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# The UK National Wind Tunnel Facility

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## Abstract

The UK National Wind Tunnel Facility is an initiative in which 23 wind tunnels across 11 UK universities operate in a co-ordinated and shared manner. The hub provides an outward-facing anchor and single point of contact for stakeholder engagement and training. NWTF constitutes a multi-sectoral, cross-discipline investment, ensuring that UK expertise remains internationally pre-eminent. It promotes collaboration nationally and removes entry barriers internationally with individual facilities acting as a node for the sharing of new knowledge and expertise. The over-arching principle is that the whole of NWTF delivers outcomes that are greater than the sum of its individual facilities which are open access for early career researchers.

**Keywords:** *wind tunnel, UK network*

## 1. Introduction

Since its initial investment in 2014, the National Wind Tunnel Facility (NWTF) has become a world leader in delivering cutting-edge science across a networked range of unique facilities in experimental fluid mechanics addressing the grand challenges of clean growth and the future of mobility across aerospace, automotive and civil engineering sectors. Through efficient and flexible organisation, NWTF provides strategic, coordinated oversight with an industrially aligned approach in the generation of new knowledge in the efficiency of fluid-based systems, $H_2$ and electric/hybrid transport, fluid-structure interaction, heating, noise, dispersion of contaminants, particle transmission (Covid-19) and human factors, wind loading, coastal erosion and offshore renewables.

NWTF continues to provide cutting-edge research, with its capacity measured by outputs, and new facilities will augment this step change in terms of new science, research capacity and pace. It will enable the development of new skills in original, challenging, highly relevant experiments, the provision of new data and the establishment of "digital twins" for AI, modelling and the rapid adoption of innovative techniques such as remote access and robotics. It provides a single point of contact for industry, driving an innovation pipeline, creating a pull-through environment with opportunities for networking and international collaboration, where facilities act as nodes of excellence attracting young researchers for scientific exchange and the hub provides an outward-facing anchor of stakeholder community engagement and training. NWTF also provides a coordination node for international projects such as the European Transonic Wind Tunnel (ETW).

NWTF has received support from UK Research and Innovation UKRI (via the Engineering and Physical Sciences Research Council) and the Aerospace Technology Institute, ATI. Its strategy is closely aligned with that of UKRI, most recently outlined in the UKRI's Landscape Analysis and Opportunities. New facilities, complementing existing ones with new capabilities, constitute a multi-sectoral, cross-discipline investment, ensuring that UK expertise remains pre-eminent.

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In the challenges of net-zero carbon transport and clean energy growth, six scientific challenges have been identified as of especial importance:

- turbulence - AI for modelling in computation and real-time control;
- energy efficiency - zero carbon-emission transport;
- fluid-structure interaction - vortex-induced vibration of large structures, infrastructure resilience, UAVs;
- scalar transport - dispersion of contaminants, airborne transmission in atmosphere and confined spaces;
- noise - propeller and jet aeroacoustics, urban air mobility, reduced environmental impact;
- high-speed aerothermodynamics - shockwaves, heat transfer, atmospheric (Mars) re-entry.

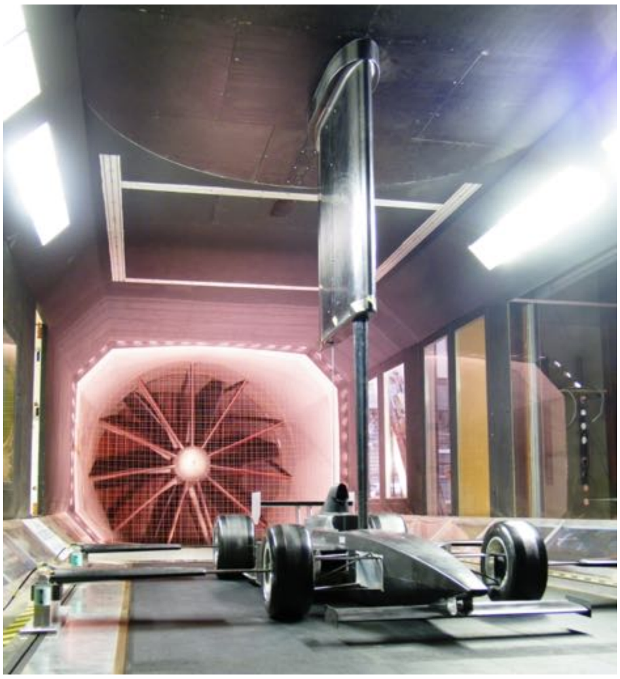

**Fig 1.** The $3.6$ m $\times$ $2.5$ m Mitchell tunnel at Southampton University. Maximum Reynolds number $3.64 \times 10^6$ /m.

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### 1.1. Underpinning philosophy

The over-arching principle is that the whole of NWTF delivers outcomes that are greater than the sum of its individual facilities. NWTF exploits the the inherent symbiosis between the facility and the host researchers for the benefit of all users. Tunnels are expected to provide excellence of a world-class facility. The host university is expected to meet the following criteria:

1. the host university is clearly committed to its wind tunnels;
2. the host university is research intensive and the lab has a proven track record;
3. the investigators local to the facility are of proven capability, willing to collaborate and prepared to demonstrate best practice, so providing an outward-facing role for the community.

While each tunnel acts as a node for attracting researchers both both nationally and internationally, other factors affecting the overall balance of tunnels is the complementary nature of the research expertise available, the overall balance of the facilities as well as their geographical location. The EDI of the host group is also important.

NWTF enables the realisation of EPSRC's overall vision and objectives within several of its themes – engineering, energy and the digital economy – particularly in delivering economic impact and social prosperity through the stimulation of research, the promotion of excellence and impact acceleration. Over the next five years, further investment in NWTF will ensure that the UK maintains its position at the forefront of aerodynamics research. Facilities are available to all UK-based researchers and aim to create nodes of excellence attracting young researchers. Coordination of these activities through the hub brings the facilities together to provide strategic oversight and management in a shared manner, ensuring a collaborative, aligned approach. As such, NWTF fully supports UKRI's and EPSRC's strategic objectives and the government's industrial strategy.

**Fig 2.** The BAE Advanced Turbo Prop model aircraft in the Glasgow University de Havilland wind tunnel (left) and development of an atmospheric boundary layer with 18 m fetch in the 10 x 5 tunnel at Imperial College, maximum Reynolds number $3.1 \times 10^6$ /m. (right)

NWTF is driving impact through several multi-institution projects in collaboration with industry, leading to faster and more cost-effective research with exploitation paths to products and service in society. For NWTF this means better, zero-emission aircraft and road vehicles, and environmentally sustainable urban development. A number of university / industry project collaborations are underway.

Investment in wind tunnel infrastructure also enables the development of engineering skills for several sectors, notably aerospace, automotive and wind engineering sectors. Aerospace, in particular, is a dominant sector for the spillover of a highly trained workforce into other sectors of the economy. The UK is the world leader in F1 to which NWTF makes unrivalled technological and skills contributions. Through the interplay between experiments and computational fluid dynamics (CFD), NWTF will generate new ideas and contributions to the digital economy as well as key industries such as off-shore renewables and coastal engineering.

Internationally, NWTF promotes collaboration, removing entry barriers. It already has influence in Japan through the "Wind and Flow (Kaze Nagare) Platform" hosted by JAXA, Chofu, which, with its large-scale facilities, provides clear opportunities for interaction between small-scale, lower TRL development and integration to higher TRL through collaborations with Japanese industries. JAXA exploits the clear synergy between world-class tunnels and supercomputing facilities. The Platform itself is supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). In Australia, an NWTF-inspired national consortium (U. Sydney, Monash, Adelaide, Queensland, Tasmania, RMIT), led by U. Melbourne, is being assembled. Based on a brown-field site in Melbourne, new flagship research facilities are being co-located with industries including Boeing Australia, BAE, Ford, Lockheed Martin, GM Holden and defence industry SME's.

## 1.2. Organisation

The NWTF infrastructure model is a hub-and-spoke arrangement, in which facilities at nodes of research expertise and activity benefit from centralised management providing coordination of facility usage, multi-sectoral industry engagement, stakeholder buy-in, training, and data management, while encouraging curiosity-driven research and the potential for game-changing ideas. NWTF operations are managed by the Management Board (MB) comprising the lead investigator at each institution plus its project manager with *ex officio* membership of EPSRC and ATI. The MB has a proven track record of designing and developing facilities to enable world-class research at UK-based facilities attracting researchers internationally from industry and academia. Its international Advisory Board (AB) comprises some thirty representatives from industry and academia. NWTF governance is continuously optimised with support and advice from the AB. It is committed to EDI and transparency.

**Fig 3.** The $1/25^{th}$-scale, 150 m-long catapult-driven TRAIN rig at Birmingham University with a 50 m test section (left) and the 138 m-long towing and wave tank at the University of Southampton with maximum carriage speed of 10 m/s (right)

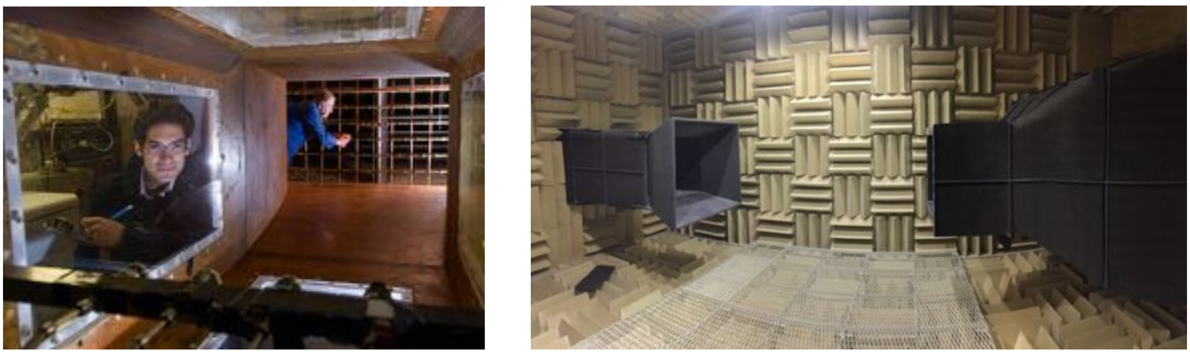

**Fig 4.** The Cranfield University Icing tunnel (left) with ice droplet measurement system and the anechoic 1 m x 0.75 m wind tunnel at the University of Southampton which has far-field microphones and a phased microphone array (right).

With an inclusive approach, NWTF provides a coordinated response to meet, principally, the Net Zero challenges of clean growth and the future of mobility through a network of world-class facilities such that scientific insights and experimental expertise are shared, and researcher mobility across academia and industry is promoted. Improved interconnectivity leads to a distributed facility that provides outcomes greater than those achievable by the same facilities operating independently.

The objectives of NWTF are:

1. keep the UK at the forefront of aerodynamic and fluid mechanics research by promoting world-class facilities to the UK talent base of researchers in both academia and industry;
2. provide a world-leading wind tunnel capability while being cost-effective;
3. stimulate cross-sectoral research;
4. promote access of facilities to all UK-based researchers;
5. create nodes of excellence that attract early-career researchers;
6. establish a closer tie with industry creating a pull-through environment and an intended spill-over of the collaboration and benefits to other sectors;
7. develop best practice for new testing techniques and data acquisition;
8. promote new experiments to provide new data for digital twins / threads and the establishment of AI within experimental aerodynamics.

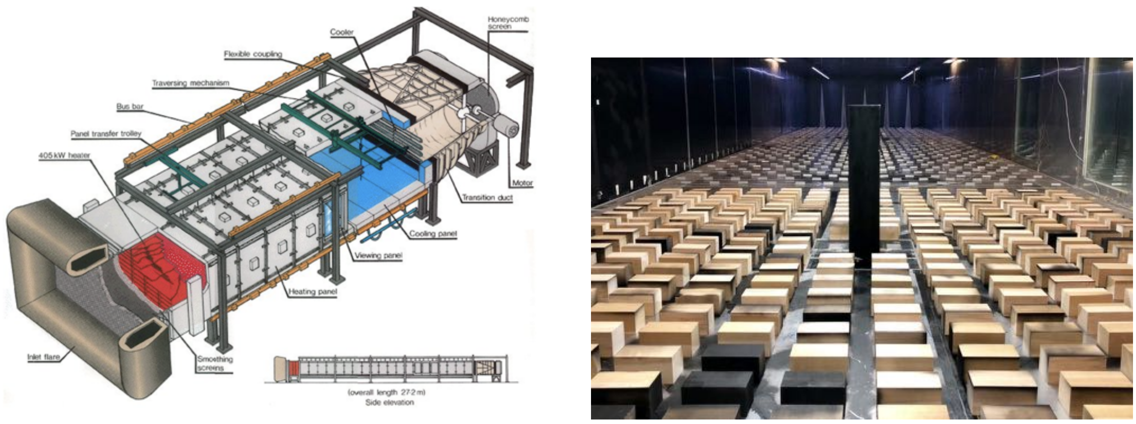


**Fig 5.** The Schematic of the EnFlo facility at the University of Surrey (left) and view upstream of tunnel working section (right). Heating arrangement simulates both stable and unstable boundary layers at scales from 1:200 to 1:1000.

## 2. Facilities

Fig. 1 - 4 show the scope of the low-speed tunnels that generate research in aerospace, automotive and wind-engineering sectors. More recent additions to NWTF include the EnFlo facility at University of Surrey (Fig. 5) used for studies in atmospheric dispersion studies, the automotive tunnel at the University of Loughborough and the anechoic tunnel at the University of Bristol.

NWTF also includes a wide range of high speed facilities at Cambridge, City, Imperial, Manchester and Oxford. While low-speed facilities can address a number of multi-sectoral challenges, higher Mach number flows are usually generated in bespoke facilities for specific aerospace challenges. Fig. 6 shows, left, the T6 Stalker Tunnel which is Europe's highest speed wind tunnel, capable of producing flows in excess of 20 km/s. It is a multi-mode facility, capable of operation either as reflected shock tunnel, an expansion tunnel or a shock tube. The same picture shows on the right, the High-Density Tunnel (HDT) which is a reconfigured and upgraded facility from the original RAE shock tube and acquired by the University of Oxford in 2012. It operates either as a Ludwieg tunnel or a Light Piston Compression Heating facility, producing cold hypersonic flow conditions with test times long enough to investigate unsteady flow effects. Operating as a Hypersonic Heated Ludwieg Tube it has a section size 0.35 m diameter, Mach number 3 – 9 and a maximum flow speed of 3 km/s.

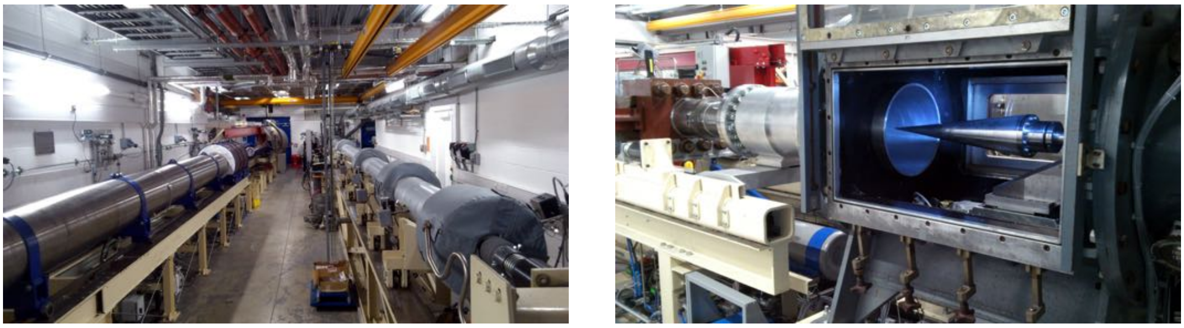

**Fig 6.** The University of Oxford, Southwell laboratories, T6 Stalker tunnel (l) and High-Density Tunnel (r) (left frame) and HDT tunnel working section (right frame).

Fig. 7 shows left, the supersonic facilities at Cambridge. There are two identical test sections 0.12 m x 0.2 m x 0.6 m working in the Mach number range 0.6 – 3.5. It boasts an internal 3-component sting balance with modern instrumentation. The figure also shows (right) the Manchester University supersonic tunnel operating at Mach Numbers 4, 5 & 6, with a maximum flow speed of 1.2 km/s. Although a blow-down facility, it has a maximum run time of 8 sec.

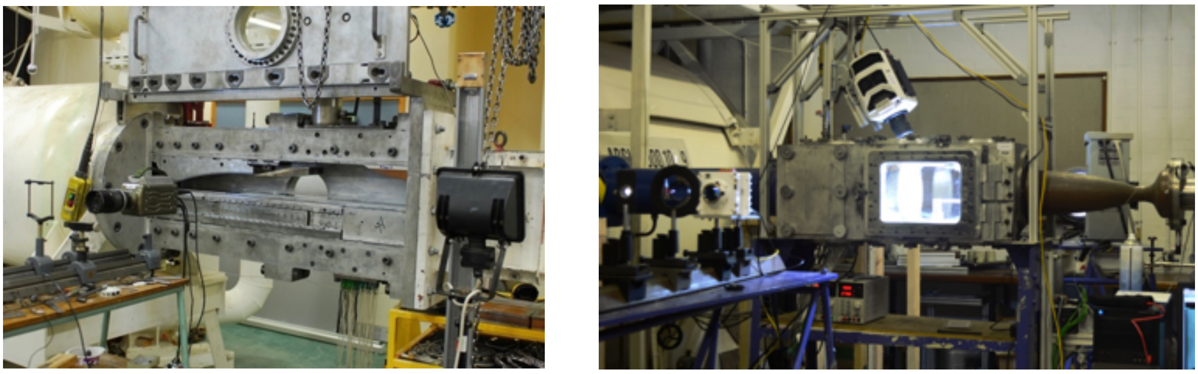

**Fig 7.** The University of Cambridge supersonic tunnel(s) (left) and University of Manchester (right).

Details of all the facilities are available at the NWTF website.

## 3. Future Developments

NWTF expects to grow, principally around the infrastructure investment to meet the goals of UK government addressing the grand challenges of clean growth and the future of mobility across aerospace, automotive and civil engineering sectors. The UK Climate Change Act, as amended in 2019, commits the UK to net zero by 2050. In April 2021 (restated "Net Zero Strategy: Build Back Greener", October 2021) the UK government?s sixth Carbon Budget enshrined in law new targets to cut emissions by 68% (78%) by 2030 (2035) on 1990 levels, incorporating UK share of international aviation and shipping emissions for the first time. The Climate Change Committee provides independent reports outlining compatibility of government policy with UK climate targets. The lead time from innovation to 'green' products and services through improved design is of order a decade.

A more recent agenda stems from the need for not only sovereign industrial capability, but also sovereign defence capability, especially in the defence sector, more especially in hypersonic flows. The UK is fortunate to have retained its research capability in experimental hypersonics, notably in those tunnels detailed above. Further investment is required and, indeed, likely in this area.