NWTF

NATIONAL WIND TUNNEL FACILITY

NWTF Conference 2025

Abstract Book

2nd - 3rd April 2025

The Exchange, University of Birmingham

Contents

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Welcome to the NWTF Conference 2025

Welcome to the second biennial NWTF conference at the Exchange, University of Birmingham. The conference aims to capture a snapshot of research at wind tunnels around the UK and internationally. This year we have a great selection of keynote speakers from ONERA, DNW, Rolls-Royce, Jaguar Land Rover, University of Oxford and Imperial College London.

The NWTF conference is a showcase of what research teams are focusing on and an overview of what industry needs. It's also a networking opportunity for industry and academic groups across all sectors including the CFD community. There is also the opportunity to review NWTF initiatives, for example the new facilities being funded by the UKRI infrastructure grant, training workshops, strategy groups such as the TRL5+ wind tunnels subgroup and the NWTF experimental database being developed by Loughborough University.

As mentioned above, this is only the second NWTF conference and we're very much open to ideas for future events. Do get in touch with any suggestions at admin@nwtf.ac.uk.

For more information on the NWTF, visit our website at www.NWTF.ac.uk.

We look forward to hosting many more of these events, bringing together industry and academia from around the UK and internationally. Enjoy!

Sponsors

We would like to thank our sponsors of this year's conference

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With a strong focus on research and development, they continuously refine their solutions to meet the high-performance demands of motorsport and aerospace engineering, providing accurate and reliable data for performance validation in the most demanding environments.

Key Information

Conference Registration and Query Desk Opening Hours

Day	**Opening Hours**
Wednesday 2nd April	9:30am – 6:30pm
Thursday 3rd April	8:30am – 4:30pm

Conference Social Events

Event	**Date/ Time**	**Venue**
Drinks Reception	Wednesday 2nd April 5:30pm – 6:30pm	Assembly Room Lounge
Buffet Dinner	Wednesday 2nd April 6:30pm – 9:00pm	Banking Hall, Ground Floor

Programme

Wednesday 2nd April

Time	Session	Presenter	Topic
09:30 - 10:30	**Conference Registration & Refreshments**	**Poster Session**	
10:30 - 10:35	**Welcome**	**Mike Jesson** University of Birmingham	
10:35 - 10:50	**About the NWTF**	**Jonathan Morrison** Imperial College, London	
10:50 - 11:45	**Session 1: NWTF Initiatives** Chair: Adrian Gaylard	**Paul White** Airbus **Gary Page** Loughborough University **Claire Mc Namara** NWTF **Chetan Jagadeesh** City, University of London	NWTF Tunnel Managers Forum (7 minutes) NWTF Experimental Database (7 minutes) NWTF Training Workshops (5 minutes) NWTF Researcher Mobility & Open Access Schemes (12 minutes)

		Mark Quinn The University of Manchester **Raul Vazquez-Diaz** Rolls-Royce	NWTF Optical Measurements Subgroup (12 minutes) NWTF Strategy Subgroup for TRL5+ Wind Tunnels (12 minutes)
11:45 - 12:15	**Coffee Break**	**Poster Session**	
12:15 - 13:00	**Keynote Speaker**	**Carsten Lenfers** **DNW** Intro: Jonathan Morrison	**K1** - Challenges, capabilities and future developments at the German-Dutch Wind Tunnels DNW
13:00 - 14:00	**Lunch**	**Poster Session**	
14:00 - 14:30	**Keynote Speaker**	**Christopher Sheaf** **Rolls-Royce** Intro: Raul Vazquez-Diaz	**K2** - Propulsion integration future challenges - role of wind tunnel testing

14:30 - 15:40	**Session 2: New NWTF+ Facilities** Chair: Jonathan Morrison	**Gary Page** Loughborough University	Spray Facility (ADAS) (7 minutes)
		Olivier Cadot University of Liverpool	Laminar Flow Facility (7 minutes)
		Shan Zhong The University of Manchester	Human-Flow Interactions Wind Tunnel (7 minutes)
		Murilo Cicolin University of Southampton	MIR Facility (7 minutes)
		Mahdi Azarpeyvand University of Bristol	Bristol Facilities: Boundary Layer Wind Tunnel, Propeller Testbed, Pressure Neutral Wind Tunnel (14 minutes)
		Liam Parker University of Oxford	**O1** - NWTF+ Icing at Altitude Tunnel – A Test Facility for SLW and Glaciated Icing Testing at the Oxford Thermofluids Institute (7 minutes)
		Nick Evans University of Oxford	**O2** - A Novel Wind Tunnel for Testing Heat Exchangers for Cryogenic Hydrogen Applications in Aviation (7 minutes)
		Morgan van Hoffen University of Oxford	Magnetic Suspension Balance System (MSBS) (7 minutes)
15:40 - 16:00	**Coffee Break**	**Poster Session**	
16:00 - 16:30	**Keynote Speaker**	**Adrian Gaylard** **JLR** Intro: Gary Page	**K3** - Integrating simulation and test in automotive aerodynamics

16:30 - 17:30	**Session 3: Joint Experimental and CFD Research/Impact & Exploitation of Wind Tunnel Data** Chair: Gary Page	**Olivier Cadot** University of Liverpool	**O3** - A complementary study of simulations and experiments to characterize the mean structure of the recirculatory flow at the rear of a 3D blunt body at different attitudes (12 minutes)
		Kevin Gouder Imperial College	**O4** - Integrated Wind Farm Control Interacting with Digital Twins (12 minutes)
		Matteo Carpentieri University of Surrey	**O5** - Urban Tall Building Clusters: Influence on Flow and Pollutant Dispersion (12 minutes)
		Dhamotharan Veerasamy Loughbourough University	**O6** - Standardizing Metadata for Experimental Aerodynamic Databases: Enhancing Accessibility, Usability, and Research Impact (12 minutes)
		Will Dixon Loughborough University	**O7** - Aerodynamic Analysis of Racing Wheelchair Athletes: Integrating Full-Scale and Scale Model Wind Tunnel Testing (12 minutes)
17:30	**Close**	**Mike Jesson** University of Birmingham	
17:30 - 18:30	**Drinks Reception (Assembly Room Lounge)**		
18:30 - 21:00	**Hot Buffet Bar (Banking Hall)**		

Thursday 3rd April

Time	Session	Presenter	Topic
08:30 - 09:30	**Conference Registration & Refreshments**		
09:30 - 09:35	**Welcome**	**Mike Jesson** University of Birmingham	
09:35 - 10:35	**Session 4: Novel Experimental Techniques** Chair: Mark Quinn	**David Birch** University of Surrey **Doug Greenwell** Cranfield and AerodynamiQ **David Soper** University of Birmingham **Dimitrios Tsioumanis** The University of Manchester **Oscar Jones** University of Oxford	**O8** - New developments and applications in flow instrumentation technology (12 minutes) **O9** - Adaptive Test Management – Moving on from OFAT and DOE (12 minutes) **O10** - Unlocking future high-speed rail freight transportation capability through aerodynamics (12 minutes) **O11** - Testing of Single Photon Avalanche Diode Cameras for pressure-sensitive paint measurements (12 minutes) **O12** - Development of binary pressure-sensitive paint for short duration hypersonic wind tunnels (12 minutes)
10:35 - 11:00	**Coffee Break**	**Poster Session**	

11:00 - 11:45	**Keynote Speaker**	**Benjamin Leclaire** **ONERA** Intro: Olivier Cadot	**K4** - Wind tunnels and metrologies at ONERA/DAAA: an overview through recent research projects
11:45 - 12:30	**Session 5: Low Speed Wind Tunnel Testing** Chair: Dan Butcher	**Chetan Jagadeesh** City, University of London **Sung Tyaek Go** University of Bristol **Esmaeel Masoudi** University of Bristol **Nurul Asyikin Abu Bakar** University of Bristol	**O13** - The influence of gaps on boundary layer transition (12 minutes) **O14** - Aeroacoustic Wind Tunnel experiments on propeller noise at the University of Bristol (12 minutes) **O15** - Aeroacoustic Wind Tunnel experiments on static and dynamically oscillation aerofoils at the University of Bristol (12 minutes) **O16** - Simulation of atmospheric boundary layer and pollutant dispersion in the wind tunnel facility at University of Bristol (12 minutes)
12:30 - 13:30	**Lunch**	**Poster Session**	
13:30 - 14:00	**Keynote Speaker**	**Matt McGilvray** **University of Oxford** Intro: Jonathan Morrison	**K5** - High speed wind tunnel scoping at Oxford
14:00 - 14:30	**Session 6: High Speed Wind Tunnel Testing** Chair: Shan Zhong	**Muhammet Tayyip Gurbuz** The University of Manchester	**O17** - Investigation of Aerodynamic Flow Structures in Mach 5 Inlet Buzz Bi-Stability (12 minutes)

		Ramachandra Kannan University of Cambridge	**O18** - Influence of Downstream Waves on Impinging Shock-Induced Separation (12 minutes)
14:30 - 15:00	**Coffee Break**	**Poster Session**	
15:00 - 15:30	**Keynote Speaker**	**Isabella Fumarola** **Imperial College** Intro: Jonathan Morrison	**K6** - AI and Machine Learning in Wind tunnels. Reinforcement learning for drag reduction of heavy road vehicles with autonomous dynamic flaps
15:30 - 16:05	**Session 7: Low Speed Wind Tunnel Testing** Chair: Chetan Jagadeesh	**Alan Robins** University of Surrey	**O19** - Mapping the effects of ozone pollution and mixing on floral odour plumes and their impact on plant-pollinator interactions (12 minutes)
		Alexander Croke University of Glasgow	**O20** - Measurements of Propeller Aerodynamic and Aeroelastic Behaviour Under Stalled Conditions (12 minutes)
		William McArdle Imperial College	**O21** - Development of Aircraft Half-Model Testing at the 10x5 Wind Tunnel (12 minutes)
16:05 - 16:15	**Close**	**Jonathan Morrison** Imperial College	

Keynote Speakers

Dr.-Ing. Carsten Lenfers

Head of Low-Speed Wind Tunnel, Braunschweig, DNW

Presentation Title: Challenges, capabilities and future developments at the German- Dutch Wind Tunnels DNW

Carsten Lenfers has led the aeroacoustic low speed wind tunnel at the German-Dutch Wind Tunnels (DNW-NWB) located in Braunschweig, Germany since 2024. His team is responsible for project acquisition and the execution of wind tunnel tests and all aspects of facility operation. He and his team are constantly pursuing the enhancement of the facility and simulation techniques. From 2016 until its reorganisation in 2024 he headed the department "Project Aerodynamics Group" within DNW. He was responsible for the acquisition and execution of wind tunnel tests at the six facilities spread over three sites in Germany. He started his engagement with the DNW foundation in 2015 as deputy head of the aeroacoustic low speed wind tunnel in Braunschweig (DNW-NWB). In 2020 Carsten Lenfers received his doctoral degree from the Technical University Braunschweig. He joined the German Aerospace Centre (DLR) in 2008 and worked as research scientist at the institute of aerodynamics and flow technology.

Christopher Sheaf

Installations Aerodynamics Senior Specialist, Rolls-Royce

Presentation Title: Propulsion integration future challenges - role of wind tunnel testing

Christopher Sheaf is a Rolls-Royce Senior Installations Aerodynamics Specialist, specialising in civil intake, exhaust, and nacelle aerodynamics. He received an honours degree in Aeronautical Engineering from City University, London, and joined Rolls-Royce upon graduation. He has worked in the Rolls-Royce Installation Aerodynamics Department for over 35 years, was appointed to a Senior Specialist Role in 2023. During his career, he has been responsible for supporting intake and nacelle aerodynamic design evaluation; and wind tunnel and engine testing for a range of Rolls-Royce civil engine programmes. Christopher has extensive experience of leading and participating in wind tunnel testing, in a significant number of facilities.

His current role includes responsibilities for co-ordinating the company's Installations Aerodynamic research. This included taking a leading role in UK (ATI) and EU R&T CleanSky2 programmes. He is a member of the Royal Aeronautical Society.

Dr Adrian Gaylard

Technical Specialist, Aerodynamics Research & Development, JLR

Presentation Title: Integrating simulation and test in automotive aerodynamics

Dr Adrian Gaylard is the Technical Specialist for Aerodynamics Research & Development at Jaguar Land Rover (JLR). He leads all research activities aerodynamics, aeroacoustics and surface contamination (exterior water management & soiling).

After a degree in Physics and Maths from Leicester Polytechnic (1987), Adrian joined British Rail's Research Division, making early applications of CFD to trains. In 1996 he moved into the automotive sector, joining MIRA, and worked on a wide range of aerodynamics projects, subsequently joining Jaguar Land Rover in 2001.

Adrian chairs the UK's National Wind Tunnel Facility Advisory Board, is a Visiting Fellow in Vehicle Aerodynamics at Loughborough University, a Board Member of the European Car Aerodynamics Research Association (ECARA). He is also a Fellow of the Institute of Physics, a Chartered Physicist and Chartered Engineer.

Adrian has a doctorate in unsteady flow, vehicle surface contamination and aerodynamic drag from the University of Warwick.

Dr Benjamin Leclaire

Head of Metrology, Data Assimilation and Flow Physics Team, ONERA

Presentation Title: Wind-tunnels and metrologies at ONERA/DAAA: an overview through recent research projects

Dr. Benjamin Leclaire heads since 2018 the Metrology, Data assimilation and Flow physics unit at the Department of Aerodynamics, Aeroelasticity and Acoustics, at ONERA, Meudon, France. His team is in charge of developing and using new measurement approaches for wind-tunnel tests, based on sensors (pressure, temperature, forces) and on optical techniques (PIV, PSP and TSP, IR thermography, BOS).

B. Leclaire is also an assistant professor at Ecole Polytechnique, within the Institute Polytechnique de Paris. His personal research focuses primarily on volumetric particle tracking velocimetry methods, with contributions in related data assimilation techniques, as-well as on mixing layer and jet flow physics. He is one of the co-organizers of the currently running 2nd Challenge on Lagrangian Particle Tracking and Data Assimilation.

Professor Matthew McGilvray

Professor of Engineering Science, University of Oxford

Presentation Title: High speed wind tunnel scoping at Oxford

Professor Matthew McGilvray is a Professor of Engineering Science at the University of Oxford. He studied at the University of Queensland for both his Bachelors (2003) and PhD (2008) in aerospace engineering and has since established two research groups at Oxford focussed on particle deposition in turbomachinery and high-speed aerothermodynamics. Professor McGilvray also heads the UK Centre of Excellence in Hypersonics Science and Technology and has led the development of multiple large scale hypersonic wind tunnels, including the Oxford High Density Tunnel and the Oxford T6 Stalker Tunnel, as part of the UK's National Wind Tunnel Facility. Professor McGilvray was awarded the Royal Academy of Engineering/MoD Research Chair in Hypersonic vehicles in 2021. He now leads the UK Hypersonic Doctoral Training network, which is in its first year of operation.

Dr Isabella Fumarola

Research Fellow, Imperial College London

Presentation Title: AI and machine learning in wind-tunnels. Reinforcement learning for drag reduction of heavy road vehicles with autonomous dynamic flaps

Dr Isabella Fumarola is a Research Fellow in the Department of Aeronautics at Imperial College London. She has been at Imperial since 2020, previously as Research Associate, working in experimental aerodynamics. She obtained a PhD from City, University of London on the subject of laminar to turbulent transition. Her main research topic is flow-control techniques to reduce drag in either on turbulent boundary layer or on bluff body wakes. She currently works for the AI4NZ project leading the experimental campaigns in the wind tunnel on a scaled model of a truck equipped with innovate autonomous flaps at the rear of the model. The flaps are moved by a Reinforcement Learning algorithm with the aim to reduce the drag force generated by the moving truck, and therefore reduce the fuel consumption.

Keynote Abstracts

K1

Challenges, capabilities and future developments at the German-Dutch Wind Tunnels DNW

Dr Carsten Lenfers[1]
[1]German-Dutch Wind Tunnels DNW, Germany

The German-Dutch Wind Tunnels DNW is one of Europe's most advanced and specialised organisations for wind tunnel testing. The nearly 50-year-old collaboration between the two nations and DNW's parent companies DLR and NLR has contributed and will contribute to the success of the European aeronautical industry.

The keynote will depict the DNW organisation in its market for aeroacoustic and aerodynamic wind tunnel testing and elaborate on the current challenges that need to be mastered. The enabling tools for DNW to meet these challenges can be found in the key assets of the organisation. One of the key assets of DNW is its portfolio of complementary wind tunnel facilities that are able to cover a large range of Reynolds and Mach number. The second part of the keynote will focus on the capabilities of these facilities.

To maintain its position on the market and meet the future requirements of DNW's customers a number of needed developments have been identified within the organisation. The development projects to be presented are either recently finished or currently executed. Among these there are:

Electric propulsion simulation
The EPS simulation technique will build an alternative to the well-established TPS technique (turbine powered simulator). The currently developed electric powered simulator (EPS) will represent an ultra-high bypass fan engine (UHBR). Using a high power dense electric motor, it offers a higher flexibility for installation and new opportunities for the aeroacoustic analysis of engine/airframe installation setups.

Automotive testing according to WLTP
The requirements and methods for testing new vehicles for approval by the authorities as well as vehicles in use have been tightened and are formulated in the WLTP (Worldwide Harmonised Light Vehicle Test Procedure) that is mandatory for all new passenger cars (since 2018) and commercial vehicles (since 2019). A significant investment by the German and Dutch governments resulting in a so called 5-belt-system that was set up in the large low speed facility (DNW-LLF) enabling DNW to supply customers from authorities and industry to test the needed aerodynamic and rolling resistance of a vehicle to comply with WLTP.

High accurate and effective model attitude sweeps
The efficient production of accurate stability and control datasets as needed especially for highly manoeuvrable aircraft requires the possibility to precisely adjust the attitude of the wind tunnel model while it is encountering high aerodynamic loads. Therefore, a stereo optical system is set up to deliver the exact position of the wind tunnel model inside the test section. This data serves as input for a control mechanism adjusting the model to the set value. This in the loop control allows for the full compensation of balance and sting deformation.

K2

Propulsion Integration Future Challenges. The Role of Wind Tunnel Testing.

Mr Christopher Sheaf[1]
[1]Rolls-Royce Plc, Derby, United Kingdom

Reducing fuel burn and CO2 emissions to meet the future EU ACARE Flightpath 2050 environmental goals is a major factor in the design of next generation of aircraft propulsion systems. Adoption of an UltraFan® lower specific thrust engine cycle to maximise propulsive efficiency leads to an increase in engine fan diameter. To maximise benefits of the UltraFan® compact low drag advanced installed powerplant designs are required. This has required the application of advanced design methods to identify new novel Nacelle, intake, and exhaust technology, which feature complex flow physics.

Wind tunnel test programmes, featuring new test rigs with high levels of instrumentation have been utilised to advance the current 'state of the art'; and explore novel design opportunities. The test phase has provided a 'data rich' source of validation data for complex aerodynamic phenomena, for benchmarking design and analysis codes post test.

This presentation will show how the expertise in the wind tunnel test community has provided valuable data to enhanced understanding of novel design space for compact powerplants.

K3

Integrating simulation and test in automotive aerodynamics

Dr Adrian Gaylard

Historically the wind tunnel has been the primary aerodynamics development tool for cars. Over the years, these facilities have become larger and more elaborate, better representing the flow around a moving vehicle. Over the last 30 years numerical simulation has become an increasingly useful development tool, particularly in the early stages of projects. Automotive aerodynamicists have been wrestling with how to combine these tools to best effect.

This presentation presents a view of this topic through the prism of the development of the current Land Rover Defender. It reviews a traditional "swim lane" view of the use of these tools and proposes a more realistic integrated model for combining test and simulation. This is illustrated with examples taken from the development of the Defender, highlighting where each of these tools both leads and supports the other.

Finally, it reflects on two challenges, one longstanding and the other emerging: (1) how much of the on-road environment should we bring into our wind tunnels and CFD models? (2) How should we integrate AI/ML methods into this process?

K4

Wind tunnels and metrologies at ONERA/DAAA: an overview through recent research projects

Dr Benjamin Leclaire

Located in the Paris and Lille regions, the Department of Aerodynamics, Aeroelasticity and Acoustics (DAAA) of ONERA operates a large variety of wind-tunnels, ranging from low-speed, research-oriented, to transonic and hypersonic semi-industrial facilities. This presentation will explore various recent research projects conducted in these wind-tunnels, so as to describe their capacities in terms of flow regimes and configurations, alongside with the research and development in accompanying metrologies. Examples will encompass wing tip vortex dynamics, interaction of vortical structures in jets, oscillatory motion of an aeroelastic wing in transonic buffet, vortex breakdown over a fighter aircraft, and hypersonic boundary layer transition, among others. Associated metrological developments will cover surface measurements such as unsteady DIC, unsteady PSP and IR thermography, as well as field techniques such as PIV, real-time BOS, volumetric PTV and thermometric PTV.

K5

Development of UK High TRL Hypersonic Wind Tunnels

Prof Matthew Mcgilvray[1]
[1]University Of Oxford, United Kingdom

High speed vehicles approaching hypersonic speeds and beyond pose significant engineering challenges in areas such as aerothermodynamics, propulsion systems, thermal-structural performance, and material durability. These vehicles require robust experimental testing facilities to develop sub-systems and full systems. Hypersonic tunnels are notoriously difficult due to the large engineering challenges in their design and extreme power requirements. Additionally, no single facility can cover all requirements. Thus, hypersonic T&E is typically complemented by numerical simulations and flight tests, the latter of which are often prohibitively costly and complex. Existing UK hypersonic test facilities lack the capability to replicate all of the extreme conditions of hypersonic flight needed for high TRL qualification. This talk will explore the development of high TRL hypersonic test facilities in the UK.

K6

Reinforcement learning for drag reduction of heavy road vehicles with autonomous dynamic flaps

Dr Isabella Fumarola[1], Dr Xianyang Jiang[1], Mr Junjie Zhang[1], Dr Max Weissenbacher[1], Dr Giorgios Rigas[1]
[1]Imperial College London, London, United Kingdom

Carbon dioxide (CO2) emissions from transport account for around one fifth of global CO2 emissions. Among the different means of transport, 29% of total emissions come from trucks carrying freight. All means of transport are subject to aerodynamic losses as a consequence of interacting with a fluid (whether air or water). Therefore, regardless of the energy conversion system (batteries, carbon fuel or hydrogen), a key aspect to achieve Net Zero by 2050 is to identify novel technologies to improve the aerodynamic efficiency of transport, and thus the overall energy efficiency.

The recent development of Artificial Intelligence (AI) entails a revolution in the subfield of Reinforcement Learning (RL), offering a new avenue for the discovery of intelligent mechanisms. These control mechanisms are designed to take specific actions to obtain a desired effect, such as increasing energy efficiency, based on observed control parameters. To that end, the primary challenges of aerodynamics are the complexity of simulating the high-dimensional flow around a vehicle in an uncertain environment and the partial observability of the high-dimensional flow states. The latter issue results from the constraint that sensors must be mounted on the vehicle for practical applications resulting in a partial observation of the flow dynamics around the vehicle.

This project aims to demonstrate the applicability of RL towards improving the aerodynamic efficiency of road vehicles. As a test case, we use a realistic scaled model of a truck equipped with newly designed intelligent flaps. The model is mounted in the 10x5 Wind Tunnel at Imperial College London, where we can reproduce the real-world environment the truck would encounter on the road thanks to a movable ground.

Four moving flaps, driven by four independent motors, are mounted on the sides and on the top and bottom of the rear of the vehicle. The role of the flaps is to modify the unsteady wake developing behind the truck, which contributes the most in the aerodynamic drag; it has been estimated that 10% in drag reduction corresponds to 5% fuel consumption reduction. The movement of the flaps is controlled by the RL algorithm based on the pressure measured at the rear face of the truck.
As mentioned above, one of the challenges is the difficulty of measuring the flow state in real time around the vehicle. In our test case, that would require additionally installing sensors at a certain distance behind the truck limiting the application to realistic cases of industrial relevance. We demonstrate that our algorithm efficiently controls the flaps' motion in a realistic configuration where the flow is only partially observed. In particular, the control increases the back pressure and alleviates the unsteadiness of the wake.

Further development will investigate the adaptability of the controller to variable environmental conditions, for instance variable wind direction. These results not only provide a novel solution to reduce drag on heavy road vehicles, but also demonstrate the impact of AI on driving decision making for improved aerodynamic efficiency in transport.

Oral Presentations

O1

NWTF+ Icing at Altitude Tunnel – A Test Facility for SLW and Glaciated Icing Testing at the Oxford Thermofluids Institute

Mr Liam Parker[1], Prof. Matthew McGilvray[1], A/Prof. David Gillespie[1,]
[1]University Of Oxford, Oxford, United Kingdom

The University of Oxford in partnership with NWTF+ and EPSRC are developing an icing at altitude wind tunnel facility housed in the Oxford Thermofluids Institute.

At high altitude water may exist as ice crystals and or super-cooled water droplets: both cause significant risk to aircraft. Externally icing is primarily driven by the nucleation of icing from droplets on the airframe and control surfaces, external probes and the inlet of engines and propellers. Glaciated icing may occur on aircraft windows, heated probes, and within the engine core. Particles range in size from <1 to >1000 µm. Damage arises from the blocking of cooling systems, engine pressure and temperature sensors; or from accretion within the core gas path. Depositions affect heat transfer properties and engine operability. Deposits may cause blockage or shed within the core gas path, causing engine flameout, loss of thrust, vibration or downstream damage. New engine architectures (Ultra High Bypass, geared turbo fan or open rotor) mean that engine certification for the particular risks posed by glaciated icing can no longer rely on the previous experience of OEMs existing products. New designs are likely more susceptible to icing through their higher porosity at intake, lower fan speeds, heat addition from gearboxes, and large changes of radius of internal components.

Oxford's new NWTF+ icing wind tunnel focuses on the higher altitude icing exposure range. Its primary aim is to allow the validation of modelling tools, the verification of flight probes and small engine components. For larger engines it enables the testing of engine subsystems with surfaces and conditions representative of those where accretion and shedding occurs. Icing conditions experienced within the engine intake, core and cooling systems have localised evaporation and convection properties specific to compressor systems at high altitude cruise and descent. These are complex three-dimensional flows with transient behaviours due to strong cooling, surface topology changes and highly turbulent, wall-bounded flow. The tunnel will allow ice particle transport, surface deposition and shedding to be examined; employ the group's bespoke optical accretion measurement techniques, thin film heat transfer instrumentation and icing characterisation probes. Inhouse modelling capabilities of the group will be available to clients to help understand the outcome of experimental campaigns.

The work builds on previous experimental and modelling experience of workers within the OTI, collaborating with other researchers worldwide. Ice crystal icing experiments are uniquely complex. They require ice crystal seeding producing cloud formed non-spherical shapes, humidity control reflective of compressor gas path operating conditions and optical measurements systems for particle size, ice accretion measurements. Lastly, gas path measurements of air, ice, water and vapour produce an interference effect which is unique to these multi-phase flows.

The Oxford tunnel specification comprises: a continuous open loop, humidity controlled, wind tunnel arrangement within an altitude chamber which also houses conventional and optical instrumentation.

Glaciated ice of prescribed size distribution is provided using an ice grinder. This facility development is underway with commissioning expected in 2028/9.

O2

A Novel Wind Tunnel for Testing Heat Exchangers for Cryogenic Hydrogen Applications in Aviation

Mr Nick Evans[1], Professor John Coull[1], Dr Mohamed Aly[2], Professor Peter Ireland[1,]
[1]University of Oxford, United Kingdom, [2]Rolls Royce, United Kingdom

The University of Oxford is developing a new test facility with the unique capability of being able to test hydrogen thermal systems for aircraft engines. The Liquid Hydrogen enabled wind-tunnel will be capable of Mach 0.6 and 50 kg/s with a test section area up to approximately 0.38m2 for variable Reynolds number conditions. The tunnel will be able to produce flow conditions comparable to a section of the bypass in a gas turbine and be able to test engine scale components. This new facility will include a self-reliant capability for producing and storing hydrogen as both a gas and a liquid on demand via an onsite electrolyser and liquefier respectively. These can then be supplied under engine representative pressures and mass flow rates to support the development of smaller, novel prototypes through to larger, full-size components. This presentation will describe the functional design of the tunnel gas path and the processes used in the design of the hydrogen facility.

O3

A complementary study of simulations and experiments to characterize the mean structure of the recirculatory flow at the rear of a 3D blunt body at different attitudes

Mr Olivier Cadot[1], Mr Yajun Fan[1], Mr Chao Xia[2], Mr Gugllielmo Minelli[2], Mrs Simone Sebben[2] [1]University Of Liverpool, United Kingdom, [2]University of Chalmers, Sweden

The recirculating flow at the rear of a flat-base three-dimensional body with ground proximity is investigated for different body attitudes defined by the pitch angle varying in the range $-1.5^\circ<\alpha<+2.6^\circ$ and the yaw angle in the range $0^\circ<\beta<+12^\circ$. Experiments measuring the three-components of the mean velocity field in two perpendicular planes intersecting the recirculation area as well as the base pressure distribution are conducted for 50 different attitudes. They provide a clear correlation between the orientation of the spatially averaged reversed flow and the gradient at the centre of the base pressure distribution. Both vectors are found to be in a same \textit{w-}plane of which the azimuthal position changes with the body attitude due to either the flow orientation at the base separation or sometimes to a ground separation for large nose-up pitch. LES simulations of the same geometry realized for 10 attitudes show satisfactory agreement with the force coefficients measured in the experiment. Base flow variations induced by attitude changes are also well captured, particularly that of the \textit{w-}plane. The full three-dimensional simulation data are used to show that the inner structure of the separation bubble is always a tilted recirculation torus, where the tilt orientation is given by the base pressure gradient. At the bubble closure, a pair of longitudinal vortices symmetrically located on both side of the \textit{w-}plane are permanently observed with circulations consistent to the circulation of the dividing streamline separation in the \textit{w-}plane. At small yaw, this circulation is created by the wake steady instability.

O4

Integrated Wind Farm Control Interacting with Digital Twins

Dr Kevin Gouder[1], Dr Craig Thompson[1], Professor Mike Graham[1,]
[1]Imperial College, London, United Kingdom

We present details of an ongoing project, ICONIC, funded by the EU's Horizon. ICONIC – "Smart, Aware, Integrated Wind Farm Control Interacting with Digital Twins" is developing innovative digital and physical tools to achieve fundamental breakthroughs for the integrated control of wind farms. Simultaneous sparse and high-resolution Particle Image Velocimetry (PIV) measurements in the wake of an instrumented wind turbine immersed in a simulated marine atmospheric boundary layer (ABL) are being taken in the primary test section of the 10x5 Wind Tunnel. The instrumented wind turbine developed specifically for this project is capable of speed, torque, inflow-factor and yaw control, and has a power coefficient at rated wind speed, similar to that of full-scale wind turbines on a wind farm of an ICONIC project partner. The flow field and turbine performance wind tunnel data contribute to Physics-Informed Neural Network (PINN) digital twin training for real-time flow reconstruction of turbine wake-ABL interactions and wake trajectory. A real-time control experiment is subsequently planned to happen in the 10x5 Wind Tunnel's much larger secondary test section, consisting of an array of six instrumented wind turbines under coordinated control. The experiment would utilise control strategies developed by project partners, as well as real time flow reconstruction of turbine inflow conditions, and demonstrate the efficacy of coordinated control, increasing total farm power output and attenuating unsteady loads on individual turbines. This is achieved through one or a combination of the speed, torque, inflow-factor and yaw control variables, steering the individual wakes to miss turbines in downwind rows.

O5

Urban Tall Building Clusters: Influence on Flow and Pollutant Dispersion

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Accommodating the growing population in urban areas is challenging. Urban areas comprise more than 50% of the world's human population [1] on a tiny fraction of roughly 3% [2] of the total landmass. As a consequence tall buildings are being built both in isolation and in clusters. Their interaction with the atmospheric flow can impact pedestrian wind comfort, pollutant dispersion, street-level ventilation, and surface temperature. The study of the flow and dispersion characteristics in and around the tall building clusters is essential to developing more efficient atmospheric dispersion modelling systems and is crucial for public health and the development of sustainable cities. The FUTURE project (https://www.surrey.ac.uk/research-projects/future) aims to understand these effects. Wind tunnel experiments on scale models of idealised tall buildings were conducted in the EnFlo wind tunnel at the University of Surrey. Various test cases with different cluster sizes (N), building heights (H_B), spacing between the buildings (W_S), wind angles (θ), atmospheric stability (neutral and stable stratification), ground roughness conditions (representing suburban and urban areas), and location of the ground level pollutant source were considered (see [3, 4]). This talk will focus on the effect of atmospheric thermal stability and background roughness on the wake and plume development. Results show that the pollutant dispersion around tall building clusters is influenced by the source location with respect to the cluster. For a scalar point source located at the cluster centre, a bimodal distribution of the lateral concentration is observed in the near wake region when measured at the building mid-height (z=0.5H_B). The plume growth has been observed to be logarithmic for different cluster sizes [5]. In the case of a weakly-stratified stable boundary layer, the mechanical turbulence generated by the building wake dominates over the buoyant production and the wake is comparable to that of the neutral boundary layer case [6]. The vortices generated from the base of the building result in an upwash of the colder fluid, leading to a decrease in temperature at the ground level downstream. Since tall buildings in cities are mostly surrounded by low-rise buildings, our current work aims to understand the effect of tall building clusters in different urban arrays. The behaviour of the wake and pollutant dispersion will be analysed. In the future, the analysis will be extended to a realistic city configuration (e.g. City of London).

References

UN DESA (2018). 2018 Revision of the World Urbanization Prospects

Liu et al. (2014). Landscape Ecology 29:763

Mishra et al. (2023). Boundary-Layer Meteorology 189:163

Mishra et al. (2024). Flow 4:E15

Bi et al. (2024). 14th WES Conference Procs:157

Mishra et al. (2024). 14th WES Conference Procs: 153"

O6

Standardizing Metadata for Experimental Aerodynamic Databases: Enhancing Accessibility, Usability, and Research Impact

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Developing comprehensive experimental aerodynamic databases is crucial for preserving expensive experimental results and advancing aerodynamics research. However, the utility and robustness of these databases are often hindered by the lack of well-organized and consistent metadata, which is essential for accurate data interpretation, validation, and reproducibility. In this presentation we will demonstrate the importance of metadata in the development of experimental aerodynamic databases, highlight the common shortcomings in existing datasets, and provide practical guidance on addressing these issues to enhance the quality and applicability of aerodynamic data.

Metadata, which includes detailed descriptions of the experimental setup including dimensions, test conditions, measurement techniques, calibration procedures, and data processing methodologies, plays a pivotal role in ensuring the reliability and traceability of experimental data. Without comprehensive metadata, experimental datasets may be prone to misinterpretation, and limitations in their application to new research or engineering designs. Proper metadata allows for the reconstruction of the experiment or proper implementation of boundary conditions in computer simulations, making it possible to reproduce results and understand the boundaries of data applicability, which is essential for both scientific inquiry and industrial implementation.

One significant drawback in many existing aerodynamic datasets is the lack of standardized metadata formats. Most of the experimental aerodynamic researchers simply compress the whole measurement datasets and publish them in an online repository, for example a university repository, which makes it difficult for the end user to retrieve the appropriate required data. Sometimes leads to disinterest in using the datasets. Here we have developed guidelines, best practices and standards that can be adopted by others. With this, we would aim to be the first place for aerodynamic datasets- catering to researchers in both UK and internationally.

In the presentation, we will showcase examples from existing published datasets to illustrate the complexities involved in accessing and utilizing aerodynamic data. We will compare these datasets with our structured metadata framework, demonstrating how a well-organized approach significantly enhances data accessibility, usability, and interpretability. This comparison will highlight the advantages of a standardized metadata system in preserving valuable experimental insights and ensuring their broader applicability in aerospace research.

In addition, we will demonstrate our standardized metadata template, showcasing how it simplifies adoption by other users and facilitates seamless implementation in repository-based publishing. To assess the effectiveness of our approach, we plan to conduct a brief Vevox survey to gather feedback on the quality and usability of the template. This input will help refine and improve the framework, ensuring it meets the needs of the aerodynamic research community. Our goal is to develop a widely accepted standard that enhances data sharing and accessibility for the benefit of researchers worldwide.

O7

Aerodynamic Analysis of Racing Wheelchair Athletes: Integrating Full-Scale and Scale Model Wind Tunnel Testing

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Aerodynamic drag accounts for 70% of the resistive force encountered by racing wheelchair athletes [1], making it a critical factor in performance. The propulsion of a racing wheelchair involves a highly dynamic movement which includes significant changes to the athlete's body position, presenting a complex aerodynamic problem. This study uses two National Wind Tunnel Facilities (NWTF) to investigate changes in an athlete's drag area based on their position. The research aims to combine full-scale testing with an athlete and scale model testing. The stroke of a wheelchair racer can be broken down into two distinct phases, the propulsive phase and the recovery phase [2]. Three key static positions can be extracted from these phases: the start of the propulsive phase (catch), the end of the propulsive phase (release) and the midpoint of the recovery phase.

Full-scale wind tunnel testing took place at the Human-Flow Interactions Wind Tunnel courtesy of The University of Manchester. An elite level wheelchair racer was asked to hold the three positions for a range of speeds (7,8,9,10 ms^{-1}). The catch position had the highest CdA, followed by the release, and then the recovery position. Across this range of speeds there seems to be no Reynolds dependency for each position. Dynamic measurements of the drag area were also taken while the athlete was engaging in a push cycle. These results showed the sinusoidal pattern of the CdA throughout the athletes push cycle, however further analysis was challenging due to the extreme maxima and minima added by the additional loading during the propulsive phase.

A generic athlete model was developed for scale testing using an anthropometric database of known wheelchair racer measurements. The model was rigged with a virtual skeleton and positioned into the three static poses. These models were 3D printed at one-third scale and placed in a replica scale racing chair. The complete setup was mounted in the Loughborough University Large Wind Tunnel, where drag and wake probe measurements were conducted. Advanced measurement techniques, such as Particle Image Velocimetry (PIV), are planned for future studies, as these methods are more easily performed using a model. A virtual replica of the experimental set up has also be generated using computational fluid dynamics (CFD). Large eddy simulations (LES) will be used to determine the time averaged drag area for each position and try to understand the behaviour of the flow. Validation of the CFD against wind tunnel data will establish confidence in its predictive capabilities. Once validated, the CFD model will be used to explore drag-reduction strategies, such as optimizing athlete positions or wheelchair designs. Promising methods will then be tested with athletes in full-scale wind tunnel experiments to assess their effectiveness for individual racers.

References

Forte P, Barbosa TM, & Marinho DA. Technologic Appliance and Performance Concerns in Wheelchair Racing–Helping Paralympic Athletes to Excel New Perspectives in Fluid Dynamics, Chaoqun Liu (Ed.), InTech; 2015; 101–121.

Vanlandewijck Y, Theisen D, Daly D. Wheelchair propulsion biomechanics: implications for wheelchair sports. Sports Med. 2001;31(5):339-67. doi: 10.2165/00007256-200131050-00005. PMID: 11347685.

O8

New developments and applications in flow instrumentation technology

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Measuring within the unique flow environment within the ultra-low-speed EnFlo Atmospheric Wind Tunnel has led to the development of a range of new measurement technologies, and some of these have found complementary uses in some unusual applications. This presentation will review some of the most recent developments, which include:

Ultra-low-range velocity probe: A major failing of conventional Pitot probes is their poor performance at low speeds. An alternative probe design has been developed using complementary metal-oxide semiconductors to infer local flow speed from surface heat flux. Because this technology is inherently IP-68 capable and tolerant of both ice and FOD, it is currently being considered for use on UAVs intended for harsh environments.

World's smallest hot-wire anemometer: Because hot-wire anemometer bridges are conventionally large rack-mounted units located far from the measurement points, the EMI noise on small-signal lines can be a limiting consideration in large facilities. A new constant-temperature anemometer (CTA) system measuring only 3 mm x 9 mm x 18 mm has been developed, which is small enough to embed in a probe holder and has a bandwidth greater than 40 kHz when used with a standard 2 mm long, 5 um diameter wire.

Fast-response, solid-state CH4 probe: In wind tunnel scalar dispersion studies, high-bandwidth fast-flame ionization detectors (FFIDs) are typically used to measure local concentrations of a tracer gas. These systems are large, invasive and costly. An alternative catalytic probe technology has been developed as an alternative, and a novel dynamic calibration technique has been developed to increase the bandwidth of the typically low-speed catalytic beads.

Robust, high temperature total temperature and pressure probes: One of the most difficult measurement environments occurs within gas turbine stages, where total temperatures are high and Mach numbers are low. A difficult combination of precision, range and temperature resistance must be achieved. An experimental series of probes have been developed using refractory materials and exotic metals for use at temperatures over 1200°C. Despite the design limitations, these probes demonstrated low directional sensitivity and high recovery factors during calibration.

On-board AI: Multi-hole velocity probes are an attractive, compact alternative to independent airspeed, incidence and sideslip for use on UAVs. However, this requires additional overhead in the flight data computer to carry out the n-dimensional interpolation to convert pressures to velocity components based on a calibration data file. A highly compact ANN having 14 neurons was developed for this application, using a particle swarm optimization (PSO) technique. This ANN can run on a 32-bit processor using only 578 bytes of memory and has enabled the development of the first compact air data probe with integrated air data computer.

Dynamic calibration of pressure measurement systems: Some additional advances have been made in the dynamic calibration of ultra-low-range pressure measurement systems, reducing uncertainty propagation and noise at higher bandwidths. Demonstrations include the simultaneous, dynamic calibration of 512 channels for a range of less than +/- 3 Pa, and the development of a new fast-response multi-hole probe system.

O9

Adaptive Test Management – Moving on from OFAT and DOE

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Effective pre-test planning and in-test management of wind tunnel experiments are critical to the success of R&D and production test programmes. Prior to starting a test, creating a run matrix needs to take into account the technical objectives of the experiment, but also constraints on cost, time, and facility capabilities. During a test, run matrices inevitably need to be updated in real-time, in response to (for example) 'data surprises', equipment failures, unanticipated facility limits, or simply running out of time or money. Pre-test planning can be done in a formal structured manner, but in-test management tends to be done under time pressure, and in a rather more ad-hoc manner.

Traditionally, run matrices are created based on a 'One Factor at a Time' (OFAT) methodology – and this remains the most common approach. However, OFAT is not necessarily the most efficient means of designing a wind tunnel experiment and is difficult to adapt during a test. In the last 20 years or so there has been a strong push (primarily from NASA) to make more use of formal 'Design of Experiments' (DOE) methodologies. These in principle give more efficient run matrices, with fewer data points needed, but this is not always realised in practice. The requirement for randomisation of data order leads to major complications in model design and in wind tunnel operation (particularly for high-speed testing). Incomplete test programmes and non-linear or unsteady aerodynamic behaviour also present serious challenges for DOE; as a consequence, DOE applications in wind tunnel have largely been limited to calibration testing.

There is therefore a need for a methodology that provides:

- a formal means to optimise a test matrix for a set of test objectives, taking account of facility limitations and costs, and making full use of any available prior knowledge, and
- a means to appropriately reconfigure a run matrix in mid-test in response to test curtailment or data surprises, so that the test objectives can still be met.

This presentation will consider a number of candidates for such a methodology, drawing on preliminary work by AeroDynamiQ Ltd and Cranfield University under the Dstl FWCAT programme. This will include for example recent Korean work on 'Adaptive DOE' and 'Cost-Conscious DOE' methods for wind tunnels but will focus on Bayesian approaches to experimental design – where a wind tunnel test can be considered as a targeted search process rather than a mapping exercise.

O10

Unlocking future high-speed rail freight transportation capability through aerodynamics

Dr David Soper

A new generation of freight locomotives and wagons have started to enter service on the GB railway network. Many have the capability to haul freight at speeds beyond that which has traditionally been possible. Yet, for freight services on the GB railway network, an upper train speed limit of 75 mph remains in place. With such divergence between train capability and permitted speeds, there is a developing, industry-led desire to unlock freight haulage at speeds beyond the 75 mph. The benefits of unlocking higher speeds for freight are significant. This will allow freight to fit in more seamlessly between passenger services, introducing a step-change in freight operation and performance, and opening new rail freight markets. It will also have additional benefits of opening additional capacity for passenger services within the operational timetable on mixed traffic lines.

In addition to the capabilities (and limitations) of the network infrastructure, one important consideration (among many others) encountered when proposed increases to freight speeds have been considered previously are the associated changes in aerodynamics. When trains travel at higher speeds, the aerodynamic effects associated with slipstream flows, pressure pulse interactions with infrastructure and other vehicles, crosswind effects and tunnel aerodynamic effects are all increased. This potentially imports additional risk to the network and needs to be assessed. RSSB project 'T1303 – 'Superfast freight' aerodynamic assessments and mitigations' provided a detailed review of industry standards and guidance related to freight train movements and associated aerodynamic risk. Through an assessment of the evidence base underpinning the requirements, it was possible to establish what is needed to remove or mitigate current risk associated with increased aerodynamic effects when running existing freight above 75 mph. This led to the development of a series of recommendations, related to the four key topics: slipstreams, pressure transients, crosswinds, and tunnel effects.

This presentation will introduce the joint industry and academia collaboration to explore these recommendations related to aerodynamic properties in the open air, namely slipstream and pressure transient effects. An extensive series of experiments were conducted at the NWTF Transient Aerodynamic Investigation (TRAIN) rig facility, in addition to a full-scale collaborative test with industry on track in operational conditions. The analysis of these datasets will support the development of risk mitigation strategies with the overall aim of enabling the removal of aerodynamic limitations to high-speed freight.

O11

Testing of Single Photon Avalanche Diode Cameras for pressure-sensitive paint measurements

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The emerging technology of Single Photon Avalanche Diode (SPAD) cameras has been used extensively in the bio-technology sector in Fluorescent Lifetime Imaging Microscopy (FLIM) measurements due to their ability to work in low-light conditions where single-photon accuracy detection is required. These SPAD sensors are a sub-category of modern complementary metal-oxide-semiconductor (CMOS) technology. Due to their photon-counting-based imaging, they output binary images, which can be summed to produce n-bit images of arbitrary depth. In this work the Pi Imaging SPAD512 sensor is tested and compared against the more traditional PCO.2000mo charged coupled device (CCD) sensor for both the intensity technique as seen in figs. 1 and 2, and the lifetime technique as seen in figs. 3 and 4. The ISSI UniFIB paint was used and tested at temperatures of 273, 288 and 303K across a pressure range of 20 to 200kPa. In these tests the SPAD camera produced pressure and temperature sensitivities that were comparable to the traditional CCD camera across all pressure and temperature ranges tested in addition to extremely low dark signals, demonstrating it as a potential technological approach to gathering PSP data in the post-CCD era. Finally, a new PSP methodology based on FLIM techniques has been developed in the calibration chamber, capable of capturing per-pixel excitation and decay curves of a PSP sample as seen in fig. 5.

O12

Development of binary pressure-sensitive paint for short duration hypersonic wind tunnels

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Binary pressure-sensitive paint (binary PSP) is a non-intrusive, quantitative measurement technique of the continuous surface pressure distribution of wind tunnel models. Previous binary-PSP experiments in the Oxford High Density Tunnel (HDT), a hypersonic wind tunnel, utilising free-flying models highlighted several challenges. The current study attempts to address the previous issues and develop a robust methodology for binary-PSP in short-duration facilities. Aspects investigated using a bespoke calibration chamber include the paint mixture, application procedures, curing method and post-processing techniques. Results will be presented for several canonical geometries that have been tested in the HDT to evaluate the paint.

O13

The influence of gaps on boundary layer transition

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This presentation focuses on the effect that surface gaps cause on the boundary layer stability and turbulent transition. Surface gaps typically interact with the boundary layer instability waves (Tollmien-Schlichting waves) and push the laminar-turbulent transition upstream compared to a smooth surface.

Furthermore, new instability mechanisms, such as the Rossiter mode, may arise associated with the mixing layer and the vorticity field inside the cavity. This seminar addresses experimental results obtained in the Gaster low-turbulence wind tunnel at City St George's, University of London.

The experimental campaign was the outcome of an exchange program between the City St George's, University of London (UK), and the University of Sao Paulo (Brazil).

The test model comprises a variable-depth cavity system inserted into a flat plate, driven remotely.

The disturbance and mean velocity were measured through hot wire anemometry, whereas a Preston tube was employed to detect the transition location. Four different regimes were observed. A regime in which the T-S mode is affected by the gap, a regime where T-S waves and mixing layer modes coexist, a regime of bypass transition, and a regime in which the Rossiter instability weakens for very deep cavities. A relaminarization-like phenomenon marks the second regime. In this process, turbulence is generated inside the cavity, mostly due to mixing layer instability, but rapidly decays downstream of the gap.

However, this process leaves a residual in the T-S wave frequency band. This phenomenon might be associated with the reported deep-gap limit, a regime in which the gap effect on the transition is independent of the gap depth. When a sufficiently strong Rossiter mode develops, it causes the boundary layer to transition. The Rossiter mode weakens for even deeper cavities, although abrupt transition still takes place.

O14

Aeroacoustic Wind Tunnel experiments on propeller noise at the University of Bristol

Dr Sung Tyaek Go[1], Mr Ismaeel Zaman[1], Professor Mahdi Azarpeyvand[1,]
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This presentation will describe the various types of experimental propeller test campaigns conducted in the national Aeroacoustic wind tunnel (https://www.bristol.ac.uk/aerodynamics-research/facilities/aeroacoustic-facility/) and the national Pressure neutral acoustic wind tunnel (https://www.bristol.ac.uk/aerodynamics-research/facilities/pressure-neutral/) at the University of Bristol in collaboration with academic and industrial partners. The experimental campaigns incorporated a wide range of techniques including far-field microphone arrays, near-field pressure measurements, Particle-Image-Velocimetry, and hot-wire flow-field measurements to create large datasets, and to permit a comprehensive evaluation of the key flow behaviour and noise characteristics produced by propellers. Observations on acoustic directivity, and spectral content were also related to noise generation mechanisms, and their sensitivity to operational and design parameters.

The propeller test configurations investigated include:
a. Distributed electric propulsion [1,2] – Where multiple propellers are distributed in parallel along the wing of an electric vertical take-off and landing (eVTOL) aircraft.
b. Boundary layer ingestion [3] – A configuration where the propellers are located close to the aircraft body such that it ingests the boundary layer.
c. Tilting rotors [4] – Used on vertical take-off and landing (VTOL) aircraft where the propellers can tilt vertically for vertical lift and horizontally for forward flight.
d. Edge-wise flight [5-7] – A configuration where the propeller axis is vertical and is subject to horizontal winds.
e. Scale model eVTOL aircraft – The University of Bristol is currently collaborating with an eVTOL company based in Bristol to build and test a 10 % scale model of its aircraft to assess the noise generated by their propellers in the national wind tunnel facilities.

The experimental setups and studies performed at the University of Bristol in the field of propellers laid the groundwork for the current project of designing and building the versatile National Propeller Testbed (NPTB).

References

Luke Bowen, Burak Turhan, Hasan Kamliya Jawahar, Djamel Rezgui and Mahdi Azarpeyvand. "Aeroacoustic characteristics of distributed electric propulsion configuration with turbulent flows," AIAA 2023-4294. AIAA AVIATION 2023 Forum. June 2023.

Burak Turhan, Hasan Kamliya Jawahar, Luke Bowen, Djamel Rezgui and Mahdi Azarpeyvand. "Aeroacoustic characteristics of distributed electric propulsion system in forward flight," AIAA 2023-4490. AIAA AVIATION 2023 Forum. June 2023.

Ismaeel Zaman, Michele Falsi, Bin Zang, Mahdi Azarpeyvand, Roberto Camussi. "Aeroacoustics of the propeller Boundary Layer Ingestion configuration for varying thrusts," Journal of Sound and Vibration. 589 118604. 2024.

Nur Syafiqah Jamaluddin, Alper Celik, Kabilan Baskaran, Djamel Rezgui, Mahdi Azarpeyvand. "Aerodynamic noise analysis of tilting rotor in edgewise flow conditions," Journal of Sound and Vibration. 582 118423. 2024.
Liam P. Hanson, Luke Bowen, Bin Zang and Mahdi Azarpeyvand. "Interactions of Propellers in Edgewise Flight with Turbulence," AIAA 2023-3656. AIAA AVIATION 2023 Forum. June 2023.

Jamaluddin, Nur Syafiqah, Alper Celik, Kabilan Baskaran, Djamel Rezgui, and Mahdi Azarpeyvand. "Experimental Analysis of Rotor Blade Noise in Edgewise Turbulence" Aerospace 10, no. 6: 502. 2023.
Liam P. Hanson, Bin Zang and Mahdi Azarpeyvand. "Experimental Characterisation of Cylinder-Induced Turbulence Ingestion in Propellers Operating in Edgewise Flight," AIAA 2024-3100. 30th AIAA/CEAS Aeroacoustics Conference (2024). June 2024.

O15

Aeroacoustic Wind Tunnel experiments on static and dynamically oscillating aerofoils at the university of Bristol

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This presentation will discuss a series of experimental campaigns on aerofoil aeroacoustics conducted at the National Aeroacoustic Wind Tunnel Facility at the University of Bristol (Aeroacoustic facility | Fluid and Aerodynamics Research Group | University of Bristol). These campaigns, carried out in collaboration with academic and industrial partners, employed a range of advanced measurement techniques, including far-field microphone arrays, near-field hydrodynamic field measurement through detailed instrumentation of the aerofoils, Particle Image Velocimetry (PIV), and hot-wire anemometry. These methodologies facilitated the creation of extensive datasets, enabling a comprehensive analysis of key flow behaviours and noise characteristics associated with both static and dynamically oscillating aerofoils.

The study examined acoustic directivity, spectral content, and the underlying noise generation mechanisms, assessing their sensitivity to operational and design parameters. Two key aerofoil test configurations were investigated are:
1. Dynamic Stall [1,2,3] – In this configuration, the aerofoil undergoes pitching motion, surpassing the static stall angle, resulting in light and deep dynamic stall regimes.
2. Static Stall [4,5,6] – Here, the aerofoil remains fixed at a specific angle of attack, allowing detailed analysis of its aeroacoustic characteristics using multiple measurement techniques in pre and post stall regimes.
3. High lift devices [7,8] – This configuration investigates high-lift devices, such as the MDA 30P30N aerofoils under several conditions, including serrations, morphing trailing edges, and slat cove fillers. The aerodynamic and aeroacoustic characteristics are then studied for these aerofoils and compared to baseline conditions.
These experiments provide valuable insights into the noise behavior of aerofoils in varying aerodynamic conditions, contributing to advancements in aeroacoustic research and its applications in industry.

References

Mayer YD, Zang B, Azarpeyvand M. Aeroacoustic investigation of an oscillating airfoil in the pre-and post-stall regime. Aerospace Science and Technology. 2020 Aug 1;103:105880

Masoudi, Esmaeel, Bin Zang, and Mahdi Azarpeyvand. "Experimental investigation of the aeroacoustic characteristics of a pitching NACA 65-410 airfoil", Journal of Sounds and Vibration, (Under review)
Zang, B., Mayer, Y. and Azarpeyvand, M., 2020. A preliminary experimental study on the airfoil self-noise of an oscillating NACA 65-410. In AIAA AVIATION 2020 FORUM (p. 2589)

Branch, J.A., Zang, B., Jones, D., Westin, M.F., Bown, N. and Azarpeyvand, M., 2025. Aeroacoustic Investigation of Thin-Airfoil Stall with a View to Improving the BPM Model. Journal of Aerospace Engineering, 38(1), p.04024099.

Branch, J.A., Zang, B., Azarpeyvand, M., Jones, D., Jinks, E. and Westin, M.F., 2022. Steady and unsteady aerodynamic loading of a NACA 16-616 aerofoil in a uniform flow. The Aeronautical Journal, 126(1305), pp.1897-1923.

Zang, B., Mayer, Y.D. and Azarpeyvand, M., 2021. Experimental investigation of near-field aeroacoustic characteristics of a pre-and post-stall NACA 65-410 airfoil. Journal of Aerospace Engineering, 34(6), p.04021080.

Jawahar, H.K., Ali, S.A.S., Azarpeyvand, M. and da Silva, C.R.I., 2020. Aerodynamic and aeroacoustic performance of high-lift airfoil fitted with slat cove fillers. Journal of Sound and Vibration, 479, p.115347.

Kamliya Jawahar, H., Showkat Ali, S.A. and Azarpeyvand, M., 2021. Serrated slat cusp for high-lift device noise reduction. Physics of Fluids, 33(1).

O16

Simulation of atmospheric boundary layer and pollutant dispersion in the wind tunnel facility at University of Bristol

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The newly commissioned National Boundary Layer Wind Tunnel at the University of Bristol offers a range of advanced capabilities, including air pollution dispersion, wall-bounded turbulence, aeroacoustics, and propulsion studies. In this presentation, we will explore the application of the new wind tunnel for atmospheric boundary layer and pollutant dispersion studies.
We will begin by presenting the results of wind tunnel flow and gas injection characterisation. This process involved velocity profile measurements, turbulence intensity assessments, and spectral analysis to ensure compliance with established wind engineering standards, such as those set by ESDU[1], as well as other benchmark data. These efforts have validated the tunnel's ability to replicate various boundary layer flows, enabling diverse research applications and enhancing our understanding of environmental wind dynamics.

Additionally, we will present preliminary findings on atmospheric boundary layer interactions with Bristol's complex topography and pollutant dispersion within the city. Ongoing studies on flow and pollutant dispersion around generic city layouts will also be discussed. This research aims to improve our understanding of air quality dynamics and inform urban planning strategies for pollution control.
Furthermore, the facility is currently being used to study indoor-outdoor air interactions using scaled-down models, with the goal of developing improved ventilation strategies that enhance both health and energy efficiency.

The presentation will provide an overview of the wind tunnel characterisation, current research activities, and future directions, emphasising its role in addressing contemporary challenges in wind engineering, urban meteorology, and environmental health studies.

References

Engineering Sciences Data Unit. (1985). Characteristics of atmospheric turbulence near the ground, Data Item 85020. ESDU International Ltd, London.

O17

Investigation of Aerodynamic Flow Structures in Mach 5 Inlet Buzz Bi-Stability

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Supersonic inlet buzz is typically classified into two primary types: little buzz and big buzz [1]. Little buzz, described by the Ferri Criterion [2], occurs under supercritical conditions and is marked by high-frequency, low-amplitude oscillations caused by shear layer instabilities near the cowl lip. In contrast, big buzz, defined by the Dailey Criterion [3], is a precursor to inlet unstart, producing low-frequency, high-amplitude oscillations that lead to total flow separation due to interactions between the expelled normal shock and oblique ramp shock in subcritical conditions [1]. Additionally, some studies suggest another classification beyond this traditional one, identifying other mixed forms of both buzz phenomena such as "added buzz" [4,5] and "medium buzz" [6].

This study explores mainly aerodynamic flow patterns of a unique bi-stability in a simple Mach 5 inlet buzz, where little and big buzz oscillations coexist within specific flow conditions. Unlike previous studies focused on lower Mach regimes, this work examines the underlying shock interactions and flow instabilities driving this phenomenon, offering new insights into high-speed inlet dynamics.

The experiments are conducted in the High Supersonic Tunnel (HSST) at the University of Manchester [7], using a blowdown system with a total temperature of 350 K, pressure of 820 kPa, and Mach 5 flow. The intake model is shown in Figure 1.

High-speed Schlieren data is captured and analysed to extract time-resolved shock positions across sequential Schlieren images. The resulting motion profile reveals oscillation frequencies and amplitudes, providing insight into shock dynamics. The image processing steps are illustrated in Figure 2, highlighting key patterns while filtering visual noise.

The outcomes of this study, including the aerodynamic characteristics of the observed bi-stability pattern and its impact on intake flow dynamics, will be explored in detail in the full paper and during the presentation.

References

Fisher, S. A., Neale, M. C., & Brooks, A. J. (1970). On the sub-critical stability of variable ramp intakes at Mach numbers around 2.
Ferri, A., & Nucci, L. M. (1951). The origin of aerodynamic instability of supersonic inlets at subcritical conditions (No. NACA-RM-L50K30).
Dailey, C. L. (1955). Supersonic diffuser instability. Journal of the Aeronautical Sciences, 22(11), 733-749.
Soltani, M. R., & Farahani, M. (2013). Experimental investigation of effects of Mach number on the flow instability in a supersonic inlet. Experimental Techniques, 37, 46-54.
Soltani, M. R., & Sepahi-Younsi, J. (2016). Buzz cycle description in an axisymmetric mixed-compression air intake. AIAA Journal, 54(3), 1040-1053.
Chen, H., Tan, H. J., Zhang, Q. F., & Zhang, Y. (2018). Throttling process and buzz mechanism of a supersonic inlet at overspeed mode. AIAA Journal, 56(5), 1953-1964.
[7] Berto, F., Benini, E., Wyatt, C., & Quinn, M. K. (2020). Time-accurate experimental investigation of hypersonic inlet buzz at Mach 5. AIAA Journal, 58(5), 2197-2205.

O18

Influence of Downstream Waves on Impinging Shock-Induced Separation

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Shock-induced boundary layer separations widely occur in many wall-bounded high-speed flow fields. They cause increased drag and fluctuating loads, resulting in the reduction of system efficiency. Controlling these separations requires a fundamental understanding of the separated flow field, and hence, any variable that influences the interaction, including any external influences, must be carefully studied. One such factor is the presence of additional waves that arrive downstream of the interaction. These waves commonly occur in laboratory studies of impinging-shock interactions (refer Fig. 1), where expansion waves originating from the trailing edge of the shock generator wedges arrive downstream of the separation. The effect of these waves on the main SBLI was considered to be negligible as they typically fall at a distance from the interaction. Recent works by Grossman and Bruce [1] observed their effect by varying the distance between the location of inviscid shock impingement and the downstream expansion. They found that the waves had a significant influence even up to 10.8 incoming boundary layer thicknesses (δ_i) downstream of the interaction. Considering the significance of these downstream waves, a systematic study has been undertaken to understand their effect on the interaction.

Wind tunnel experiments are carried out at Mach 2.5 with an 8° wedge mounted on the top wall to generate the oblique shock. The downstream waves are generated using wave generators mounted aft of the shock generator leading edge (refer Fig. 2). Both expansion and compression waves impinging at three different locations (df = $1.25\delta_i$, $3.76\delta_i$, $6.27\delta_i$) downstream of the inviscid shock-impingement location are studied. Further, the imposed pressure and their gradient of spread on the bottom wall are also varied. Schlieren imaging, surface oil flow visualization and pressure-sensitive paints (PSPs) are employed to diagnose the flow field.

Results from flow visualization show that the downstream waves have a considerable influence on the main separation. The expansions are found to decrease the centreline separation length (L_{sep}) whereas the compressions enlarge the bubble (refer Fig. 3), with the influence decreasing with distance to the interaction. Varying the pressure gradient imposed by the waves indicates that the compressions could cause a greater variation in L_{sep} than the expansions and hence, can adversely affect the interaction. Further, it was observed that an increase in L_{sep} is associated with a change in position and size of corner separation. This was also accompanied by a transition in the three-dimensional topology of the bubble for larger separations. The surface pressure traces are found to follow the predictions of the Free Interaction theory irrespective of any downstream waves. At this point, two possible mechanisms by which the downstream waves could influence the main separation are hypothesized and they will be presented at the conference.

References

Grossman, I. J., and Bruce, P. J., "Confinement effects on regular-irregular transition in shock-wave-boundary-layer interactions," Journal of Fluid Mechanics, Vol. 853, 2018, pp. 171-204

O19

Mapping the effects of ozone pollution and mixing on floral odour plumes and their impact on plant-pollinator interactions

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The critical process of animal-mediated pollination is commonly facilitated by odour cues comprising mixtures of volatile organic compounds (VOCs), often with short chemical lifetimes. These form the strong concentration gradients necessary for pollinating insects to locate a floral source. Atmospheric oxidants, including ozone pollution, may react with and alter the odour cues, impairing the ability of pollinators to locate a source and the pollen and nectar on which they feed. There is limited empirical evidence to explain the processes within an odour plume at temporal and spatial scales relevant to insect navigation and olfaction.

Reaction rates found in the literature assume complete mixing, though this is unlikely to be the case in nature. The difference is particularly critical for highly reactive compounds because their chemical lifetime is of the same order as the mixing time scale. Spatial segregation between oxidant and VOC is thus overlooked and understanding of the applicability of reaction rates derived in these circumstances but then used in the atmosphere is uncertain.

A series of controlled experiments in the EnFlo wind tunnel at the University of Surrey was used to investigate the impact of ozone pollution and turbulent mixing on the fate of model floral compounds within odour plumes.

The wind tunnel is open circuit, implying that ozone levels had to be maintained throughout the whole laboratory. Two levels were used, one during the working day (of order 50 ppb, based on the ambient air quality standard of 60 ppb) and a higher level at other times (of order 150 ppb, based on the work-place standard of 200 ppb). Extensive use was made of remote tunnel operation to limit the exposure of those involved to high levels of ozone. Releases were made from an elevated source into a 1m deep simulated atmospheric boundary with a freestream speed of 0.7m/s to provide adequate time for reaction to proceed in the 20m long working section. Releases of a non-reacting hydrocarbon tracer were also made to provide reference data with good time resolution.

Average rates of chemical degradation of the VOCs were slightly greater than predicted by literature rate constants, but mostly within uncertainty bounds. Incomplete mixing reduced reaction rates by about 10% in the first 2 m following release. Reaction rates also varied across the plumes, being greatest at the edges, where VOCs and ozone mixed most efficiently, and least in the centre.

Honeybees were trained to learn a four VOC blend equivalent to the plume released into the wind tunnel. When subsequently presented with an odour blend representative of that observed 6 m from the source at the centre of the plume, 52% recognised the odour, decreasing to 38% at 12 m. When presented with the more degraded blend from the plume edge, recognition decreased to 32% and 10% at 6 and 12 m respectively.

The findings highlight a mechanism by which man-made pollutants can disrupt the VOC cues used in plant-pollinator interactions, which likely impacts on other critical odour-mediated behaviours such as mate attraction.

O20

Measurements of Propeller Aerodynamic and Aeroelastic Behaviour Under Stalled Conditions

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The recent resurgence of the airscrew propeller in both military and civilian tiltrotor technology has led to a reinvigoration of rotary wing off-design research. Modern rotorcraft blades are required to operate both as propellers and rotors and will therefore operate in unexplored regions of the operational flight envelope, where aerodynamic and aeroelastic instabilities may occur, leading to unfavourable and potentially dangerous operational conditions. Despite several experimental investigations focused on rotary wings over the past century, there is a clear lack of a comprehensive aerodynamic and aeroelastic experimental data set of sufficient resolution to provide further insight into these complex phenomena.

To address this gap in experimental data, a wind tunnel test campaign focused on stall onset of tiltrotor blades in propeller mode was performed at the 9ft x 7ft De Havilland wind tunnel at the University of Glasgow making use of the United Kingdom National Rotor Rig. A 1.25m diameter propeller was tested for a range of advance ratios, propeller rotational frequencies and blade pitch angles to probe the stall boundary. Blades were instrumented with both fully bridged axial and shear strain gauges to monitor the flap bending and torsional strain at several radial locations. Propeller performance was analysed using a rotating shaft balance and motor feedback data. Blade tip deflections were obtained using a stereoscopic digital image correlation system.

A non-conventional stall identification criterion primarily based on the measurement of blade structural response using strain gauge bridges was developed and supported by the comprehensive measurements obtained via more conventional stall identification techniques. Analysing the unsteady blade structural response, it was shown that stall manifested in the strain spectra as non-harmonic content mainly identifying the blade eigenmode frequencies, particularly the first flap bending mode.

O21

Development of Aircraft Half-Model Testing at the 10x5 Wind Tunnel

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An extensive design and build exercise has been pursued at the 10x5 Wind Tunnel in the last few months. An aircraft model motion system (MMS), able to provide an aircraft half-model with pitch degree of freedom, has been designed and manufactured and is currently undergoing commissioning.

Ahead of the MMS, a two-stage floor boundary layer suction system, and a moving floor, have been recently commissioned and the inflow boundary layer at various suction settings is being characterised. This system enables the incoming flow conditions hitting an aircraft half-model to be optimised, enforcing half-model symmetry plane, and exploring on- and off body flow sensitivity to its variation.

In addition, a second design exercise is currently underway. We are using Boeing-NASA's CRM-HL open access surface model to design and manufacture a wind tunnel in-house half-model at 4% scale, to fit in the 10x5 Wind Tunnel on and the developed MMS. We expect to do this at a far lower cost than the planned Boeing UK's high fidelity 4% half-model. We have pursued a multitude of design and manufacturing options to include as much on-body and off-body measurement capabilities, and model modularity as possible. The model is now approaching the start of manufacture, a carbon fibre composite wing, 3D-printed high-lift devices and 3D-printed fuselage. A Peniche and a labyrinth seal system contribute to the enforcement of the half-model symmetry plane. Readily established capabilities at the 10x5 Wind Tunnel support the model commissioning and testing. A FaroArm scanner enables us to establish how faithful is the manufactured model to the model in CAD. Particle Image Velocimetry (PIV), 3D-Laser Doppler Anemometry (LDA) and hot-wires provide detailed velocity measurements, on-board taps and microphones provide on-body pressure data, an array of cameras and photogrammetry software enable model live model deformation data, while a 6-axes balance measures direct loads.

The 10x5 Wind Tunnel (formerly Honda) has, to date, had limited opportunities for research utilising realistic aircraft geometries. The developed MMS and boundary layer control will now enable this, and the CRM-HL will become one of our test platforms. The in-house model enables an element of staff and student training on handling and testing aircraft geometries. This opens the opportunity and experience for sustainable aviation projects through, for example, the Department of Aeronautics' Brahmal Institute for Sustainable Aviation, to have an element of wind tunnel testing where necessary. It enables researchers anywhere, to pursue proposals with the combination of the 10x5 Wind Tunnel and the available half-model in mind.

When Boeing UK's CRM-HL 4% half model becomes available, it will travel around the UK to wind tunnels that can test it, and therefore we expect to have limited time access to it. We envisage the -house model will therefore become the workhorse of our training and early testing efforts on a realistic geometry, enabling testing research ideas in between the Boeing UK model's shorter and intermittent visits. The capability development enables our participation in other similar eco-system initiatives with other industrial and academic partners.

Poster Presentations

P1

The Oxford 3-DoF Magnetic Suspension and Balance System - Introduction and Recommissioning Update

Mr Nnaemeka Anyamele[1], Mr Morgan van Hoffen[1,2], Dr Luke Doherty[1], [1]Oxford Thermofluids Institute, University of Oxford, Oxford, United Kingdom, [2]University of Southern Queensland, Australia

This presentation provides an introduction to and outline of the refurbishing and recommissioning progress of the Oxford 3-DoF Magnetic Suspension Balance System (MSBS) for use in the Oxford Low Density Tunnel (LDT). The LDT operates in the rarefied slip and transition regimes, capable of simulating altitudes above 60 km. In these regimes, diffuse shock waves and large viscous interaction regions exacerbate the influence of a sting in traditionally mounted models. Further, the small model size necessary to achieve high Knudsen numbers, coupled with the low flow densities, result in force magnitudes on the order of milli-Newtons which cannot easily be measured with strain-based force balances. The MSBS allows sting-interference free, low uncertainty (typically <2%) measurement of the lift, drag and pitching moment. Recommissioning is expected to be complete by the end of Q3 2025; the MSBS will then be used in Q4 2025/Q1 2026 to carry out force measurements on winged/non-axisymmetric bodies at hypersonic rarefied conditions.

P2

Blowdown Operation of Ludwieg Tunnels

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This paper presents the commissioning of two blowdown modes of operation in the Oxford High Density Tunnel (HDT) at Mach 7: Extended Ludwieg Mode (ELM) and Plenum Augmented Ludwieg Mode (PALM). ELM is a quasi-steady blowdown mode, producing a steady decrease in supply pressure to the facility nozzle, whilst PALM offers steady supply conditions at the expense of total pressure and Unit Reynolds number capability. ELM has been commissioned across the full range of HDT's current operating pressures, whilst PALM has been demonstrated for 3 fill pressures: 14 bar, 30 bar and 55 bar. Test times in both modes were limited by facility unstart to at most 400 \si{\milli \second}, greater than a factor of 10 improvement relative to Ludwieg Mode, though for the 14 and 30 bar PALM cases this came with a reduction of Unit Reynolds capability of 40\% and 30\%, respectively. The 55 bar PALM case demonstrated a test time of 160 \si{\milli \second} for a 20\% reduction in unit Reynolds number capability. Theoretical performance maps predict that operation in PALM can provide a factor of 10 improvement to the test time capability for HDT for all M7 unit Reynolds numbers run to date in the facility without any upgrades.

P3

Machine Learning Driven Tuft Detection and Analysis for Flow Separation Characterisation

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Flow separation on aerodynamic surfaces, particularly wings, can substantially impair aircraft performance and stability, thereby necessitating advanced diagnostic techniques. Although tuft-based flow visualisation provides a practical means of monitoring surface flow dynamics, the manual analysis of tuft behaviour is both time-consuming and susceptible to human error. This study proposes an automated system that integrates sophisticated image processing and machine learning to accurately characterise flow separation based on tuft behaviour. High frame rate videos capturing tuft motion on the wing surface are acquired during wind tunnel experiments and pre-processed through contrast enhancement and noise filtration to clearly delineate tuft features. A convolutional neural network (CNN), trained on a diverse dataset of labelled tuft images varying in size and orientation, is then employed to detect and localise tuft positions in each frame. Subsequent post-processing quantifies changes in tuft angle, movement frequency, and other dynamic parameters between frames, ultimately generating a severity score that assesses both the state and intensity of flow separation along the wing's surface.

This study presents experimental results obtained in the Donald Campbell closed-loop subsonic wind tunnel at the University of Nottingham, utilising a custom-built, swept DLR-F15 wing. The wing, featuring a 900 mm semi-span, 340 mm chord, and a 600 mm leading-edge slat cut-out, has been designed to assess flow control methods for wings modified to accommodate ultra-high bypass ratio (UHBR) engines and their larger nacelle diameters. This is achieved through the inclusion of a large leading-edge slat cut-out that facilitates engine integration, but creates a region prone to flow separation, particularly at high angles of attack. By conducting tuft analysis with machine learning, the flow separation associated with the slat cut-out can be more effectively understood.

Wind tunnel tests were conducted at a freestream velocity of 30 m/s, corresponding to a Reynolds number of 10^6. Over 100 tufts were attached to the aerofoil surface to visualise the flow, and the captured video was analysed to characterise the separation due to the presence of a large slat cut-out at a range of angles of attack. These findings provide insights that can inform the optimisation and development of effective flow separation control strategies in the slat cut-out region. The robustness of the tuft-based analysis was further corroborated through validation against pressure distribution data and complementary flow visualisation techniques, including oil and smoke visualisations. These results build upon previous experiments conducted with the same scale wind tunnel model at the University of Nottingham[1].

References

[1]Bahri, et al. DOI: 10.13009/EUCASS2023-748, Proceedings of the Aerospace Europe Conference - EUCASS (2023).

P4

Design and Manufacture of a Mach 7 Nozzle for the Oxford T6 Stalker Tunnel

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Experimental ground testing for hypersonic flow conditions which attempts to simulate the flow thermochemistry requires specialised facilities which can only produce steady test conditions for a few milliseconds or less [1]. The work presented here describes the current progress towards the design and manufacturing of a larger nozzle for the T6 Stalker Tunnel at the University of Oxford. This nozzle will be a significant capability improvement for the Hypersonics Group, allowing the testing of large scramjet models and further research into external aerodynamics at true flight enthalpies. In addition to being a larger size, the new nozzle design provides access for measurements along the nozzle's axial length, allowing thermo-chemical effects (particularly non-equilibrium) in the nozzle flow to be studied. The nozzle was designed using an iterative CFD optimisation method, following the same procedure as was used to design several nozzles for the T4 tunnel at the University of Queensland [2]. The optimisation process assumed thermochemical equilibrium, so equilibrium, chemical non-equilibrium and thermochemical non-equilibrium models were used to assess the resultant effect on flow properties at the nozzle exit. The nozzle manufacturing is currently being finalised, with pressure testing and commissioning expected to occur in 2025.

References

R. J. Stalker, "Modern developments in hypersonic wind tunnels," The Aeronautical Journal, vol. 110, no. 1103, pp. 21–39, Jan. 2006. [Online]. Available: https://doi.org/10.1017/S0001924000004346

W. Y. K. Chan, P. A. Jacobs, M. K. Smart, S. Grieve, C. S. Craddock, and L. J. Doherty, "Aerodynamic Design of Nozzles with Uniform Outflow for Hypervelocity

Ground-Test Facilities," Journal of Propulsion and Power, vol. 34, no. 6, pp. 1467–1478, Nov. 2018. [Online]. Available: https://doi.org/10.2514/1.B36938

P5

Novel Streak Visualisation System for Particulate Pipe Flows

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Detecting the transition from laminar to turbulent flow in particulate pipe systems is a critical yet challenging aspect of fluid dynamics, often hindered by the limitations of traditional, resource-intensive visualization techniques. This study introduces a novel streak visualization method, leveraging a cost-effective laser-camera system to capture particle streak angles in neutrally buoyant particulate flows. By analysing the statistical distribution of these angles, this technique effectively

identifies laminar, transitional, and turbulent flow regimes. The method's reliability is validated through comparisons with established approaches, including Particle Image Velocimetry (PIV) and pressure drop measurements. A key feature of the technique is its robustness at low particle concentrations and its ability to detect transitional flow patterns using the standard deviation of streak angles. Furthermore, the critical Reynolds number for the transition to turbulence is determined using the Kullback-Leibler divergence, offering information about the flow state transitions. This accessible and versatile method expands the scope of turbulence detection in both controlled laboratory environments and industrial settings, where simplicity and scalability are crucial. Future applications could include automation and adaptation for non-circular geometries, enhancing its utility across diverse engineering domains.

P6

Cloud dispersion in complex flows

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Robins and Fackrell (1998) reported a wind tunnel study of dispersion of short duration, ground level emissions in deep turbulent boundary layers. This focused-on comparison with the analytical theory developed by Chatwin in 1968. Recently, the DAPPLE project, 2002 to 2010, treated short range dispersion in central London. In addition to a series of 15-minute field releases, a set of wind tunnel experiments examined cloud dispersion and the causes of variability. Some simple correlations were developed for cloud travel time, rise and fall time and advection speed, as functions of fetch in the near field. Further cloud dispersion studies were carried out in the DIPLOS project, where the underlying geometry was a regular array of cuboids. Recently, detailed wind tunnel studies of cloud dispersion in the presence of a surface mounted cube have been completed.

The focus is the short-range dispersion of pollutant clouds emitted from elevated sources, using wind tunnel data from the projects discussed above. The objective is to use the concentration measurements to describe the structure of the dispersing clouds and to develop simple scaling rules that reduce the data to universal forms and can be used in a predictive manner. When the emission duration exceeds the time of flight the ensemble-averaged cloud has a plateau region, and we might term this plume-like (but with end regions). Further downwind, where time of flight exceeds the emission duration, the structure becomes puff-like, as longitudinal spread fully erodes the plateau region. Between the two limiting regions, there is an intermediate regime, where the form should be simply referred to as a cloud.

Dispersion around a cube work was studied in the EnFlo wind tunnel using a 1m deep neutrally stable boundary layer. The 0.24m cube was orientated so that the oncoming flow was normal to the front face. Emissions were made from a source of height 0.06m, located 0.6m up of the cube centre. Large numbers of clouds were released in each case to ensure low uncertainty in derived results; typically, the number of emissions in an ensemble was 200-399 for emission duration 0.05s; 170-399 for 0.1s; 150-200 for 0.25s; 120-250 for 0.5s; 100-120 for 1.0s. These allowed the full range of cloud behaviour to be observed. Concentration measurements were made with a Cambustion Fast Flame Ionisation Detector that had a spatial resolution of order 1 mm and a frequency response of about 200 Hz.

The distortion of clouds passing around the cube was derived from mean time of flight results. This clearly showed hold-up in the recirculation region, and the downwind consequences of that. Results enabled the relationship, D = C.Te, between dimensionless mean plume concentration, C, cloud mean dose, D, and release duration, Te, to be demonstrated in a much more complex flow than previously. The relationship was further demonstrated using data from the DIPLOS array.

References

Robins, AG and Fackrell, JE, 1998. An experimental study of the dispersion of short duration emissions in a turbulent boundary layer. Transactions of Ecology and the Environment 21, 697-707.

P7

Design of a nozzle featuring boundary layer bleed for a hypersonic wind tunnel

Ms. Tracey Saber[1], Dr Luke Doherty[1], Mr Nnaemeka Anyamele[1, 1]Oxford Thermofluids Institute, University of Oxford, United Kingdom

This project focuses on designing an efficient nozzle for the Low-Density Tunnel at the University of Oxford to address the challenges of boundary layer growth in rarefied and hypersonic flows. Thick boundary layers result in large non-uniformities and consequently smaller usable test sections, limiting the range of experiments. Suction and cooling can contribute to reducing the boundary layer thickness. The project revisits past NASA initiatives from Stalder [1] and Bottorf [2] to design nozzles with porous walls for suction and cooled walls for temperature regulation with modern computation and optimisation techniques.

The simulations are conducted using Eilmer4 to understand the flow behaviour and optimise the nozzle shape. Eilmer4 is a Navier-Stokes-based (NS-based) Computational Fluid Dynamics (CFD) code developed by the University of Queensland and provides a new perspective on the historical work of NASA and a more accurate method to maximise the flow quality.

The resulting optimized design will be constructed and tested in the Low-Density Tunnel. The experimental tests will focus on assessing the nozzle's performance. We will also compare the CFD NS-based predictions to the experimental results to understand the reliability of the Eilmer code for rarefied flows where continuum-flow assumptions break down. By incorporating this new nozzle as part of the Low-Density Tunnel's equipment, this project will contribute to advancing experimental capabilities of the facility.

References

Stalder, Jackson R., Glen Goodwin, and Marcus O. Creager. Heat transfer to bodies in a high-speed rarified-gas stream. No. NACA-TR-1093. 1952.

Bottorff, M. R., and K. W. Rogers. Theoretical and experimental investigation of boundary layer control in low-density nozzles by wall suction and cooling. No. NASA-TM-X-53008. 1964.

P8

Investigation of unsteady hydrodynamics using free-running models in Boldrewood Towing Tank

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The use of free running models to explore ship efficiency and unsteady hydrodynamic phenomena is gaining popularity. An additional approach is to explore and capture, for example, representative trajectory, kinematics, powering and propulsion performance, as well as collecting information from a flow field of interest simultaneously, using an underwater PIV system. Such experimental campaigns can provide extensive information about the fundamental dynamics and flow physics of the flow around hull models as well as the attached appendages. This paper presents example results from educational, research and commercial testing campaigns in the Boldrewood towing tank at the University of Southampton using free running ship models. The results demonstrate the potential of free running models including manoeuvring and seakeeping experiments and the development towards future cyber-physical or HIL experimental campaigns.

P9

Improvements to the UWE Wind Tunnel – challenges and solutions

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The main low subsonic wind tunnel at the University of the West of England is of a Göttingen-type closed loop, single air return design. The tunnel has two test sections: the high speed 2.14m by 1.53 m (Figure 1) and the low speed 3.66 m by 3.05 m. The maximum speed is 50 m/s.

The Wind Tunnel has been used continuously since its installation supplying aerodynamic and aeroelastic information for aerospace, mechanical and civil engineering projects. In this paper we will present results from a selection of past projects ranging from the testing of drones; vertical and horizontal wind turbines; flow control sections, aircraft, automobiles and buildings - to more bespoke and unusual designs from personal mobility devices to launch vehicles.

The current tunnel was moved to its existing site from a previous campus over forty years ago with the low-speed section becoming integral to the building. At that time a replacement roof balance donated from industry was incorporated into the fast section. Since that point the tunnel has seen little changes to its construction. However, a programme of improvements for the tunnel is underway. This covers the tunnel control, the range and precision of measurement devices, improved flow correction data, reduction in turbulence levels, increased visibility, up to date results capture and post-processing, and maintenance access. Some of the improvements has necessitated changes to the fabric of the tunnel which have been challenging due to the restrictions of the space and the funding available.

The improvements will provide a safer and easier access to the tunnel ensuring better inclusivity for students, staff and visitors. Other benefits include more extensive student learning facilities as well as increasing the numbers of people able to benefit from the tunnel.

Author List

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