# INSIGHT

Brought to you by

AEROSPACE TECHNOLOGY INSTITUTE

NPL National Physical Laboratory

## Introduction

This paper has been compiled to disseminate the findings of an aerospace sector consultation enabled through a partnership with the National Physical Laboratory. The consultation aimed to identify the critical metrology needs that will assure performance and quality across the high-value manufacturing landscape. The paper analyses the sector perspectives from academia, research organisations and industry to propose opportunities where investment in product verification could make a significant positive impact on productivity, product performance and fuel efficiency.

# 05 PRODUCT VERIFICATION

*Growing UK Productivity and Competitiveness*

## EXECUTIVE SUMMARY

Product and Process Verification are critical elements that are considered from the initial design and development phase through to full scale industrialisation, realising a robust and repeatable methodology and resulting in a data output that can be utilised to measure critical process and product parameters.

The National Physical Laboratory (NPL) and the Aerospace Technology Institute (ATI) have developed a framework to articulate the key priorities, challenges and research areas required to maximise the opportunities presented by Product Verification. The framework provides an analytical basis to consider metrology devices, management methodologies, application analysis, material validation, design for product verification and digital enablement.

The framework analysis has identified four key topics that will drive future series production volumes and rate flexibility through addressing design intent and cost of quality, maximising opportunities throughout the end-to-end value chain. These topics are:

1. Enablement of the Factory of the Future through continuous in-cycle process measurement to support a 'right-first-time' philosophy
2. Adding value through embodiment of verification in the product life cycle value chain to realise benefits through data capture and manipulation enabled by the digital revolution
3. Virtual Product Verification toolsets for future factory assets facilitated by data mining techniques applied in a real-time environment
4. Enabling conformance of key product and process characteristics for complex high-value architectures, materials and manufacturing methodologies

Identification of the four key topic areas through the framework has enabled further detailed analysis with key subject matter experts on structures, propulsion and systems from industry, research organisations and academia. The outcome of the analysis has revealed numerous opportunities for ATI programmes, focussed on the following technology challenges and opportunities:

1. Digital Transformation through Product and Process Verification integrated into the end to end supply chain
2. Product and Process Verification integrated into critical design toolsets and future factory to remove the non-value-added end of the value chain inspection
3. Provision of access to metrology capability through regionally-based centres of expertise
4. Enabling the development of skills to meet the needs of future metrology technologies that impact the aerospace sector and spill over into many other high-value manufacturing industries.

# THE UK COST OF QUALITY CHALLENGE

The UK aerospace industry generates substantial turnover and contribution to the UK economy, sustaining and safeguarding more than 200,000 high-value UK jobs. The growth in aircraft passenger traffic is strong and resilient, with air traffic expected to double every 15 years, and 33,070 new aircraft required by 2035.[1]

As demand for aircraft increases, so do the demands on the whole supply chain. UK industry is responding to this demand, and large aircraft production continues to rise in the UK, with Airbus breaking an annual record of 688 aircraft produced in 2016.[2] While the UK is a global leader in components and assemblies, in 2016 it was suggested that the UK structures supply chain generated a defect level approaching ten times higher than its global competitors.[3]

# WHAT IS PRODUCT VERIFICATION?

Product Verification (PV) is the confirmation, through qualitative and or quantitative evidence, that specified product requirements (designers' intent, engineering specifications) and process requirements have been met.

Product Verification is considered at all stages of the product lifecycle up to, or release into, service (i.e. Concept Development, Product Design, Prototyping & Testing, Qualification, Process Planning, Production & Acceptance) and considered imperative to meet Through Life Engineering Services (TES) needs.

Product Verification is an essential element in avoiding non-conformance, or inferior quality, enabling a manufacturer to invest time, effort and resources in conformance and high-quality output. This approach improves productivity and competitiveness, and will help to grow the UK aerospace industry in line with the sector's strong growth expectations. This paper highlights ways in which the UK can lead in Product Verification and surpass the current standards globally.

# KEY FINDINGS

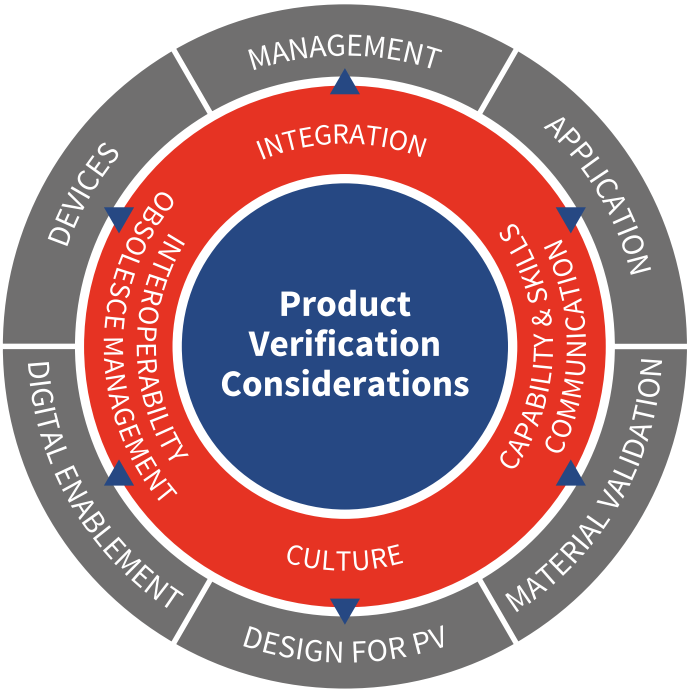
Advanced manufacturing is facing significant challenges, with continued pressure to reduce costs and increase quality and output while leveraging the benefits from innovative technology and materials. Product Verification (i.e. having complete confidence in measurement data, and using this data to improve quality and productivity) is more important now than ever but, as this work has shown, is an underutilised capability.

The National Physical Laboratory (NPL), together with the Aerospace Technology Institute (ATI), has developed a framework to articulate the key priorities, challenges and research areas required to maximise the opportunities presented by Product Verification. This has identified four key topics that will drive future rate and quality challenges:

- Metrology will enable faster, automated factory processes, creating greater flexibility and agility in manufacturing systems and better 'right-first-time' manufacturing.
- Product lifecycle value chains (from Research to Through-Life Engineering Services) and supply chains will be transformed through the combination of manufacturing data and cyber systems, putting much greater pressure on manufacturers to build confidence in data through metrology.
- Data from assets and production will be used to generate a virtual factory tool-set to improve product and process design, as well as decision making. Better data will be used in a blend of virtual and real-world testing to achieve certification more efficiently.
- Disruptive technologies and architectures are generating greater complexity in design and manufacture, driving demand for new inspection capabilities that can be embedded in the end to end value chain to ensure conformance is achieved against key characteristic requirements.

# PRODUCT VERIFICATION FRAMEWORK

The study identified six areas of Product Verification that should be addressed when developing any manufacturing R&D or industrialisation projects.




## Devices

Measurement equipment required for new and legacy applications. Includes both the functional and operational characteristics of measurement technology e.g. accuracy, repeatability, mobility, cost, durability, device compatibility and interoperability.

## Management

The knowledge and skills required to enable Product Verification performance to be evaluated so as to drive business and operational excellence e.g. real-time asset tracking for dynamic scheduling, in service dynamic calibration, benchmarking current practice.

## Application

The use of PV devices, tools and methods to drive operational excellence and increase product awareness throughout the product lifecycle e.g. right-first-time integration, supply chain collaboration, scale and rate enablement, hidden feature recognition and validation, evaluation of consistency, flexible manufacturing.

## Material Validation

Refined evaluation of material properties to enhance material selection, design, manufacture and test e.g. test methods and standards, environmental control.

## Design for Product Verification

Improving design through better data secured throughout the product life cycle, incorporating the analysis outcome into future research and development e.g. uncertainty quantification, tolerance and capability awareness, structural health monitoring and quantification, and design understanding in support of TES.

## Digital Enablement

Connecting physical and digital systems to increase traceability, confidence in data and to improve decision making e.g. coherence of data architecture, integration with legacy systems, data security.

Barriers to these themes, shown in the red circle within Figure 1, fall into four areas:

1. Cultural: The sector consists of very few companies at the top level, providing little opportunity for the supply chain to change its business model. The lack of transparency and opportunity to change is largely driven by not quantifying the value of the PV data.

2. Capability, skills, communication: Future competitiveness will be rooted in PV skills and knowhow. The high-skill, high-value jobs of tomorrow will require the understanding of, and ability to operate across, numerous disciplines.

3. Integration: Leveraging shared PV information can enable the extended enterprise concept to advance in the UK, improving productivity in the supply chain. Seamless integration of PV can reduce non-value-added tasks, and enable multi-partner product realisation.

4. Interoperability and obsolescence management: End-to-end integration and information sharing for PV processes that support technology challenges.

## Case Study: New Measurement Technology developed at NPL

Emerging and future manufacturing practice will require high accuracy, flexible metrology systems embedded in processes. NPL is developing a new class of high accuracy coordinate measurement systems aimed at the next generation of automated manufacturing applications. The Frequency Scanning Interferometer (FSI) operates in a similar way to global navigation using GPS and deploys a minimum of four sensors around the artefact to achieve this.

The system has the advantages of high accuracy (capable of a distance repeatability in the order of 1µm and an accuracy in the order of 2 parts per million over a range of up to 10 meters), self-calibrating (using a technique called multilateration), direct traceability to the SI (by incorporating a quantum frequency reference in the form of a gas absorption cell into the system) and integrated uncertainty measurement (provided by the multilateration mathematics).

## THE BUSINESS CASE FOR THE ADOPTION OF PRODUCT VERIFICATION

Product Verification in high-value manufacturing can be complex and challenging, especially from a technology perspective. This can impede UK companies from competing effectively in global markets.

The benefits of effective PV are clear however: 75% of manufacturing errors arise during the initial stages of production and 80% are not picked up until much later[4], leading to costly rework and reputational damage. An example of this came from the automotive sector where, in 2010, a successful OEM was involved in a high-profile case of a key component causing a significant safety concern. The cost of rework of this problem was c. US$120 million, but the cost of the failure of measurement and control was over US$2bn from lost output and sales worldwide.

Given the highly-regulated and safety-critical nature of aerospace manufacturing, measurement and inspection can account for up to 20% of the finished product cost. Aerospace and Defence industries contributed c.£54bn[5] of turnover to the UK economy in 2016; improving the efficiency of PV by just 2% could free up £1bn of capacity a year, as well as achieving other benefits highlighted in Table 1.

## AEROSPACE CHALLENGES

The sector consultation generated PV challenges and technology research opportunities with potential solutions falling into the ATI’s Secure (Entry into Service (EIS) <5 years), Exploit (EIS <10 years) and Position (>15 years) timeframes. The most frequently cited, or those considered as most relevant to PV and which fall into the Exploit or Position timeframes (the focus for this strategy), have been grouped under seven technology themes. These are discussed below in terms of current state, challenges and UK Research & Development opportunities recommended for potential funding.

## Improving Efficiency of PV

### Quality

- Improve confidence in products
- Reduce measurement uncertainty
- Better appreciation of control limits
- Better data on product performance

### Cost

- Increase productivity
- Reduce waste and rework
- Increase machine utilisation
- Shorter lead times

### Delivery

- Faster diagnosis of product failure
- Better communication in supply chain
- Part of an efficient supply chain
- Faster product to market

### Other

- Product innovation
- Strengthen skills for long-term flexibility & impact
- Process innovation
- Greater confidence and trust
- New business won
- Capacity to grow
- Reputation for world-leading products

## INSPECTION, MEASUREMENT & ASSEMBLY

### Current State & Challenges

Industry is undergoing a transition from manual to fully automated (and fewer) measurement and inspection processes in its drive for higher build rates and productivity. These changes need highly integrated and often high rate processing systems with flexibility, agility and adaptability to product specifications.

Enhanced capability for on-machine and embedded data collection throughout the manufacturing process will underpin the need for continuous monitoring against statistical control limits and early detection of defects. Higher production rates can be achieved by removal of physical certification procedures from the process. Enhanced understanding of the associated physics, virtual design, machine-to-machine data sharing and analytics in the factory environment will greatly improve process (rather than product) knowledge, enabling virtual certification. This goal is dependent upon robust data analytics, which in turn is reliant upon data traceable to national standards.

Variable factory environmental conditions affect measurement uncertainties; simplified and traceable measurement and inspection methods for large surfaces should be considered at the design stage.

There is a time, cost and materials issue arising from high-value product rejection from test-beds due to integration and system failure. Problems may only be apparent after integration of parts. Accumulated dimensional variation or tolerance stacking can lead to distorted and unacceptable systems.

### Research & Development Opportunities

Development of technologies and/or methods for:

- High dynamic range real-time correction, on-machine metrology and self-calibration with traceability for machine tool integrated sensors, supporting on-machine self-correction/ compensation capability;
- Pre- and post-processing measurement and inspection of hidden surfaces and at-depth features; Accurate positioning, orientation and joining of large surfaces;
- Simplified measurement and inspection (e.g. reduced measurement and inspection points) of complex and fully unitised structures;
- Fully-automated in-process monitoring, inspection and very-high-confidence defect detection and classification;
- Use of digital twin and data assimilation to update knowledge of the integrity of a component or structure based on in-situ measurements. This includes not only generation of more data, but also making better use of existing data;
- Verification of transmission assembly and integration e.g. virtual simulation that aggregates module functions at the system level;
- Improved gas turbine throat area measurement.

Development of models or simulations to use knowledge from 'stage build' tools to predict performance of first build of prototypes.

## NON-DESTRUCTIVE EVALUATION (NDE) AND DEFECT DETECTION

### Current State & Challenges

Non-Destructive Evaluation techniques are used for inspection of conventional materials in process and through life; existing technologies are mostly reliant upon operator skills and interpretation to maximise effectiveness.

To meet higher rate demands, NDE for industrialised high-speed in-process (and automated) inspection with high detection rate and precise location of defects is needed. Low cost is a major driver for gaining acceptance across the supply chain. Reliable operation in harsh environments will benefit some industrial operations e.g. forging and forming.

NDE inspection for hidden defects in complex, novel and additively manufactured components will raise confidence in these technologies. Embedded sensors within structures can introduce weaknesses that could be assessed with precision NDE.

Through-life, reliable damage detection and measurement would support assessment and application of repairs; drivers are precision, reliability and low cost.

### Research & Development Opportunities

Development of NDE technologies and/or methods for:

- High speed metrology and inspection (in factory and through-life) with high probability of (automatic) detection, recognition, identification and precise location of defects.
- Reliable and repeatable operation in harsh environments, especially high temperatures;
- Inspection of hidden surfaces within complex, novel and additively manufactured components;
- Determining integrity of sensor host structure;
- Prediction of properties and in-service product performance e.g. using defect and porosity measurements;
- In-service reliable damage detection & quantification.

## COMPOSITE, HYBRID AND OTHER NOVEL MATERIALS

### Current State & Challenges

Use and confidence in composites and hybrid materials in large and structural components is well established. Propulsion applications include fan casings and blades. High-performance alloy discs are being considered for improved stiffness and weight savings, although costs are an obstacle. Structures applications include unitised primary structures and a switch to out-of-autoclave processes that demand high levels of in-process control to meet the key characteristics requirement. Manufacturing processes are slow, with variable quality of raw materials and product; and costs can be high. Novel and composite material properties in process and through life are poorly understood; resultant problems range from poor prediction of dimensions and features in factory to incomplete understanding of through-life performance and impact resilience.

Confidence in lower cost raw materials could be raised with better understanding of the relationship between properties before, during and after processing, including their effect on product quality. Inspection standards and traceable test methods for raw materials, production and products including novel materials are either lacking or absent

Surface texture can affect functional surface performance, but modelling of the effects is difficult. There is poor understanding and means of effective and reproducible measurement of surface texture (from nano to macro scales). The ability to specify requirements is a challenge.

Wider use of composites for lightweight propulsion structures requires higher-temperature-capable materials and associated measurement and inspection techniques e.g. thermometry technologies for engine and landing gear components.

### Research & Development Opportunities

Development of composite and novel material technologies and/or methods for:

- In factory, in-process measurement, quality assessment and defect recognition for raw ingredients, including fibres, resins and graphene - automated techniques would be of particular value;
- Consistent and accurate material manufacture including fibre/resin dispersion, placement, dimensions, stress management and surface finish. Solutions will include measurement/inspection/ testing technologies and methods for novel materials throughout the manufacturing process;

- Assessment of graphene dispersion in resins;
- Consistent and producible measurement of surface texture and development of supporting models for in-operation conditions e.g. engine oil coking;
- Measurement that supports the development and manufacture of high-temperature-capable composites.

Underpinning work to include:

- New (common) standards and test methods for novel or unconventional materials;
- Establish better understanding of the multi-scale physics of materials to support design and planning for manufacture;
- Development of design tools and models for simulation and analysis of designs, production, defects and through-life processes are needed, including those that identify how and when defects arise e.g. early stage manufacture.

### **Systems Challenge** – New ice protection systems

Ice protection systems are a strategic priority. New architectures in airframes and engines present new challenges to the sector. New engine inlet architectures increase vulnerability of ice accretion and the trend towards lower rotating speeds for next generation geared turbo fans raises mass of ice shed into engine cores.

Increasing airport congestion and aircraft operating for extended periods at low altitude leads to greater risk of wing icing. Use of composite structural materials demands new ice protection system technologies, leading to challenges for manufacturing, materials integration and sensors e.g. FP7 ON-WINGS programme.

More electric architecture and the push to reduce energy consumption and weight restrict the application of legacy systems, many of which are not compatible with new composite architectures. Changes in regulations to cover additional environmental phenomena including crystal icing and super large droplets create additional challenges where existing certification infrastructure and methods to validate compliance are inadequate.

Development of these systems will require measurement and inspection devices for composite components, coatings and hidden and complex surfaces. Embedded sensors will be operating in harsh environments and these will require technologies and test methods for device functionality and host structure integrity.

In common with the other value streams, new (common) standards and test methods must be established.

## SENSOR TECHNOLOGIES

### Current State & Challenges

With the trend to smaller, lower-cost devices, sensors are increasingly finding application in products and processes to provide real-time condition and state monitoring, reduce error and predict early life failure. Product applications include structural monitoring, engine and wing ice-protection system and machine tool wear sensors. Technologies for embedded sensor integrity and function verification are needed e.g. wing airflow sensors.

In process, sensors are used in machine tools for continuous condition feedback as well as for NDE and other inspection technologies. Measurement and inspection of harsh factory processes, e.g. high temperatures, require development of robust devices.

For the digitally enabled supply chain, calibration of sensors (and associated costs) is a challenge for multiple device real-time feedback.

### Research & Development Opportunities

Development of technologies and/or methods for:

- In-factory verification of buried and embedded sensors' and other devices' function and integrity of interconnects;
- Assessment of integrity of sensor host structures (see NDE & Defect Detection);
- Robust sensors for reliable measurement and inspection of high-temperature processes.

Underpinning work to include:

- Establishment of internationally recognised standards for data interoperability and traceability;
- Development of demonstrators to tackle challenges associated with measurement uncertainty, traceability and data validation.

### **Structures Challenge** – Factories of the Future

Demand for high value and complex products manufactured at high rate against a backdrop of increasingly varied customer and technical requirements needs flexibility and responsiveness from industry. This applies to factory processes and throughout the product lifecycle. The structures value stream, and wing manufacture in particular, are feeling this pressure.

Industry and academia responses include R&D into novel exploitation of evolving architectures, enhancements to materials processing and digitisation via advanced test beds and future factory concepts. The AMRC Factory 2050 and Airbus Factory of the Future are two examples of UK initiatives to test and develop concepts enabling cyber-physical systems for manufacturing.

Factory automation and data analysis can make factories up to 50% more efficient in terms of productivity[6]. The ability to adapt to variations in product, maintain tighter quality control and conduct effective but non-disruptive product verification are clear benefits. This study has highlighted complementary technology needs and methods across a broad front. Examples include in-process measurement and inspection of large and complex surfaces, composite and novel materials and components, and their joints and bonds.

## COATINGS AND SURFACE FINISHES

### Current State & Challenges

Coatings and surface finishes are used in a wide range of applications across aerospace e.g. engine thermal coatings. Quality of coating systems and seal integrity (e.g. adhesion, surface finish, residual stresses and thickness) is critical to the component lifetime e.g. turbine blades. However, these properties are not well understood or easily determined in the factory or laboratory. Dissimilar materials require surface preparation at joint interface.

### Research & Development Opportunities

Development of technologies and/or methods for:

- In-process measurement and inspection of coatings and surface finishes e.g. for integrity, adhesion and durability.

Underpinning work to include:

- Supporting research and development of models to identify the key factors and predict failure of the above e.g. assessment of performance of de-bonded coatings (particularly thermal performance for engine coatings) to predict how damage affects function, leading to a better understanding of criticality of damage levels and improved maintenance schedules.

## JOINTS AND BONDS

### Current State & Challenges

A wide range of materials offering high performance against very specific requirements is enabling development of aircraft architectures, systems (including combined electronics and sensors) and propulsion components, comprising mixed material structures. This mix leads to an increasing occurrence of joints and bonds between dissimilar materials.

Different (possibly incompatible) surface and other physical properties, e.g. differential thermal expansion, present a challenge for joining or bonding in new architectures. Capability for assessment and inspection technologies and techniques in-process and through-life for adhesives, joints and bond-lines between novel, dissimilar materials and even similar materials e.g. metallic welds, remain a challenge. Cost of inspection technologies should be low to ensure access across the supply chain.

### Research & Development Opportunities

Development of technologies and/or methods for:

- Assembly and measurement of components for alignment and joining to the required standards;
- Assessment of bonds, welds and other joints in-process, through-life and at low cost.

Underpinning work to include:

- Development of the physics of bonding of dissimilar materials to focus the above technology development;
- Development of a validated and traceable materials adhesions and bonding compatibility database to support design.

### **Propulsion Challenge** – Additive Manufacturing for engines

The UK has a world class capability in production of large turbo-fans and components; demand for engines continues to grow. Technologies that enable higher efficiency and reduced cost and weight are receiving attention.

Additive Manufacturing (AM) techniques offer solutions to some demands through production of conventional parts using novel means, and also design and manufacture of novel designs not conceivable using conventional subtractive methods. Examples of AM components as used in service or demonstrator programmes are the LEAP fuel nozzle, R-R Trent XWB-97 front bearing housing and PW1100G-JM bore-scope bosses.

Strength and finish of parts is variable and, whilst waste can be kept to a minimum via powder recycling, contamination of the reused material is a challenge. Whilst there are barriers to serious introduction in production components, AM offers reduced development, production and lead times and thus, costs. Furthermore, exploiting digitalisation and the concept of the 'digital twin', identical component replacement through life is foreseeable. Engine parts could be produced on demand and closer to point of need e.g. Additive Laser Manufacture (ALM) offers the opportunity for repair of complex geometries.

Challenges point towards topics for PV technology research that are common to the other Value Streams, including development of devices for accurate and rapid measurement and inspection of hidden surfaces and at-depth features.

Powder quality and contamination is a challenge in production and repair, needing measurement techniques and analysis tools. Models for evaluation of 'as built' properties from measurements of porosity and bulk material properties would offer insight into environmental and manufacturing factors on the product.

## ADDITIVE MANUFACTURING

### Current State & Challenges

Additive Manufacturing (AM) supports the long-term vision of zero defects and 'right-first-time'. At present, the technology is finding increasing acceptance and application in rapid product development, spares and assembly jigs, and other applications where it is suited to part customisation and small scale production runs. The aerospace industry is adopting AM for some production items, including parts for the Rolls-Royce Trent XWB-97. A wide range of materials have been applied to AM, including metals, polymers and some ceramics.[7]

Challenges include the need for understanding of AM product performance and effect of manufacturing/ machining (e.g. hybrid processes) on AM and other novel materials and processes. The effect of processing on finish needs further research. The capability to produce complex and hidden features presents a challenge for measurement and inspection of hidden features and defects.

Interoperability/data compatibility between differing AM systems is a challenge that should be addressed as part of digitalisation of the factory.

### Research & Development Opportunities

Development of technologies and/or methods for:

- Accurate measurement and inspection of hidden surfaces and at-depth features;
- Characterisation and measurement of surface finishes of AM products;
- High dynamic range devices for automated rapid detection, precise location, measurement and classification of AM defects;
- Assessment of AM raw material quality, contamination and impact on product quality and life e.g. powders.

Underpinning work to include:

- Models of effective 'as built' AM properties based on component material properties and responses to the build process.
- Development of accurate AM (and other near-net) 'Design for Manufacture' tools to support in-process and post-process defect prediction and design phase correction;
- Establishment of new (common) AM standards and test methods.

## CATALYSING CHANGE

The UK needs to be ambitious in its approach to Product Verification at all levels of the supply chain. It has the capability, eco-system and skills to provide the necessary leadership, training and R&D. This framework, produced in consultation with key stakeholders, articulates the priorities, challenges and research areas required to assure performance and quality across aerospace manufacturing. It recommends where investment in Product Verification will have the greatest impact by describing more than 65 challenges. These challenges, when addressed, will help prepare UK aerospace manufacturers for opportunities provided by:

- Greater confidence in new manufacturing processes and materials that underpin innovation, reduction of waste and sustained competitiveness;
- Reconfigurable manufacturing capabilities with agile, flexible and adaptable in-process measurement and inspection;
- Sustainable manufacturing value chain and supply chain enabled by reliable and traceable data;
- Improving design and decision making for better, higher performance and more reliable products.

UK aerospace manufacturing is facing significant challenges, but also tremendous opportunity. The benefits and rewards of adopting Product Verification technology and good practice – such as shorter product development lead times, increased productivity and greater confidence and trust in the supply chain – will be well over £2 billion p.a. to the UK economy.

## NEXT STEPS

The following actions will enable the UK to maximise the opportunities identified through this work.

**1. State-of-the-art research:** investment in the following priority themes:

**a)** Faster, automated processes with reduced inspection: research and development to enable faster, self-correcting, self-calibrating and high dynamic range, in-process measurement covering the micro mm to mm scales;

**b)** Digital transformation: technologies and methods for improving data traceability, uncertainty and interoperability across design, production, supply chain processes and TES;

**c)** Establishing greater confidence in new manufacturing processes and materials: research and development to industrialise technologies for inspection of near net/net shape components, physically complex or large products, surfaces, coatings, bonds and raw material quality arising from new manufacturing processes and materials e.g. composites;

**d)** Virtual factory: research and development to generate a virtual factory tool-set to improve High Value Design and decision-making tools.

**2. Demonstrators**

**a)** Provide access to metrology capability through regional centres of expertise

**3. Skills**

**a)** Develop and deliver accredited metrology training for workforces and apprentices;

**b)** Support metrology outreach programmes to schools, colleges, industry and academia;

**c)** Embed the 'PV Considerations' methodology (on page 3) across all research, capability or product development programmes, and apply throughout the product life cycle;

**d)** Ensure cross-sector benefit from this work by sharing the outcomes with other sectors;

**e)** Support supply chain capability development programmes that build measurement capability.

## REFERENCES

[1] Airbus Global Market Focus 2016-2035 "Mapping Demand"

[2] ADS Commercial Aerospace Market Information: 2016

[3] NATEP Showcase, 20th September 2016, NATEP and the Need for Supply Chain Excellence, Airbus Operations Ltd

[4] Kunzmann, H., T. Pfeifer, R. Schmitt, H. Schwenke and A. Weckenmann (2005), Productive metrology - Adding value to manufacture, CIRP Annals - Manufacturing Technology, Volume 54, Issue 2, p.155-168

[5] https://www.adsgroup.org.uk/facts/facts2016/

[6] Industry 4.0 Report, June 2016, IMechE/BDO

[7] NPL AM Strategy

## ACKNOWLEDGEMENTS

Our sincere thanks go to all the subject matter experts and business development managers from academia, research organisations and industry who were consulted during the course of this work.

## GLOSSARY

**AM** Additive Manufacturing

**ATI** Aerospace Technology Institute

**CAA** Civil Aviation Authority

**CFRP** Carbon fibre-reinforced plastics

**MMC** Metal matrix composite

**NDE** Non-destructive evaluation

**NPL** National Physical Laboratory

**NPVP** National Product Verification Programme

**OEM** Original Equipment Manufacturer

**Ppm** Parts per million

**PV** Product Verification

**R&D** Research and Development

**R&T** Research and Technology

**SME** Small and Medium Enterprise

**TES** Through-Life Engineering Services

# WHO WE ARE

The **Aerospace Technology Institute** (ATI) is the objective convenor and voice of the UK's aerospace technology community. The Institute defines the national aerospace technology strategy that is used to focus the delivery of a £3.9 billion joint government-industry funded aerospace technology programme.

The **National Physical Laboratory** (NPL) is the UK's National Measurement Institute, and is a world-leading centre of excellence in developing and applying the most accurate measurement standards, science and technology available. NPL undertakes research and shares expertise with government, business and society to help enhance economic performance and the quality of life.

## Contact us


### Aerospace Technology Institute

Martell House
University Way
Cranfield
MK43 0TR

**www.ati.org.uk**

**info@ati.org.uk**

### National Physical Laboratory

Hampton Road
Teddington
Middlesex
TW11 0LW

**www.npl.co.uk**

## INSIGHTS

Download our full suite of INSIGHT papers - **https://www.ati.org.uk/resources/publications/#insight**