WES Research Day 2023

At the

UNIVERSITY OF SOUTHAMPTON,
DEPARTMENT OF AERONAUTICAL AND ASTRONAUTICAL ENGINEERING
BOLDREWOOD INNOVATION CAMPUS, SO16 7QF

BUILDING 176, ROOM 1125

Monday 26th June 2023

ORGANISERS:

Christina Vanderwel and Zheng-Tong Xie, University of Southampton

WEBSITE:

https://personal.soton.ac.uk/zxie/WES/WESresearch2023.html

Programme

Monday 26th June, 2023

930-1000	**Registration / Coffee**		
1000-1030	**Welcome & Introduction – Christina Vanderwel and Stefano Cammelli**		
1030-1210	**Session 1 – Chairs: Abhishek Mishra & Kaveh Heshmati**		
	1	Measurements of scalar plume dispersion over a scaled water-channel model of Southampton	**Tomos Rich,** University of Southampton
	2	Using surface pressure and concentration correlations to improve urban air quality	**Joy Schmeer**, University of Surrey
	3	High-fidelity simulation of atmospheric flows	**Keertan Maskey**, University of Southampton
	4	Unsteady flow and dispersion in complex environments	**Silas Purja**, University of Southampton
	5	uDALES v2.0: towards exascale simulation of urban airflow, heat transfer, and pollutant dispersion	**Sam Owens**, Imperial College London
1210-1240	**Poster Quickfire Presentations – Chairs: Sam Owens & Tomos Rich**		
	Dominic Clements, University of Southampton; **Xiao Hu**, Imperial College London		
	Youssef Elashmawi, University of Southampton; **Steven Daniels,** AKT II		
	Donnchadh MacGarry, University of Southampton; **Matthew Coburn**, University of Southampton;		
1240-1320	**Lunch and Networking**		
1320-1500	**Session 2 – Chairs: Joy Schmeer & Keertan Maskey**		
	6	Improving accuracy of low-speed skin friction sensors in wind tunnel studies of pedestrian-level winds: a novel physics-guided general regression neural network (GRNN) calibration approach	**Zixiao Wang**, City, University of London
	7	Turbulent characteristics in the wake of tall building cluster	**Abhishek Mishra**, University of Surrey
	8	Effects of wind-induced vibrations on tall building occupants	**Kaveh Heshmati**, WSP
	9	Simulating bluff body aeroelasticity using Gaussian processes	**Igor Kavrakov**, University of Cambridge
	10	Effect of free-stream turbulence on wake flows of an array of square cylinders	**Saad Inam**, University of Southampton
1500-1530	**Coffee break / Committee Meeting**		
1530-1545	**Young Researcher Prize / Closing Remarks – Stefano Cammelli**		
1600-1700	**Lab Tours – Boldrewood Facilities; RJ Mitchell Wind Tunnel**		
1730	**Informal Social at Brewhouse & Kitchen (47 Highfield Ln, Southampton SO17 1QD)**		

Measurements of scalar plume dispersion over a scaled water-channel model of Southampton

Tomos Rich and Christina Vanderwel
Department of Aeronautics and Astronautics, University of Southampton

Air pollution remains a significant global concern, contributing to a considerable number of annual excess deaths. Accurate modeling of air pollution requires an understanding of scalar dispersion. An investigation into scalar dispersion over a 3D-printed model of Southampton city was carried out. This model was created to represent 1 km^2 of Southampton's city centre and the model scale is 1:1000. In this model, both terrain elevation and building height are represented, and the flow direction corresponds to the predominant wind direction of an onshore south-south-westerly.

Experimental measurements were made in the University of Southampton's Recirculating Water Tunnel. The incoming flow was conditioned to have a boundary layer thickness of approximately 300mm and a freestream flow velocity of 0.6 m/s. Using the maximum building height of 45 mm as the length-scale, the Reynolds number was 27,000.

In order to experimentally simulate an onshore pollutant plume from the docks, a scalar source was introduced 50mm upstream of the model. The scalar used was a fluorescent dye. This was so that both particle image velocimetry (PIV) and planar laser induced fluorescence (PLIF) could be used simultaneously to measure maps of flow velocity and concentration. PLIF data was post processed using custom Matlab code. In total, 25 cross-sections in various stream-wise, cross-stream, and wall-normal orientations were captured. This many planes were required as the plume spread significantly as it progressed downstream.

Mean concentration maps of the plume, and velocity maps of the flow over the city will be presented. It was found that mean plume dispersion direction diverged from the mean flow direction by approximately five degrees, and instead aligned closer to street canyon orientation.

Using surface pressure and concentration correlations to improve urban air quality

Joy Schmeer, Marco Placidi, Paul Hayden, and David M Birch
Centre for Aerodynamics and Environmental Flow, University of Surrey

Pollution levels in cities are an increasing concern for the respiratory health of those living and working in urban environments. To better understand how pollutants move around buildings, this research aims to simplify future wind tunnel studies of pollutant transport by developing a model called the Smart Cube and using this to identify and understand correlations between surface pressure and pollutant concentration. A correlation is expected as the transport equation and Bernoulli equation link concentration and pressure to velocity respectively.

Pollutant concentration is difficult and expensive to measure; meanwhile, measuring surface pressure is inexpensive, non-intrusive, and a well-established technique. If information about concentration can be inferred from pressure measurements, dispersion studies can be significantly simplified.

A dynamic pressure calibration technique has been developed to enable instantaneous and simultaneous pressure and concentration measurements around the Smart Cube model in the University of Surrey's Environmental Flow facility.

The Smart Cube is placed in a turbulent boundary layer in the EnFlo tunnel with an upstream pollutant source, as a single cube and as part of a cube array. A correlation is identified between surface pressure fields and concentration at one location adjacent to the cube measured with a Fast Flame Ionisation Detector. By conditionally sampling a series of concentration measurements based on differential pressure fluctuations in time, the lateral meandering of the plume can be characterised, and information about concentration therefore inferred from pressure measurements.

The results can be used to help design building ventilation strategies with a view to improving air quality.

High-fidelity simulation of atmospheric flows

Keertan K Maskey and Ralf Deiterding
Department of Aeronautics and Astronautics, University of Southampton

This project focuses on the release of chemical and biological hazards which can be detrimental to public safety. Examples could be an accidental release from nuclear installations or petrochemical plants. The current simple models have difficulties predicting realistic cases. LBM is used since it produces high-fidelity simulations within a reasonable timescale for hazard assessments. The LBM code is currently being developed on the AMROC framework which uses Adaptive Mesh Refinement. A combination of multi-distribution functions alongside scalar transport assumptions is used for modelling the cases. Cases have been conducted on single cube and cuboid arrays to simulate flow around buildings. The single cube cases are a 2.5m cube in uniform and specified boundary layer flow at various Reynolds number. The cuboid array cases are based on the DIPLOS project (www.diplos.org).

Unsteady flow and dispersion in complex environments

Silas Purja and Zheng-Tong Xie
Department of Aeronautics and Astronautics, University of Southampton

The atmospheric boundary layer undergoes continuous changes due to varying wind directions, speeds, and their interactions with the urban environment. These changing meteorological conditions can trigger non-stationary phenomena, impacting the aerodynamics of buildings, and pollutant dispersion. This project aims to better understand the non-stationary phenomena and focuses on associated uncertainties to enhance predictive capabilities, particularly in emergency response scenarios. By utilising computational methods and statistical analyses, the project plans to investigate the effects of meteorological condition changes on uncertainty in flow and dispersion prediction, and to explore the use of data-driven techniques to process meteorological data, enabling a rapid and reliable prediction of flow, turbulence and near-source dispersion without the need for a great number of high-fidelity CFD simulations. The project will give implications of assessing the suitability of existing emergency response tools, and suggest the information and data requirements for real-time short-distance dispersion simulations.

uDALES v2.0: towards exascale simulation of urban airflow, heat transfer, and pollutant dispersion

Sam Owens[1], Dipanjan Majumdar[1], Chris Wilson[1], Paul Bartholomew[2], and Maarten van Reeuwijk[1]
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uDALES is an open-source large-eddy simulation framework designed for outdoor flows in the built environment. It is capable of simulating airflow, sensible and latent heat transfer, and pollutant dispersion within the urban atmospheric boundary layer at microscale resolution. Buildings are resolved using the immersed boundary method (IBM), with wall functions for surface shear stresses and heat fluxes. The latter are two-way coupled with a three-dimensional surface energy balance model that is able to capture both man-made and vegetative materials.

Recently, the framework has been improved in two substantial ways that together constitute a new version: uDALES v2.0. Firstly, by using the library 2DECOMP&FFT it is now possible to decompose the domain in two dimensions for the purpose of parallelisation. This allows the user to fully utilise the resources available on supercomputers such as ARCHER2 and prepares the codebase for exascale computing. Secondly, the IBM has been extended so that the geometry can be specified independently of the Cartesian computational grid, meaning the immersed boundary need not sit on cell edges. This enables greater flexibility and fidelity in object representation, thus increasing the applicability to realistic cases.

This presentation outlines the physical and numerical considerations made in the model development and validates against several idealised studies. It also demonstrates the advantages offered by the new version by comparing the performance and scaling with the previous version, and by varying the numerical (but not physical) set-up of the validation cases such that the immersed boundary does not align with the computational grid.

Improving accuracy of low-speed skin friction sensors in wind tunnel studies of pedestrian-level winds: a novel physics-guided general regression neural network (GRNN) calibration approach

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Pedestrian-level wind comfort is an important factor to consider in urban planning and design, especially in areas comprising high-rise buildings and/or dense urban configurations. For complex projects involving extensive developments featuring unique and irregular building designs, wind tunnel experiments are generally required to provide qualitative and quantitative characterisation of the airflow around buildings and assess its impact on pedestrian wind comfort. In these experiments, low-speed omnidirectional skin friction sensors, originally developed by Irwin [1], are utilised to measure the wind flow at critical locations in scaled-down wind-tunnel urban models. However, despite their wide use, empirical evidence suggests that these sensors may not always provide sufficient accuracy, particularly when measuring turbulence intensity in regions with low wind speeds and high turbulence, such as in the front and wake areas of tall buildings (see [2]). To address this issue, this study presents a novel calibration approach that combines a physics-based model, derived by extending Irwin's original calibration equations [1], with an adaptive general regression neural network data-driven model to enhance the accuracy of the sensor for experimental investigations of pedestrian-level winds. Different experimental setups are established in the Industrial T7 wind tunnel facility at City, University of London to generate separate datasets for training the proposed hybrid model and for assessing its accuracy and generalisation performance. This is accomplished by calibrating sensors on an empty flat plate and subsequently testing the calibrated sensors using a benchmark urban model at a scale of 1:400. The results demonstrate that the proposed calibration approach significantly improves the accuracy of turbulence intensity measurements compared to previous works [],[2] , while also enhancing the accuracy of mean wind speed measurements.

References

[1] Irwin HPAH. 1981. A simple omnidirectional sensor for wind-tunnel studies of pedestrian-level winds. Journal of Wind Engineering and Industrial Aerodynamics, 7: 219—239.
[2] Wu HQ, Stathopoulos T. 1994. Further experiments on Irwin's surface wind sensor. Journal of Wind Engineering and Industrial Aerodynamics, 53: 441-452.

Turbulent characteristics in the wake of tall building cluster

Abhishek Mishra, Marco Placidi, Matteo Carpentieri and Alan Robins
Environmental Flow Research Centre, University of Surrey

Wind tunnel experiments have been conducted to understand the wake of tall building cluster in an atmospheric boundary layer. The buildings are arranged in a regular square array of different array size (2x2, 4x4 and 8x8), different spacing between buildings (equal to 0.5, 1 and 3 times of building width), and different wind angles (θ = 0^o, 22.5^o, and 45^o). The results show the existence of 3 different wake regimes based mean streamwise velocity profiles (U), each having distinct characteristics, (a) *Near wake regime* where individual wakes behind each building is observed, (b) *Transition wake regime* witnesses the merging of the individual wakes, and (c) *Global wake regime* which is similar to the wake of a single building. We propose distinct scaling laws for near wake and global wake regime. An interesting phenomenon which is observed in our study is the reduction in the turbulence (u_{rms} and v_{rms}) within the cluster region in the transition wake regime compared to freestream turbulence (12% at the centreline compared to 18% in the freestream region), followed by an increase in the magnitude in the global wake regime.

Effects of wind-induced vibrations on tall building occupants

Kaveh Heshmati
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PhD Graduate from Department of Architecture and Civil Engineering, University of Bath

Wind-induced vibrations might resonate with tall buildings which have inherently low natural frequencies. If that happens, it can cause discomfort, and even fear, in tall building occupants. This research investigated the effects of wind-induced vibrations on comfort and wellbeing of tall building occupants. The research was conducted in laboratory using VSimulator, the state-of-the-art motion simulator facility at the University of Bath. The VSimulator reproduced vibrations, specific to tall buildings, on the horizontal plane due to wind loads. The VSimulator's virtual Reality equipment resembled an open plan office with an outside view of a tall building.

A MATLAB-code was developed to generate realistic wind-induced vibration signals, typical of tall buildings, in both along-wind and crosswind directions. Different motion signals were generated with different natural frequencies, peak accelerations, and exposure durations using numerical wind engineering techniques/theories. The acceptability of vibration was evaluated by testing research participants under fully controlled motion conditions, with a level of details and breadth never done before, through measuring their comfort and wellbeing. The results suggested that wind-induced vibrations, which were deemed acceptable according to the current serviceability criteria, negatively affected comfort and wellbeing of participants. Peak acceleration was identified as the most influential motion characteristic affecting occupant comfort.

Simulating bluff body aeroelasticity using Gaussian Processes

Igor Kavrkaov
Department of Engineering, University of Cambridge

Wind-induced vibrations are commonly the primary design criterion for slender structures such as long-span bridges and tall towers. The study presents a data-driven model of the self-excited aerodynamic forces acting on bluff bodies. Gaussian Processes are employed as a reverse-engineering machine learning method to construct a nonlinear input/output system of the aerodynamic forces. The structural motion is considered as a lagged input to account for fluid memory, while aerodynamic forces serve as the output. To train the model, a bespoke method is introduced, facilitating an input broadband motion that excites aerodynamic nonlinearity in the forces through Computational Fluid Dynamics (CFD) simulations. The framework is initially verified using the analytical solution of a flat plate and then applied to a bridge deck based on CFD data. Both cases involve verifying the forces and aerodynamic parameters, such as aerostatic coefficients and flutter derivatives. Additionally, aeroelastic analyses are conducted by coupling the presented model with a structural mass-damper system to simulate flutter and post-flutter behavior. The results demonstrate the model's capability to capture specific aerodynamic features that are intractable for state-of-the-art linear aerodynamic models, such as higher-order harmonics in the forces and amplitude modulation during limit cycle oscillation. The framework holds potential for application in the structural analysis, design, and monitoring of slender line-like structures.

Effect of free-stream turbulence on wake flows of an array of square cylinders

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School of Mechanical Engineering Sciences, University of Surrey

The wake flow and aerodynamic behaviour of a cluster of two-dimensional sharp-edged bluff bodies are characterized by complex unsteady phenomena in both the near and far fields. However, a complete understanding of these characteristics is lacking, particularly regarding the effect of free-stream turbulence (FST). This paper reports the results from an ongoing FUTURE project (www.surrey.ac.uk/research-projects/future). Large Eddy Simulations (LES) are carried out in various flows (i.e., flow directions and turbulence quantities) for clusters of 2x2 and 4x4 aligned square cylinders with an infinite height separated by various spacings, i.e., 0.5*b*, *b*, 1.5*b*, 2*b*, where *b* is the cylinder width. For smooth flow, the wavelet analysis of the instantaneous velocity in the wake region shows that the characteristic length and time scales are close to cluster size 2*b* (Cung et al., 2023). This phenomena is known as the "cluster effect" which is more prominent for large incidence angles. For instance, in a 45° wind, the dominant dimensionless vortex shedding frequency (i.e., the Strouhal number *St*) of a 2x2 cluster scaled by *2b* is equal to that of a single square cylinder. For FST flows, the wavelet analysis shows that by increasing the FST integral length scales equal to or greater than the cluster size i.e., *3b*, the dimensionless dominant shedding frequency *St* is reduced evidently (by 6% at least) compared to smooth inflow. This finding highlights the crucial importance of the large FST integral scale. More results and discussion will be reported at the Research Day.

Reference:

Nguyen, CH, Inam S, Lasagna D, and Xie ZT, 2023. Aerodynamics and wake flow characteristics of a four-cylinder cluster. *Flow, Turbulence and Combustion*, 110: 1091-1115.