Underpinning the development of next generation composites manufacturing processes
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1 Executive Summary

“Welcome to the Hub’s fourth Annual Report. As we pass the mid-term point, we are starting to see a real impact from our investments despite the challenges of this year and the disruption caused by COVID-19. I am extremely grateful to all our stakeholders for the dedication and commitment shown in support of the Hub, without which we would not be able to achieve our vision and goals.”

As our research portfolio has expanded, the Hub has continued to improve quality by reinforcing synergies between project teams and by building on other UKRI research investments across materials, design, characterisation and manufacturing for composites. Our cohort size has grown to 36 PhDs, 46 EngDs and 26 postdoctoral researchers, based within 15 UK universities. This expansion includes a consortium of 57 industrial companies and partnerships with four High Value Manufacturing (HVM) Catapult Centres, across a wide range of industrial sectors.

The Hub’s research portfolio currently consists of 34 past and present projects including 6 Core Projects, 19 Feasibility Studies, 4 Fellowships, and 5 Synergy projects. £4.7m has so far been committed to fund collaborative research activities within the Hub, from a total research budget of £7.3m. Future funded projects will be aligned with emerging and increasing industrial interest in thermoplastic processing technologies and sustainability. We launched our latest Feasibility Study Call in May 2021 with funding allocated for 5 new projects.

There have been significant outputs this year across the whole portfolio with the publication of 16 papers, taking our total journal publications to 57. Wider dissemination of Hub research has taken place in the form of Hub and project webinars which have proved extremely popular. We will continue to host these throughout the year given the interest generated, with each webinar focussing on one of the Hub Work Streams.

I am pleased to see the impact generated from some completed and ongoing Hub Investments. Congratulations to

2 Headline Achievements

The Hub has grown to a network of

- 15 UNIVERSITIES
- 37 INDUSTRY
- 4 HVMC

For every £1m invested in research by the Hub, we have leveraged £7.3m

- Hub research funding spent to date £4.7m
- Additional leveraged grant income £18.9m
- Leveraged industrial support £3.2m
- Leveraged institutional support £1.8m

Prof Nick Warrior
Hub Director

Professor Emile Greenhalgh, Principal Investigator on the Multifunctional Core Project. Emile has been awarded a Chair in Emerging Technologies by the Royal Academy of Engineering. This is a very prestigious award and recognises Emile’s international reputation in the field of structural power composites. Furthermore, the low-cost thermoplastic fibre-metal laminate technology, developed by the University of Edinburgh during a previous Hub funded Feasibility Study has received support from the Offshore Renewable Energy Catapult. This technology has great potential in the renewable energy sector and the Hub is pleased to hear this work is continuing.

I hope you enjoy reading our latest report, and look forward to working with you all in the foreseeable future.
3 Hub Vision and Objectives

The Hub vision is founded on two industry inspired Grand Challenges:

- Improving existing composites manufacturing processes
- Developing new technologies

Since 2017, the Hub has built on the success of the EPSRC Centre for Innovative Manufacturing in Composites (CIMComp; EP/I033513/1), with a vision to develop a national centre of excellence in fundamental research for composites manufacturing – delivering research advances in cost reduction and production rate increase, whilst improving quality and sustainability.

Our aim is to underpin the growth potential of the UK composite sector by developing the underlying manufacturing process science and technology needed by industry, whilst enabling rapid dissemination of that knowledge into the UK industrial base.

Composites manufacturing research is the key to further exploitation of composites in existing sectors (aerospace, automotive, energy and defence) and more widespread adoption in emerging sectors such as infrastructure, rail and marine.

To achieve this vision, the Hub aims to deliver against core objectives in four key areas: research excellence, technology transfer, training and network building.

Hub Funding Model:

- £3.7m Institutional Commitments
- £8.9m Industrial Commitments
- £10.3m EPSRC Funding
- £22.9m Total Commitments

Academic Institutions and Industry have committed to a further £12.6m in support of the £10.3m EPSRC investment.
## 4 Hub Cumulative Growth

<table>
<thead>
<tr>
<th>Funding Decision</th>
<th>Date</th>
<th>Hub Growth</th>
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<tbody>
<tr>
<td>Hub launched</td>
<td>Jan 2017</td>
<td>Initial academic partners include Nottingham, Bristol, Imperial College, Manchester, Southampton and Cranfield</td>
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<tr>
<td>3 Core Projects funded</td>
<td>Jun 2017</td>
<td>3 new Spokes join the Hub - Edinburgh, Cambridge, Glasgow</td>
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<tr>
<td>2 Feasibility Studies funded</td>
<td>Oct 2017</td>
<td>1 new Spoke joins the Hub - Brunel</td>
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<tr>
<td>6 Feasibility Studies funded</td>
<td>Jul 2018</td>
<td>3 new Spokes join the Hub - Ulster, Wrexham, Sheffield</td>
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<tr>
<td>3 Core Projects funded</td>
<td>Dec 2018</td>
<td>2 new Spokes join the Hub - Warwick</td>
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<tr>
<td>2 Feasibility Studies funded</td>
<td>Jun 2019</td>
<td>1 new Spoke joins the Hub - Bath</td>
</tr>
<tr>
<td>following Innovation Fellowship interviews</td>
<td>Jul 2019</td>
<td>1 new Spoke joins the Hub - Warwick</td>
</tr>
<tr>
<td>3 Feasibility Studies funded</td>
<td>Sep 2019</td>
<td>1 new Spoke joins the Hub - Bath</td>
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<tr>
<td>Active RTM Core Project funded</td>
<td>Jan 2020</td>
<td>1 new Spoke joins the Hub - Bath</td>
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<tr>
<td>2 Innovation Fellowships funded</td>
<td>June 2020</td>
<td>1 new Spoke joins the Hub - Bath</td>
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<tr>
<td>UK Composites Challenge Roadmap launched</td>
<td>Sep 2020</td>
<td>1 new Spoke joins the Hub - Bath</td>
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<tr>
<td>2 Core Projects funded, 4 Feasibility Studies funded</td>
<td>Jan 2021</td>
<td>1 new Spoke joins the Hub - Bath</td>
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<td>Hub Mid-Point</td>
<td>May 2021</td>
<td>1 new Spoke joins the Hub - Bath</td>
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<td>5 Synergy Promotion Projects launched</td>
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<td>Mid-Term Review</td>
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<tr>
<td>Feasibility Study Call launched</td>
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5 Hub Research

The Hub project portfolio is based on meeting the research challenges facing the UK composites sector and aims to accelerate the uptake of composite materials by reducing the costs of engineered products whilst increasing quality, increasing functionality and striving to meet the 2050 Net Zero targets.

All projects and leveraged studentships are linked to a Work Stream, which is led by the principal investigator of a Core Project or one of the Platform Fellows. The aim is to increase research excellence by ensuring that each Work Stream is driven by national leaders in that technology area, adopting best practices in experimental and modelling manufacturing science across all associated projects.

Our Feasibility Study programme offers up to £50k for novel, ambitious six month projects, which are encouraged, where appropriate, to be developed into proposals for Core Projects (36 month collaborations), of values between £375K and £700K. The rate of continuation from Feasibility Study to Core Project has typically been one in five.

Pathways to Impact

The Hub plays a key role in the composite manufacturing technology pipeline, pushing proven research outcomes through to the HVM Catapult Centres (The National Composites Centre (NCC), Advanced Manufacturing Research Centre (AMRC), Warwick Manufacturing Group (WMG) and Manufacturing Technology Centre (MTC)) so that they mature through the Technology and Manufacturing Readiness Levels (TRL, MRL) into successful products and manufacturing activity, to be exploited by UK industry.

The relationship between individual researchers, their projects and the Work Stream can be viewed using the SharpCloud data visualisation platform.

Grand Challenges

The Grand Challenges are addressed by five Research Themes, with composites sustainability underpinning all of the Themes. This includes considering life cycle assessment, energy use and environmental impact measures across the research portfolio. The challenges in each Research Theme are met by relevant technologies from across the eight Work Streams.

Research Themes

- High rate deposition and rapid processing
- Design for manufacturing via validated simulation
- Multifunctional composites and integrated structures
- Inspection and in-process evaluation
- Recycling and re-use

Grand Challenges

1) Enhance robustness of existing processes via understanding of process science
2) Develop new high rate processing technology for high quality structures

Feasibility Studies + Core Projects + Fellowships

Associated Leveraged Projects
## 5.1 Hub Projects by Work Stream

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<tr>
<td>Feasibility Study: In-situ polymerisation of Fibre Metal Laminates</td>
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Work Stream 1
Automated Fibre Deposition Technologies

Work Stream Overview
Automated Fibre Deposition is currently used for high specification, often large structures (10m+), requiring precise fibre placement to produce complex geometries. The Universities of Nottingham, Bristol and Edinburgh are researching process parameters to reduce defects, improve manufacturing performance and develop next-generation fibre placement technologies. Flexibility in the use of different materials, such as dry preforms, thermoplastic tapes and recycled fibres, optimising design for manufacture and in-line process monitoring, are key to broadening industrial applications of this technology. WS1 is linked to a £36.7m capital investment programme at the NCC, aimed at transferring the technology to state-of-the-art industrial hardware.

The challenges for automated deposition of composites are closely aligned with the Hub’s Grand Challenges of improving quality and rate. There is significant industrial effort at TRL 4-6 to develop existing technologies through incremental changes to the process such as Automated Fibre Placement, and there’s a great deal happening in the field of manufacturing which impacts this work. There’s also progress in the world of computational science to improve CAE tools, as well as Industry 4.0 trends. This leads to potential work in a number of TRL 1-3 areas:

- Improve the understanding of material behaviour during deposition to improve rate and quality
- Understand the barriers to process implementation
- Make full use of dry fibre formats and exploit the advantages
- Facilitate a Digital Twin for composites manufacturing

Work Stream 1
Automated Fibre Deposition Technologies

Work Stream Aims

- Investigate the rate and quality limiting barriers during the deposition of dry fibres. New AFP processing equipment is being developed alongside a novel Digital Twin programming methodology to enable real-time influencing and inspection of the deposition process, ensuring optimum speed and part accuracy.
- Investigate ways to acquire large quantities of real-time data, which will be integrated within the machine to provide real-time control during fibre deposition. The Digital Twin will subsequently be used to quantify the local permeability effects post deposition to predict preform infusion behaviour through a network based model.
- Rapidly produce components that are not currently manufacturable using conventional AFP, using a combination of novel prepreg material formats and new process developments.
- Modify the University of Bristol-developed Continuous Tow Shearing (CTS) process to feed highly-aligned discontinuous fibre tapes, produced from recycled fibres, to further optimise the drapeability of preforms and enable a step-change in material cost.

Work Stream Team

Principal Investigators: Dr Thomas Turner, Nottingham; Prof Stephen Hallett, Bristol; Prof Janice Barton, Bristol; Dr Byung Chul (Eric) Kim, Bristol; Dr Robert Hughes, Bristol; Dr Dongmin Yang, Edinburgh.

Co-Investigators: Dr Andreas Endruweit, Nottingham; Dr Jonathan Belnoue, Bristol; Dr Marco Longana, Bristol; Prof Stephen Hallett, Bristol; Prof Ian Hamerton, Bristol.

Researchers: Dr Adam Joesbury, Nottingham; Dr Anthony Evans, Nottingham; Dr Ric Sun, Bristol; Dr Logan Wang, Bristol; Dr Marco Longana, Bristol; Dr Lei Wan, Edinburgh; Dr Colin Robert, Edinburgh; Dr Daniel Bull, Southampton; Dr Michael Elkington, Bristol; Dr Bohao Zhang, Bristol; Dr Thomas Noble, Edinburgh.

PhDs: Usman Shafique, Nottingham; Shimin Lu, Nottingham; Murat Celik, Edinburgh.


Work Stream Projects

- **Core Project:** Automated Dry Fibre Placement Technology & Fibre Steered Forming Technology (Nottingham & Bristol)
- **Feasibility Study:** Virtual Un-manufacturing of Fibre-Steered Preforms for Complex Geometries (Bristol)
- **Feasibility Study:** Evaluating In-process Eddy Current Testing of Composite Structures (Bristol)
- **Feasibility Study:** 3D Printing of Continuous CF Powder Epoxy Towpreg (COMPrinting) (Edinburgh)
- **Feasibility Study:** Strain-based NDE for Online Inspection (Southampton)
- **Platform Fellow:** Automated Manufacturing Technologies and Tactile Sensing (Michael Elkington, Bristol)
- **Innovation Fellow:** Development of a Powder-Epoxy Carbon Fibre Towpreg for High-speed, Low Cost Automated Fibre Placement (Dr Colin Robert, Edinburgh)

Leveraged Industry Support
£246k

Leveraged Academic Support
£271k

Leveraged Grants
£11.2m

Hub Investment
£2.0m
Work Stream Progress

1. A novel and unique experimental rig has been constructed at the University of Nottingham to closely emulate commercial tape-laying processes, which will be used to study process parameters and expand the ADFP operating range.

2. The ADFP Core Project at Nottingham aims to rethink the existing composite design and manufacturing process by producing a new way of describing the structure of a composite part. A Digital Twin has been developed to emulate the ADFP process, encompassing both as-designed data and manufacturing data, which can be used alongside real-time sensor data from the machine to influence the manufacturing of future parts.

3. Continuous Tow Shearing developments at the University of Bristol will enable reclaimed/reused fibre material from the HiPerDif process to be used for AFP. This will deliver a high-quality sustainable material, which can be formed into complex curved shapes. The project seeks to provide a novel solution to the challenges of complex 3D AFP parts which cannot be produced by direct 3D deposition:
   
   • The material behaviour of the HiPerDif tape samples and diaphragm materials are being characterised, and the material models for unforming simulation have been developed and are being validated.
   • The laboratory tests are underway to guarantee the consistent property of the tape for preform production.
   • Initial trials of active feeding mode in the CTS process have been successfully completed.
   • The simulation model is currently being tuned, using different full-field measurement techniques to capture material deformation during forming.

4. Edinburgh is developing a tack-free powder epoxy for automated deposition processes. A novel powder-based epoxy from FreiLacke is used in this study. The powder epoxy has significant advantages compared to its liquid equivalents: low minimal viscosity, low exotherm, ability to preshape different parts and co-cure them in a one-shot process and stability at ambient temperature (no refrigeration requirement). These advantages result in lower manufacturing costs and quicker production of mechanically superior composite parts compared to standard liquid epoxy-based composites. This material will be tested on the UoN ADFP rig.

5. A rotational printing technique has been developed by adding a rotation degree to the traditional FFF 3D printer. A special nozzle is used along with the rotation of the printer head which is synchronised with the printing paths, enabling better fibre alignment when printing composites with complex shapes. The printing of this thermostetting based composite has been tested and compared with thermoplastic based composites through various case studies.

Work Stream Outputs

Work Stream 2

Optimisation of Fabric Architectures

Work Stream Overview

3D woven composites offer significant improvements in inter-laminar mechanical properties over more conventional 2D laminated composites. The Universities of Nottingham and Manchester are developing new forms of 3D fibre reinforcement architectures outside of the constraints of conventional textile manufacturing.

Nottingham is leading on developing multi-scale modelling techniques linked to a multi-objective optimisation framework based on geometries and conformal meshes created in the well-established TexGen software. Manchester is developing complementary fibre placement techniques and machinery to manufacture multi-axial 3D fibre preforms.

The 3D woven fabric approach has been demonstrated to yield over 10% weight-savings compared to optimised non-crimp fabrics (NCFs). 3D fabrics are already used in the aerospace industry (e.g. fan blades) but there is a demand for optimisation tools as well as new forms of preforms.

The research challenges being addressed are:

- How to model complex 3D preforms and optimise their structure.
- How to manufacture these 3D preforms.
- Demonstrate advantages over existing architectures and ensure research is transferrable to industry.

Work Stream Aims

- Establish a computational framework for textile preform optimization not limited to existing manufacturing processes.
- Identify classes of materials with improved properties over existing forms, by conducting a series of case studies.
- Develop new or modified textile preforming technologies to realise these material forms.
- Validate predicted properties and demonstrate performance benefits to materials suppliers and end users.

Work Stream Team

Principal Investigators: Prof Andrew Long, University of Nottingham; Prof Prasad Potluri, University of Manchester.

Co-Investigators: Dr Louise Brown, University of Nottingham.

Researchers: Dr Debabrata Adhikari, Nottingham; Dr Mikhail Matveev, Nottingham; Dr Shankhachur Roy, Manchester; Dr Vivek Koncherry, Manchester.

PhDs: Jinseong Park, Manchester; Kazi Sowrov, Manchester; Sarvesh Dhiman, Manchester/M Wright & Sons; Christos Kora, Nottingham; Syed Abbas, Manchester.

Industry Partners: Luxfer Gas Cylinders, AMRC, SigmateX, Airbus, NCC, ESI, BAE Systems, Hexcel, GKN Aerospace, M Wright & Sons, Shape.

Work Stream Project

- Core Project: Optimisation of Fabric Architectures (Nottingham & Manchester)
Work Stream Progress

Advances in meshing, multi-scale mechanical modelling and permeability modelling:

- Development of a special meshing technique suitable for textiles of arbitrary geometry, while maintaining accuracy and reasonable computational costs.
- A Multi-axial 3D weaving concept has been developed in order to create optimised preforms without imposing the manufacturing constraints of conventional weaving technologies. Manchester has developed a 1m x 1m 3D preform for an automotive floor panel.
- Application of the developed optimisation framework for two demonstrators. Conventional 3D woven textiles have poor properties in the off-axis direction hence either bending or torsion is compromised when these textiles are used as a reinforcement. The optimisation framework has been applied to find an optimum geometry of multi-axial 3D preforms and a technique to manufacture such preforms has been developed.

Work Stream Outputs

- Developed Meshing Technique is Released as a Part of Open-source Code within TexGen www.texgen.sourceforge.net.
- 6 presentations at conferences including a plenary lecture at the 22nd International Conference on Composite Materials in 2019.
- Keynote speech by Prof Prasad Potluri at virtual 9th World Conference on 3D Fabrics and their Applications, 8-9th April 2021.

Figure 1: Multiaxial 3D weaving concept has been developed in order to create optimised preforms without imposing the manufacturing constraints of conventional weaving technologies.

Figure 2: Braid-winding machine developed at the University of Manchester.
Work Stream 3
Multifunctional Structures

Work Stream Overview

Imperial College has demonstrated that a structural composite sandwich panel can be used to store energy as a supercapacitor, by embedding carbon fibres in a carbon aerogel (CAG). This technology could be transformative for transport and mobile electronics sectors, removing the need for conventional battery storage and delivering a substantial weight and volume reduction. WS3 aims to research the challenges in manufacturing 3D components from these panels. Imperial College is working with Bristol to develop a novel printing process to produce a textile with discrete regions of CAG structure, which can be shaped into a 3D preform structure for liquid moulding. Bristol is using its explicit Finite Element (FE) forming expertise to develop a specific modelling approach for these structures. Functional sub-elements from microbraids with metallic filaments have also been developed by Bristol to provide added functionality through improved electrical and thermal conductivity.

Work Stream Aims

Multifunctional structural composites, in which structural composites are imbued with additional functions, offer solutions to achieve a step change in weight/volume savings, as well as facilitate new design freedoms. The overarching aim of the Core Project is to create a set of tools to facilitate the design and manufacture of complex, multifunctional structures. These will be used to overcome the challenges associated with using multifunctional materials and provide a methodology to compare and contrast multifunctional systems.

The specific application under investigation is structural power (structural composites which store/deliver electrical energy). The carbon aerogel used in the devices is very rigid, but brittle, so the processing is challenging, but is a critical step to promote adoption of this emerging composite technology by industry.

Integration of functional elements can be achieved in different ways. The project focuses on integration of (a) metal-carbon braided hybrid threads by means of tufting and (b) micro-additives by means of local injections. The enhanced properties are then examined in sensing, inductive heating, and structural properties.

There are two key objectives:
1. To explore the manufacturing issues associated with the creation of structural power materials formed into complex geometries, and develop tools to predict performance and enable multifunctional design.
2. To explore the design and manufacture of multi-matrix / multi-fibre composites to optimise heat and electrical conduction.

Work Stream Team

Principal Investigators: Prof Emile Greenhalgh, Imperial College London; Dr Dmitry Ivanov, University of Bristol.

Researchers: Dr Ian Gent, Bristol; Dr Laura Pickard, Bristol; Dr Sang Nguyen, Imperial; Dr David Anthony, Imperial.

PhDs: Caroline O’Keeffe, Bristol; Arjun Radhakrishnan, Bristol; Mark Turk, Bristol; Maria Valkova, Imperial.

Industry Partners: BAE Systems, Airbus, NCC, Hexcel, Qinetiq, Chomarat, Oxeon, GKN Aerospace.

Work Stream Project

• Core Project: Manufacturing for Multifunctional Composites (Imperial College & Bristol)
**Work Stream Outputs**

- Prof. Emile Greenhalgh has been awarded a Chair in Emerging Technologies on Structural Power and ten years of funding (£2.7M) to support his research in this area.

**Work Stream Outputs**

- Manufacture and demonstration of curved structural power components:
  - Exceeded structural supercapacitor target performance: Energy and Power densities of 1.4Wh/kg & 1.1 W/kg respectively achieved.
  - A collaboration between ICL/UoB led to the successful demonstration of masking and barriers to facilitate the infusion of curved multifunctional structures.
  - Developed scale up for current collection, encapsulation, multicell assembly and demonstration.

- Modelling and Multifunctional Design for Structural Power:
  - Fabric compaction model developed & published, providing the foundation for the electrochemical & mechanical model development.
  - Numerical model developed to predict compaction effects, which includes the influence of CAG defects.
  - Multifunctional design methodology developed and demonstrated against several platforms, including aircraft cabin, air-taxi and fully electric aircraft.

- Conductive sub-reinforcements:
  - The feasibility of improving the through-thickness properties of composites by tufting of hybrid micro-braided threads has been proven to be feasible, creating novel hybrid composites.
  - Tufted hybrid composites show elevated electrical conductivity, capability for delamination sensing and superior structural properties.
  - New modelling tools have been created and validated for assessing electrical conductivity of hybrid braids.
  - Induction heating/curing trials have been conducted for reference and tufted panels (quick repair applications). The architecture of the through-thickness tuft is shown to act as a potentially strong heat sink – this feature can be exploited as a tool to aid thermal management during cure.

- Multi-matrix composites:
  - Modelling tools have been developed for allocating multifunctional patches and examining forming deformation of remaining monofunctional, structural, material.
  - A concept to mitigate against forming defects by stabilising preform with liquid resin patches has been demonstrated.
  - New experimental procedure developed for deriving local properties of patches hosted in dry preform – virtually confirmed for viscous and non-linear elastic behaviour of materials.
  - Design tool has been developed for liquid resin printing for void free creation of patches and barriers for flow separation – thermal history / loading rates / applied pressure.
  - Relatively high conductivity is demonstrated for locally integrated micro-additives.
  - Demonstrator for complex sizeable tool has been designed to showcase some of the key features of forming with functional elements.
Workstream 4

Online Consolidation

Work Stream Overview

Placement, consolidation and curing have historically remained separate and sequential steps carried out to manufacture composites structures. There is an urgent need to move to automated lay-up to reduce production time for high performance composite structures manufactured from pre-impregnated material. Layer by Layer curing combines deposition, consolidation and curing of thermosetting composites into a single manufacturing step that controls material microstructure at the point of application to eliminate defects and decrease costs by avoiding the autoclave. Cranfield and Bristol are developing a fully coupled (thermal-consolidation-thermomechanical) 3D simulation of the Layer by Layer (LbL) curing process, aiming to maximise interfacial toughness, minimise process duration and control residual stresses. A laboratory scale pilot plant will be constructed to demonstrate the applicability of LbL to other composites manufacturing technologies.

Work Stream Aims

Starting in June 2020, the aim of the LbL Core Project is to develop the scientific and technological tools necessary for industry to successfully implement the LbL concept, and to establish the new process at the scale and level of complexity required for application to advanced composite structures. This will be achieved by addressing the following objectives:

2. Development of constitutive models and associated characterisation using conventional and snap-curing systems with LbL curing.
3. Process optimisation to maximise interfacial toughness, minimise process duration and control residual stresses.
4. Development of tailored process setups for complex geometries/components, including end effectors and zonally heated reusable bagging.
5. Optimisation of LbL process implementation to minimise defect generation due to ultralow viscosity, ply drop offs, gaps and curvature.
6. Demonstration of applicability based on pilot scale LbL implementations of automated fibre/tape placement, pultrusion and filament winding.
7. Demonstration of LbL process capabilities through the development of hybrid thermoset/thermoplastic components, stabilised preforms and laminates with tailored residual stress state.

Work Stream Team

Principal Investigators: Dr Alex Skordos, Cranfield University; Dr James Kratz, University of Bristol.

Researchers: Dr Gabriele Voto, Cranfield University; Dr Mehdi Asareh, Cranfield University; Dr Arjun Radhakrishnan, Bristol; Dr Robin Hartley, Bristol; Dr Mario Valverde, Bristol.

PhDs: Michael O’Leary, Bristol/Airbus; Adam Fisher, Bristol/Nantes; Axel Wowogno, Bristol/Rolls Royce.

EngD: Anastasios Danezis, Cranfield University/Heraeus.

Industry Partners: National Composites Centre, Rolls Royce, Exel Composites, Heraeus Noblelight, Airbus.

Work Stream Projects

- Core Project: Layer by Layer (Cranfield & Bristol)
- Feasibility Study: Layer by Layer Curing (Cranfield & Bristol)
Work Stream Progress

Key research questions being addressed by the Core Project Case Study on thick laminate:

- Interfaces: will the layers stick together?
- Consolidation: will the laminate have the desired fibre volume fraction and low porosity?
- Dimensional stability: will residual stresses create warpage?
- Hybridisation: will high temperature processing thermoplastic layers degrade the properties of underlying thermoset prepregs?

The LbL Curing Feasibility Study previously demonstrated:

- ~50% saving in cure times for thick components.
- Linear scaling of process time with component thickness, making manufacturing of ultrathick components feasible.
- Using LbL process to merge consolidation with curing for planar geometries provides equivalent quality to a conventional autoclave process.
- Interfacial properties preserved in partially cured interfaces.

Work Stream Outputs

- An EPSRC Impact Accelerator Account was awarded for a project with Airbus (Oct 2019 to Mar 2020), “Infusion of Integrated Structures With Partially Cured Elements” with a leveraged grant value of £97,864. Concepts developed in the LbL Feasibility Project were used to partially cure a part that was integrated into a demonstrator. The scientific challenges identified in the higher TRL demonstrator are being addressed in the LbL Core Project, as part of an Airbus sponsored CDT studentship.
Workstream 5
Liquid Moulding Technologies

Work Stream Overview
Liquid Moulding Technologies, where resin is injected into a dry fibre preform, offer significant rate improvements over traditional autoclave-based manufacturing processes. However, variabilities in the preforming and moulding aspects and limitations in existing simulation methods compound to add uncertainty and increase the risk of defects.

A collaboration between Mathematics and Engineering at Nottingham is developing novel Bayesian Inversion algorithms for detecting defects during the moulding stage using in-process data and applying a correction to process parameters via estimation algorithms to eliminate defects. The algorithms have been validated for defects of arbitrary shape using Digital Twin models and laboratory experiments.

Industrial needs:
- Standardisation of procedure for reliable permeability characterisation.
- Development of tools for better process design.
- Utilisation of in-process sensors to achieve better process control.

Work Stream Aims
Starting in November 2019 the Active Resin Transfer Moulding (RTM) Core Project was developed from a successful Feasibility Study. The aim of this project is to create an in-process NDE system for the RTM process. There are two objectives to achieve this aim:

1. The creation of a Digital Twin for the RTM process to capture in-process data to estimate local deviations from the design for any manufactured part. The project will develop, improve and test innovative Bayesian Inversion algorithms (BIA) to restore the local permeability of composite components, based on data collected from sensors during resin injection into the reinforcement.

2. The project will develop and test an active control system based on information from sensors and on physical models together with on-line parameter estimation algorithms to improve resin injection. This control system will minimise the occurrence of defects and ensure process robustness.

These objectives are being delivered via an interdisciplinary approach between engineers and applied mathematicians, which will lead to a set of algorithms and tools that can be applied across a wide variety of technologies and industry sectors.

Work Stream Team
Principal Investigators: Prof Michael Tretyakov, University of Nottingham.
Co-Investigators: Dr Andreas Endruweit, Nottingham; Prof Andrew Long, Nottingham; Dr Marco Iglesias, Nottingham.
Researchers: Dr Mikhail Matveev, Nottingham; Dr Andrew Parsons, Nottingham; Dr Adam Joesbury, Nottingham.
PhDs: Gwladys Popo, Nottingham.
Industry Partners: ESI, LMAT, NCC, GNK Aerospace, AMRC.

Work Stream Project
- Core Project: Active Resin Transfer Moulding (RTM) (Nottingham)
- Platform Fellow: Permeability testing Methods (Dr Andreas Endruweit - Nottingham)
- Platform Fellow: Local Resin Printing for Preform Stabilisation (Dr Adam Joesbury - Nottingham)
- Feasibility Study: Active Resin Transfer Moulding (Nottingham)
**Work Stream Progress**

1. A novel Regularising Ensemble Kalman filter Algorithm based on the Bayesian paradigm was applied to RTM processes to estimate local porosity and permeability of fibrous reinforcements using measured values of local resin pressure and flow front positions during resin injection. The algorithm enables the detection of locations of defects in the preform. It was tested in virtual experiments with two geometries, a two-dimensional rectangular preform and a more complex 3D shape, as well as in laboratory experiments. In both the virtual and laboratory experiments, it was demonstrated that the proposed methodology is able to successfully discover defects and estimate local porosity and permeability with good accuracy.

2. The algorithm also provides confidence intervals for the predictions and estimations of defect probabilities, which are valuable for analysis of the process. The algorithm can cope with more localised but still important defects (e.g. race-tracking).

3. Development of a virtual lab demonstrator is underway.

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**Work Stream Outputs**

- Impact Exploration Grant (Nottingham Impact Accelerator) helped to better understand industrial needs.
Workstream 6
Composite Forming Technologies

Work Stream Overview
Automated composite forming is recognised as an important enabling technology, offering significant improvements on manufacturing rate, volume and quality compared to hand layup. Starting in September 2020, the Core Project leading WS6 was developed from the combination of two successful Feasibility Studies which developed a process-specific forming limit diagram for dry non-crimp fabrics (NCFs) and a finite element forming simulation of composite sandwich panels incorporating NCFs.

The mechanics of fabric deformation in forming has been developed to an advanced level, but defect formation and forming limits are not clearly characterised. Bath, Cambridge and Nottingham will deliver enhanced experimental material characterisation methods and high-fidelity explicit FE simulation techniques to enable 3D formed composite components to be manufactured from woven and Non Crimp Fabric (NCF) textiles with a high degree of precision.

Research challenges:
- The mitigation of defects during forming.
- Lack of robust and validated simulation tools including defect avoidance.

Work Stream Aims
The aim of the Design Simulation Tools for NCF Preforming Core Project is to provide process improvements and simulation design tools that will enable composite components to be designed and manufactured from textile preforms more efficiently and with greater confidence in their performance. The project will focus specifically on dry non-crimp fabrics (NCFs) and Double Diaphragm Forming (DDF), to create high-performance preforms suitable for liquid moulding.

Selected materials and manufacturing routes have been strongly influenced by the experience of the industry collaborative partners.

Work Stream Projects
- **Core Project**: Design Simulation Tools for NCF Preforming (Bath/Cambridge/Nottingham)
- **Innovation Fellow**: Compression moulding simulation (Connie Qian – Warwick)
- **Feasibility Study**: Sandwich Panel Forming (Nottingham)
- **Feasibility Study**: Composite Forming Limit Diagram (Cambridge)
- **Feasibility Study**: Braid Forming Simulation (Nottingham)
- **Feasibility Study**: Incremental Sheet Forming (Bristol/Nottingham)

Work Stream Team
Principal Investigators: Prof Michael Sutcliffe, Cambridge.
Co-Investigators: Dr Lee Harper, Nottingham; Dr Andrew Rhead, Bath; Prof Richard Butler, Bath; Dr Evros Loukaides, Bath.
Researchers: Dr Shuai Chen, Nottingham; Dr Andrea Codolini, Cambridge; Dr Connie Qian, Warwick.
PhDs: Angela Lendinez Torres, Nottingham; Guy Lawrence, Nottingham; Rajan Jagpal, Bath; Verner Viisainen, Cambridge; Salem Erouel, Nottingham; Fei Yu, Nottingham.

Work Stream Progress

1. A global to local finite element forming simulation tool has been developed to increase the fidelity of fabric drape modeling. The model has been developed to predict the occurrence of small amplitude wrinkles (~1-2 mm) for large length scale components (+10 m).

2. An intra-ply stitch removal algorithm has been developed to remove local stitches in NCF plies to improve formability, in an effort to reduce ply wrinkling. The model uses a multi-objective Genetic Algorithm to selectively remove stitches from each ply in the layup with the objective of reducing the maximum shear angle, whilst minimising the area of stitches removed to maintain stability during handling.

3. A novel resin printing method has been explored, using additive manufacturing techniques to locally control the shear stiffness of non-crimp fabrics.

4. A wrinkle prediction tool has been developed using a Deep Learning approach to understand why defects occur according to certain features within the tool geometry, ensuring designers can produce parts that are fit for manufacture via the DDF process.

5. A new friction characterisation method has been developed to capture the inter-ply frictional behaviour during DDF. The rig has been designed to determine the dynamic coefficient of friction under an applied normal pressure of 0.1 MPa, whilst enabling the effects of in-plane fabric shear and fabric saturation to be studied.

Work Stream Outputs

Workstream 7
Microwave Processing Technologies

Work Stream Overview

Microwave heating has long promised great potential for increased control and reduction in curing time via rapid and localised heating, as well as a reduction in processing power requirements. However, significant technical and safety challenges remain unsolved. WS7 aims to research microwave technologies for fibre tow-based manufacturing processes and in-mould heating for curing of thermosets and polymerisation of thermoplastics. This will include development of microwave cavities and waveguides suitable for material deposition rates in the range of 100 kg/hour to meet industry productivity demands. Research challenges related to conductive fibres and containment of radiation will be addressed with modelling and laboratory experiments.

WS7 is led by Wrexham Glyndŵr as a combination of smaller projects, and was established in February 2019 following the Hub Synergy Workshop, which identified Microwave Processing Technologies as a key enabler for high rate material deposition and processing. There is currently no Core Project to lead this Work Stream, but this presents an opportunity for the three Feasibility Studies and development of future projects within this research area.

Work Stream Aims

Three Feasibility Studies have been conducted to optimise the use of microwave heating for three different sets of materials and production methods. The latest Feasibility Study “Microwaves for Automated Fibre Placement” finished in January 2021. The Project aimed to:

1. Develop microwave cavities suitable for in line heating of tows at 2.45 GHz and to couple to an existing 2 kW microwave system.
2. Assess the potential heating rates achievable on narrow static tows in the laboratory using a sealed system.
3. Investigate designs of microwave choke or screening to ensure that the microwave radiation is contained during processing with conductive fibres.
4. Conduct simple trials at UoB to assess the potential of the microwave system in enhancing the lay down rate of wide (100 mm) tape. This objective was modified due to restrictions caused by COVID-19, and a rig for narrow tape was built at WGU and tested instead.
5. Consider methods for increasing the power delivered in follow on projects.

Work Stream Team

Principal Investigators: Prof Richard Day, Glyndŵr; Prof Derek Irvine, Nottingham; Dr Mihalis Kazilas, Brunel.

Co-Investigators: Dr Betime Nuhiji, University of Sheffield; Dr Chris Dodds, Nottingham; Dr Andrew Parsons, Nottingham.

Researchers: Dr Nataliia Luhyna, Glyndŵr; Dr Asimina Manta, Sheffield.

PhDs: Dimitris Fakis, Brunel.

Industry Partners: MX Group, BAE Systems.

Work Stream Projects

- Feasibility Study: Microwaves for Automated Fibre Placement (AFP) (Sheffield/Wrexham)
- Feasibility Study: Microwave Heating through Embedded Coaxial Cables (Brunel)
- Feasibility Study: Monomer Transfer Moulding (Edinburgh/Nottingham/Sheffield)

Work Stream Progress

Results from the recently completed Microwaves for AFP Feasibility Study:

1. A truncated WR9a waveguide section was identified as the most promising cavity design based on modelled and laboratory trials, where power was limited to 200W. Heating rates in the trials showed that the target layup rate of 100kg/hr for carbon/epoxy could potentially be achieved with a power of 6 kW, similar to that used in diode laser heating systems.
2. Models of the selected microwave cavity were assessed using the electromagnetic simulation software to determine optimal containment. The modelling demonstrated the effectiveness of a Faraday cage solution and the limitations of a choke design for an AFP system.

Work Stream Outputs

- Discussions are underway to create a demonstration facility for microwave-based tape laying at the AMRC in Sheffield.
- A follow-on project, subject to funding, has the potential to provide a step change in layup rates, either on its own or combined with laser heating, and is being undertaken in collaboration with BAE Systems to understand susceptibility of BMI-based materials to high frequency microwaves.
- Continuation of work at 200 W/ 5.8 GHz (BMIs) and 2kW/ 2.45 GHz for higher power/laydown rate to test modelling further (and further outputs).
- There is potential for collaboration with Nottingham and Bristol since both are working on AFP projects and Nottingham have a project on direct heating.
- There is overlap with other work at Bristol and Southampton, now part of a Synergy project connecting the work on microwave processing of composites with expertise in sensor development looking at residual stress and temperature development during microwave cure.
Workstream 8
Thermoplastic Processing

Work Stream Overview
Thermoplastic composites offer potential for rapid consolidation, the possibility of multi-stage forming, jointing by welding and relative ease of recycling. They also offer reduced Takt times compared to thermosetting materials, making them attractive for high-volume applications. The UK is currently some way behind the research leaders in the Netherlands, who are Hub international partners, therefore the aim is to accelerate this activity.

In 2020, a Hub Thermoplastics Working Group was established with objectives to generate a new collaborative project and applications for external funding. An international mission with a focus on engaging with thermoplastic composites groups in the Netherlands and Germany will be conducted in 2021. With UK companies such as Victrex, the creators of PEEK polymer, and investments from the likes of GKN in the recently completed Filton Aerospace Technology Centre, the UK is well placed to be competitive in this area.

Research opportunities and challenges:
- High rate forming and thermal cycling.
- Assembly and bonding.
- Liquid moulding.
- Additive manufacturing.
- Sustainability of manufacturing and end of life waste.

Work Stream Aims
The overarching aim of this Work Stream is to support and expand the UK’s thermoplastic research activities and capabilities, promoting the benefits of thermoplastic composites and establishing new collaborations. Research into Thermoplastic Processing has been active since the Hub began, but the recent Hub Synergy Promotion event has enabled links to be created between a range of Hub investments. A number of Feasibility Studies have investigated the forming behaviour of fibre reinforced thermoplastic sheet materials, under the Composite Forming Technologies Work Stream 6. These include “Incremental sheet forming of thermoplastics”, “Monomer transfer moulding using microwaves”, and the “Layer by Layer” Feasibility Study.

Work Stream Team
Principal Investigators: Dr Andreas Endruweit, Nottingham; Dr Lee Harper, Nottingham; Dr Dipa Roy, Edinburgh; Prof Derek Irvine, Nottingham; Andrew Mills, Cranfield; Dr Mike Johnson, Nottingham; Prof Ton Peijs, Warwick; Dr Philip Harrison, Glasgow; Dr Edward Archer, Ulster; Prof Richard Day, Glyndwr.

Researchers: Dr Andrew Parsons, Nottingham; Dr Mikhail Matveev, Nottingham; Dr Adam Joesbury, Nottingham; Dr N Reynolds, Warwick; Dr A Bras, Cranfield; Dr L Cook, Cranfield; Dr J Hurley, Cranfield.

PhDs: George Street.


Work Stream Projects
- **Platform Fellowship**: Development of Rapid Processing Routes for Carbon Fibre/ Nylon6 (Nottingham)
- **Feasibility Study**: Thermoplastic Framework (Cranfield)
- **Feasibility Study**: In-situ Polymerisation of Fibre Metal Laminates (Edinburgh)
- **Feasibility Study**: Multi-step Thermoforming (Glasgow)
- **Feasibility Study**: Micro-integration of Polymeric Yarns (Ulster)
- **Feasibility Study**: VARIOTHERM (Warwick)
- **Feasibility Study**: Thermoplastic Double Diaphragm Forming (Edinburgh/Nottingham)

Leveraged Industry Support
- £5k

Leveraged Grants
- £181k

Leveraged Academic Support
- £145k

Hub Investment
- £526k

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Work Stream Progress

1. Ulster demonstrated the successful incorporation of through-thickness thermoplastic micro-yarns into fabrics to improve delamination resistance.

2. Cranfield provided an extensive assessment of proof of concept for automotive assembly without fasteners. Cranfield was one of the first partners to engage with the thermoplastics working group and is leading the Layer by Layer Core Project.

3. The recently completed Incremental Forming Feasibility Study at Nottingham has successfully demonstrated the use of bulk vacuum forming with precision robot forming to produce difficult geometries. The feasibility study demonstrated the concept of die-less forming using local heat and pressure.

4. The Double Diaphragm Forming project at Nottingham has progressed through its first milestones, successfully producing a nylon test panel between flexible tooling and the production of a small scale forming frame, which is currently being evaluated.

5. Glasgow demonstrated a new concept for multistage forming with novel induction heating and that work is continuing, with a recent paper published and a presentation at the British Plastics Federation Webinar.

6. The Variotherm project successfully demonstrated the use of thermoelectric heating and cooling to achieve a very rapid heat and cool cycle, cooling and then heating by a rate of 40 degrees centigrade per minute. A larger, double sided multicell system is in development which will demonstrate the ability to vary heating control across a tool face.

Work Stream Outputs

- A Researcher from the University of Edinburgh has visited University of Auckland, New Zealand to support their work in developing a next generation mixing system for in-situ polymerisation of Nylon.
6 Hub Network

The key to sustaining the Hub is in developing the national and international communities to establish important ongoing partnerships for future research programmes. One of the KPIs defined for the Hub was to leverage a further £20m of funding for new research projects, some of which were intended to extend beyond the life of the current programme. The current total leveraged grant income stands at £18.9m.

6.1 Academic Partners

The Hub continues to engage with the national academic network in composites manufacturing research through active collaboration with UK research groups. Engagement beyond the original Hub membership of Nottingham and Bristol and four Spokes (Manchester, Imperial, Southampton and Cranfield), has primarily been through Feasibility Study calls. Successful applicants are invited to become Spokes and we currently have 15 academic members participating in the Hub.

6.2 International Network

The Hub has developed a network of 23 leading institutions across 11 countries. This is important not only for sharing information and developments in composites manufacturing, but also in our training aspirations, as Hub postgraduate students will have the opportunity to spend a three months secondment at one of the linked institutions, accessing new expertise and facilities and developing their personal networks. We have successfully funded three Study Placements within our international partner network, helping students to foster independence.

- Aachen
- Dresden
- École Centrale
- EPFL
- Federal
- Fraunhofer ICT
- Institut Clement Adler
- Kaiserstauten
- Leuven
- Munich
- Porto
- Stuttgart
- Twente
- UNNC
- UNMC
- British Columbia
- Concordia
- Delaware
- McGill University
- Michigan State
- Purdue
- LEL-IPT
- Auckland
- Southern Queensland
6.3 Industry and Catapult Partners

Industrial support has grown strongly over the life of the Hub. Research projects are supported by a network of 37 industrial partners and four centres within the HVM Catapult, providing £3.2m of leveraged support in the form of studentships, supervision, materials and access to equipment.

Industry contributions totalling £3.2m to date; Largest contribution is for studentships, the National Composites Centre is the largest supporter to date - £1.4m.

The Hub is pleased to welcome PAC Group, Northern Ireland, as the latest company to join the consortium as an Industrial Partner.
Industrial Engagement

Support from our Industry Partners helps to ensure our research is industrially relevant and that outputs progress towards commercialisation. This occurs through two mechanisms; support from the Hub’s Advisory Board and hosting regular technical project review meetings with our Industry Partners. All project leads are appointed a mentor from the Advisory Board to help identify opportunities for exploitation. This insight helps to coordinate project-level technical meetings for each Work Stream, where specific partners are invited biannually to engage in comprehensive reviews of the projects and offer guidance.

We have endeavoured to create a balanced portfolio of partners, including material suppliers, Tier One Suppliers and OEMs, supporting aerospace, automotive and energy (including high pressure gas storage) sectors equally, and emerging industry sectors such as rail and construction, marine and renewables. We actively encourage our industrial partners to put forward ideas for academia to adopt, ensuring the research is industrially relevant and also ambitious and high-risk. Mechanisms for interaction with new and existing partners are outlined in the Hub’s Industrial Engagement Strategy. This provides a framework for engagement and supports our aim to create a collaborative environment where fundamental research can be developed with the support and involvement of industry.

The cumulative value of support from our Industrial Partners to date is presented below, in addition to other leveraged contributions including student support, supply of materials, use of facilities and software. The graph summarises the contributions made by the 18 industry partners, plus the contributions from the 4 HVM Catapult Centres who originally wrote letters of support for the Hub. By April 2021, we had leveraged 54% of our £6m 2021 target. We have successfully engaged with 17 of the original 22 proposal supporters, with the largest contribution (£1.4m) coming from the HVM Catapult National Composite Centre (NCC).

There are still a number of significant opportunities across the sector and two Business Development Managers have been actively working with other composite partners to realise these and leverage additional support. In addition to our Industry Partners, a further 45 companies (who did not provide letters of support in the Hub proposal) have actively supported or contributed to Core Projects and Feasibility Studies. By April 2021 we have achieved 58% of our £5m 2021 target for additional industry support.

Associated Leveraged Projects

Links with associated leveraged projects have enabled us to build a wider network and develop key skills. Over £18m has been leveraged for new grants, including an EPSRC Strategic Equipment Grant (EP/T006420/1) and a Programme Grant (EP/5017038/1), underpinned by a further £2.9m of industrial support. In addition, an exciting international collaboration is underway with universities in the USA, linked to the Institute for Advanced Composites Manufacturing Innovation (IACMI) and their partner companies.
7 Hub Training

We are currently training 36 PhD students, 46 EngDs and 26 postdoctoral researchers.

The Hub is committed to training 150 researchers over the lifetime of the Programme to help support the anticipated growth in the UK composites sector over the next ten years. The flexibility of our funding model offers an effective way for early-career researchers to develop and express their own ideas. Under our training remit, all Hub Spokes are eligible to study the taught EngD modules within the EPSRC Industrial Doctoral Centre in Composites Manufacturing (IDC), encouraging the Spoke members to continue to engage with the Hub beyond their initial project, widening their expertise and skills.

Our Staff Development Policy outlines a culture where postgraduate students, researchers and academics are supported throughout their affiliation with the Hub. The policy aims to provide Hub members with opportunities to support their career progression above and beyond those typically on offer by their home institution. The policy is built around a network of senior academics and members of the Advisory Board, who focus on giving support to junior members of the team. We actively encourage researchers to engage with the Management Group and Advisory Board, requiring them to present technical project summaries at the quarterly meetings to help build their independence.

Researchers Network

The Hub’s Researcher Network has been an effective delivery mechanism for developing skills and providing training. This network administers our Early-Career Feasibility Studies (£5k), which give younger Hub members the opportunity to express their independent ideas and experience the peer-review process. The researchers organise their own workshops to develop composite manufacturing skills. These offer practical experience to all students, who might otherwise only be involved in simulation-based projects. In January this year, a virtual event was organised for PhDs and researchers who shared their work and gave virtual lab tours. The event was well attended with 30 attendees.

Fellowships

Fellowships are an effective first step for researchers looking to establish an independent career. To date, we have funded 3 Platform Fellows and 2 Innovation Fellows across 4 Hub institutions. A Call for a third Innovation Fellowship will be launched this year with a view to the position starting in early 2022. A Transitional Fellow will also be recruited this year enabling an additional senior postdoctoral researcher to progress over a 3-year period to a permanent academic position in the Faculty of Engineering at Nottingham.

Industrial Doctoral Centre in Composites Manufacturing (IDC)

All activities of the IDC have been impacted to different extents by the circumstances of this year but despite the challenges to our industry support base, the IDC have been able to welcome five new Research Engineers since the summer of 2020, bringing the total number of EngD students being trained through the IDC to 46 students.

Industrial Doctoral Centre in Composites Manufacturing new recruits:

- Joe Soltan, NCC, Project Title: Manufacturing complex, large-scale composite components through “Modular Infusion”
- Patrick Sullivan, NCC, Project Title: Effective Use of Recycled Composites
- Will Darby, NCC, Project Title: Advanced Thermoplastic Composites Manufacturing - Understanding Defects and Failure
- Benjamin Chappell, iCOMAT, Project Title: CRaToS 3D (Carbon Rapid Tape Shear 3D)
- Humza Mahmood, Airborne, Project Title: Digitalisation of composite manufacturing

Recent Industrial Doctoral Centre EngD awards and destinations:

- Oliver Parks “The Future of Composites for Marine Applications” EngD project was supported by and conducted at Airborne UK. Post EngD work involved the development of a one-shot vertical infusion process for a 6m high hull structure https://youtu.be/_a6B8zpgbYO.
- Sarvesh Dhiman is employed at his EngD supporter company M Wright & Sons Ltd, as a Composite Development Engineer and awaiting his viva.
- Laxman Sivanathan “Developing process control in contact moulding and infusion processing for low cost, high volume manufacture of critical safety products” is sponsored by JoBird Ltd, Laxman is now head of R&D in this progressive SME.
- Petar Zivkovic “The Investigation of Pseudo-Woven Automated Fibre Placement Laminates” was sponsored by Rolls-Royce and is now employed at the National Composites Centre.
- Simon Wilkinson, Daniel Griffin and Matt Etchells are due to submit their EngD theses shortly and all have started working for the National Composites Centre.
- Jack Linley-Start has submitted his Rolls-Royce supported thesis on repair processes in composites.
8 Outreach Activities

Hub Webinars

The Hub hosted its first virtual webinar on 4th November 2020. The session focused on the latest hub research and development projects in Rapid Composite Processing Technologies:

- Executive Summary: A Mid-Term Review, Prof Nick Warrior, Hub Director and Professor at the University of Nottingham
- Optimised Manufacturing of Structural Composites via Thermoelectric Vario-thermal Tooling (VarioTherm), Dr Neil Reynolds, Hub Researcher and Senior Research Fellow at Warwick Manufacturing Group
- Design simulation tools and process improvements for NCF preforming, Dr Lee Harper, Hub Manager and Associate Professor at the University of Nottingham
- Layer by Layer Curing, Dr James Kratz, Hub Investigator and Lecturer at the University of Bristol

The second virtual event took place on 17th February 2021. The session focused on Work Stream 1, Automated Fibre Deposition Technologies:

- Hub Introduction, Prof Nick Warrior, Hub Director and Professor at the University of Nottingham
- Technologies Framework for Automated Dry Fibre Placement, Dr Thomas Turner, Hub Deputy Director, Chair of the Strategic Development Committee and Associate Professor at the University of Nottingham
- Fibre Steered Forming Technology, Dr Eric Kim, Associate Professor in Composites Design and Manufacture at the University of Bristol
- Automated Production of Powder Epoxy Carbon Fibre Tape for Automated Fibre Placement, Dr Colin Robert, Hub Innovation Fellow and Chancellor’s Fellow at the University of Edinburgh
- COMPrinting: Novel 3D Printing of curved continuous carbon fibre reinforced powder-based epoxy composites, Dr Dongmin Yang, Senior Lecturer at the University of Edinburgh

Each webinar was well attended with over 100 attendees and there were opportunities for further discussions in a Q&A session at the end of each webinar. Recordings of the webinars are available on our website.

Project Webinar

The Hub recently supported a webinar for the Core Project Active RTM. The webinar took place in March 2021 and welcomed guest speaker Francisco Chinesta, Professor of Computational physics at ENSAM Institute of Technology (Paris). Francisco presented his work on data-driven modelling in the seminar “Empowering Hybrid Twins from Physics-Informed Artificial Intelligence”. The webinar reached an international audience of over 50 people and positive feedback was received. The recording of the session has been made available on CIMComp’s YouTube channel and website.

Researchers Network

In February 2021 the Researcher Network participated in the Festival of Science and Curiosity (FOSAC). The Festival is an annual event in Nottingham which encourages students and researchers to engage with the local community. The Researcher Network contributed to the festival by producing a video targeted at school students with an Engineering perspective. It featured Hub PhD student Matthew Thompson showing how a simple composite material can be made at home with household ingredients such as water, a refrigerator and spaghetti. The video was a great success reaching an audience of over 300 people, the Researcher Network also submitted a magazine entry for the online audience.

STEM activities allow the hub the opportunity to influence the younger generation with the academic discipline of engineering as well as initiating involvement with the wider community.

Hub PhD student; Matthew Thompson performing an experiment for the FOSAC to show how a simple composite material can be made at home. Click here to view the video.
SAMPE Seminar and Media competition – March 2021

In March 2021 the Hub supported the Annual SAMPE UK seminar “Composites – Progressing from the Pandemic” which was held online. The event welcomed a diverse range of topics, processes and speakers from academia and Industry, one of the keynotes included Hub Spoke representative; Dr Dipa Roy, Senior Lecturer at the University of Edinburgh. The event was held over two days and featured a ‘Young Engineer and Students’ Media competition based on the ‘Resilience of the composite materials community during the COVID-19 pandemic’.

Students were invited to produce their composites research or services through a creative and informative video for the wider community, based on the following criteria:

- How the research has been affected by COVID
- Development of new products to diversify business
- New opportunities or services they have offered during the pandemic to support the local community

The competition had six team entries from across academia and industry. The videos were reviewed by a panel of experts. All video submissions were of high quality making it difficult for the judges to select one winning team, consequently, two teams were chosen, each were awarded cash prizes and free SAMPE UK and Ireland annual membership.

The winning teams were ‘FAC Technology’ from industry, their winning video can be viewed here.

The second winning team were the ‘Pandemic Preforms’ from the University of Nottingham, their winning video can be viewed here.

University of Nottingham, Future Composites Manufacturing Research Hub students from left to right; James Mortimer, Christos Kora, Preetum Mistry and Matthew Thompson show their resilience to the global pandemic.
Publications support the delivery of the Hub programme and vision, in both high impact factor journals and at international conferences and workshops. Hub investigators have continued to publish research from previous projects initiated by the EPSRC Centre (EP/I033513/1), bringing the total journal paper output for CIMComp to 57 since January 2017.

2021


The Management Group (MG) is chaired by Prof Nick Warrior, the Hub Director, with overall responsibility for developing and delivering the Hub’s strategy. He is supported by two Deputy Directors, Prof Ole Thomsen and Dr Tom Turner, and the Chairs of the KEC, SDC and PDC committees.

The Advisory Board (AB) is chaired by Prof Mike Hinton and takes a high level, strategic view of the needs of all the Hub stakeholders, offering guidance on the delivery and impact of research, ensuring the needs of the UK composites community are addressed. The AB membership is a mix of independent academic and industrial members from the UK and abroad. Members represent a broad section of the UK supply chain, including end users from automotive and aerospace, material suppliers and HVM Catapult Centres. This year the AB aims to increase its membership to 12 and include membership from the infrastructure, marine and renewables sectors.

The Strategic Development Committee (SDC), chaired by Dr Tom Turner, engages with funders, industry and government bodies to develop knowledge and strategies to evolve the Hub’s priority areas, using the two Hub Business Development Managers to secure additional R&D funding, map capability and influence research priorities.

The Knowledge Exchange Committee (KEC), chaired by Prof Ole Thomsen, is the formal link between the Hub and the HVM Catapult stakeholders and contains representatives from four Centres. The KEC is responsible for identifying and strengthening collaboration opportunities between Hub Spokes, administering funding for synergy promotion and technology pull-through (NCC TPT fund), and managing IP emerging from Hub projects.

The Postgraduate Development Committee (PDC), chaired by Dr Mike Johnson, oversees the training and progression of research students, at doctoral level via the IDC and at postdoctoral level via the Researcher Network (RN, chaired by Dr Mikhail Matveev). The RN is led by postdoctoral researchers to promote collaboration and enhance the cohort experience, engaging in outreach activities as STEM ambassadors. The PDC also manages an international student exchange scheme through the International Researcher Network, establishing partnerships in research programmes across 23 leading institutions in 12 countries.

The Hub is represented within the national Composites Leadership Forum (CLF). The Hub Director sits on the main board and members of the MG and AB are active members of the CLF sub-committees supporting Working Groups in Technology, Sustainability, Automotive, Aerospace, Workforce Development and Regulations. This strong interaction enables a continued alignment of the Hub activities with the UK Composites Strategy, ensuring that the Hub research priorities address evolving long-term sector needs. The CLF has facilitated dissemination of the CiRCL road mapping activity to an industrial audience and resulted in the Hub’s involvement in an Innovate UK International Mission to the USA to develop collaborative research programmes. Prof Pickering’s involvement in the CLF Sustainability Working Group also led the Hub’s contribution to the UK Vision and Roadmap for Sustainable Composites.
11 The Hub Team

Management Group

Professor Nick Warrior  
Hub Director  
University of Nottingham

Professor Ole Thomsen  
Deputy Hub Director  
University of Bristol

Dr Thomas Turner  
Deputy Hub Director  
University of Nottingham

Dr Lee Harper  
Hub Manager  
University of Nottingham

Dr Mike Johnson  
Chair of the Postgraduate Development Committee  
University of Nottingham

Andrew Mills  
Deputy Chair of the Postgraduate Development Committee  
Cranfield University

Dr Mikhail Matveev  
Chair of the Researcher Network  
University of Nottingham

Professor Ivana Partridge  
Director of Industrial Doctorate training Centre  
University of Bristol

Professor Janice Dulieu-Barton  
Deputy Director of Industrial Doctorate Training Centre  
University of Bristol

Dr Dipa Roy  
Hub Spoke Representative  
University of Edinburgh

Alex Hammond  
Hub Deputy Manager  
University of Nottingham

Dr Edward Archer  
Ulster University

Professor Janice Barton  
University of Bristol

Professor Richard Butler  
University of Bath

Professor Richard Day  
Wrexham Glyndwr University

Professor Chris Dodds  
University of Nottingham

Dr Andreas Endruweit  
University of Nottingham

Professor Emile Greenhalgh  
University of Nottingham

Professor Stephen Hallett  
University of Bristol

Dr Lee Harper  
University of Nottingham

Dr Philip Harrison  
University of Glasgow

Dr Robert Hughes  
University of Bristol

Dr Darren Hughes  
University of Warwick

Dr Marco Iglesias  
University of Nottingham

Professor Derek Irvine  
University of Nottingham

Dr Dmitry Ivanov  
University of Bristol

Dr Mike Johnson  
University of Nottingham

Dr Mihalis Kazilas  
Brunel University

Dr Eric Kim  
University of Bristol

Professor Vasileios Koutso  
University of Edinburgh

Dr James Kratz  
University of Bristol

Professor Andrew Long  
University of Nottingham

Edward M’Carthy  
University of Edinburgh

Dr Euan M’Gookin  
University of Glasgow

Professor Alistair M’Ilhagger  
Ulster University

Dr Andrew Mills  
Cranfield University

Dr Daniel Mulvihill  
University of Glasgow

Professor Conchur O’Bragaigh  
University of Edinburgh

Professor Ton Pejs  
University of Warwick

Professor Steve Pickering  
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Craig Carr  
Industrial Representative  
GKN Aerospace

Dr Enrique Garcia  
Industrial Representative  
National Composites Centre

Brett Hemingway  
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BAE Systems

Dr Warren Hepples  
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Professor Mike Hinton  
Advisory Board Chair CTO, HMV Catapult

Tom James  
Industrial Representative  
Hexcel Reinforcements

Dame Professor Jane Jiang  
Scientific Expert  
University of Huddersfield

Professor Ian Kinloch  
Scientific Expert  
University of Manchester

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Dr Drongmin Yang  
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Dr Daniel Richards  
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Professor Paul Robinson  
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Dr Michael Sutcliffe  
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Professor Ole Thomsen  
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Professor Alistair M’Ilhagger  
Ulster University

Dr Andrew Mills  
Cranfield University

Dr Daniel Mulvihill  
University of Glasgow

Professor Conchur O’Bragaigh  
University of Edinburgh

Professor Ton Pejs  
University of Warwick

Professor Steve Pickering  
University of Nottingham

Professor Prasad Potluri  
University of Manchester
12 Students

Researchers

Dr Debabrata Adhikari  
University of Nottingham

Dr Ankur Bajpai  
University of Edinburgh

Dr Jonathan Belnoue  
University of Nottingham

Dr Kaan Bilge  
Imperial College, London

Dr Aurele Bras  
Cranfield University

Dr Dan Bull  
University of Southampton

Dr Shuai Chen  
University of Nottingham

Dr Andrea Codolini  
University of Cambridge

Dr Lawrence Cook  
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Dr Thomas Dooher  
Ulster University

Dr Wenbo Duan  
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Dr Alex Ilchev  
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Haoqi Zhang  
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### EngD Students

<table>
<thead>
<tr>
<th>Student Name</th>
<th>University and College</th>
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<tbody>
<tr>
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<td>University of Bristol</td>
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<tr>
<td>Ashley Barnes</td>
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<tr>
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<td>Ben Chappell</td>
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<td>Sarvesh Dhiman</td>
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