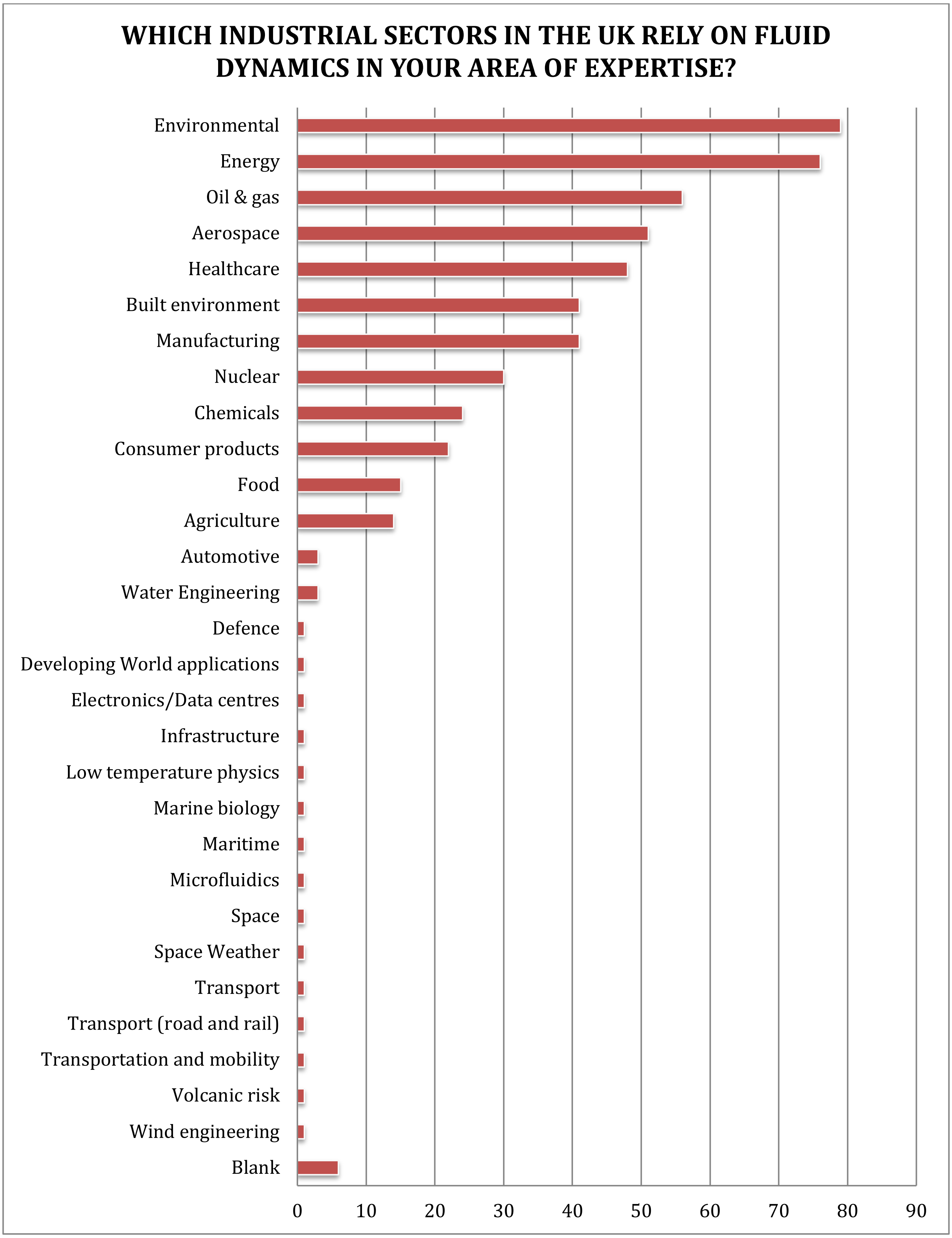
Questionnaire about a National Initiative in Fluid Dynamics

This report contains a summary of the responses to a questionnaire sent to the UK Fluids community by the UK Fluids Network in October 2020.

5th November 2020

Which industrial sectors in the UK rely on Fluid Dynamics in your area of expertise?



In the above industrial sectors, what are the main challenges Fluid Dynamics research can address, and how could it do so?

Summary

The main challenges identified by colleagues were spread across many industrial sectors, in particular environmental, energy, oil & gas, aerospace, healthcare, built environment, and manufacturing.

Environmental: Climate and weather modelling

Climate change is the greatest long-term challenge faced by this and forthcoming generations. It can only be solved through combining technological advances, public trust, and effective policy. All of these will require increasingly accurate climate and weather models and rigorous comparison with experimental data.

Environmental: Resiliant infrastructure

As predictions of the future climate improve, it becomes possible to plan for resiliant infrastructure, which will have to withstand higher sea levels and more extreme weather. Many of the solutions that will be required involve a fundamental understanding and modelling of Fluid Dynamics.

Environmental: Pollutant / microplastic dispersal and decontamination

As we become more aware of the harm caused by pollutants to humans, animals, and the natural environment, we need more accurate models of pollutant dispersal and more effective methods for decontamination. At their heart, these are Fluid Dynamics problems.

Energy: Efficient power generation, efficient transport and carbon footprint reduction

Fluid Dynamics and heat transfer is fundamental to almost all power generation, whether conventional, nuclear, or renewable. Large reductions in carbon production are possible with small improvements in design leading from better Fluid Dynamics modelling, both for power generation and for power consumption, e.g. in transport.

Oil and Gas

Although oil and gas will become used less for fuel in the long term, they will remain the primary feedstock for hydrogen and chemicals manufacture in the medium to long term. The Fluid Dynamics of oil extraction is becoming increasingly important as nations deplete their easily-accessible reserves and, for their energy security, rely on more elaborate mechanism to extract remaining reserves. Measurements down oil wells are sparse and noisy so better three-phase modelling needs to be combined with physics-based statistical inference and sensitivity analysis. This also applies to CO2 sequestration.

Aerospace

Although many respondents considered Aerospace to be an industrial sector that relies on Fluid Dynamics, there were only a few comments about the main challenges that Fluid Dynamics can address in this area. These mainly concerned turbulent drag reduction but also included hydrogen combustion.

Healthcare

Fluid Dynamics and chemical transport are central to the workings of the human body, such as the vascular and the lymphatic systems. Better understanding of the body's Fluid Dynamics will lead to better models of healthy humans, increased understanding of the mechanisms of disease, improved treatment, innovative diagnostics, and improved drug delivery.

Built environment: Air quality

In developed countries, most humans live in built-up areas which both affect and are affected by the climate around them. This coupling is through Fluid Dynamics and heat transfer but currently suffers from an artificial division between building research (EPSRC) and climate research (NERC). Improved understanding of this Fluid Dynamical coupling will lead to technological solutions that will improve energy efficiency, air quality, and building design.

Manufacturing and Consumer Products

Most manufacturing involves Fluid Dynamics. Not only is this a key UK industry but recent developments in Fluid Dynamics, experimental measurements, and Big Data have created unprecedented opportunities for good design and efficient and safe operation. In manufacturing, many fundamental Fluid Dynamical questions remain open or as yet unapplied. Fluid Dynamics also is central to the design of functional products - i.e. where the Fluid Dynamical behaviour ***is*** *the product.*

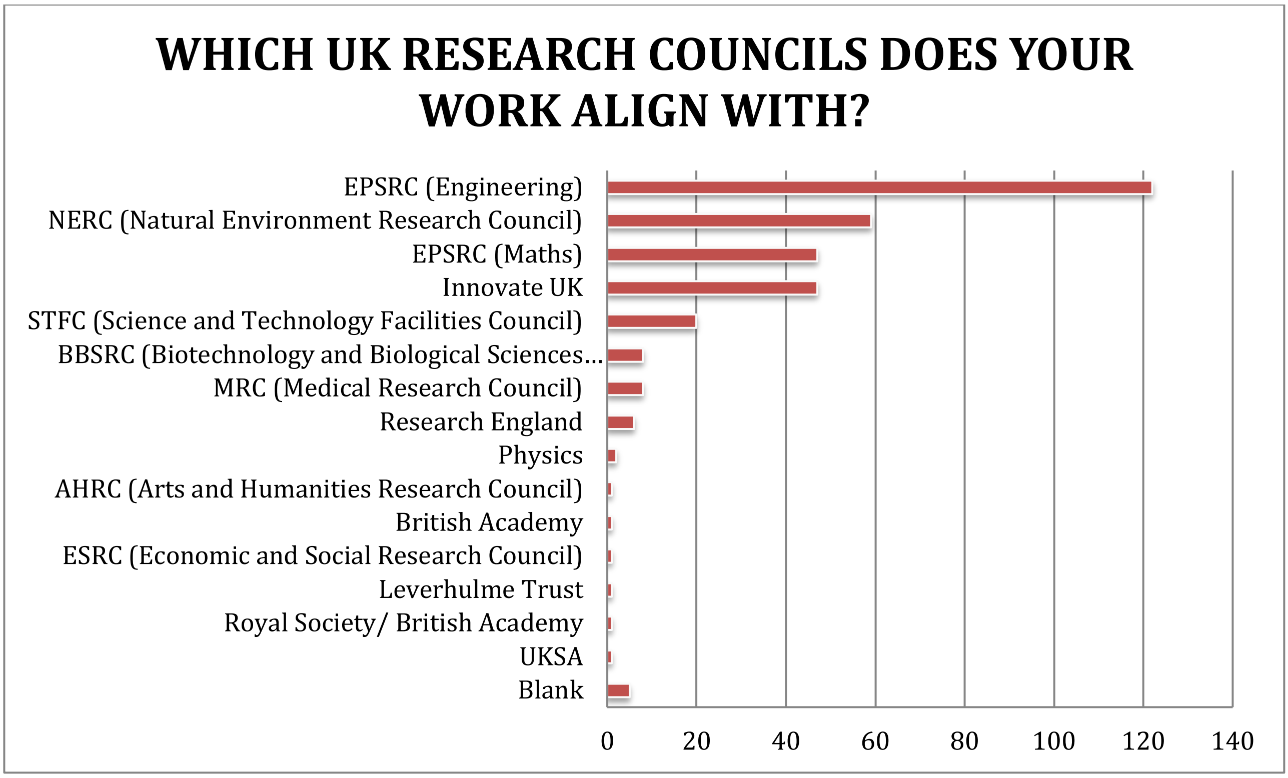
The combination of Experiments, High Performance Computing and Modelling

In response to the question 'how can Fluid Dynamics address these industrial problems', many respondents mentioned the combination of Experiments with CFD on High Performance Computers, using machine learning where appropriate, leading to optimisation on feasible timescales. Finding a common language and tool between academic and industrial researchers is also important.

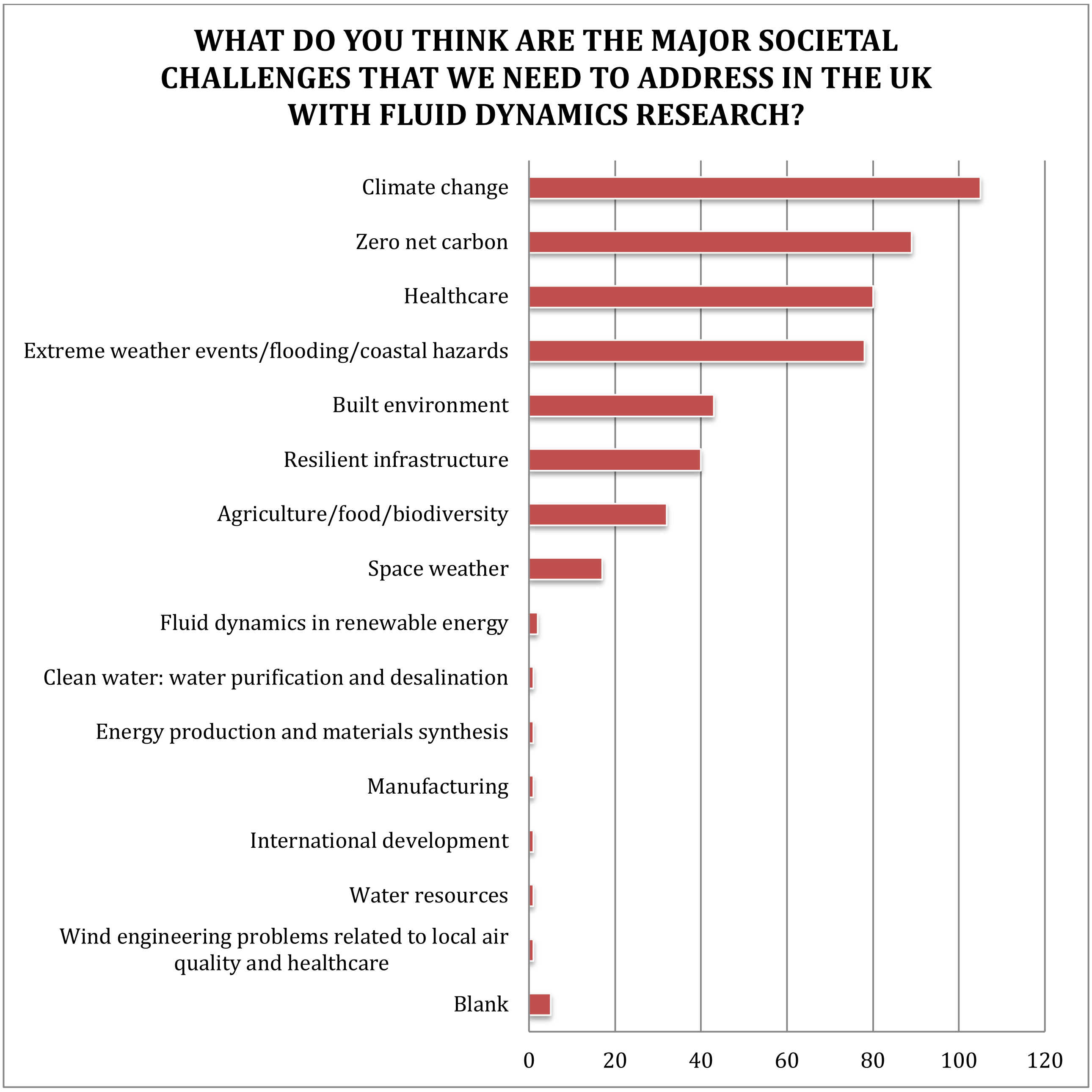
Nuclear

Fluid Dynamics is fundamental to the safe and efficient function of nuclear reactors and the disposal of nuclear waste. Nuclear energy provides a reliable base load, which is particularly important because renewable energy is usually intermittent, so is likely to remain part of the UK's energy mix in the future.

Which UK Research Councils does your work align with?



What do you think are the major societal challenges that we need to address in the UK with Fluid Dynamics research?



How could Fluid Dynamics research address the societal challenges you mention above?

Summary

Climate change and zero net carbon are the two most cited societal challenges that can be addressed with Fluid Dynamics research. When asked how Fluid Dynamics research could address these problems, however, most respondents replied that fundamental research is essential. The answers to this question overlapped significantly with those of the previous question but were instead written through the prism of societal challenges rather than industrial challenges.

Improved fundamental understanding in Fluid Dynamics

In response to the question "How could Fluid Dynamics research address these societal challenges", most respondents replied that improved fundamental understanding of Fluid Dynamics is essential. Whatever the societal challenge, Fluid models in the future will need to utilise high performance computing and data-driven methods intelligently to create predictive tools that can be used to tackle the challenge.

Better weather and climate modelling for increased public trust and engagement

As well as being an industrial challenge, better weather and climate modelling are required to respond to the societal challenge of building and keeping the trust of policy makers and the public when making consequential policy decisions about the mitigation of climate change. Fluid Dynamics plays the central role in climate and weather models. It also plays a crucial role in many mitigation strategies.

The Built Environment

Fluid Dynamics is central to the societal challenge of creating a built environment that is well-ventilated, low energy, and in which particle dispersal can be controlled. One example is to create tools that can be applied by non-specialists to design or assess the flow in their own environment.

Healthcare/Medical

To be a prosperous nation, the UK needs to be a healthy nation. Many mechanisms in the body rely on fluid transport. Knowledge of Fluid Dynamics is required to model this successfully, as well as to model what goes wrong during disease, and how to alleviate problems with therapy. Today it is possible to model the fluid mechanics and structural dynamics of organs and the cardiovascular system, allowing us to model therapies, predict how drugs will be distributed around the body, and how diseases are transmitted from one body to another. More generally, the tools of data assimilation can be applied to medical imaging of fluids and to improve healthcare provision.

Energy generation, energy use, carbon sequestration

One of the most important societal challenges is matching energy supply with energy demand while also reducing CO_2 emissions. Fluid Dynamics is central to many aspects of power generation, whether through traditional routes or renewables. Fluid Dynamics is also key to reducing energy demand, through increasing efficiency and improving rates of heat transfer. Finally, Fluid Dynamics is central to carbon sequestration and storage.

Agriculture/biodiversity

The planet's population is predicted to stabilise at 11m within a generation. This population can only be sustained by industrial agriculture, which in turn requires diseases to be controlled, fertilisers and insecticides to be distributed, and water to be delivered without being wasted. Knowledge and modelling of Fluid Dynamics is required for most of these activities.

Manufacturing

Fluid Dynamics plays an important role in manufacturing

Space Weather

Fluid Dynamics is the fundamental driver of Space Weather, which is a societal challenge because it can affect so much of our electronic infrastructure.

What do you see as important new innovations in Fluid Dynamics?

Summary

The majority of the important new innovations suggested were in the areas of Data-driven, Computational, and Experimental methods. These proposed innovations were often at the interface of all three.

The broadly-defined tools of machine learning can be used to assimilate data from CFD or experimental datasets, even when those sets are sparse and noisy. This becomes particularly important as the storage of experimental and computational datasets becomes impractical because there is so much data. Digital twins (quantitatively-accurate models of real life systems), which are enabled by data-driven methods, can be combined with optimization for automated design and control beyond that which could be achieved by humans alone.

Innovations in computational infrastructure will continue to change Fluid Dynamics. On the supply side, computational power will continue to increase, HPC architectures will change, and quantum computing could become relevant to Fluid Dynamics. In these cases, the field needs innovative algorithms to harness the infrastructure. On the demand side, which we could label the democratization of CFD, it will become possible to perform real-time CFD and output the results to a handheld device. We will also see CFD being used increasingly in design and design optimization.

For measurements in the laboratory, high speed 3D PIV and its combination with concentration measurements was mentioned several times. The capabilities of this technique is advancing quickly, giving experimental detail down to the smallest scales of turbulence (the Kolmogorov scale) with a correspondingly vast amount of data. New sensors (e.g. biological sensors), distributed measurements in the field (e.g. for atmospheric or oceanic measurements), and the combination of experiments with rapid 3D prototyping were also mentioned.

There were fewer suggestions around physical modelling alone, which tended to focus on modelling across scales, multi-physical flows, and complex fluids. This probably reflects the fact that the physics of most commonly-used fluids is already well-known. A popular theme within this broad question was the combination of data-driven methods with physics-based models.

Data-driven methods - Integration with experimental or CFD datasets

The broadly-defined tools of machine learning can be used to assimilate data from CFD or experimental datasets, even when those sets are sparse and noisy. This becomes particularly important as the storage of experimental and computational datasets becomes impractical because there is so much data. This has strong implications for turbulence, which is often described as the last unsolved problem in Classical Mechanics.

Data-driven methods - Combination with physics-based models

A popular area of innovation is the combination of physics-based approaches with data-driven approaches. This can unlock major advances, and also align better with future directions of HPCs (e.g. to use graphics cards rather than CPUs).

Data-driven methods - Digital twin and Design

Data-driven methods allow quantitatively-accurate models to be developed, known as DIGITAL TWINS. These extend the capability of fluid mechanics from physical understanding to design. These Digital twins, which are enabled by data-driven methods, can be combined with optimization for automated design and control beyond that which could be achieved by humans alone.

Computational - Infrastructure

One area, which we might call the 'democratisation of CFD' is to perform real time CFD, perhaps on a handheld device, using remote servers. Quantum computers for CFD were mentioned (for CFD problems that can be tackled with quantum computers). As expected, innovations in High Performance Computing will continue to have significant impact.

Computational - Modelling / Algorithm development

Continual innovations in algorithm development and capability. Algorithms will need to be developed specifically for CFD with quantum computing.

Computational - Impact

For impact of CFD, one innovation is the combination of computation with sensitivity analysis and optimization, together with the incorporation of experimental measurements. The impact of High Performance computing will continue to increase, along with the generation of data. The community will continue to consolidate behind a few open source codes.

Experimental - PIV

For measurements in the laboratory, high speed 3D PIV and combination with concentration measurements was mentioned several times. Although not written below, this technique produces vast amounts of data and therefore naturally joins with 'data-driven methods'

Experimental - Distributed measurements

For measurements in the field, low cost distributed sensors (and corresponding large amounts of data) are a significant innovation

Experimental - Other

3D printing for experiments, biological sensors, and acoustic sensors.

Modelling - Mathematical developments

A couple of mathematical developments were mentioned, although only one (the shadowing method) is novel in fluid mechanics.

Modelling - Physical modelling

Modelling across scales down to the molecular scale, Multi-physics modelling, modelling non-Newtonian fluids

How could an initiative build on the activities of the UK Fluids Network?

Summary

Many respondents regarded the Special Interest Groups as the natural starting point for a National Initiative in Fluid Dynamics. Respondents were keen to keep up the momentum and the contacts that have developed over the last four years. Many respondents also recognized that more ambitious grand challenges and wider engagement can only be achieved with a national initiative. Some suggested grouping SIGs either around grand challenges or around inter-disciplinary projects. There was support for Early career training, activities such as Summer Programmes, and some central network provision.

Building on the Special Interest Groups (SIGs)

Many respondents were impressed by the outputs and ethos of the SIGs and suggested that a National Initiative should build on their achievements. This could be by funding targeted research projects arising from the SIGs, by sharing ideas across several SIGs to identify Grand Challenges, or by creating clusters of excellence in key subdomains. There was a clear desire for more inter-disciplinary research, although there were no suggestions that could not be started through existing or new SIGs.

Engagement with industry and policy-makers

There was support for continued engagement with industry and policy makers, noting that this can be difficult. Apart from the suggestion of starting a Catapult and a UK-wide Industrial collaboration centre, there were few actionable ideas for how to do this beyond existing SIG meetings, which seem to encourage the friendly exchange of knowledge. Some respondents thought that now would be a good time for the community to identify a small number of national priorities in the area of Fluid Dynamics and for the government to invest in them.

Early career training and a Summer Programme

There was significant support to use a National Initiative for training, particularly at the post-doctoral and fellowship level. There was support for a network-wide summer programme and a desire for resources to be pooled e.g. via a resource-sharing platform.

Central UKFN provision

The questionnaire provided useful feedback on the more value aspects of central network provision. These were to maintain the website, newsletter, and to continue to support SIG meetings across the UK.

Responses categorized by themes

SIGs - Developing and funding targeted research projects

There was support for continued funding of SIGs, for example through targeted programme grants arising from the SIGs.

SIGs - Sharing ideas to identify grand challenges

There was support to share ideas across SIGs to identify grand challenges. This would involve brokerage between SIGs, rather like the brokerage activity we did at the start of UKFN to identify common areas for SIGs. This is a good steer for the National Initiative, but also for the UKFN to do anyway.

Training

There was support to use a National Initiative for training, either in person or via MOOCs.

Engagement with industry and policy-makers

There was support for continued engagement with industry and policy makers, noting that this can be difficult. One respondent mentioned a catapult.

Facilitate inter-disciplinary research

There was a clear desire for more inter-disciplinary work, although nothing actionable that cannot be achieved through SIGs (new or existing) and Programme Grants

Central network provision

The questionnaire provided useful feedback on the more value aspects of central network provision

Outreach

There was support for outreach as part of a National Initiative, although not as much as support for research

Workshop / Summer program

There was support for a network-wide summer programme but there seemed to be more support for more focused programmes on activities around the size of a SIG or small group of SIGs

Resources

There was desire for resources to be pooled e.g. via a resource-sharing platform.

Which other disciplines would benefit from a national initiative in Fluid Dynamics, and how?

Summary

It is clear from numerous statements that research in fluid dynamics and other disciplines would benefit from a national initiative in fluid dynamics. For example, "Almost every scientific/application discipline has a fluid involved one way or another. Process engineering, complex chemistry, astronomy (stars, planets, etc.), atmospheric science, etc. These disciplines all explicitly or implicitly require an understanding of fluids within models, for optimisation, etc.".

It is also evident that supporting this type of collaboration would help drive forward innovation "I've been surprised by how specialists in other disciplines have found solutions to their pressing problems in my work- because I know so little about other disciplines, I didn't even realize there was opportunity for collaboration. For example, a technology I developed for use as a boundary-layer micropillar is being investigated for use". Three main areas mentioned by many respondents are listed below.

Healthcare

"Currently, healthcare is a shining example of a discipline which benefits from fluid dynamics research, but could be better served by a national fluid dynamics initiative.";

Environment / Climate

"The disciplines chiefly involved in understanding the natural environment, how it is changing, and how we prevent or adapt to that change would benefit from advanced modelling and data analysis techniques provided by the fluid dynamics community (e.g. flood / storm prediction and modelling)"; and

Energy/reducing carbon footprint

"A number of disciplines are interconnected with Fluid Dynamics. Readily those that come to mind are Heat Transfer Engineering to provide better, more compact, efficient cooling and heating solutions for houses, data centres and electronics that will lead to an important reduction in carbon footprint".

Other

In addition, there is support for a national initiative "A national initiative in Fluid Dynamics would benefit not only the traditional disciplines of Engineering, Physics, Computing and Mathematics but will cut across (deeper) into Healthcare, Biology, Geology, Atmospheric Sciences and Oceanography. This will ultimately will also cut through humanities and sociology - given all global challenges affect society deeply".

Which industry partners and end users do you think would engage with a national initiative for Fluid Dynamics?

Summary

Most respondents suggested names of industry sectors, industry partners and end users. Some respondents shared their experience of working with industry and end users and their digested comments are included here.

Respondents wrote that most companies are willing to be involved if a strong business case can be made and they feel that it is not a financial drain. It helps for projects to be partially funded by government. On the other hand, industry does not have enough bandwidth to connect with many organisations. The research community needs to make engagement easy for industry to engage. SMEs in particular have difficulties in releasing staff so need support if they are to be involved. One respondent reported that industry can be suspicious of academic involvement, expecting the university to overpromise and under-deliver.

One respondent wrote that Healthcare, Energy, Aviation and Manufacturing are all areas that have been impacted by global events and could be considered to be undergoing varying degrees of flux. Therefore, there would be strong arguments to implement change and improvements in these sectors, through further and enhanced engagement with the scientific communities.

Which international collaborators do you think would engage with a national initiative for Fluid Dynamics?

Summary

Respondents listed societies with a broad remit (e.g. Americal Physical Society), societies with a specific remit (e.g. European Geosciences Union), international funders (e.g. NSF), National Labs (e.g. CNRS), as well as institutions and individuals.

If the UK Fluids community were to make a case for a national initiative over 5 years (with the expectation of it lasting 10 to 20+ years), what might it look like, what might the outcomes be, and what difference could this investment make to the UK?

Summary

In general the response to this is full of good ideas. There is a broad consensus that this is an excellent idea and the community is fully behind the idea of a National Initiative. The responses to what we should do focus on two sets of orthogonal considerations (a) What are the societal/industrial problems that are important to tackle with an initiative (b) What are the best mechanisms for achieving this. The answers can be summarized as

(a) Important problems
   - (i) Net Zero Energy (e.g. Carbon capture, efficient transport etc.)
   - (ii) Climate (e.g. atmosphere/ocean)
   - (iii) Health (e.g. drug delivery, flows in the body, virus control)
   - (iv) Environment (e.g. urban environment, flooding, air quality)
   - (v) Industrial processes

(b) Strategies
   (i) Development of a National Centre (central hubs and a few spokes)
   (ii) Training (this should run through everything we do – pipeline including fellowships etc)
   (iii) Support for Computational Fluids (liase with exascale)
   (iv) Support for Experimental Fluids (liaise with industry)
   (v) Data as a common theme (verification/validation optimal design)
   (vi) Support for fundamental research and to get the research to address problems of industrial/societal importance.

There is a consensus that this requires co-ordination and a critical mass. We should be looking at a 20 year program. Further details are summarised below

Structure of a National Initiative

Most respondents thought that a National Initiative should be geographically-distributed and many mentioned a hub and spoke model with more than one hub. Several said that the Initiative should plan for a 20 year timescale

Focus research around challenges across institutions, disciplines, and research councils

Regarding a strategy for engagement across the UK, many respondents said that the initiative should focus on particular challenges and should bring together researchers across multiple institutions, multiple disciplines, and multiple research councils. There were several ideas for current societal and industrial challenges, many of which would be highly suitable.

Focus research around facilities

A signiciant number of respondents suggested that the initiative should focus around facilities rather than challenges in order to create critical mass in local labs around the country.

Activities

Some proposed activities would continue naturally from the UK Fluids Network and CDTs, such as the UK Fluids Conference (which is predominantly for PhDs), and more dynamic SIGs.

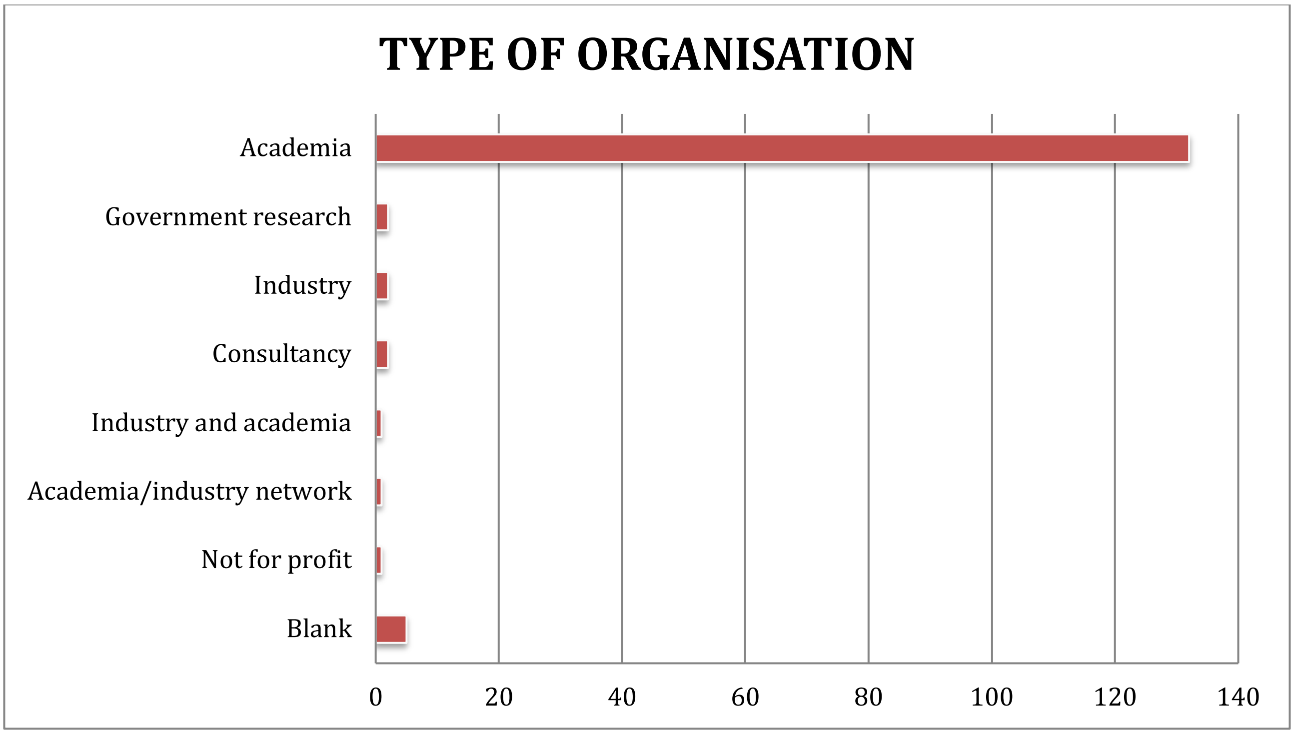
Training from doctorate to permanent academic position

Many respondents considered people to be crucial to any National Initiative. They considered it important to train and mentor people from a doctorate to a permanent academic position.

Why the National Initiative would be a good investment for the UK

Respondents were excited about the opportunities this would create for the UK, in terms of world leadership in the field, increased R&D investment in related industries, and measureable improvements in innovation.

Respondents' type of organisation



Respondents' role in their organisation