THE POWER OF PRECISION: HOW BETTER MEASUREMENT DRIVES ENGINEERING EXCELLENCE.

Institution of MECHANICAL ENGINEERS

NPL National Physical Laboratory

Improving the world through engineering

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> If you cannot measure it, you cannot improve it.
>
> **Lord Kelvin**, c.1883.[1]

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Measurement in engineering

Engineers are at the forefront of driving innovation and commercialising new technologies, bridging the gap between scientific advances and practical applications. Their expertise is crucial in advancing and applying measurement technologies to support precision and reliability across industries. No matter what business you are in, better measurement leads to better outcomes, ensuring safety, efficiency and sustainability. Selecting appropriate measurement tools and establishing robust protocols for their maintenance and performance management are crucial steps in mitigating the risks associated with inaccurate data.

To maintain these standards, investment in training and education is essential. Engineers must be equipped with a diverse skill set that includes not only technical knowledge but also an understanding of metrology's broader implications. Comprehensive training programmes help professionals stay adept at navigating the challenges posed by emerging technologies, ensuring the accuracy and reliability of measurements in ever-evolving engineering contexts.

We believe that better measurement can make for greater impact in engineering, which is why the Institution of Mechanical Engineers (IMechE) has collaborated with the National Physical Laboratory (NPL) to emphasise the critical role engineers play in advancing measurement science and technology. This partnership has focused on showcasing how precise and reliable measurement supports engineering innovation, ensures safety and drives efficiency across diverse sectors. Together, the two organisations published a Good Practice Guide titled 'Beginner's Guide to Measurement in Mechanical Engineering' in 2013 which remains relevant and widely used today.[2] By jointly promoting awareness of best practices in metrology and the need for robust training, we aim to equip engineers with the tools and knowledge necessary to address the challenges posed by emerging technologies. Together, IMechE and NPL are championing the importance of accurate measurement as a cornerstone of engineering excellence and innovation.

Benefits of good measurement

Accurate measurement is fundamental to engineering success. It ensures designs meet specifications, improves manufacturing precision and enhances the reliability of complex systems. Engineers who apply good measurement practices can reduce waste, optimise processes and improve product quality, leading to greater efficiency and cost savings.

Beyond technical accuracy, strong measurement practices also support better decision-making. Reliable data enables engineers to diagnose issues more effectively, predict maintenance needs and drive innovation with confidence. In industries where safety and compliance are critical, robust measurement reduces risk and ensures regulatory requirements are met.

Good measurement is also key to bringing new technologies to market. By providing confidence in performance, reliability and scalability, accurate measurement helps engineers validate breakthroughs, secure investment and accelerate the adoption of innovative solutions. Whether in developing next-generation materials, precision components or cutting-edge automation, engineers rely on measurement to turn ideas into reality.

Investing in better measurement is not just about improving individual projects—it strengthens entire industries. By refining measurement techniques, engineers contribute to higher productivity, enhanced sustainability and the seamless integration of emerging technologies.

Measurement in the UK

For 125 years, the National Physical Laboratory (NPL) has been the home of measurement in the UK. NPL is the UK's National Metrology Institute (NMI), responsible for developing and maintaining the UK's measurement standards and infrastructure, and ensuring that all of the UK's measurements are traceable back to the International System of Units (SI).[3] This traceability enables consistency and comparability of measurements across the UK and globally and gives us confidence in the measurements that are essential for business, trade, science, research, engineering and innovation.

The International System of Units

The foundations of the globally agreed system of measurement units were laid out in 1875 in the Metre Convention and formalised in 1960 as the International System of Units (SI). The SI covers units for every type of measurement, but at its heart are the 7 base units of measurement:

kilogram (kg)	Unit of mass
metre (m)	Unit of length
second (s)	Unit of time
ampere (A)	Unit of electric current
kelvin (K)	Unit of thermodynamic temperature
mole (mol)	Unit of amount of substance
candela (cd)	Unit of luminous intensity

These units were originally based on physical artefacts but, as metrology has advanced, they are now based on constants of nature such as the speed of light in a vacuum. These units, when combined, are also the foundation for all other 'derived' units of measurements, such as metres per second.

As a member of the Metre Convention since 1884, the UK agrees to ensure that all measurements made in the UK are traceable back to the globally agreed units of measurement (the SI). Other members recognise this and commit to do the same in their respective countries.

The Department for Science, Innovation and Technology (DSIT) funds NPL and UK's designated measurement institutes, such as TÜV-SÜD National Engineering Laboratory and the National Gear Metrology Laboratory, to deliver the UK National Measurement System (NMS). They provide the UK's underpinning measurement infrastructure and develop new measurement capabilities.[4] The impact of the NMS is far-reaching: each year the NMS laboratories work directly with over 1,000 UK businesses and collaborate with over 500 academic institutions. Over 75,000 firms have certified standards and calibrations that are traceable back to the National Measurement System, providing confidence in measurement across the UK.[5]

The UK's Measurement Institutes

National Physical Laboratory (NPL)	UK's National Metrology Institute (NMI), developing and maintaining the national primary measurement standards, as well as collaborating with other NMIs to maintain the international system of measurement.[6] NPL develops the metrology required to ensure the timely and successful deployment of new technologies and works with organisations as they develop and test new products and processes.
National Engineering Laboratory (TÜV-SÜD)	The world's foremost authority on flow measurement technology and the UK's Designated Institute (DI) for Flow Measurement.[7]
National Gear Metrology Laboratory (NGML)	The UK's DI for gear measurement based at Newcastle University.[8] NGML is part of Design Unit, a small, financially self-supporting research and consultancy group specialising in the design, modelling, analysis, measurement and testing of gears, gearboxes and mechanical drivetrain components.
National Measurement Laboratory at LGC	The UK's DI for chemical and biological measurement, which supports the work of the Government Chemist.[9]
Office for Product Safety and Standards (OPSS)	The UK's national product regulator, within the Department for Business and Trade (DBT), responsible for the regulation of most consumer goods excluding food, medicines and vehicles.[10] Its primary purpose is to protect people and places from product-related harm, enabling trade and growth by ensuring consumers and businesses can buy and sell products with confidence.
National Institute for Airborne Acoustic Metrology (NIAAM)	The UK DI for Sound in Air responsible for the dissemination of the unit of sound pressure (Pa) via its secondary microphone calibration service. It represents the highest metrological level of microphone calibration in the UK.[11]
Medicines and Healthcare products Regulatory Agency (MHRA)	Within the MHRA, the National Institute for Biological Standards and Control (NIBSC) plays a leading national and international role in assuring the quality of biological medicines and diagnostics.

Occupations involving measurements

It is estimated that the UK spends £58.3 billion each year on measurement, with 6.3% of the UK workforce in occupations that involve taking measurements.[12] Metrology is the science of measurement and is how we maintain and improve our measurement infrastructure to deliver benefits. Improved measurement can:[13]

- improve the effectiveness and efficiency of science
- build greater confidence and trust in outcomes
- reduce waste and increase value for money and productivity
- unlock the potential of innovation faster, allowing earlier market entry
- reduce the time taken to implement change and add value
- develop and assess evidence-based policy
- accelerate progress in science and in society

When NPL was first established 125 years ago, it was primarily focussed on the measurement of physical entities. Over time, this expanded to include chemical and biological measurements. Today, advancements in measurement science are emerging at the intersections of disciplines, combining physical measurements with their digital counterparts.

New measurements and measurement techniques are under development as we move from physical to digital infrastructure. With an ever-evolving technology landscape, it is essential that the measurement infrastructure and standards needed to quality assure, test and validate are ahead of the technology, so that investors and consumers can have confidence that it does what it is supposed to do.

Data is the big challenge and the big opportunity. Emerging technologies depend on reliable data to interpret information from the world around them and make decisions, such as in smart manufacturing, smart cities and smart cars. The world now runs on data, making it crucial to establish testing validation, standards and quality assurance for the digital and cyber-physical world, in line with what we have had in place for many years in the physical world. The next steps in innovation across many fields involve the automation of procedures and processes and managing an ever-growing volume of data. As the volume of available data continues to grow exponentially, it is crucial that we can trust its accuracy and reliability in order to make effective use of it.

Impact for industry

Through a range of industry engagement programmes, NPL enables businesses to access the expertise of its scientists and engineers alongside its world class measurement facilities, helping businesses to solve problems.

Innovate UK Analysis for Innovators

NPL has been a partner in Innovate UK Analysis for Innovators **(A4I)** programme since its inception in 2016.

The programme is focussed on boosting the productivity and competitiveness of companies by helping them solve a challenge with an existing product, service or process through introducing them to experts at providers of the UK's national measurement capability.

Each round of **A4I** is open to UK businesses of any size for projects taking a maximum of 6 months with total costs of up to £100,000.

Analysis of self-reported feedback from companies that have participated in collaborative R&D projects shows that:

- 87% of companies think that their commercial opportunity increased because of their project
- 51% were able to introduce a new product or service within a year of completion
- 82% of companies expect to see financial benefit from their project
- 83% say that their projects would not have gone ahead, or would have done so at a smaller scale, without the intervention from A4I.

https://www.npl.co.uk/analysis-for-innovators

Measurement for Business

Measurement for Business **(M4B)** is an NPL industry support programme launched in 2023 which enables UK businesses to get their products to market sooner by supporting companies at an earlier stage of their product development journey.

Through **M4B** companies can access short term (up to 20 days), agile technical support, expertise and advice at no charge to solve a measurement problem that is stopping them from getting their product to market.

M4B has had targeted calls to SMEs in different regions of the country and in different technology areas such as green technologies, Engineering Biology, Sensors & Instrumentation and semiconductors.

Involvement with **M4B** provided a number of commercial benefits, including:

- 71% of companies said their commercial opportunities have greatly or moderately increased as a result of their M4B project
- 80% of companies expect to secure more investment for their product/service from either external investment or internal sources.

https://www.npl.co.uk/measurement-for-business

Precision Products UK (PPUK)

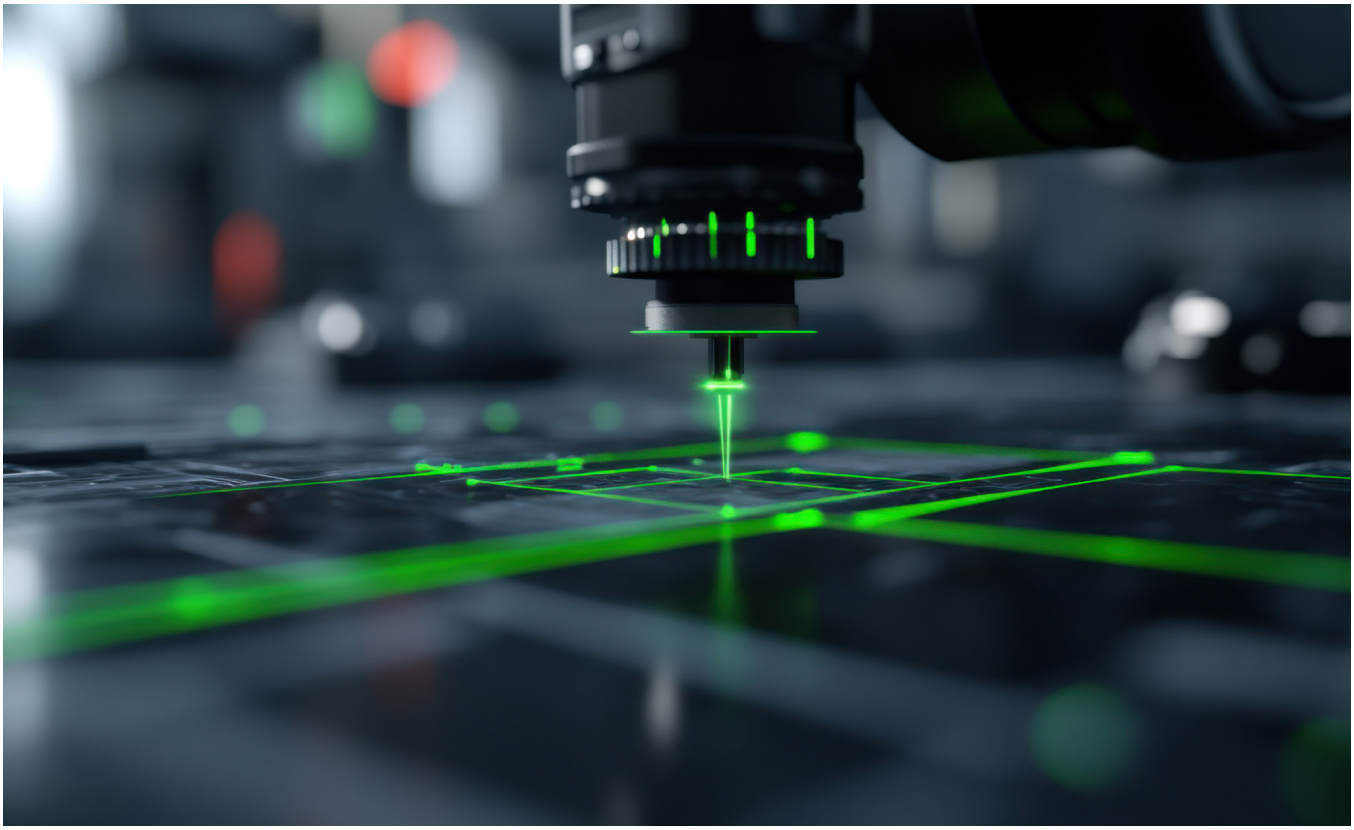
PPUK makes chrome plated piston rings that are used in hostile environmental conditions (extremes of temperature, pressure, and pH) such as diesel engines. The chrome plating is done via electrolysis and is a slow process, representing a bottleneck in their production line. PPUK worked with NPL to improve the consistent quality of their product and speed up the process. NPL helped PPUK to identify the optimum conditions (temperature, current density) for the process. The changes are expected to halve chrome plating times, reducing electricity costs and increasing its throughput, meaning that they can fulfil more orders.

Intelliconnect

There is an increasing demand for low temperature electronic components which can support the development of quantum technologies, including quantum computers. One of the factors limiting the scaleup of the computing power of quantum computers is the limit on how many connections can be contained within a set space. Intelliconnect asked NPL to validate the reliable performance of their new RF connector which had more connections in a smaller footprint. NPL was able to show that the connector maintained its performance and was suitable for use in cryogenic environments. The validation of the technology enabled Intelliconnect to grow its business in the cryogenic market with a new product that supported the scale up of quantum computers.

JET Connectivity

Jet Connectivity (formerly JET Engineering Systems Solutions) is an SME that has collaborated with NPL to develop and commercialise its innovative communications technology for maritime use. The harsh marine environment presents two major challenges for technology development: the impact of sea movement and wave height on performance, and the need to optimise limited electrical power generation. The NPL team tested Jet Connectivity's 5G buoy and identified enhancements that will improve its communications range by 300%. These advancements, along with increased trust in the product's reliability, have enabled the company to secure additional contracts, expand its operations, and recruit more staff.



Recognising the importance of engineering in measurement

In the last few years, NPL recognised that engineering is becoming a key growth area and is therefore building its engineering capability. Delivering programmes such as the UK Telecoms Lab (UKTL) and the National Timing Centre R&D programme has meant further demand for its skilled engineers.[14,15]

What does the measurement engineering community need?

- Confidence that any instrumentation that is purchased, designed or built is fit for purpose, installed and operated correctly, safe for colleagues and customers to use
- Procedures and processes in place that allow for growth, while being flexible enough to deliver larger and more complex projects
- To ensure that all of this is documented, so that compliance can be demonstrated
- Most importantly, we must have the right people and invest in them to develop the skills that are needed to deliver our engineering capability

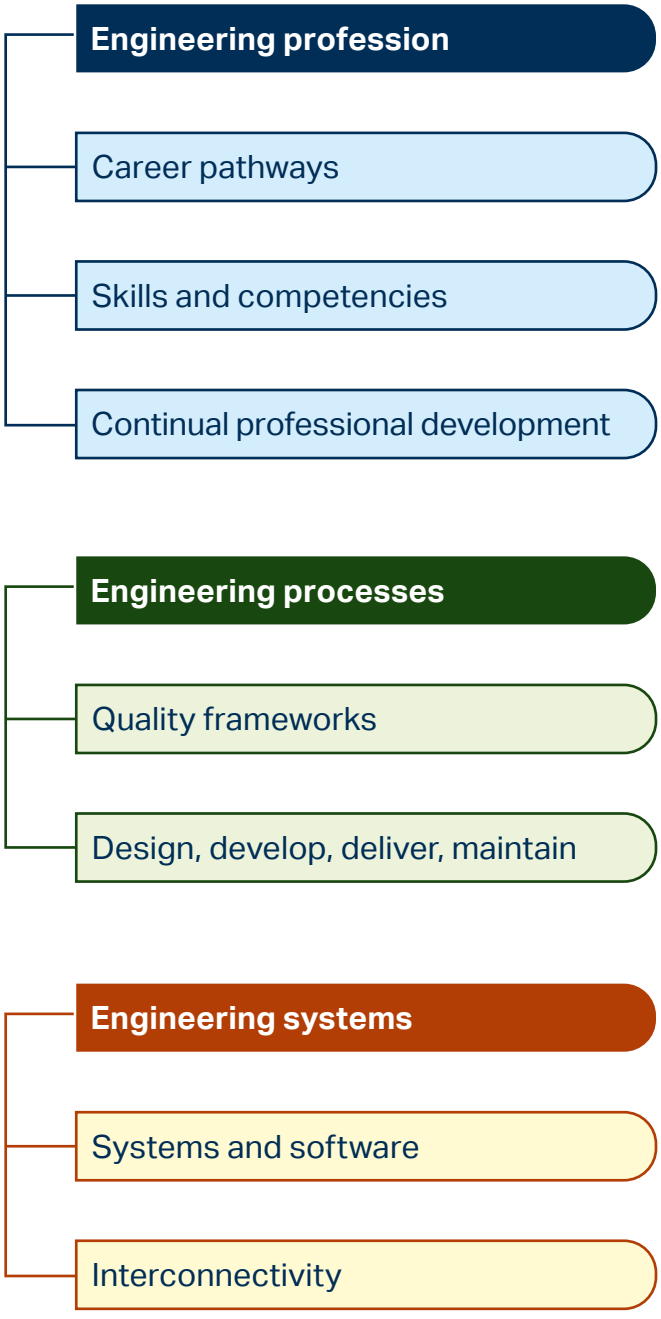


Fig 1a Pillars for building engineering capability.

Implementing a Product Lifecycle Management (PLM) System at NPL

To improve how engineering projects are managed and delivered within the organisation, NPL has updated both its processes and systems to ensure a quality-controlled approach, leading to the implementation of an NPL PLM system.

The implementation of engineering and delivery procedures will be built into workflows within the PLM which will also encompass other areas such as materials resource planning, inventory and stock management. The tracking of projects will also be key, as will ensuring traceability of the testing, validation and verification of applications, products and services to assure safety and compliance. NPL is working to consider how this will interface with the other systems that are currently in place and evolve to an integrated approach as future capabilities come online.

Alongside the move to change processes and develop better systems, the engineering skills pipeline must grow. Engineers play a crucial role in precision measurement and ensuring the successful implementation of innovative solutions.[16] Their expertise underpins the development of reliable systems, helping to translate scientific advancements into practical applications by working closely with scientists, as outlined in Figure 2. The processes being developed for the design and development of instrumentation and technology must reflect both the traditionally decentralised engineering model at NPL and the need for increased levels of engineering rigour required by large and complex projects, which can only be achieved with a dedicated engineering team. To support this, there is now a dedicated central engineering function that works across projects and programmes, as well as an engineering career pathway to foster the development of all engineers at NPL—from engineering apprentice to senior engineer and head of engineering.

Meet a measurement engineer!

There are challenges to instilling good measurement practices within industry, stemming from a lack of appreciation for the value of measurement. Concepts of accuracy, precision and measurement uncertainty are often poorly understood or overlooked.

Industry requires individuals equipped with specialised skills and a keen appreciation for the intricacies of measurement. Beyond technical proficiency, cultivating a workforce that values and integrates measurement into every stage of operations is essential. The most successful companies understand that excellence in design, manufacture and measurement form the three pillars of a robust quality assurance framework, akin to a sturdy three-legged stool. Fostering a culture that champions measurement as a cornerstone of quality not only demands technical acumen but also necessitates a fundamental shift in perception towards recognising its pivotal role in driving excellence and innovation.

Measurement engineering is often seen as a narrow field, but metrology spans a wide range of engineering disciplines, as well as mathematics and science. Understanding a measurement device requires expertise in instrumentation, electronics, electrical power, data communications, software, process engineering and the underlying physics and chemistry of what is being measured. Additionally, engineers must apply uncertainty theory, ensuring that all measurement errors are correctly accounted for and traceable to national and primary standards.

There are over 1,000 scientists and engineers working at NPL on a diverse range of areas from quantum communications to engineering biology, from materials characterisation to environmental monitoring and from telecoms to Earth observation.

James Berry (IMechE member)
Higher Engineer
Mass Metrology Group

James has a BEng in Mechanical Engineering from UCL. He is a Chartered Engineer through the IMechE.

James has been working at NPL for the past 20 years, with the team that is responsible for the traceability of all mass measurements for the UK.

Materials Characterisation

James has led work on density calibration which is essential in the characterisation of new 3D-printed materials so that they can be compared with those made using traditional manufacturing processes. This helps assess material uniformity, detect voids and verify density. A recent request was to establish the density of polystyrene granules, to inform research on microplastics in soils. In another context, density measurements are important in nuclear safety for fuel manufacturing, and reference standards used for quality control in the nuclear fuel manufacturing process have their densities measured by NPL.

Getting components into orbit

If you are a component manufacturer for application in space missions or satellites, it is important to understand the centre of gravity of your object. Predicting the centre of gravity in components such as batteries is not easy as they are very dense materials which are not necessarily uniform. James has led the development of a new measurement service at NPL, achieving centre-of-gravity measurements with uncertainties reduced to just a few micrometres from 100 micrometres.

Cleaning The Kilogram

In 2008, James went on secondment to BIPM (the International Bureau of Weights and Measures) in Paris, the home of the SI, where his role was to find a standardised way to clean primary mass standards.

The international protype kilogram, known as Le Grand K, is a polished cylinder of platinum iridium alloy. Before the redefinition of the Kilogram in 2019, Le Grand K was the reference kilogram for mass measurements globally and every few years the reference kilograms from countries across the world are brought together to be compared against it. Over time the mass of these artefacts can gradually change. For example, holding a kilogram might leave fingerprint residue which alters the mass. Cleaning of the kilogram must be done in a repeatable standardised way to avoid altering its mass. James developed a new instrument and automated method to clean the kilogram, tested it and compared it to the existing manual cleaning method.

Timothy Kamps
Senior Engineer
Advanced Engineering Materials Group

Tim has a Master of Engineering and PhD in Tribology from the University of Southampton. Before joining NPL he had worked on a variety of research grants, including knowledge transfer secondments with UK industry. Now he leads a team of scientists and engineers applying traceable measurement science to industrial friction and wear challenges.

Tim's engagement with the IMechE

Tim has been a member of IMechE since he was a student. In that time, he has supported activities and events for the tribology community. In 2015 Tim was awarded the Tribology Trust Bronze Medal for his work on scuffing failure in automotive engines which was critical to reducing CO_2 tail pipe emissions of internal combustion engines through downsizing.

He received a travel grant that enabled him to undertake research at Southwest Research Institute in San Antonio, Texas.

In 2018 Tim undertook chartership with IMechE. Becoming a chartered engineer has helped Tim to demonstrate to industrial stakeholders that he has the professional skill sets required to deliver complex projects.

In 1966, Sir Peter Jost estimated that the impact of friction, wear and corrosion as a result of the loss of lubrication was costing the UK 1.1-1.4% of GDP.[17] Today, with increased automation, understanding how surfaces interact with each other is even more important. Friction, wear and lubrication all impact upon the efficiency and lifespan of a machine. These are complex systems where an understanding of different material chemistry, heat transfer, physics, mechanics and awareness of how the system changes in time and space are all necessary to be able to measure, analyse and interpret data from the system and make decisions. Tribology is important for all moving systems and being able to ensure surfaces are suitably lubricated prevents them failing prematurely. Being able to accurately predict system lifetime enables effective maintenance scheduling, reducing down-time of machinery and costs.

Tim delivers collaborative R&D for industrial partners including projects through **A4I** and **M4B** programmes focused on friction and wear challenges. Since 2019 he has delivered projects across energy, transport and manufacturing sectors ranging from cereals and bicycles, to sewers and air bearings.[18,19,20,21]

Over the last two years Tim has been invited to present NPL's work on digital tribology at a series of seminars organised by IMechE and the Institute of Physics. He is currently leading projects to develop and deliver digital test platforms capitalising on recent advances in machine learning and computer vision. This will provide the information acquisition and processing required to produce digital twins of critical and high value equipment and infrastructure, enabling step changes in performance and lifetime to be realised. The platforms have data assurance and traceability built in from the start to ensure that people can have as much confidence in them as in the physical systems.

Apprenticeships

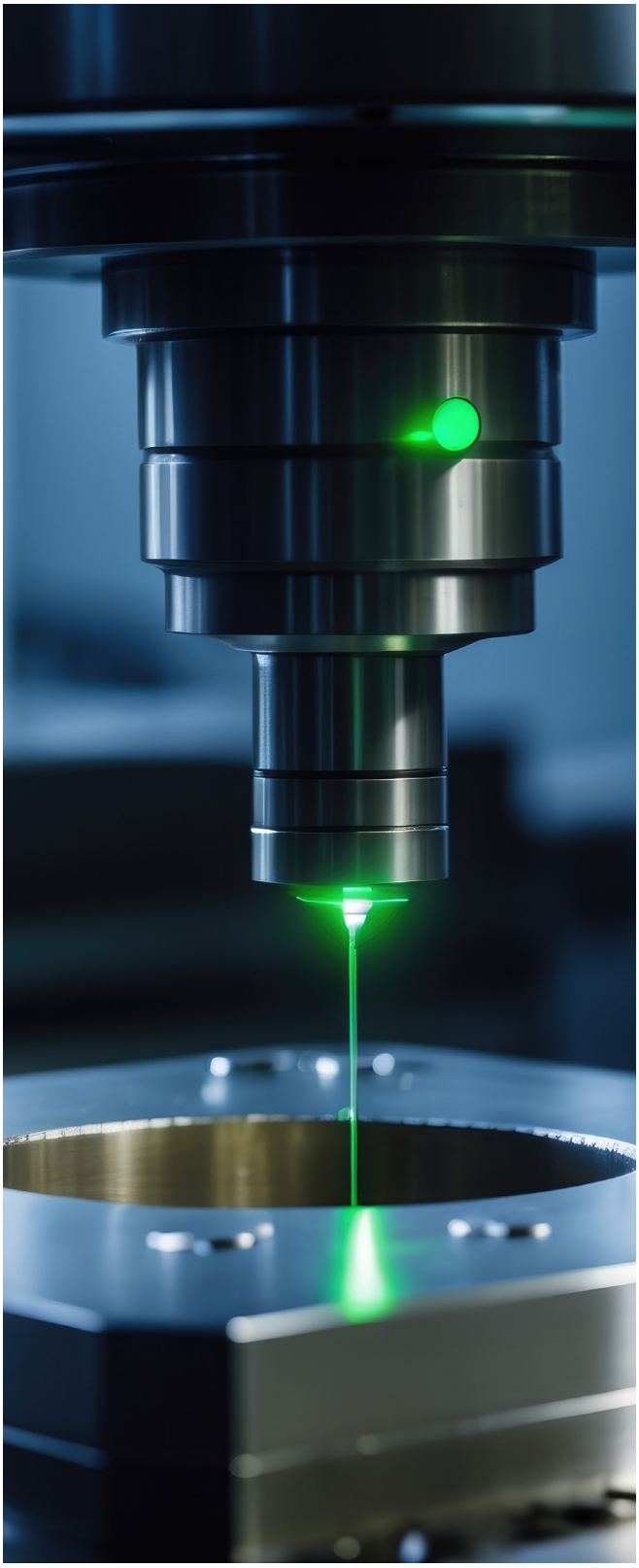
NPL restarted its apprenticeship scheme in 2013 and welcomed its 100th apprentice in 2019. Thirty of the apprenticeships to date have been in engineering. During the three- or four-year programme, apprentices go on a number of rotations to gain experience across a variety of areas at NPL. Many apprentices continue to permanent roles at NPL, and some continue with their studies, undertaking degree level courses.

Esther Rowland
Apprentice Engineer

Esther is in the fourth year of her engineering apprenticeship, studying a Higher National Certificate (HNC) in Mechanical Engineering at Kingston College and working at NPL.

In her first year at NPL, Esther studied at Kingston College, earning a Level 2 Diploma in Advanced Manufacturing Engineering, where she gained practical skills in hand fitting, lathe operation and milling. She later completed a two-year Level 3 BTEC in July 2023, expanding her knowledge of health and safety, materials and machining processes.

Last summer, Esther began training on the XYZ CNC milling machine. Most recently, Esther has been contributing to projects for the small space satellite calibration facility which is a collaboration between NPL and RAL Space.[22] She has been involved in machining some of the parts and assembling sections of the STARWELL machine, which will be used for calibrating scientific instruments on satellites prior to launching into space.



Conclusion

Engineers play a vital role in turning ideas into reality, but their impact is only as strong as the measurements they rely on. Precision in measurement is not just about accuracy—it is about efficiency, reliability and driving progress. When measurements are right, decisions are smarter, processes run smoother and productivity soars.

No matter the industry, better measurement leads to better results. It reduces waste, prevents costly errors and helps businesses optimise performance. Investing in improved measurement practices is not just a technical necessity but a strategic advantage. Small improvements in measurement can lead to significant gains in productivity and performance. By prioritising better measurement, you are not just fine-tuning processes but also driving innovation, strengthening competitiveness and building a more efficient and sustainable future.

To explore how you can enhance measurement in your work, check out resources like IMechE's Learning & Development programmes, NPL's training courses, and 'Good Practice Guide No.131: Beginner's Guide to Measurement in Mechanical Engineering'.[2]

With thanks to colleagues for informing the piece:

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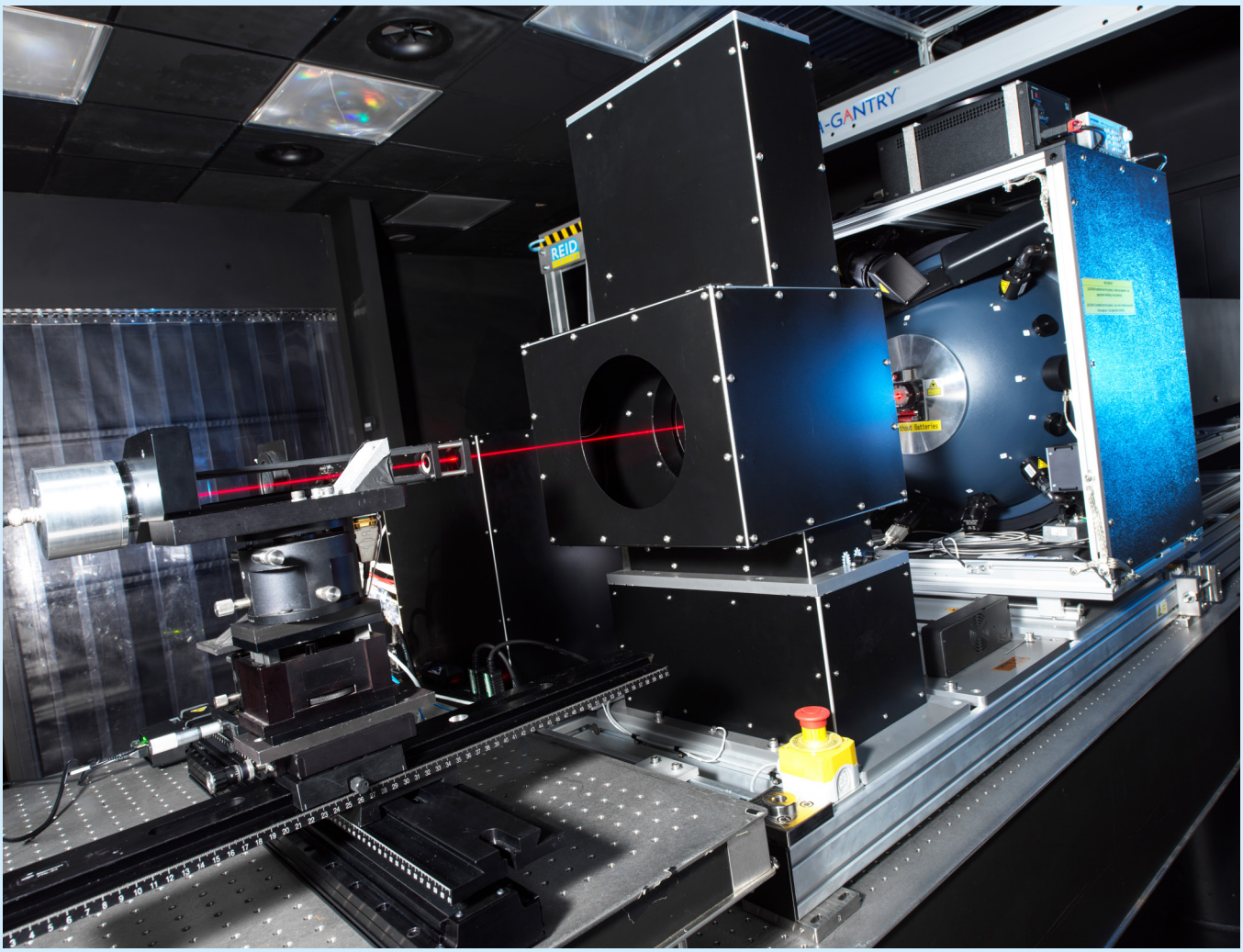
National Gears Laboratory: Robert Frazer

IMechE: Isobel Pollock-Hulf



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1 *"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be."* Thomson W. 1889. Popular lectures and addresses in three volumes. Volume 1: Constitution of Matter. London (UK): MacMillan and Company. Electrical Units of Measurement. p. 73–74

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