20-10:40: Dr. Ali Haghiri (*University of Leicester*) - **Machine learning for improving RANS predictions of natural convection flows with high Rayleigh numbers**

A. Haghiri; X. Xu; R. Sandberg; K. Tanimoto; and T. Oda

Accurate prediction of natural convection heat transfer is of significance for investigating a wide range of engineering applications. This study presents data-driven modelling of the Reynolds stress tensor and turbulent heat flux vector for improving unsteady RANS (Reynolds-averaged Navier Stokes) predictions of natural convection problems. While RANS-based calculations are cost-effective, conventional models fail to deliver the requisite predictive precision for high-Rayleigh-number practical engineering flows. To rectify this limitation, a gene-expression programming (GEP)- based machine-learning technique was employed to train novel models. This investigation carries implications for cost reduction in the design process of thermal engineering applications involving high-Rayleigh-number natural convection flows.

Morning Session 2 - Chair Dr. James Jewkes

Talk 1 – 11:00-11:20: Prof. Andrew McMullan (*Aston University*) - **A numerical study of the initially-turbulent plane mixing layer**

W. A. McMullan; J. Mifsud; M. Angelino

The plane turbulent mixing layer remains a confoundingly challenging flow type. The sensitivity of the flow to its initial conditions, wide variations in growth rate, the downstream distance required to attain similarity, and the nature of the large-scale vortex structure in the layer, are a few of the outstanding issues. In an attempt to solve some of these problems we simulate a low-speed, incompressible mixing layer using Large Eddy Simulation. The mixing layer originates from a turbulent high-speed side boundary layer, and a laminar low-speed side boundary layer. The Reynolds number of the high-speed side boundary layer is 1350, and the maximum local Reynolds number of the mixing layer is 200,000, based on the velocity difference across the layer, and its visual thickness. We present some preliminary findings from the study.

Talk 2 – 11:20-11:40: Dr. Sotos Generalis (*Aston University*) - **The sequence of bifurcations approach in ubiquitous shear flows**

S. Generalis; T. Akinaga; P. Trevelyan

The mechanism of the sequence of bifurcations approach (SBA) of a Newtonian shear fluid flow from its laminar state to more complex flows will be described. The formulation includes fluid systems that are homogeneous in two spatial dimensions and in time and the SBA determines bifurcations through symmetry breaking and it will be shown that the solutions generated are periodic in the homogeneous dimensions and in time. The secondary solutions of these systems that bifurcate from the laminar (basic) flow are generically formed in terms of rolls or stripes, while higher order bifurcations are in the form of structures that are specific to the ubiquitous flow under consideration.

Talk 3 – 11:40-12:00: Dr. Chandan Bose (*University of Birmingham*) - **Bioinspired Fluid-Structure Interaction of Flexible Flaps and Foils**

C. Bose

The present talk will focus on the computational modelling of fluid-structure interactions involved in different flight mechanisms of small flyers in the low Reynolds number regime. Modern aviation faces significant challenges due to the unpredictable nature of operating air vehicles in unsteady environments, especially when the scale of environmental flow disturbances is comparable to the vehicle's airspeed. In such cases, a wind gust may give rise to significant flow separation over the vehicle's lift-generating surfaces. Wings with variable flexibility, emulating the adaptability found in natural flyers, have become a substantial area of research due to their potential to optimize aerodynamic performance across various flight conditions. This study aims to numerically investigate the response dynamics of flexible flaps and foils when subjected to canonical gust types, such as transverse gusts, vortex gusts, and streamwise gusts. The two-way coupled FSI simulations use a partitioned strong coupling approach. The incompressible flow is simulated using a finite volume approach-based Navier Stokes solver in OpenFOAM. A dynamic meshing strategy is employed based on quadratic inverse distance diffusion-based mesh morphing. The structural counterpart is simulated using the Finite Element Method-based solver CalculiX. The structure is governed by the St. Venant-Kirchhoff constitutive law. To facilitate the two-way coupling between the structural and the fluid solver, preCICE is used to aid in data exchange between the employed solvers. The Radial Basis Function interpolation technique facilitates the information exchange between the interface of fluid and structural domains. Strong coupling is achieved through the parallel implicit scheme with the IQN-ILS acceleration method. The findings of this study may be useful for the design of futuristic micro-aerial vehicles.

Talk 4 – 12:00-12:20: Mr. Larry Godwin (*Aston University*) - **Transition in Supercritical Convective Regime Of A Vertical Channel With Relative Moving Walls**

L. Godwin; P. Trevelyan; S. Generalis

The investigation of fluid flow evolution, particularly the transition from laminar to turbulent behavior, remains a central focus in scientific research. This interest arises from the complexity of the intricate dynamics in fluid bodies subjected to various disturbances, which are crucial for industries such as aerospace, automotive, computing infrastructure, and petrochemicals. Understanding these transition phases holds the potential for groundbreaking advancements in these fields.

This study explores the bifurcation sequence in a vertical, laterally heated channel flow transitioning from laminar to turbulent behavior, specifically focusing on cases involving relatively moving walls and a moderately high Prandtl number (Pr). The research reaffirms prior findings that the vortex induced by moving walls can trigger both oscillatory and monotonic instabilities under certain conditions. A key concern in this work is the monotonic instability, which arises from a growing thermal perturbation. This critical region is explored using the Sequence of Bifurcation (SOB) method and Direct Numerical Simulation (DNS).

The study investigates the secondary to higher-order states emerging from the observed monotonic bifurcation in linear stability analysis. Additionally, solutions for steady supercritical finite amplitudes are obtained for various wave numbers, providing valuable insights into the flow transition from laminar to turbulent states.

Afternoon Session 1 - Chair Prof. Andrew McMullan

Talk 1 – 14:00-14:20: Dr. Shailesh Naire (*Keele University*) - **Thermo-viscous fingering instability in cooling and spreading flows**

S. Naire

Molten fluid flows that cool as they spread are important in a wide variety of contexts, e.g., lava domes in geophysical flows and coolant in nuclear reactors. The interplay between the flow and cooling can also give rise to a variety of intriguing flow features and fingering instabilities. Motivated by the above, we consider theoretically a model system of a molten viscous drop extruding from a source and spreading over an inclined plane that is covered initially with a thin liquid precursor film. Lubrication theory is employed to model the one-dimensional spreading flow using coupled nonlinear evolution equations for the film thickness and temperature. The coupling between flow and cooling is via a constitutive relationship for the temperature-dependent viscosity. This model is parameterized by the heat transfer coefficients at both the drop-air and drop-substrate interfaces, the Péclet number, the viscosity-temperature coupling parameter and the substrate inclination angle. A systematic exploration of the parameter space reveals a variety of solutions illustrating the dynamics of a spreading flow undergoing cooling. These solutions are compared to a simpler model that results due to a further approximation of the temperature equation in the limit of small Péclet number. The stability of the one-dimensional solutions to small-amplitude variations in the thickness and temperature in the transverse direction is also investigated using linear stability and transient growth analysis, and numerical simulations. The existence of a thermo-viscous fingering instability is revealed. Two-dimensional numerical simulations confirm the stability analysis elucidating the underlying thermo-viscous mechanism.

Talk 2 – 14:20-14:40: Dr. Patrick Geoghegan (*Aston University*) - **CFD study of glaucoma surgical interventions**

N. Basson; W. Ho; S. Williams; P. Geoghegan

Trabeculectomy is the gold standard of glaucoma filtration surgery. The effectiveness of newer procedures, like non-penetrating deep sclerectomy (NPDS), is still being questioned. Comparative in vivo studies have been performed but are subject to varying eye geometry and unknown parameters. This study compares trabeculectomy and NPDS procedures computationally. An idealized 3D model of the anterior eye was created and permeability of the trabecular meshwork adjusted to simulate glaucomatous conditions. Then trabeculectomy and NPDS, as well as a modified NPDS procedure, were simulated. Trabeculectomy resulted in an intraocular pressure (IOP) decrease of 74.1%. However, the anterior chamber experienced low flow, especially at the corneal wall. This may explain why trabeculectomy often presents with complications. NPDS achieved an overall IOP reduction of 13.3%. The modified NPDS showed a comparable effectiveness to trabeculectomy with a 74.1% decrease. Results confirm that trabeculectomy is more effective at lowering IOP than NPDS. However modified NPDS results are comparable to trabeculectomy in terms of lowering IOP, indicating that the modification is crucial to the success of NPDS.

Talk 3 – 14:40-15:00: Ms. Hibah Saddal (*University of Birmingham*) - **Mathematical and Computational Modelling of Vortex-Induced Vibrations**

H. Saddal, C. Bose

Vortex-induced vibration (VIV) occurs when the shed vortices behind a bluff body exert oscillatory forces on flexible structures. VIV can limit the life expectancy of materials through fatigue damage and may even lead to catastrophic failures in engineering systems, such as chimneys, suspended cables for bridges, power transmission lines, marine risers, and towing cables, to name a few. This study aims to develop a mathematical model for VIV based on wake oscillator models, focusing on cylindrical structures subjected to an oncoming free-stream velocity. To complement the mathematical model, Computational Fluid Dynamics (CFD) simulations will be performed using the open-source library OpenFOAM, focusing on the detailed fluid-structure interaction and vortex-shedding phenomena under the same parameters and conditions as the mathematical model. These simulations will provide a comprehensive flow field analysis. The accuracy of both the mathematical model and the CFD simulations will be validated against experimental data from existing literature. The validation process will analyse both qualitative and quantitative aspects, including vibration amplitude, frequency, and phase differences. The numerical analysis will then be extended to the flow-induced vibration of tandem cylinders to gain insights into the wake-induced galloping of the rear cylinder. The present findings can benefit the design of engineering structures capable of withstanding these vibrations, ensuring safety and stability.

Talk 4 – 15:00-15:20: Dr. Philip Trevelyan (*Aston University*) - **Instabilities in a Porous Media Induced by a Non-monotonic Viscosity Profile**

A. Urooj; J. Kent; S. Generalis; P. Trevelyan

In this study we investigate a viscous instability in which a fluid containing a species, which affects the viscosity of the fluid, is injected into a two dimensional porous medium. The initial concentration of the species is linearly decreasing except for an isolated discontinuity where the concentration increases. Using the quasi-steady state approximation the stability of the system can be reduced to a coupled system of ODEs. The initial stability of the system can be reduced to a algebraic equation. As the species diffuses the instantaneous growth rates evolve in time. At later times, the stability of the system is obtained numerically. Although the discontinuity initially destabilises the system, eventually, after a finite amount of time, the system becomes stable. Numerical simulations were performed to validate the predictions made by the linear stability analysis.

Afternoon Session 2 - Chair Dr. Chandan Bose

Talk 1 – 15:40-16:00: Dr. Mykyta V. Chubynsky (*Coventry University*) - **A model of hysteresis in two-phase fluid flow in a fracture**

M. V. Chubynsky; R. Holtzman; M. Dentz; M. Moura; R. Planet; J. Ortin

Understanding multiphase flows in disordered porous and fractured media is important for applications such as water transport in soils and rocks, drying, and oil and gas production. One interesting aspect is interfacial instabilities leading to hysteresis (history dependence) and associated energy dissipation even in the quasistatic limit (infinitely slow changes of external conditions, such as the applied pressure). We study these phenomena in a simple model of a fracture: a tilted Hele-Shaw cell, in which one of the walls has bumps ("defects"). In the quasistatic limit the two-phase flow problem is reduced to finding the sequence of equilibrium shapes of the interface between the phases. A single defect can be "weak" (non-hysteretic, non-dissipative) if there is a single equilibrium state for any pressure difference, or "strong" (hysteretic, dissipative) otherwise. Defects "interact" due to capillarity, so that a pair of nearby weak defects can be strong. These properties can be understood in a linear 2D approximation, treating the interface as a 1D curve in a 2D plane, but I will also briefly discuss nonlinear and 3D effects, as well as going beyond quasistaticity without solving for the full fluid flow.

Talk 2 – 16:00-16:20: Ms. Eleanor Barton (*Aston University*) - **In vitro particle image velocimetry analysis of blood flow through endovascular grafts in the thoracic aorta**

E. Barton; J. Lowe; J. B. Souppez; J. Simms; M. Boumpouli; C. Maclean; L. Leslie; P. Geoghegan

Cardiovascular diseases affecting the aorta can be managed with endovascular grafts, which are surgically implanted to repair or replace damaged or diseased arteries. It is crucial that these grafts maintain a consistent flow to ensure effective perfusion of organs and tissues. This study focuses on the thoracic aorta, including the ascending and descending aorta and the aortic arch, which has three branches: the brachiocephalic artery (BA), left carotid artery (LCA), and left subclavian artery (LSA). The aim is to visualise and analyse flow patterns within three different rigid phantoms — one untreated, one with graft A, and one with graft B — to assess how anatomical variations, particularly in the BA branch, affect these flow fields. The rigid phantoms, designed based on existing literature, were created using the lost core casting technique with Sylgard 184 silicone. To match the phantoms' refractive index (n = 1.414) and replicate blood dynamics, a working fluid composed of water, glycerol, and urea was used. Particle image velocimetry (PIV) was employed to capture near-instantaneous velocity measurements of particles in the working fluid. A steady pump was utilised to circulate the working fluid at flow rates corresponding to key Reynolds numbers in the aorta's physiological waveform. Based on the PIV flow visualization results, we ascertain: (i) the impact of anatomical variations caused by the presence of an aortic graft on the thoracic aorta's flow; (ii) the areas of high and low flow velocity in the BA branch, as affected by each phantom's geometry; and (iii) the influence of Reynolds numbers for values of 4500 (peak), 3400 (mean), and 225 (for the reverse flow). These results offer experimental insights into the haemodynamics of both untreated and graft-treated thoracic aortas and may help inform future improvements in the design of branched aortic grafts.

Talk 3 – 16:20-16:40: Mr. Michael Okolo (*Loughborough University*) - **Numerical Modelling of Non-Premixed Hydrogen Blended Combustion in 3D-Combustor with Jets Optimisation**

M. E. Okolo; D. S. Adebayo; C. Oduoza

The United Nations Sustainable Development Goal (SDG) 7 emphasises the importance of transitioning to cleaner fuels for energy generation to mitigate the adverse effects of fossil fuel pollution on climate change. In response to these challenges, the integration of hydrogen into fuel mixtures has emerged as a promising solution, particularly with modular combustion systems. This study explores the optimisation of hydrogen and methane mixtures in a 3-D combustor with multiple jets, utilising Computational Fluid Dynamics (CFD) technique. The study models the operational and geometric characteristics of the combustor, focusing on variables such as fuel flow rate, jet number, and hydrogen concentration. The findings indicate a reasonable agreement between the numerical simulations and existing experimental data. The analysis revealed that of the 24, 16 and 8 jets that were investigated, the 16 jets provided an efficient and optimum combustion on all concentrations of hydrogen in the fuel mixture. While the 24-jet configuration yielded similar results, its shorter residence time in the mixture chamber impacted flame stability. Additionally, the study showed that increasing methane inlet velocity between 5 m/s and 10 m/s raised the combustion temperature, though a temperature drop occurred at 15 m/s. The analysis also revealed that higher hydrogen content in the fuel mixture leads to a gradual increase in NOx emissions. These results offer valuable insights for enhancing modular combustion systems, contributing to the advancement of clean energy technologies.

MFMM 2024 Participants

Name	Institution
Dr. Abhishek Kumar	Coventry University
Mr. Akshay Masetty	University of Birmingham
Dr. Ali Haghiri	University of Leicester
Prof. Andrew McMullan	Aston University
Dr. Benjamin Bugeat	University of Leicester
Mr. Bilal Alhawaisil	University of Leicester
Dr. Chandan Bose	University of Birmingham
Dr. Christopher Ellis	University of Nottingham
Dr. David Adebayo	Aston University
Mr. Dimitris Kyriakou	Coventry University
Dr. Dongdong Xu	Aston University
Ms. Eleanor Barton	Aston University
Ms. Hibah Saddal	University of Birmingham
Dr. Jacqueline Mifsud	University of Leicester
Dr. James Jewkes	University of Leicester
Mr. Jason Boateng	University of Leicester
Mr. Jason Ferguson	Aston University
Mr. Jeric Ng	Reading University
Mr. Larry Godwin	Aston University
Mr. Michael Okolo	Loughborough University
Dr. Mykyta Chubynsky	Coventry University
Dr. Nwabueze Emekwuru	Harper Adams University
Mr. Niall Hanevy	Aston University
Dr. Patrick Geoghegan	Aston University
Dr. Philip Trevelyan	Aston University
Ms. Priyadharshini Murugan	University of Birmingham
Dr. Shailesh Naire	Keele University
Ms. Sheila Bhatt	University of Cambridge
Dr. Sotos Generalis	Aston University
Prof. Stephen Garrett	Aston University
Dr. Svetlana Aleksandrova	University of Leicester
Mr. Xiao Shan	University of Leicester