Part of the conference series
Breakthrough science and technologies
Transforming our future

Innovation in sport: accelerating breakthroughs in engineering, optimisation and performance

Held on 14 November 2022

Conference report

THE ROYAL SOCIETY

Introduction

On 14 November 2022, the Royal Society hosted a hybrid conference on Innovation in sport: accelerating breakthroughs in engineering, optimisation and performance. This meeting forms part of the Royal Society's Transforming our future series.

The Transforming our future conferences are unique, high-level events that address scientific and technical challenges of the next decade and which bring together leading experts from the wider scientific community including industry, academia, government, and charities. They are organised with the support of the Royal Society Science, Industry and Translation Committee.

The conference series forms part of the Royal Society's Science and Industry programme which demonstrates the Society's commitment to integrate science and industry across its activities, promote science and its value, build relationships, and foster translation.

The programme was organised by Professor Alan Wilson FRS, Royal Veterinary College, and Professor Philip Bond FREng, Council for Science and Technology. It brought together stakeholders from across industry, academia and competitive sport to explore how cutting-edge advances and innovations in data, modelling, simulation, and design engineering are enabling humans and machines to operate ever closer to peak functional and mechanical capacity. Talks included case studies from Formula 1, high-performance sport and Paralympic engineering, and discussed the key scientific, translational and commercial opportunities and challenges of the coming decade within the elite and everyday sporting industries.

"Individuals working at the cutting edge of science and sport share some key attributes: they like taking measurements, they are often passionate about technology, and they are continually endeavouring to do the best that they possibly can"

Professor Alan Wilson FRS, Royal Veterinary College

Image: Dame Sue Ion GBE FREng FRS (Chair of the Royal Society Science, Industry and Translation Committee) and Professor Philip Bond FREng

The conference concluded with a panel discussion to consider debates around ethics, accessibility, and interdisciplinary innovation.

This report is not a verbatim record, but a summary of the discussions that took place during the day and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily those of the Royal Society.

Executive summary

The UK benefits from an exceptional breadth of specialist scientific expertise that serves to support and develop elite athletes. The advent of National Lottery funding in the mid-1990s proved decisive for British professional sport, stimulating collaborative scientific research and accelerating investment in novel technologies. Many of these technologies have subsequently evolved to benefit everyday users who engage in varying levels of physical activity.

Image: Professor Alan Wilson FRS and delegates during the conference

The conference offered an opportunity to reflect upon scientific and technological developments in data acquisition, modelling, design engineering, and performance optimisation, and to consider future priorities. Key points include:

- Uptake of wearable devices by everyday users has increased rapidly over the past decade. There is significant potential for these devices to generate continuous data to inform training regimens, prevent injury, guide rehabilitation activities, and influence decisions around health and wellbeing.

"The case studies that we have seen today exemplify how so many people in so many places have worked together to drive cutting-edge innovations"

Professor Philip Bond FREng, Council for Science and Technology

"The materials revolution within elite sport has been remarkable"

Dame Sarah Springman CBE FREng, University of Oxford

- Challenges persist, however, in ensuring that these devices remain accessible and useful. Further research and development activity will be essential to ensure that data generated by these devices is accurate, reliable, and comprehensive for a diverse range of users. Mass market users require varying levels of information to make sense of their data, and many of these individuals do not meet recommended activity levels. There is considerable debate about the role that consumer wearables might play in helping users to enhance and maintain their fitness, and achieve sustained improvements to their quality of life.

- Consumer wearables typically balance data availability and variety against fidelity and specificity. Advances in Global Navigation Satellite systems (GNSS) sensor technology demonstrated in other disciplines offer the potential to improve the positioning, navigation and timing (PNT) capacities of wearable devices.
- The drive to identify and secure marginal performance gains for humans and machines is relentless. The UK remains at the forefront of many advances such as additive manufacturing and 3D printing, wind tunnel testing, machine learning, and virtual reality simulation for race preparation. Ongoing refinements to such technologies are likely, in some cases, to achieve cost reductions over time.

> "If we could study how someone is improving, just by looking at changes in their continuous data, this would be really important"
>
> Professor Cecilia Mascolo, University of Cambridge

> "Sometimes it feels like you have gone as far as you can go, but there are always further marginal gains to be made"
>
> Dr Bryce Dyer, Bournemouth University

- Case studies such as the design and development of a novel sitski for the GB Cross Country Paralympic team demonstrate the importance of collaboration between industry and academia when optimising modelling tools, performance, and athlete comfort.
- Future priorities are likely to include further optimisation of the athlete-equipment interface, exploitation of cloud-based and machine learning technologies to facilitate the analysis of large quantities of complex data, and integrating highly accurate real-time data from multiple sources to drive athlete performance.

KEYNOTE

Accelerating breakthroughs in engineering, optimisation and performance in triathlon and other sports through innovation and entrepreneurship

Dame Sarah Springman CBE FREng, University of Oxford and former international triathlete and sports leader, reflected on the evolution of innovations in elite sport over the past four decades and explored some of the advances that are likely to shape the industry in the coming years.

As a new and multidisciplinary sport, triathlon harnessed the potential of emerging technologies to enhance training and performance almost from its inception. The first world championships took place in 1989, and following formal recognition as an Olympic programme sport in 1994, triathlon made its debut at the 2000 Games in Sydney.

During the early 1980s, the acquisition and interpretation of physiological data was recognised to be increasingly important in offering a competitive advantage within triathlon specifically and elite sport more broadly. Loughborough University played a pioneering role in physiological testing – including measurement of VO_2 max (the maximum level of oxygen that an individual can utilise during peak exercise, indicating maximum aerobic capacity), heart rate monitoring and lactic acid analysis – to guide training endeavours and to facilitate transition between disciplines. High-performance training focussed initially upon propulsion (such as endurance, ergonomics, nutrition and hydration), resistance (drag, positioning and core stability) and nutrition. Technologies to harvest data and customise equipment were relatively embryonic, and many nascent innovations did not progress beyond the proof-of-concept stage.

An innovative heart rate monitoring device was obtained and tested at the Ironman World Championships in 1987. It offered two selected athletes the opportunity to gather real-time data before, during and after races to aid race decision-making, enhance efficiency, mitigate fatigue and allow effective post-race interpretation. Research into athletes' variable responses to nutrition, temperature and apparel gathered momentum. The performance gap between individuals and teams who placed more or less emphasis upon the value of science to inform training and racing strategy steadily increased.

Image: Dame Sarah Springman, University of Oxford

1997 marked a watershed for Olympic and Paralympic sport. The UK National Lottery was established in 1994 and three years later committed substantial funding to develop British elite sport through the newly-founded public body UK Sport. This investment played a crucial role in Team GB's success in the 2000 Olympic Games. It later helped to promote acceptance of new technologies and training strategies and highlighted the potential of scientific research to offer ideas, prototypes, and insights to individuals and teams. Innovation within elite sport progressed apace, and collaborative enquiry across disciplines intensified.

In subsequent years, attention focused increasingly upon marginal gains. Preparation for the 2012 London Olympics centred around incremental improvements. The GB Rowing Team's Olympic strategy was informed by over 20 science and technology projects supported by UK Sport's growing capabilities in data strategy and mathematical modelling.

Priorities for the future

The pace and scale of innovation in elite sport within just four decades has been remarkable. Priorities for the coming years are likely to include:

- Materials engineering, including 3D printing, bio-inspired and biomimetic materials, developments in the human-machine interface, and ongoing refinements to core engineering parameters such as weight, stiffness, strength and load-carrying design
- Machine learning and artificial intelligence to learn predictively from data. This will require careful handling of the risks associated with gender-based and gender-biased models and algorithms
- Virtual / augmented reality, to enhance coach-athlete interactions and to experience and learn movements within the spatial environment around athletes
- Environmental impact, with elite sport increasingly under the spotlight
- International and supranational governance, with a critical role for the International Olympic Committee and other international organisations in promoting equity within elite sport, even when this proves controversial

Some of the most exciting innovations in recent years have emerged within Paralympic and disability sport. The first international Cybathlon took place in 2016, organised by the Swiss Federal Institute of Technology (ETH Zürich). It brought together individuals living with physical disabilities to compete as 'pilots' in a range of sporting disciplines supported by technical assistance provided by 'rehabilitation' engineers using cutting-edge engineering science. High-profile innovations included exoskeletons, stair-climbing wheelchairs, and videogame events with avatars controlled by electrical signals in the brain.

It is recognised that such competitive events are an effective means of assembling leading innovators across industry and academia to drive advances in science and technology with the potential to offer tangible improvements to participants' quality of life worldwide through ongoing entrepreneurship.

"The potential for cutting-edge technology to enhance Paralympic sport is enormous. In the next three decades, I expect to see a Paralympian beat an Olympic athlete at a 100m running race'

Dame Sarah Springman CBE FREng

Setting the scene: challenges and opportunities around data acquisition and usage within elite sport

Beth Potter, UK Triathlon, emphasised how physiological and performance data can enhance training and racing success. She highlighted the evolutions in data acquisition and interpretation that will be needed to enable triathletes to increase and maintain their competitive advantage.

Image: Beth Potter, UK Triathlon

Performance in multidisciplinary endurance sports such as triathlon can be enhanced by the acquisition and interpretation of data. Conventional training regimens – typically dominated by low-intensity aerobic work-outs combined with vigorous VO_2 max and threshold sessions – may neglect some of the precise and comprehensive data which can drive marginal gains across a variety of race environments.

The optimal cadence (swim strokes per minute) will differ between coastal waters, lakes, and rivers. Water temperature can influence breathing and stroke technique. Different road gradients demand varying degrees of cycle acceleration, and wind tunnel testing illustrates the advantages of adjustments to limb positioning. Deploying real-time data to inform pacing can offer a crucial competitive edge.

Triathlon events are increasingly dynamic, marked by decisive moments such as transitions between disciplines, and breakaways during the cycling stage. Challenges remain to maximise the potential for data to enhance race modelling and performance. There is significant scope for industry scientists and engineers to help address these questions.

- **Acquiring accurate real-time data across multiple sources**
  Integrated software platform INCUS Performance has developed a wearable device to help triathletes track and adjust body rotation during the swim stage in real time in response to the positioning of other competitors. There is scope for comparable insights during the cycle and run stages, including how to train for stage transitions and manage fatigue.

- **Integrating contexts from different data sources**
  Physiological and performance datapoints including heart rate, lactate profile, power, and cadence can be captured easily using a range of devices, but this typically occurs in silo. There are currently few platforms which offer the opportunity to record, present and analyse multiple parameters simultaneously.

- **Improving ease of access to meaningful data**
  Many applications – especially those available for free – present data in an established format using a standard set of graphs. These can offer insufficient detail for elite athletes and highly committed amateurs. Interpreting full sequences of raw data typically requires time and specialist expertise. An intermediate tool that provides the flexibility to explore and analyse data without the need for advanced technical skills would be a valuable asset.

- **Interpreting and actioning data as a cohesive entity**
  It will nonetheless be increasingly important to access expert skills to interpret integrated data as they evolve over time. Real-time information on power output, for example, is of limited value if its impact upon other physiological and biomechanical parameters remains unclear. Cross-domain expertise will be required to draw together multiple insights and help athletes and coaches to apply them for performance gain.

Ultimately, ongoing innovation in data acquisition and interpretation will be essential to anticipate and fulfil the evolving needs of professional triathletes.

> "It would be really useful to know how to pace myself in real time rather than base decisions simply on my perceptions of how I feel"
>
> Beth Potter, UK Triathlon

Wearable technologies: Looking to the future

Ray Maker, also known as DC Rainmaker, reflected on the evolution of wearable sensor technology over the past 15 years, discussed some of the limitations associated with the acquisition and deployment of wearable data, and explored emerging trends in data interpretation for human performance and wellbeing.

The wearable sensor industry has grown exponentially over the past fifteen years. Increasingly specialised devices occupy a crowded market, offering diverse monitoring capabilities encompassing traditional physiological markers such as blood pressure and heart rate, and advanced algorithmic indicators including altitude acclimatisation, stress levels, and even aerodynamic efficiency.

Many devices generate information on a continuous basis and can be deployed across a range of sporting activities. The 'daily readiness scores' and bespoke training recommendations now supplied by Fitbit and Garmin devices illustrate the potential for wearable technologies to offer holistic, personalised evaluations of fitness and health both for elite athletes and for individuals with more moderate activity levels.

With this in mind, users – including those who coach and support professional athletes – must maintain confidence in data generated from wearable devices. Current challenges include:

- Accuracy and consistency: Whilst most devices supply metrics such as heart rate and walking speed to a high degree of accuracy, experiments using multiple GPS sensors have revealed significant variation in positioning and distance measurement. This has implications for training efficacy, training load, and equity during competitive events.
- Sleep cycle data, which inform tailored recommendations around training and rest, suffer from significant inconsistency between devices. There is little agreement amongst developers as to how sleep scores should be configured.
- Published research: Many academic studies analyse older versions of devices, and do not keep pace with technological innovation. Some studies draw upon raw data rather than the processed information available to users, compromising the validity of their conclusions. Industry research tends to be more responsive and informed by direct user experience.

Image: Ray Maker, DC Rainmaker

- Actionable data: The wealth of data generated by wearable devices is most valuable if it motivates individuals to maintain or alter activity levels or training strategies. Devices are not infallible, and information should be regularly sense-checked.

The COVID-19 pandemic prompted a significant increase in the use of data for personalised health monitoring, particularly around heart rate and respiratory indicators. Wearable technology companies are channelling resources into strategies to help individuals better understand these data.

The surge in workouts recorded on esports platforms – such as Zwift – during successive lockdowns offered a rich source of performance data drawn from consumer-grade wearable devices. Professional teams used this information to identify individuals to participate in high-profile virtual competitions. Some teams devised strategies to maximise success by combining data from wearable devices with questionnaires that tracked performance over time. Such strategies are now becoming accessible to ordinary individuals, helping to bring elite performance to the mass market.

> "Wearable devices are becoming more like coaches: not just generating physiological indicators, but asking questions such as 'how did you sleep?', 'how did you eat?', and 'how do you feel?', all of which impact athletic performance"
>
> Ray Maker, DC Rainmaker

How to improve data acquisition and quality: Future challenges and opportunities

Professor Marek Ziebart, University College London, outlined the potential for wearable devices to benefit from advances in satellite navigation technologies.

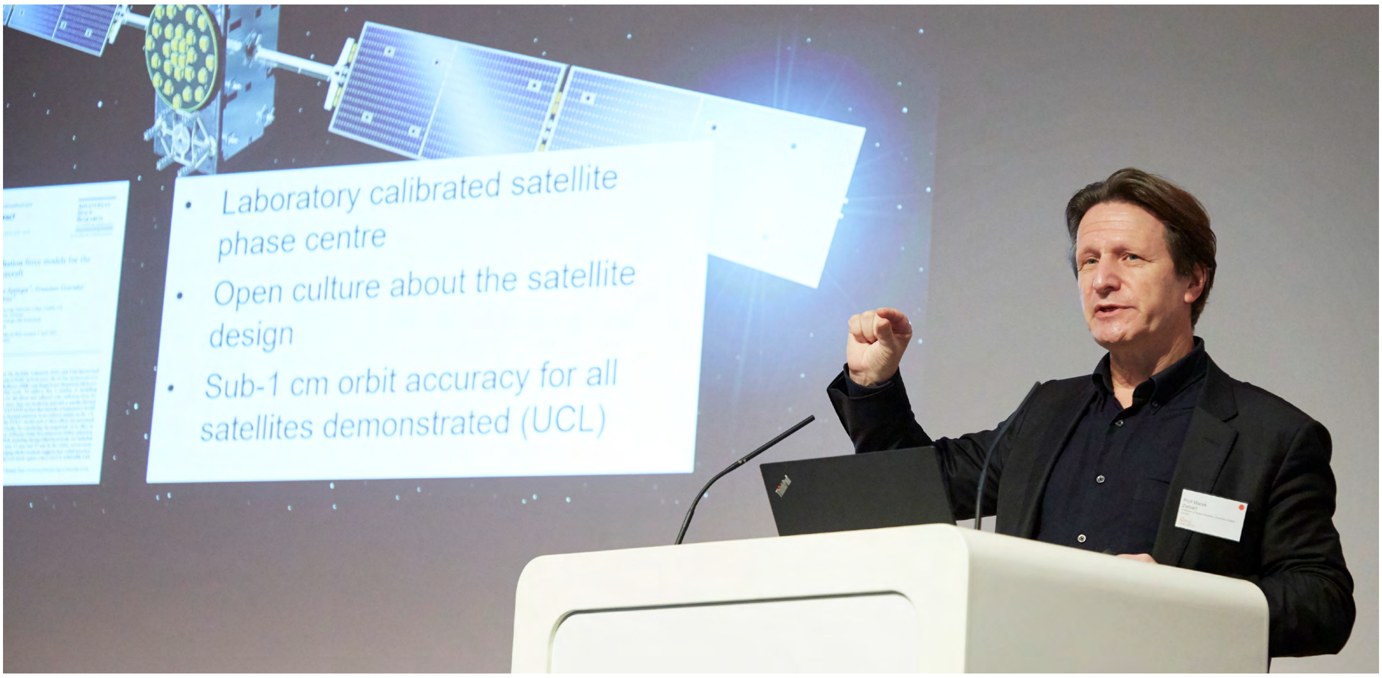


Image: Professor Marek Ziebart, University College London

Global Navigation Satellite systems (GNSS) is a satellite technology that provides positioning, navigation, and timing (PNT) services on Earth. GNSS, which includes constellations of satellites and augmentation systems, has significant capabilities which have yet to be fully exploited by the sports industry.

Basic GNSS positioning requires a constellation of approximately 30 satellites orbiting at 20,000km above Earth, moving at 3.5 - 4km per second, and uses the principle that the distance between two objects (such as a satellite and a terrestrial receiver) can be determined by multiplying speed of propagation of a signal transmitted between the objects by the time taken for the signal to travel between them. Orbiting satellites emit high-frequency sinusoid carrier waves to Earth onto which they modulate a code that indicates the time at which the signal was transmitted. This code is used by a receiver on Earth to establish travel time.

The distances between a device and three satellites identify the device's latitude, longitude, and height. Incorporating a fourth satellite helps to mitigate timing discrepancies between satellites' stable atomic clocks and the less accurate oscillating clocks used in receivers within the wearable device.

GNSS capability

Most wearable devices in the sports industry rely on the US constellation of satellites called Global Positioning System (GPS). There are over 120 navigation satellites currently in orbit and many other satellite systems, all of which could be used to improve PNT capability. By enhancing the receiver in wearable devices with an augmented system, such as the European Geostationary Navigation Overlay System (EGNOS), corrections can be applied in real time to signal distortions caused by the Earth's ionosphere. This can increase the positioning accuracy of wearables to match high-precision GPS tracking devices to within 10cm in height under ideal circumstances, and routinely gives positioning accuracy below 0.5m.

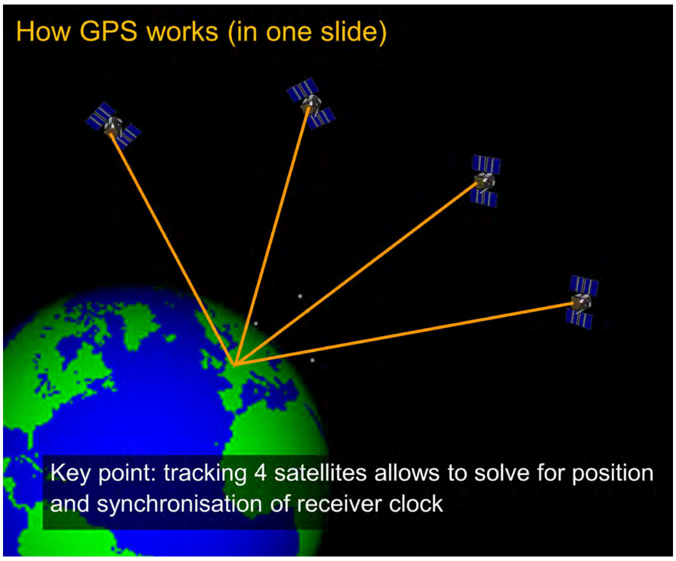


Image: A simple visualisation of GNSS technology

Time precision can also now be enhanced to within 0.2ns, reducing satellite ranging error to within 6cm. Galileo (the European GNSS constellation) is at the forefront of such advances.

Several emerging technologies are further revolutionising GNSS. Shadow matching uses geometric models of cities to predict the availability of signals at street level to improve positioning calculations. Precise Point Positioning (PPP) employs signals from either geostationary (GEO) or low Earth orbit (LEO) satellites to offer more reliable and geographically widespread positioning in real time. Typical PPP precision is in the order of 10cm in the horizontal position. Military research around alternative navigation satellite technologies, such as the US' Navigation Technology Satellite-3 (NTS-3) research programme also has the potential to accelerate advances in GNSS.

Future developments:

GNSS struggles at frequencies above 100Hz. Performance and accuracy are influenced by noise disruption, signal availability and tracking ability. Further innovation will be required to advance:

- Integration with AI
- Greater PNT accuracy
- Indoor positioning
- Anti-spoofing and anti-jamming capabilities (which serve to block external attempts to degrade signals)

Integrated sensors combining GNSS with in-built accelerometers or gyroscopes could meet these challenges. Accelerometers and gyroscopes can detect change in positioning, velocity and orientation without input from external satellite systems, and can operate at frequencies up to 200Hz. Using an ultra-tightly-coupled filter, integrated sensors combine information from GNSS and from the accelerometer or gyroscope to modify the wearable's measuring device and influence how it operates in real time. Integrated sensor technology is already being successfully employed in seismology and related disciplines and has strong potential to advance the PNT capabilities of sport wearables in the coming decade.

"The user community could drive the manufacturers of sports devices to say, 'we want better because you can do better'"

Professor Marek Ziebart, University College London

Sounding out health and fitness with wearable and earable data

Professor Cecilia Mascolo, University of Cambridge, outlined how health and fitness sensors could be brought closer to the user in a novel way.

Although data from commercial wearable devices already benefits health and wellbeing many challenges and opportunities remain around using such devices. These include:

- Continuous and longitudinal sensing: The increasing uptake of wearables has made continuous sensing of health signals feasible and widely accessible.
- 'Free living' analysis: Studies are traditionally conducted in controlled and artificial environments. Wearables provide a new opportunity for large-scale analyses in everyday 'free living' conditions.
- Uncertainty estimation: An enhanced understanding of uncertainties in algorithms would help to identify margins of error and improve data accuracy.
- Data privacy and computational efficiency: The significant volumes of wearable data uploaded onto servers raises privacy and security concerns. These can be reduced by retaining and analysing data locally.
- Sensor modalities: New sensor technologies can be integrated into fabrics or even into the skin. There are also opportunities for innovation within devices that are already widely used.

Innovation in continuous and longitudinal sensing

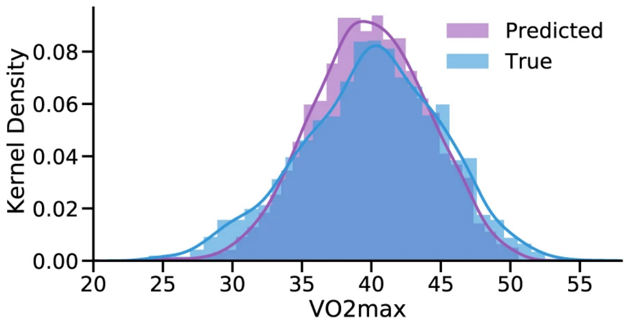
Traditionally, cardiovascular health is assessed using an individual's VO_2 max (the volume of oxygen that the body can produce and convert to energy). However, the required equipment is cumbersome, and tests are physically demanding.

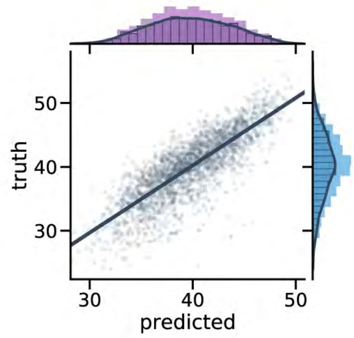
Certain wearable devices can elicit proxies that indicate cardiovascular health, such as a user's heart rate in relation to their speed or distance. However, such experiments are still small-scale and typically conducted in artificial environments. Algorithms offered by commercial wearables remain opaque and largely unverifiable.

Image: Professor Cecilia Mascolo, University of Cambridge

FIGURE 1

The true VO_2 max of individuals vs. predicted value using a wearable. The wearable consistently underpredicted VO_2 max with a correction of 1640.72 and R2 of 0.49.





Spathis et al. Longitudinal cardio-respiratory fitness prediction through wearables in free living environment. Npj Digital Medicine. 2022;5(176). https://www.nature.com/articles/s41746-022-00719-1 (Accessed 3 January 2023).

A UK-wide study[1] used data from 12,000 individuals to examine if wearable devices could predict cardiorespiratory fitness in free living environments, without prior information about the user. The experiment fed anthropometric measurements and data from questionnaires and surveys into deep neural networks to predict users' VO_2 max. Despite consistently underestimating VO_2 max, the study demonstrated that wearables could be used to continuously monitor proxies for cardiovascular health, as well as to predict the user's change in fitness over time.

Innovation in sensor modalities

'Earables', such as in-ear headphones used by many, utilise the occlusion effect, when a device (such as the rubber earpiece) blocks the ear canal, amplifying vibrations within the space. In addition to sound waves, vibrations such as bone conductance are magnified, enabling the measurement of features such as step count, gesture recognition from the user tapping parts of the face and forehead, activity recognition and gait. In the future, 'earables' could also be used to monitor heart rate and respiration. Studies indicate that in-ear sensors are more effective at detecting user activity than sensors such as accelerometers because received signals are not confused by the user's head motion[2].

Before earables can be used effectively to assess health and fitness, existing challenges must be overcome to:

- Improve device accuracy: Personalised training data is currently still required to obtain the necessary levels of data accuracy.
- Balance data privacy and uncertainty estimation with computational efficiency: To increase data security, analysis should be brought onto the earable device. However, this would increase the energy intensity, memory and cost of the technology, especially if the algorithm is programmed to calculate the uncertainty of its predictions.
- Strengthen industry/academia collaboration: At present, academic researchers must usually create lower-quality prototypes and collect their own data, as they do not have access to commercial raw data.

"We are looking at sensors which belong to some of the devices that we already use, and are trying to get them to do other things beyond the purposes for which they were invented"

Professor Cecilia Mascolo, University of Cambridge

1. Spathis et al. Longitudinal cardio-respiratory fitness prediction through wearables in free living environment. Npj Digital Medicine. 2022;5(176). https://www.nature.com/articles/s41746-022-00719-1 (Accessed 3 January 2023).
2. Ma et al. OESense: Employing Occlusion Effect for In-ear Human Sensing. 19th ACM International Conference on Mobile Systems, Applications, and Services. MobiSys 2021. https://arxiv.org/pdf/2106.08607.pdf (Accessed 3 January 2023).

Peak performance for all: Opportunities and challenges for consumer wearables

Professor Rob Harle, Google Fitbit, highlighted some of the key differences between elite athletes and everyday consumers and discussed the potential for machine learning to guide the development of wearable devices to benefit the mass market.

Currently, 80% of the global population fail to achieve the minimum level of recommended physical activity, which is 150 minutes of moderate exercise or 75 minutes of vigorous exercise per week. With some exceptions, the average mass market consumer does not value marginal gains in the order of milliseconds, instead prioritising improvements to their quality of life such as enhancing overall fitness, performing routine tasks pain-free, becoming more productive at work, or simply feeling energised. Again with exceptions, a typical consumer is likely to possess lower intrinsic motivation than an elite athlete and will require more frequent external prompting to maintain or improve their fitness and activity levels.

Developers of wearable devices must remain mindful of these differences when designing and testing technologies for the mass market. Consumer devices typically generate large volumes of complex data characterised by:

- Lower fidelity: specialist sports and medical technologies are designed to measure a specific element in a controlled situation with well-bounded accuracy. They are optimised with the highest-quality sensors. Consumer devices, on the other hand, are 'jacks of all trades' and are not optimised with equivalent specificity. The continual need to reduce costs, increase battery life and ensure that the aesthetics remain acceptable to consumers means that the sensors integrated into such devices do not offer the same fidelity that is usually available in specialist arenas.
- Availability: while measurements from consumer devices may not be as accurate as those from specialist counterparts, consumer devices typically generate data with much greater availability. Many users wear their devices 24/7. This availability offers new opportunities to contextualise performance holistically and during more naturalistic settings. Performance at a given task is often influenced by other factors beyond the immediate context.

Image: Professor Rob Harle, Google Fitbit

- Diversity: laboratory research, especially involving elite athletes, is typically conducted with a narrow subset of individuals in a highly controlled setting. Consumer devices, in contrast, provide data from a broad pool of users across many environmental configurations.

Machine learning helps to make sense of the abundance of noisy, messy data from consumer devices from which to elicit accurate insights. The Google Pixel watch was released in October 2022, and its ability to provide real-time physiological data was informed by machine learning at multiple stages of the development process:

- Testing: a diverse group of users – of different ages, and with varying skin tones and body mass indices – wore chest straps to generate continual heart rate and ECG trace data over multiple days.
- Evaluation: data were scrutinised to identify all metrics associated with heart rate to maximise the device's eventual expediency for the general population. Academic studies have typically relied upon a very few criteria.
- Analysis of longitudinal data: the watch's 'readiness' score, for example, offers a personalised evaluation of an individual's potential for a productive workout. It is informed by data such as recent sleep activity and heart rate variability but does not account for important influences that are difficult to quantify, such as mental health.

Future priorities

Continual improvements across consumer devices must harness the quality and precision of academic research together with the potential to scale innovations typically offered by industry. Large-scale studies are essential to acquire a full grasp of trends in data and to minimise bias. Joint industry-academia publications are likely to enhance transparency. Longitudinal data acquisition from consumer wearables offers significant potential to boost the credibility of existing health and wellbeing metrics such as walking cadence and to devise additional novel metrics for the mass market that serve to benefit health and wellbeing across society.

> "The average consumer is not the average athlete. I hadn't appreciated how substantial the gulf would be, and behaviour change is not easy"
>
> Professor Rob Harle, Google Fitbit

PANEL DISCUSSION

Q&A discussion: Innovations in data

Speakers from Session 1 – Dame Sarah Springman, Beth Potter, Ray Maker, Professor Marek Ziebart, Professor Cecilia Mascolo and Professor Rob Harle – considered questions including data saturation, medical devices, and the impact of environmental change.

Image: (Left to right) Ray Maker, Professor Cecilia Mascolo, Dame Sarah Springman, Beth Potter, Professor Marek Ziebart and Professor Rob Harle

- A major research focus for the next five to ten years will be how to balance increasingly tailored training recommendations with the need to safeguard privacy in line with GDPR and other data-processing frameworks. 'On-device learning', where personal data remains on wearable devices or phones rather than being transferred to a third party device for processing, offers a promising starting point.

"Intelligent athletes are able to identify the most relevant pieces of data at a given time. They stand a better chance of converting these insights into their best possible performance, depending of course on external conditions"

Dame Sarah Springman CBE FREng, University of Oxford

- Whilst data from wearable devices can be used to inform health decisions, and may in certain cases indicate health concerns, it is unlikely that all wearables will be officially recognised as medical devices in the near future. The barrier for medically regulated devices is high, and many wearables designed for elite athletes and the mass market have not been formally evaluated in clinical trials.
- Some users may feel overwhelmed by the volume of data that can be generated from wearable devices. Developers must prioritise the effective presentation of information to support decision-making by athletes and consumers. Sustained improvements have been made to the accuracy of 'readiness' scores – or iterations thereof – which synthesise data into actionable metrics. Such metrics are not, however, infallible, and athletes must listen to their bodies when deciding how to balance exercise and rest.

- Aside from providing post-event data for individual team members, wearable devices are not yet widely deployed in team sports. At present, video analysis appears to offer greater potential to analyse structures and team strategies.
- Material enhancements to support female athletes and consumers have been introduced only in the past year. These include tailored guidance for pregnant users and greater sensitivity to variations in the menstrual cycle. Developing these further will be a priority in the coming years.

"It is exciting to finally see concrete developments in women's health within wearable devices. It seems likely that in two years' time we will be vastly further forward than where we are today"

Ray Maker, DC Rainmaker

- The language featured in training discourses remains largely male-oriented. When planning and implementing training regimens male coaches and teammates must be mindful of the different output capacities and recovery needs of female athletes.
- The climate crisis is leading to more variable, extreme, and unpredictable weather conditions. This has important ramifications for training and performance within competitive sport. Rowing teams are already undertaking meteorological data capture and analysis, in particular for wind speed and direction. It is likely that other sports will follow suit and that data collection will take place at increasingly high resolutions. The significant costs associated with the acquisition and operation of supercomputers may be mitigated by the availability of crowdsourced data from citizen science projects.

Engineering the world's first artificial luge track

In 2021, students from schools across Renfrewshire, led by David Rigmand (STEM lead and Depute Head Teacher at Todholm Primary School, Paisley), worked with researchers and students from Glasgow Caledonian University (GCU) to design and develop the UK's first artificial luge track for the Royal Navy Luge team, supported by a Royal Society Partnership Grant.

During the COVID-19 pandemic, luge athletes (who ride a sled in a supine, forward-facing position) were unable to train on real luge slopes and were therefore in need of an artificial track. Over 250 children aged 9-11 from six primary schools partnered with four Mechanical Engineering Masters (MEng) students from GCU and the Royal Navy STEM Engagement Team and Luge Teams to create the world's first mobile luge track.

Under the supervision of Professor Patricia Muñoz-Escalona from the School of Computing, Engineering and Built Environment at GCU, this successful partnership enabled pupils to learn first-hand about scientific investigation and problem solving. They were also exposed to some of the skills required for a range of engineering careers such as product design, electrical circuits, welding, pneumatics, and coding. The MEng students from GCU likewise developed their experience in education outreach, public engagement and communication.

The finished track was delivered to the Royal Navy in June 2022 and may be used to help the GB Luge Team prepare for the Winter Olympics in 2026.

Four Primary 7 students from Todholm Primary School – Isla, Ellie, Mohammed and Cai – joined the conference virtually to discuss their involvement in the project and to put questions to some of the speakers.

Image: The team from Todholm Primary School participating via video-link

Student Q&A

The most exciting experiment of the project

Isla: My favourite experiment was the chocolate welding. We used pieces of chocolate to build structures of different shapes and sizes. We then placed weights on top of the chocolate buildings to observe how much tension they could hold. We also dropped the buildings from a height to see which ones would or would not survive. At the end, we were allowed to eat our chocolate constructions - this was the best part!

How the experience changed what students think of engineering

Ellie: Before participating in this project, I thought that engineering was boring. The project helped me to realise that engineering is all around us. I now understand how important it is for our society and for the future. When we visited GCU and spoke to the engineering students there, I realised that there are so many exciting jobs in engineering, from electrical engineering to additive manufacturing. I am looking forward to high school so that I can learn more about engineering.

The most exciting aspect about working with Glasgow Caledonian University

Mohamad: The most exciting experience was when we saw a professional athlete going down the luge ramp that we had designed. This was my first time visiting the university, and I saw multiple 3D printers creating so many interesting things. We met so many inspiring people and now I want to be an engineer when I grow up.

Speaker Q&A

Cai: How do athletes mentally – as well as physically – train to compete on the international stage?

Dame Sarah Springman CBE FREng: The most important thing is to work hard and prepare well – do your homework! For example, if you are competing in the triathlon, you need to make sure that you understand the racecourse – including the weather, the cycling route, the running route – and analyse the maps to ensure that your training regimen is appropriate for the race environment. It is also vital to know who your opposition will be, and how likely they are to adopt certain tactics.

Ellie: What values do you see in the world class athletes with whom you work?

Naomi Stenhouse: The best athletes are determined, passionate, curious and willing to attempt something even though they know that they may not succeed straight away. Importantly, they are excellent at learning from their mistakes and trying again.

"This collaborative project solved the Luge Team problem – the lack of a training ramp – by bringing together primary school pupils, university students, academics and the Royal Navy."

Professor Patricia Muñoz-Escalona

"Now I can imagine myself going to university in the future, which would not have been possible without this project"

Mohamad, Todholm Primary School

This project formed part of a wider initiative led on the schools side by David Rigmand and on the university side by Professor Patricia Muñoz-Escalona. David was one of the winners of the 2020 Primary Science Teacher Awards, and received a Royal Society Partnership Grant in 2018 to support STEM activities in schools across Renfrewshire over a period of several years. Commander David Pinder, Royal Navy STEM/UTC (University Technical Colleges) Lead, and Lt Commander Emma Miles provided additional support through STEM engagement activities to reinforce and contextualise the teaching and learning.

The Royal Society Partnership Grants scheme provides funding to schools of up to £3,000 to run investigative STEM projects in partnership with STEM professionals from academia or industry. The scheme demonstrates the range of STEM careers available to students, fosters long-term working relationships between schools and STEM professionals and provides an opportunity for students to develop key skills, including research, problem-solving and data-handling which will be invaluable for their future studies and careers. For more information about this scheme, please email education@royalsociety.org.

Modelling and simulation in Olympic and Paralympic sport: generating performance gains for our athletes

Naomi Stenhouse, English Institute of Sport, offered an insight into some of the challenges and opportunities associated with enhancing the performance of athletes and their equipment when preparing to compete at Olympic and Paralympic level.

Image: Naomi Stenhouse, English Institute of Sport

Through its national network of high performance centres and partner sites the English Institute of Sport (EIS) seeks to maximise the probability of Olympic and Paralympic medal success. The EIS directly contributed to over 90% of medal wins secured by Team GB at the 2016 Olympic Games.

The EIS' Performance Innovation team works with elite athletes and coaches across a range of sporting disciplines, offering scientific, medical, and technical expertise to help drive marginal performance gains and increase user confidence in their equipment and training regimens. The team employs practitioners from diverse fields including ergonomics, data science, and nutrition. Collaboration with industry organisations and individuals leverages specialist expertise to tackle some of the thorniest problems and to develop laboratory-based inventions into innovations with the potential to enhance human and technological performance.

Team GB has achieved particular successes in skeleton and rowing events. These disciplines illustrate some of the challenges in maximising training efficacy and enhancing performance. They also present opportunities to improve modelling, simulation, and engineering technologies.

Skeleton is a physically and mentally taxing discipline, with a limited number of productive runs per practice session. Training for skeleton events – along with other winter sports – depends upon access to specific environmental conditions which persist for only part of the year. Travelling to suitable locations is usually time-consuming and expensive, and the onset of COVID-19 lockdowns made it impossible. During 'official' training sessions, moreover, instrumentation devices were not permitted.

Rowing performance has traditionally been measured through external metrics such as speed, pace, and distance. It is increasingly important for coaches to access data for individuals and teams to assess the physiological impact of incremental changes to output, understand the influence of environmental conditions, and optimise crew performance.

> "We work to take our athletes and coaches on a journey from invention to innovation. We want to draw upon the accuracy and the sophistication of technical research taking place in defence and in aerospace, but wrapped up like a Google Fitbit"
>
> Naomi Stenhouse, English Institute of Sport

Opportunities and challenges include:

- Devising strategies to maximise data collection during weeks when snow and ice are present
- Improving methodologies to measure the forces at play in athlete-ice interactions
- Developing models for vibration and other critical indicators of equipment fatigue
- Analysing the impact of variable weather and ice conditions upon safety and performance, and optimising sled design for a range of conditions
- Controlling for wind and air temperature when evaluating crew performance week-on-week
- Improving the design of virtual reality environments and artificial equipment to emulate real-world conditions with greater accuracy

A project undertaken in the Tokyo cycle in conjunction with Loughborough University and the Paralympic long-jump teams illustrated the potential to undertake advanced modelling in a controlled environment using interactive force plates and reflective markers. Ongoing collaboration with industry specialists will be critical to maximise the potential of these – and other – emerging technologies and to apply them to multiple sporting disciplines without compromising training time or quality.

Data and telemetry: lessons from Formula 1

Ben Waterhouse, Head of Performance Engineering at Red Bull Racing, highlighted some of the priorities for Formula 1 teams and explored the potential of virtual simulation and machine learning to improve data capture, enhance interpretation, and drive incremental performance gains.

Image: Ben Waterhouse, Red Bull Racing

The Formula 1 (F1) World Championship serves as an excellent showcase of some of the most advanced scientific and engineering innovations in elite sporting industry. F1 operates within tight technical and sporting parameters and the engineers and scientists working within the sport seek continual marginal performance gains in design, operations and vehicle performance. With bi-weekly races and a need for a rapid development rate, teams capture a wealth of data from multiple sources to allow them to achieve these continual improvements.

"We need the human and the machine to operate in unison. Our general approach is to gather as much data as we can from as many sources as possible, all in search of an incremental performance gain."

Ben Waterhouse, Red Bull Racing

During a typical lap all areas of the car are extensively monitored. A F1 car generates over 1,000,000 data points per second from approximately 400 sensors per vehicle. These are condensed to create over 7,000 performance metrics from every lap which are then used to further develop the performance of the car.

The key performance drivers from a vehicle performance perspective include:

- Tyres, which serve as the sole point of contact between the car and the track. Each tyre can deliver up to 15,000N of force and engineering teams invest significant resource in continually refining the operation of the tyre to maximise both tyre grip potential and tyre durability.
- Aerodynamic design has the largest influence on performance differentiation between teams. To seek an advantage, teams are working to continually optimise the downforce and drag that is generated by the aerodynamic surfaces, while still ensuring that the airflow is able to cool the powertrain and dissipate the energy generated during braking

- The suspension serves as the system that links the tyres and chassis on which the aerodynamic forces are applied. Its main purposes is to mitigate the impact of road surface irregularities and kerbs, but is also used to maximise tyre grip and influence the usage of the aerodynamic performance of the vehicle.
- Power units determine the vehicle's acceleration capacity and maximum speed. The latest generation of power units allow energy to be captured and stored during braking, redeploying it to increase acceleration on straight sections of the racetrack for a faster lap time.

Red Bull Racing recruits engineers and drivers who are able to harness the potential of cutting-edge engineering and data science, and to operate effectively in advanced virtual training environments. These environments can generate up to 100 terabytes of data per week and support almost 80% of innovation and development activity. Engineers use computational fluid dynamics to model flow field dynamics around vehicles and to assess downforce, drag and cooling configurations. Driver-in-the-Loop simulators offer highly authentic racetrack preparation. Statistical modelling and interpretation of real-time data informs strategic decision-making during each 90-minute race.

Maximising the value of data

The quest for incremental performance gains drives Red Bull's full spectrum of activities. Filtering and smoothing large quantities of granular data inevitably compromises their potential to offer performance insights.

Machine learning technologies developed within industry offer a significant opportunity to enhance data analysis and interpretation. This includes retrospective computation of missing data from faulty channels, enabling rapid photo identification of competitors and vehicle components, increasing the transcription rate for radio messages, and scrutinising data libraries to identify trends. The next – and arguably the most important – challenge will be to exploit machine learning innovations to identify triggers and prevent operational issues before they occur. This will require concerted interdisciplinary collaboration between scientists and engineers from across industry, academia, and elite sport.

The quest for aerodynamic gains in Olympic sport

Dr Rob Lewis OBE, Managing Director of TotalSim Ltd., discussed recent advances in the modelling and optimisation of aerodynamics within Olympic sport and explored some key priorities for the coming years.

Image: Dr Rob Lewis OBE, TotalSim Ltd.

Aerodynamic engineering plays a critical role in securing marginal gains and performance advantage within Olympic sport. The basic physics of aerodynamics are underpinned by the Reynolds number, which relates density, speed and viscosity, and which determines the balance between laminar (smooth) and turbulent flow in air and water.

The most successful innovations prioritise elements with the potential to deliver significant aerodynamic improvements. The stakes are high: in 2008, TotalSim engineers contributed to the delivery of a 10-12% reduction in drag for Team GB track cyclists at the Beijing Olympics. Relatively minor adjustments to equipment, apparel, or body position can generate marked reductions to drag, lift, or side force. In other cases, accruing multiple small improvements results in marginal gains which prove decisive during races.

Many Olympic sports encounter both laminar and turbulent flow. Water-based disciplines such as swimming and sailing involve simultaneous multiphase flows (both air and water) which add complexity and unpredictability to aerodynamic modelling. Other challenges include:

- Complex fluid-structure interactions – between, for example, wind and sails
- Inconsistent athlete movement, particularly when fatigued
- Confidence in the accuracy and reliability of data
- Separation of cause and effect
- Determining how to apply limited time and resources to analyse and interpret large volumes of data.

Image: Wind tunnel testing of track cycling skinsuits using a 3d printed mannequin. Courtesy of TotalSim Ltd.

Aerodynamic modelling activities have traditionally been informed by advanced computational fluid dynamics (CFD), but CFD is not yet able to adequately model the full suite of aerodynamic parameters for certain elite disciplines, including cycling. To take simulation to the next level many engineers are focussing upon parametric optimisation to devise robust solutions and designs which offer minimal drag and which are resilient to fluctuations in speed in a range of race environments.

Recent innovations have included the construction of the dedicated bicycle wind tunnel at the Silverstone Sports Engineering Hub in Buckinghamshire. It offers the opportunity to evaluate thousands of parameters from textiles to body positioning, and to create bespoke equipment and apparel for elite athletes. A 3D-printed mannequin cyclist serves to circumvent rider fatigue during testing. Another new facility, Catesby Tunnel (a former Victorian railway tunnel) opened in 2021 and is currently the longest stretch of aerodynamic testing track in the world.

"We need new tools and new thinking to investigate new ways to achieve marginal gains. We must focus our attention in particular upon the critical 0.1% performance improvements"

Dr Rob Lewis OBE, TotalSim Ltd.

As an indoor facility the tunnel offers a regulated environment with no fluctuation or unpredictability in air temperature, wind speed, or wind direction. This is not, however, a faithful representation of real-world racing conditions. Repeatability from controlled conditions is partially offset by reduced data reliability.

Future ambitions for TotalSim include:

- Developing a robotic rider for the Catesby tunnel to enhance data acquisition
- Further research – for example, using thermal cameras – to deepen scientific understanding of the precise mechanisms of drag reduction
- Manufacturing bespoke fabrics in-house using a dedicated weaving machine

TotalSim has focussed much of its activity to date upon cycling and vehicle aerodynamics. A priority for the coming years will be to extend its expertise to disciplines such as swimming where CFD modelling is of limited value and where new experimental techniques are being developed. An improved understanding of energy wastage, biomechanics and efficiency in water-based disciplines should help to identify actionable marginal gains for success at elite levels.

Collaborate to innovate: the journey of the sitski programme

Paul McNamara, Technical Director, Williams Advanced Engineering, drew upon the example of creating a new sitski design for the GB Cross Country Paralympic team to highlight the importance of collaboration in the development of a new product.

Image: Paul McNamara, Williams Advanced Engineering

An athlete's performance is often influenced by their comfort and confidence when using their equipment. Sitskis have conventionally been ill-adapted to the needs of individual athletes, typically consisting of a metal frame with no tailoring to the athlete's anatomy. As a result, British biathletes and cross-country skiers have struggled to secure Paralympic wins.

In 2018 Williams Advanced Engineering, Coventry University, GB Snowsport and BAE Systems formed a unique collaboration to design and manufacture bespoke sitskis for the 2022 Winter Paralympics. Despite a lack of prior research in sitski design and significant disruption to the development process occasioned by COVID-19 restrictions, the final sitskis demonstrated increases in speed of 4.5% on the flat and 6% downhill. Team GB recorded consistent top 10 finishes for Paralympic skiing in Beijing.

The development of the novel sitskis followed five steps:

1. Understanding the user: the performance of Team GB athletes was measured using baseline heart rate zones, power output, power consistency and on-snow testing pressure mapping (including testing areas of pain). Biomechanics of Bodies (BoB) - a biomechanical modelling software package which uses musculoskeletal modelling to analyse body interaction with objects – was also deployed for performance analysis.

2. Developing a model: Seat-fitting technology borrowed from Formula 1 enabled each athlete's unique physique to be mapped using putty, foam and 3D scanning.

3. Prototype testing: Features including the balance, angle and height of the seat and the position of the skis were tested on the snow by Team GB athletes. This data was then compared to the BoB research undertaken at Coventry University to understand the interaction of the athletes with their sitski.

4. Improving aerodynamics: Higher speeds and an increased frontal area of the sitskis compromised aerodynamic performance. To address this CFD analysis undertaken in wind tunnels helped to optimise sitski and athlete positioning.

5. Refinement: Analysis undertaken by BAE Systems on stress and strain measurements of the carbon fibre elements resulted in further reductions to the weight of the sitskis. Personalised foam seating enclosures were designed for each athlete, increasing comfort and safety. Durability and cornering capabilities were tested by athletes on slalom slopes, and the prototype design adjusted accordingly. The new sitskis demonstrated increased power transfer to the snow and a reduction in drag.

"The athlete and the equipment are two elements of a single system, and their interaction is essential when developing new products"

Paul McNamara, Williams Advanced Engineering

Lessons from the sitski programme can be applied to the development of other sporting products. Allowing athletes to train for longer periods of time with equipment prototypes provides multiple opportunities to make technical adjustments. Evaluating the flexibility of the product and the resultant effect on performance may improve understanding of the athlete-equipment interaction. Investigating the interaction between the equipment and relevant external conditions (such as snow) can help to further refine product design. Collaboration between organisations is a powerful tool to drive performance gains in the athlete-equipment system, and engineers should consider this for future product development projects.

The use of 3D printing in the development and manufacture of sporting equipment

Dimitris Katsanis, founder and CEO of Metron Additive Engineering, explored case studies to discuss the benefits and costs of using 3D printing for the design and development of sporting equipment.

Image: Dimitris Katsanis, Metron Additive Engineering

3D printing, also known as additive (layer) manufacturing, is the process of making a physical object from a 3D digital model by laying down many thin layers of a material in succession. It can be used to develop products from metal, plastic or other materials.

3D printing is often favoured when production timelines are tight, or when it is not possible to use traditional manufacturing methods to create certain desirable features. These may include:

- Aerodynamic interventions, such as trips, turbulators, sharp corners and tubercles (ridges on a bicycle frame)
- Anatomic/ergonomic customisation, which tailors a product to a specific athlete's anatomy. This is especially important for elite sports, including the Paralympics
- Part integration, which facilitates iterative product adjustments
- Functional designs, such as integration of aerodynamic features with focussed direction of air flow, helping to cool athletes such as cyclists
- Weight reduction

Additive manufactured products typically have short production times; physical printing of a product can occur within two to three days. All parts can be manufactured and post-processing completed in less than a week.

A widely acknowledged drawback to 3D printing is cost. While mass production of carbon fibre composite goods is usually far more economical than 3D printing, creating one-off units and small production runs in carbon fibre can be expensive when mould costs are included. At present, manufacturing bespoke items using 3D printing can reduce costs by up to two-thirds.

Case study 1: 3D printing reduces design and manufacture time

In May 2022, Metron was approached by Pinarello to create a world class performance bicycle to beat the Union Cycliste Internationale (UCI) World Hour Record in August of the same year. Inspired by the tubular structure of bone, Metron developed a SCALMALLOY® and titanium bicycle frame using additive manufacturing. Unlike carbon fibre manufacturing, 3D printing does not require mould design and manufacture, or laminate definition. This reduced the production time by nearly 50%, from 21 to 12 weeks.

Case study 2: 3D printing enables customisation for athletes

To create bespoke bicycle handlebars, Metron combined scanning and photography to record and visualise the optimum rider position in 3D computer-aided design (CAD). Several design iterations were created for additive manufacturing and enabled the Metron team to finalise the design in conjunction with athletes, coaches and aerodynamicists. The resulting 'TT handlebar' design was verified using CFD to optimise aerodynamic performance, and finite element analysis to provide sufficient strength and decrease weight.

Case study 3: 3D printing introduces novel features to designs

To improve bicycle aerodynamics, tubercles were incorporated into the design. A parametric study of 8-10 variations developed using CFD informed the final tubercle design. Whilst it is extremely difficult to create such complicated frame and fork models using current carbon fibre manufacturing techniques, 3D printing allows for rapid and accurate manufacturing.

The TT handlebar, frame and fork were integrated into a bicycle that broke the UCI Hour Record twice – first by British cyclist Dan Bigham on 19 August 2022 with 55.548km/h and then by Italian rider Filippo Ganna on 8 October 2022 with 56.792km/h. Ganna also rode the bicycle to break the Individual Pursuit World Record, covering 4km in 3 minutes and 59.636 seconds.

3D printing is versatile, can be used to manufacture equipment for a wide range of sports and is likely to grow more affordable over time as CFD, design, and printing technology develop. In the future, additive manufacturing will play an increasingly important role in influencing the outcomes of races and other sporting events as it becomes more widespread.

> "The product must be designed with the manufacturing process in mind. The result will be sub-optimal if this is not considered"
>
> Dimitris Katsanis, Metron Additive Engineering

Aligning the virtual with reality: the evolution and challenges of simulation in the America's Cup

Dr James Roche, formerly Simulation and Performance Team Lead at INEOS Britannia, discussed some of the unique challenges associated with optimising simulation, modelling and execution in the America's Cup.

Image: Dr James Roche, Neural Alpha Ltd.

The America's Cup is the most celebrated international sailing event and the longest-standing trophy within competitive sport. Races are typically held every three or four years. The defending team retains a number of privileges around rule-setting and race preparation, and design regulations can vary over time. This means that whilst challenger teams can face formidable obstacles if they are to prevail, there are plentiful opportunities for innovation within development, modelling and simulation.

Sailing presents unique challenges for engineers and performance specialists. Training time on the water is often limited. The complex and changeable interplay between the atmospheric boundary layer, course wind angle and power output can generate unreliable data. Current regulations prohibit teams from enhancing their understanding of the physics of the atmospheric boundary layer. Concept design decisions are typically made at an early stage before refinement and large-scale modelling take place.

In June 2014 Jaguar Land Rover and Ben Ainslie Racing (BAR) formed a partnership ahead of the 35th America's Cup in 2017, ending an eleven-year hiatus in UK participation. The timing was propitious: the advent of hydrofoil engineering in the 34th Cup demonstrated significant potential for performance gains, and the mainstreaming of virtual reality (VR) technologies offered opportunities to improve pre-race simulation. At their headquarters in Portsmouth the BAR team established their velocity prediction programme and made extensive use of CFD modelling to optimise hydrofoiling stability and speed, although CFD alone was unable to model dynamic stability systems with sufficient accuracy. Drawing upon advances within motorsport, VR simulation proved successful within a small operational window.

The BAR team advanced to the challenger semi-finals in 2017 and to the challenger finals in 2021, having rebranded in 2018 as INEOS Team UK. Significant changes during this period included the development of monohull yachts, deployment of soft (twin skin) sails and a 50% increase in boat length. The introduction of lightweight race simulators with the capacity to replicate race-day environmental conditions helped sailors to strategise with precision. Collaboration with industry partners consolidated the control code between simulators and yachts.

> "Maximising the accessibility of our simulation technologies to foster organic discussions around how best to exploit tools and data is essential to develop sailor skills and enhance the design process"
>
> Dr James Roche, Neural Alpha Ltd.

Successful defenders have consistently embraced bold and high-risk innovations. Priorities for the next America's Cup are likely to include:

- Enhancing the human-machine interface in the design process and during race preparation
- Persisting in endeavours to establish mechanisms that provide live sensor data to sailors, and which retain this data for post-race modelling and analysis
- Addressing 'blind spots' in modelling and simulation, such as energy requirements for turning, and problems associated with ventilation and cavitation (vaporisation of water at low pressures)
- Increasing the flexibility of the campaign process to provide space, where possible, for iterative design
- Further advancing the potential for cloud-based VR technologies to turbocharge design, modelling and simulation

The quest for 'perfection' should not stymie efforts to drive continuous improvement across a range of modelling and simulation parameters. Collaboration with highly specialised industry partners will remain critical to preparations for the 37th America's Cup in 2024 and beyond.

Q&A discussion: Innovations in materials, modelling and simulation

Speakers from Session 2 – Naomi Stenhouse, Dr Ben Waterhouse, Dr Rob Lewis OBE, Paul McNamara, Dimitris Katsanis and Dr James Roche – considered a number of specific questions, in particular the importance of the athlete-equipment interface.

Image: (Left to right) Ben Waterhouse, Dr James Roche, Paul McNamara, Naomi Stenhouse, Dimitris Katsanis and Dr Rob Lewis

- Organisations that support the elite sport industry seek to hire individuals from a range of backgrounds. Younger interns and employees enrich the working environment, typically bring high levels of commitment and determination, and offer innovative ideas to enhance human and mechanical performance.

"We want to understand the driver better, and how to maximise their performance in conjunction with the vehicle. We have only just started to make our first steps, and this is where we hope to identify more performance gains in the future"

Ben Waterhouse, Red Bull Racing

"Now that we and others have shown the way, it will ramp up the competition in the future"

Paul McNamara, Williams Advanced Engineering

- Wind tunnel testing is an essential and integrated element of all performance modelling endeavours for both humans and machines. The tunnel at the Silverstone Sports Engineering Hub offers the opportunity to integrate mechanical and physiological evaluation and helps professionals (especially cyclists) to adopt new racing positions to achieve marginal gains.

- A future priority for Red Bull Racing will be to develop telemetric monitoring technologies to acquire physiological data from drivers both during and between races. Evaluating this information alongside mechanical performance data is likely to prove instrumental in securing further performance gains.
- The innovative sitski developed by Williams Advanced Engineering has inspired other teams to optimise their structural designs and has intensified the competition. Additional marginal gains may soon be within reach.

"The wind tunnel is an essential tool when conducting a bike fit to optimise trade-offs between power performance, fatigue, and aerodynamics"

Dr Rob Lewis OBE, TotalSim Ltd.

Panel Discussion: ethics, accessibility, interdisciplinary collaboration and translation for societal benefit

The panel discussion was chaired by Professor Steve Haake OBE, Sheffield Hallam University, and featured Professor Joanna Wakefield-Scurr, University of Portsmouth, Henry White, BAE Systems, Naomi McGregor, Movetru, and Dr Bryce Dyer, Bournemouth University.

Wearable technology

- Poor musculoskeletal health has a major impact upon quality of life, and prevention is preferable to cure. Further collaborative enquiry in injury epidemiology across both industry and academia is urgently needed to better understand the propensity for specific injuries in relation to gender, demographics, and regions, and how incidence might be reduced. Anterior cruciate ligament injuries, for example, are up to eight times more common in teenagers and young women, in particular at around 14 years of age. Wearable technologies have significant potential to harness data to inform this research and to drive subsequent improvements in both longevity and quality of life.
- Developers are investing significant resources in understanding how users can exploit data from wearable devices to drive health benefits. Collaboration with NHS stakeholders can help establish correlations between data points and specific health outcomes. There is also a clear opportunity for wearable technologies to enhance physical and mental rehabilitation through provision of real-time data. This will require additional funding from government and the private sector.

> "The fundamental role of government is to improve the quality of life of the national population. How we value health and wellbeing interventions is therefore of the utmost importance"
>
> Professor Steve Haake OBE, Sheffield Hallam University

Image: Professor Steve Haake OBE, Sheffield Hallam University

- Traditionally, wearable devices have been designed primarily for male users. Research into experiences that are unique to women – such as breast pain and breast movement during exercise, which impact breathing and gait – is inadequate. It is essential to understand why this lack of data persists. Existing technology must be enhanced and new innovations prioritised. Dedicated funding for female-led research and innovation within sports engineering will be critical. The fact that a female car crash dummy was released only in late 2022 demonstrates that this issue is not unique to sports technology.

Image: (Left to right) Professor Steve Haake, Professor Joanna Wakefield-Scurr, Henry White, Naomi McGregor and Dr Bryce Dyer

Accessibility

- Some wearable devices remain ill-adapted to the diverse ethnicities of individuals who participate in elite and everyday sport. Evidence demonstrates that the accuracy of heart rate measurements and the number of data points generated from wearable sporting devices are substantially lower in individuals with darker skin tones. The decision to release such technologies onto the market has been met with some resistance, held back by a lingering perception that adapting devices for a diverse user population will generate minimal financial benefit.
- Users desire different quantities and types of data to inform their training and physical health. Large volumes of raw data are not meaningful for everyone and may alienate certain individuals. Others may prefer detailed information but require support and guidance to understand it. Comfort and ease of use are decisive for both elite and everyday athletes. These considerations are critical when developing wearable devices for the mass market.

"We have heard about amazing datasets collected from unique groups of individuals and which have applicability for the general population. If we can get better and better at sharing data across academia and industry we will learn so much more"

Professor Joanna Wakefield-Scurr, University of Portsmouth

"Comfort is so important to athletes and the everyday person. We cannot think about technology and neglect to consider comfort"

Henry White, BAE Systems

- Many Paralympic athletes are ex-service personnel who have developed unusually high pain thresholds for tissue damage. Improvements to communication tools between athletes and coaches would help ascertain the points at which performance enhancement endeavours become unsafe.

Public health and funding

- Currently, one-third of the UK population is classed as 'inactive'. The significant socioeconomic inequalities in the UK and the rise in material deprivation over the past months hinder attempts to provide a level playing field for individuals to participate in sport. Although 'gamified' resources such as Zwift can increase motivation it is unlikely that emerging technologies alone will boost uptake and engagement. Reasons for inactivity are complex and are not limited to motivation levels, affordability, or sociocultural barriers.

- To identify high-potential athletes from diverse backgrounds, partnerships with public health initiatives – such as wellbeing and skills services hosted by foodbanks – are important. Encouraging uptake of sport at a young age increases the likelihood that individuals will maintain an interest in exercise, health and wellbeing throughout their life. Communication strategies which seek to emphasise that elite sport is not only for the affluent must evolve for impact.

"Science communication is incredibly important. We need to engage with our communities – with school children, with the general public – to show that elite sport is not necessarily disconnected from society"

Dr Bryce Dyer, Bournemouth University

"We haven't solved all the problems yet. The more collaboration that we undertake, the better everyone's life will be. Let's do everything that we can to reduce the barriers within science and engineering to change the world"

Naomi McGregor, Movetru

- Grant selection processes may fail to consider the fact that applicants from under-represented backgrounds or regions of the UK may enjoy fewer established connections which would assist them in developing a concept and in advocating for its potential. Both public and private funders can help to break down barriers and make innovations more efficient by providing opportunities to forge connections.
- Developing strong collaborations with commercial partners – such as apparel companies who promote innovative sports bra technology – can accelerate the translation of laboratory research to the mass market for societal benefit.

The Royal Society

The Royal Society is a self-governing Fellowship of many of the world's most distinguished scientists drawn from all areas of science, engineering, and medicine. The Society's fundamental purpose, as it has been since its foundation in 1660, is to recognise, promote, and support excellence in science and to encourage the development and use of science for the benefit of humanity.

The Society's strategic priorities emphasise its commitment to the highest quality science, to curiosity-driven research, and to the development and use of science for the benefit of society. These priorities are:

- The Fellowship, Foreign Membership and beyond
- Influencing
- Research system and culture
- Science and society
- Corporate and governance.

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