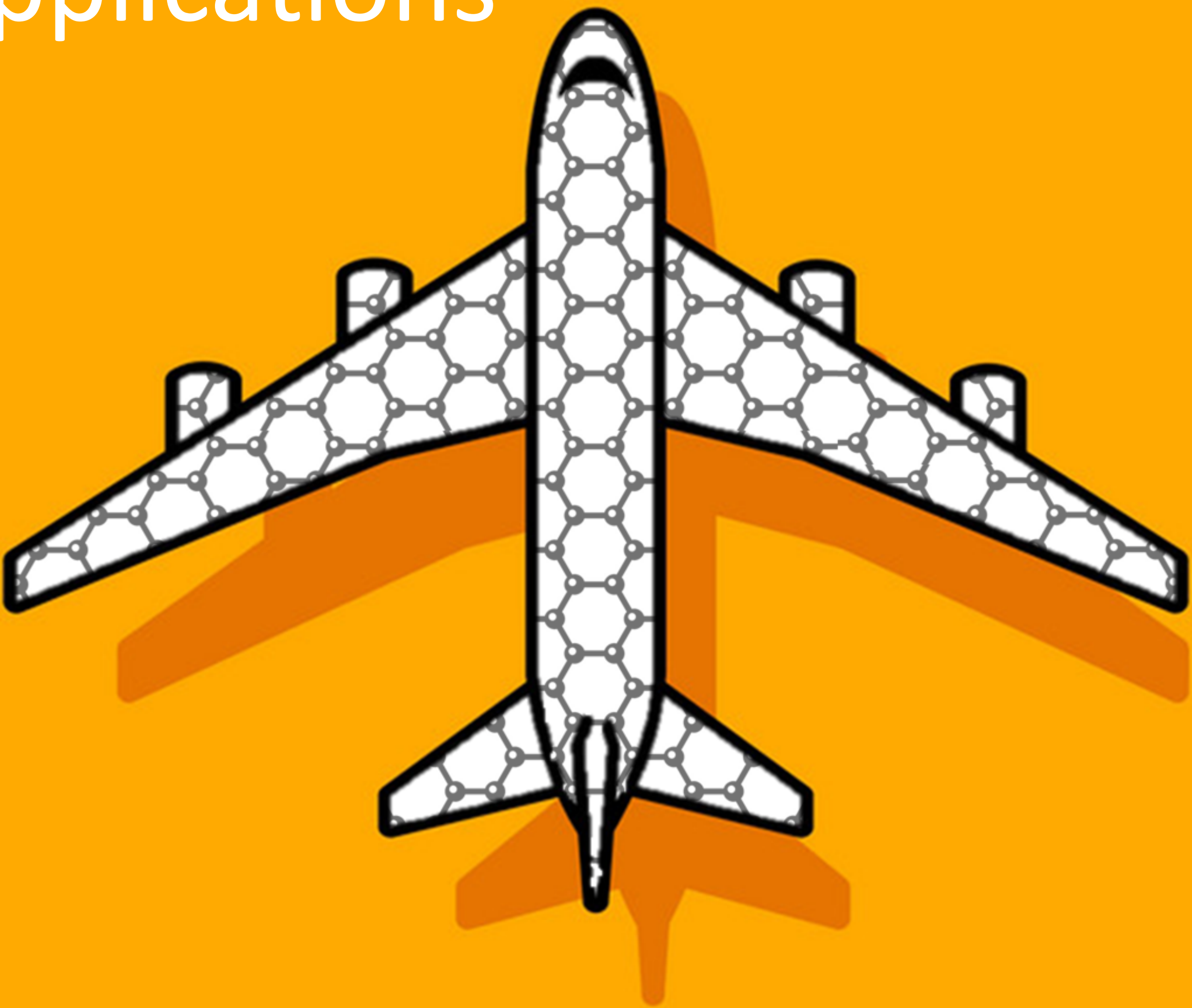
Versarien PLC

Trajectory of graphene-based **aerospace** applications



Executive Summary

This report has been written to stimulate discussion and comment within the Aerospace Technology Institute (ATI) about the emergence of graphene in aerospace applications. The past two years have witnessed the slow but steady advancement of graphene-based applications within the aerospace sector with key examples of how graphene and related materials can bring added benefits to the design and construction of next-generation aircraft structures and components. This white paper highlights many instances where graphene-based materials have moved from lab towards commercialization, and global projects that have been funded to help realize this commercialisation at a faster pace.

Authors: S. A. Hodge, D. T. L. Galhena, J. A. Benson, S. Li, D. J. Smith, M. Kemp

2nd June 2020

Introduction

First isolated in 2004 by two researchers at the University of Manchester, pure graphene is hexagonal lattice of carbon atoms In a layer of a single atom thickness - referred to as a two dimensional (2d) material. Single-layer graphene has some very impressive properties over and above it's 'parent' graphite, in particular, exceptional mechanical, thermal, electrical and optical properties. Bi-layer and few-layer graphene has properties that measure in the same ranges as single-layer graphene, but as the number of layers increase, these properties tend to reduce significantly. Today, we have a whole family of graphene and related 2d materials (GRMs) at our disposal, with wide ranging properties giving the ability to replace conventional materials, or to develop completely novel technologies.

In March 2018, the ATI published an INSIGHT report [1], "GRAPHENE EXPLOITATION Material applications in aerospace", disseminating the findings from an aerospace sector consultation enabled through a partnership with the National Graphene Institute (NGI) at the University of Manchester to identify applications of two dimensional materials, specifically graphene, that can be incorporated into structures, systems and propulsion components. As a result, the ATI concluded to seek to identify suitable opportunities for 2d materials such as graphene that generate technological impact and economic benefit for the sector, through helping the formation of suitable technology projects that address key areas:

1.Materials Research: Screen, optimise and functionalise candidate graphene materials where potential applications for 2d materials within aerospace exist.

2. Component and Manufacturing Research: Achieve TRL4 for structural, propulsion and systems applications. Ensure a robust study is completed to underpin the basic scientific discoveries within structures, propulsion and systems themes.

3. Systems & Components Demonstration: Invest in large scale industrial demonstrators that enable TRL6 to be achieved in target applications within secure, exploit and position timeframes.

4. Industrialisation: Ensure that the UK capability is realised to manufacture graphene materials at high volume, in suitable material forms, and at a competitive price, that addresses the sector requirements.

5. High Value Design: Develop 2d material knowledge that can be incorporated into future aircraft design to improve the performance, efficiency and cost of multiple platforms. Consideration will be given to the realisation of complex, computational modelling that minimises physical testing, reducing the overall development timeframe.

6. Business Cases: Detail and communicate example business cases that catalyse the aerospace sector to consider the rapid development of 2d material solutions.

Since March 2018, several graphene-based applications have emerged and are now moving from lab to commercialisation, enable through access to both UK and European funding routes.

To date, ATI funded graphene projects total ~£1.4 million [2]:

- ✈ CTES - Lower cost, Higher Performance Composite Tooling—£150k
- ✈ Nano-Enhanced Aerospace Interiors (NEAT)—£150k
- ✈ Graphene Composites Evaluated in Lightning Strike (GraCELS) 1 and 2—£150k, £150k
- ✈ Electro-Magnetic Flux Imaging Scanner (EMFIS)—£380k
- ✈ Graphene Enhanced Adhesive Technology through Functionalisation (GrEAT Fun) 1 and 2—£150k, £150k
- ✈ HP1 Impact Classification System (HP1ICS) —£150k
- ✈ Inkjet Printed Graphene Composite Materials—£150k

Across Europe, the €1 bn EC funded Graphene Flagship (GF) project has also viewed aerospace as a key sector for GRM applications. The "Plane of the Future" concept (page 3) highlights some of the key areas currently under development within the GF. 2 Spearhead projects were launched in April 2020, Graphene-based Thermoelectric Ice Protection System (GICE) [3] - **€4.6 million** with key industrial partners Airbus and Sonaca, and Next-Generation Aerospace Filtration (AEROGrAFT) [4] - **€4.8 million**, including Lufthansa Technik as industrial partner.

In this report, selected case studies of graphene-based application development in the aerospace sector have been highlighted:

- ✈ Lightweighting
- ✈ Additive Manufacturing
- ✈ Fire retardancy
- ✈ Airport infrastructure
- ✈ Lightning Strike Protection (LSP)
- ✈ Ice Protection Systems and Sensors
- ✈ Electrification

[1] ATI Publications. GRAPHENE EXPLOITATION Material applications. viewed 01 June 2020, <https://www.ati.org.uk/publications-tools/publications/> (2018)
[2] ATI project portfolio, Viewed 01 June 2020, <https://my.sharpcloud.com/html/#/story/9517f066-5610-4308-bf0b-4be1eace4bd4/view/099e65a9-3608-4eba-8660-cd2fab3645c0>
[3] Graphene Flagship, Viewed 01 June 2020, <https://graphene-flagship.eu/project/spearhead/Pages/GICE.aspx>
[4] Graphene Flagship, Viewed 01 June 2020, <https://graphene-flagship.eu/project/spearhead/Pages/AEROGrAFT.aspx>

Trajectory of graphene-based **aerospace** applications

Plane of the Future

Courtesy of the Graphene Flagship

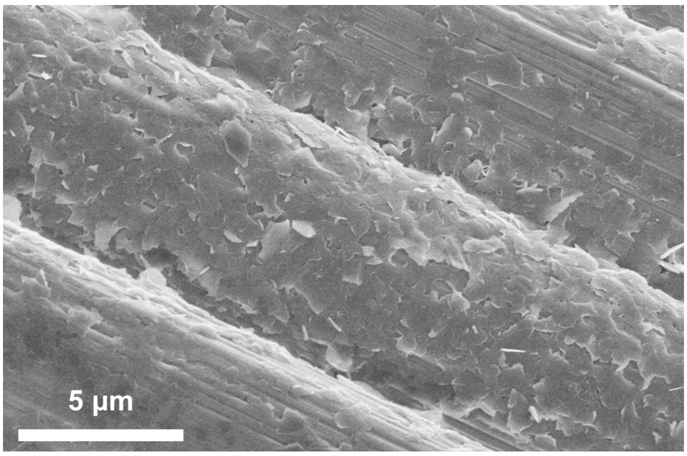
Graphene-based Composites for Lightweighting

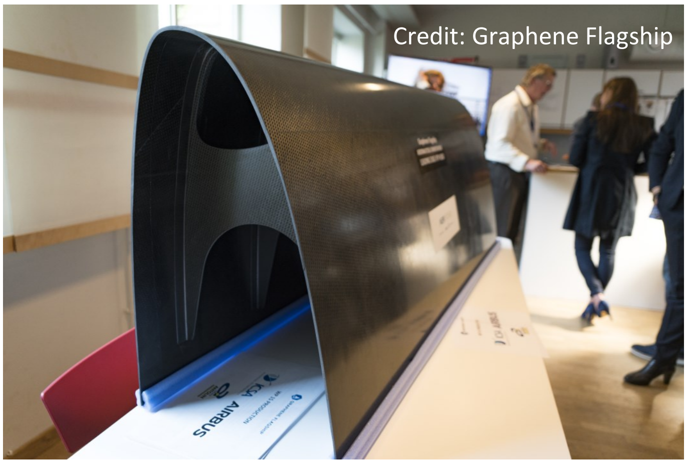
The philosophy of lightweighting has been extensively developed and applied in transportation industries, especially in aerospace applications. Statistically, a reduction of 450g in weight to every plane in a fleet can save 53,000 litres of fuel per year, adding up to tens of thousands of dollars [1]. Whether in response to address the challenge of aviation emission or to achieve flight performance upgrade and cost reduction, lightweight design for both ecological and commercial levels is critical.

A typical approach to implement lightweight design is to manufacture aircraft with less materials or by utilizing materials with lower density while maintaining or enhancing the structural performance. Although metal materials such as aluminum alloys still account for a large proportion of the airframe weight, carbon fibre reinforced polymer (CFRP) composites have been extensively developed to compete and substitute the metal materials in various aerospace applications due to the outstanding specific strength and stiffness and their intrinsic higher resistance to corrosion, moisture and fatigue than metals.

The emergence of GRMs opens a new door to further enhance multifunctional performance by modification at the nanoscale. With a minimal incorporation of nanoparticles, impressive improvement can be achieved in many aerospace applications without perceptible increase of material density. The development of nanocomposites offers the opportunity for eliminating redundancy and reducing weight, which provides significant potential in promoting the properties of aerospace components, especially through lightweighting.

Graphene has received significant attention from academia and industry due to the potential promising prospect that resides in composite applications. The ultra-high aspect ratio, high stiffness and possibility for surface modification makes graphene a useful tool in materials construction and weight





reduction. Specifically, the presence of a small amount of graphene can significantly reinforce both thermoplastic and thermosetting systems through stress transfer at the filler-matrix interfaces, which allows the components to bear more load [2-3]. Over the past decade, graphene has been hybridised into CFRP composites and shown to facilitate the interfacial bonding between the fibre and resin system and result in further mechanical reinforcement.

Representative mechanical parameters extracted from stress-strain curves such as strength, stiffness and toughness can be greatly enhanced which offer the opportunity to fabricate thinner or lighter polymeric components such as interior parts, panels, gears and bearings etc. Structural components which offer core support to the airframe are expected to further eliminate weight and contribute to the energy conservation and cost reduction.

As an example, GF partners Aernnova, Grupo Antolin-Ingenieria and Airbus produced a leading edge for an Airbus A350 horizontal tail plane using graphene-based CFRP composite (photo above) [4]. At a component level the team found that the resin showed increased mechanical and thermal properties upon graphene addition, including enhanced fracture performance. “By increasing the resin properties with graphene it will be possible to make the tail edge thinner, decreasing its weight while maintaining its safety. This will give a significant saving in fuel and therefore costs and emissions over the aircraft lifetime.”

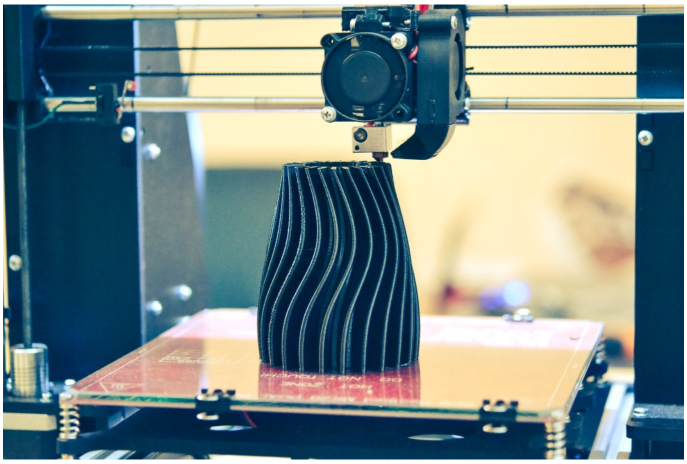
[5]
LIGHTWEIGHTING
1% of mass reduction on a medium range, narrow-body aircraft could save more than $1 BILLION per year on fuel

[1] Traveller, Viewed 01 June 2020, <https://www.traveller.com.au/airline-weight-reduction-to-save-fuel-the-crazy-ways-airlines-save-weight-on-planes-h14vlh>
[2] R.J. Young et al., Composites Science and Technology, 72, 1459-1476, (2012)
[3] D.G. Papageorgiou et al., Progress in Materials Science, 90, 75–127, (2017)
[4] Graphene Flagship, Viewed 01 June 2020, <https://graphene-flagship.eu/news/Pages/The-Leading-Edge-Graphene-Flagship-leads-the-way-in-graphene-composites-for-aerospace-applications.aspx >
[5] Ansys blog, Viewed 01 June 2020, <https://www.ansys.com/blog/3-tips-lightweighting-aircraft >

Graphene-based Composites for Additive Manufacturing

According to the ATI's 2018 INSIGHT report [1] into "COMPOSITE MATERIAL APPLICATIONS IN AEROSPACE", additive manufacturing (AM) and graphene were identified by industry as potentially disruptive technologies to the composites industry. AM is currently utilised by the aerospace industry to produce highly intricate 3D objects layer-by-layer for many structural and repair applications. The multifunctional properties of graphene opens up new opportunities for many practical aerospace applications when combined with advanced thermoplastics.

Polyetheretherketone (PEEK) is a semi-crystalline advanced material from the polyaryletherketone (PAEK) family, which exhibits excellent mechanical and chemical resistance properties even at high temperatures [2-4]. Further improving PEEK properties through the use of graphene's multifunctionality can be used to improve the wear resistance, mechanical, thermal and electrical properties, which are beneficial for the aerospace industry. An Innovate UK funded project developing multifunctional PAEK nanocomposites for AM (F4 PAEK), led by Qioptiq Ltd., has been set up to develop novel nano-composite materials offering multifunctional capabilities including lightweighting, thermal, and electro-magnetic properties. The development opportunity focuses on the defence and aerospace sectors aided by Thales Ltd. and Airbus Ltd. The developments, however, have potential implications and benefits that are far reaching, bringing together the advantages of improved material properties with the design freedom and lightweight potential of AM [5]. The F4 PAEK project is being driven forward by a strategic partnership with a range of expertise and supply chain partners from organisations including graphene suppliers 2-DTech Ltd. (part of Versarien



plc.), GRM functionalisation specialists Haydale Ltd. and PAEK suppliers Victrex Manufacturing Ltd, who currently provide PAEK based products for over 20,000 aircraft [6]. Both fused deposition modelling (FDM) and selective laser sintering (SLS), a common AM technique, primarily used for rapid prototyping and direct digital manufacture of non-critical components within the aviation industry [2], are being carried out by the University of Exeter. The venture is also assessing the application of other 2d materials such as hexagonal boron nitride (hBN) within PAEK composites for similar applications.

It has been forecast that 41,000 new and replacement planes will be required by 2035. To address this demand, AM concepts have advanced greatly to fabricate designs faster, cheaper, and smaller with increased accuracy [7]. Printing GRM-based composites, with improved polymer specifications can open up new opportunities for design engineering of aerospace components - improved efficiency due to thermal properties of GRMs results in faster prototype development and manufacture, and the enhanced mechanical properties may allow AM plastics to be used for more non-critical and, potentially, critical components.

[1] ATI Publications. COMPOSITE MATERIAL APPLICATIONS IN AEROSPACE, Viewed 01 June 2020, <https://www.ati.org.uk/publications-tools/publications/> (2018)
[2] Joel Najmon, Sajjad Raeisi, Andres Tovar, Review of additive manufacturing technologies and applications in the aerospace industry, (2019)
[3] Binling Chen, Silvia Berretta, Ken Evans, Kaylie Smith, Oana Ghita, Applied Surface Science, 428, 1018-1028, (2018)
[4] J. A. Puertolas, Miguel Castro, J. A. Morris, Ricardo Rios, A. Anson-Casaos., Carbon, 141, 107-122, (2018)
[5] Haichang Guo, Ruicong Lv, Shulin Bai, Nano Materials Science, 1, 2, 101-115, (2019)
[6] UK Research and Innovation, Viewed 01 June 2020, <https://gtr.ukri.org/projects?ref=104051>
[7] Aerospace Manufacturing, Viewed 01 June 2020, <https://www.aero-mag.com/peek-at-40/>

Graphene-based Composites for Fire Retardancy

Due to the forecast growth of aviation within the next decade, safety concerns are increasing over the flammability of plastics used for aerospace components. Plastics are a growing trend within aviation due to their lightweight, ease of design and low installation and production costs. Therefore, the plastic flame retardant market is expected to rise to meet this demand and increase safety of the occupants within aerospace.

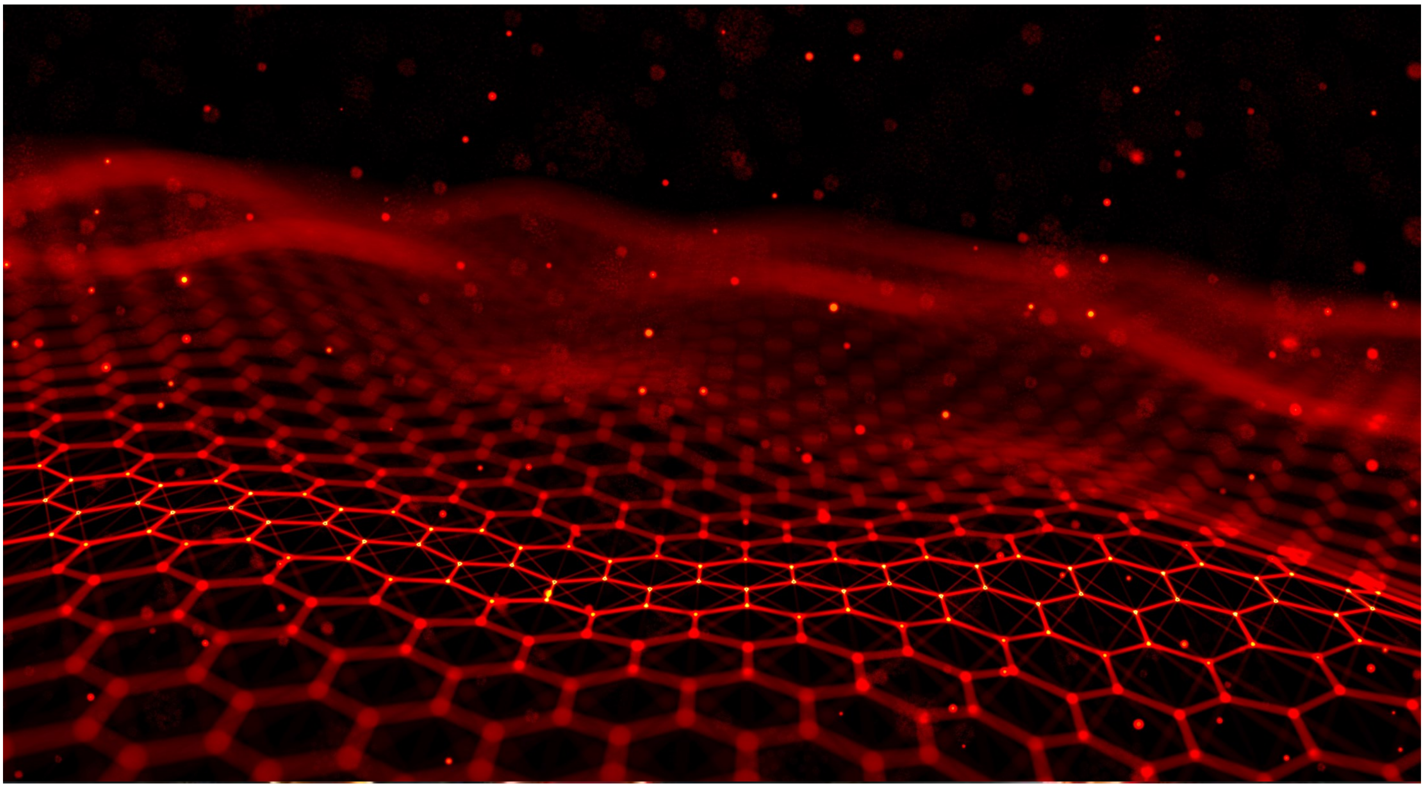
High performance fibre, such as carbon fibre and glass fibre can reinforce various thermoplastic and thermosetting matrix polymers and are some of the most extensively used materials in the aviation industry due to their intrinsic low density, excellent mechanical performance and chemical resistance. These reinforced plastics have a vast range of applications such as wings, decks, cabins, kitchens, propulsions systems, bearings, cooling systems, and other critical and non-critical components [1]. However, many polymer resins used in FRPs are organic and can be flammable; releasing smoke and toxic gases upon combustion [2, 3]. Flame retardant additives, such as halogen, phosphorus, metal oxide and hydroxide based materials are commonly used to reduce the flammability of these plastics. Many, however, are being phased out due to the environmental concerns and toxic gases produced during combustion, as well as the degradation in mechanical properties due to high filler content.

Versarien are currently researching the use of graphene within thermoplastics and FRP composites with the aim of developing materials which can be widely used for multiple applications including aerospace cabin interior components, with improved fire resistance and lower toxic fume release properties compared to the currently used composites. Specific aircraft interior parts using Versarien's graphene materials have gained the necessary certification from a USA-based, Federal Aviation Administration (FAA) certified fire testing laboratory.

Cabin interior components could take advantage of graphene's thermal properties as it has been known to effectively change the pyrolysis route as well as the heat absorption and thermal conductivity when infused into a polymer matrix [4]. The combustion process can be disrupted through many key aspects such as limiting the heat and fuel sources from ignition [5]. This is achieved through a synergistic effect caused by graphene's decomposition creating an effective char layer upon the surface, creating a dense physical barrier when burned [6]. The charred barrier creates a 'tortuous pathway' effectively blocking heat propagating through the polymer, preventing further burning. Additionally, the char barrier can also prevent and delay the escape of toxic gas byproducts from polymers created during decomposition.

Melt flow behaviour of thermoplastics can also be affected by the addition of graphene. When added, graphene can affect the rheometry of a molten polymer, reducing the dripping effect and potential spread of fire [4].

As graphene can provide a safer and thermally robust polymer composite, a range of promising applications for cabin components could be explored within the aerospace industry.



[1] Fire retardancy of polymers, Viewed on 01 June 2020, <https://polymer-fire.com/2016/10/11/aerospace-plastic-flame-retardant-market-analysis/>
[2] Xin Wang, Lei Song, Wiwat Pornwannachai, Yuan Hu, Baljinder Kandola, Composites Part A. 53, 88-96, (2013)
[3] Bin Sang, Zhiwei Li, Xiao-hong Li, Lai-gui Yu, Zhi-jun Zhang., Journal of Material Science, 51, 18, (2016)
[4] Lu S, Hamerton I., Prog Polym Sci, 27, 1661-1712, (2002)
[5] Higginbotham AL, Lomeda JR, Morgan AB, Tour JM., ACS appl mater interfaces, 1, 10, 2256-2261, (2009)
[6] Dongxian Zhuo, Rui Wang, Lixin Wu, Yanhua Guo, Lin Ma, Zixiang Weng, and Jinyu Qi, Journal of Nanomaterials, 820901, (2013)

Graphene-based Composites for Airport Infrastructure

Airports and airport runways need to operate at optimal capacity to ensure revenue generating access for airlines at all times. A delay of one minute to a take-off time can run into thousands of pounds of extra costs for the airline and the airport.

However, safety of the airport and its infrastructure is of critical importance. Any changes to materials, construction methods or high-performance asphalt pavement systems, must exceed the current standards and achieve the minimum construction timespan.

The drive for "a Circular Economy" and eco-sustainability, has accelerated the development of technological solutions such as graphene enhanced asphalt, that allow reuse of materials and extend the pavements' service life.

Research has shown improvement in mechanical properties for graphene nanoplatelet (GNP) enhanced asphalt binders with 3-6% GNPs by weight of the binder leading to as much as 130% increase in flexural strength.

"With a relatively low material cost, the GNP-reinforced asphalt binders and mixtures have a potential for large-scale applications in the pavement industry, which includes both new pavement construction and pavement rehabilitation."

Research has shown faster installation of Graphene enhanced asphalt since "the addition of GNPs can significantly reduce the number of gyrations needed to compact the mixtures to a target air void content. This reduction ranges from 15% to 40% for different mix designs. Furthermore, the GNPs also allow successful compaction at a lower temperature" which could significantly reduce the energy input during the compaction process which could make the construction process faster, safer and cheaper than current methods.

A graphene enhanced asphalt that has been trialled for road applications since 2017 is now to be tested at Rome's Fiumicino airport [2]. Fiumicino, is Italy's largest airport in terms of passenger traffic, with over 40 million passengers traveling through it. The runways are used by heavy class aircraft such as Boeing 777s and Airbus A380s. The testing commenced in January 2020 for one year trial.

The Graphene enhanced asphalt trialled contains a particular plastic that would not normally be recycled but rather sent to waste-to-energy plants. The graphene enhanced asphalt can be 100 percent recycled which will reduce the industries need for first-use bitumen.

The expected whole life cost of the graphene enhanced asphalt is lower than traditional asphalt due to the greater life span and lower maintenance where airports will realize the cost benefits in the medium to long term.

The new technology was developed by Iterchimica, a company which makes products to enhance asphalt, graphene-maker Directa Plus, A2A's recycling and waste management unit G.Eco and the University of Bicocca in Milan.

[1] Jialiang Le, Mihai Marasteanu, Mugurel Turos, Graphene Nanoplatelet (GNP) Reinforced Asphalt Mixtures: A Novel Multifunctional Pavement Material - University of Minnesota, (2016)
[2] Graphene Info article, Viewed 01 June 2020, <https://www.graphene-info.com/directa-plus-supply-iterchimica-graphene-materials-asphalt-applications>

Graphene-based Lighting Strike Protection

Lightning strike is an extreme high-energy impulse lasting 1-10µsec which induces an electrical pulse of 1 billion volts and current of 10k-200kA, and a thermal spike of up to 30,000°K. Due to the short time duration, the overall power is minimal, and overall temperature rise of up to 50°C. However, the strike can cause extreme mechanical damage and even loss of an aircraft due to structural damage to flight surfaces.

With the trend to replace metallic structures with CFRP composites, the significant drawback with CFRP composites arises from their poor through-thickness conductivity combined with the electrically insulating thermoset resin. As a result, CFRP components are prone to damage from the lightning strike, and thus require alternative lightning strike protection (LSP) strategies. Current protection systems include the use of woven and non-woven metal meshes of aluminium or copper attached to the outer surface of the composite parts or systems that include metal coated carbon fibres; these systems add additional weight and costs due to regular repair due to galvanic or environmental corrosion of the metal [1] .

Carbon nanomaterials such as graphene have attracted great research interest for thermal management applications due to high electrical conductivity (>10^8 S/m) and higher intrinsic thermal conductivity than traditional filler materials. The in-plane thermal conductivities of free-standing and supported graphene film are 5000, and 600 W/mK, respectively. However, the improvement of electrical and thermal conductivity of composites is well below the value expected from the rule of mixtures, which can be explained by the large contact resistances between the nanofiller and polymer matrix caused by scattering events, and their poor dispersion in composites. Further improvements and combinations of nanofillers, and improvements to dispersion strategies will enable LSP performance to be improved.

Aside from graphene dispersion in thermoset resin, graphene can be added to surface coatings (to the base layer or primer) to have multi-functionalities such as LSP, de-icing, electromagnetic interference (EMI) shielding, ultraviolet (UV) light and corrosion protection.

Haydale, an advanced materials group, has launched a range of functionalised graphene and multiwalled carbon nanotube (MWCNT)-enhanced prepreg materials for LSP, with improved electrical conductivity to be used as structural components as well as for enclosures for electronic avionics systems. The material has been developed in collaboration with Airbus UK, BAE Systems, GE Aviation and Element Materials Technology Warwick, within the NATEP-supported GraCELs 2 project. This technology has additional applications with regards to wind turbine blades particularly in offshore locations which are susceptible to lightning strike [2].

Talga's conductive graphene-enhanced composites have also been shown to serve as an alternative to the traditional copper mesh in composite aircraft and wind turbine applications, maintaining both stability and LSP whilst potentially offering weight reductions [3].

[1] Alemour, B., Badran, O. & Hassan, M. R. A Review of Using Conductive Composite. 1–23 (2019)
[2] Inside composites, New graphene-enhanced prepreg for lightning strike protection. (2019)
[3] Talga ASX Release, <http://www.talgagroup.com/irm/PDF/2360_0/Talgagrapheneboostscompositeconductivity> (2018)

Graphene-based Ice Protection Systems

Ice accumulation on aircraft flight surfaces or within the aircraft's engine is a prevalent problem faced by aircraft both grounded and during flight. Roughness added by the ice layers on the aircraft surfaces also affects the aerodynamic performance by altering airflow over the wing and tail, reducing the lift force that keeps the plane in the air, and potentially causing aerodynamic stall, leading to a temporary loss of control, decrease in lift and manoeuverability, and increase in drag, weight, and consequently power consumption [1]. Current de-icing/anti-icing solutions are mainly bleed air method [2], mechanical boot method and addition of chemical spray to the aircraft flight surfaces on the ground to prevent building ice in the air [1]. Besides the excessive costs, time and toxic chemicals involved pose environmentally hazardous runoff. As an alternative, electrothermal ice protection systems are already finding use on commercial aircraft. State-of-the-art systems consist of metal or composite structural aircraft components coated with polymers containing a high amount of graphite and carbon black particles in order to enable sufficient electrical conductivity required for efficient de-icing applications.

The ability to integrate graphene into complex 3D structures, its low weight, reduced thermo-mechanical stress during heating cycles, higher efficiency with lower power consumption, chemical inertness are key advantages in aircraft de-icing applications [3].

As a result, the GF Spearhead project graphene-based thermoelectric ice protection system (GICE) is set to advance the technology readiness level (TRL) of graphene-based ice protection systems, by developing three technology demonstrators for specific use cases desired by Airbus. Supply chain partners including graphene suppliers (Versarien and Nanesa) will work alongside components suppliers Sonaca [4]. Demonstrator systems will be rigorously tested in an icing wind tunnel during the project (https://youtu.be/_tFwScaNWS4) [3].

GRAPHICING is similar EC funded project focusing on application of graphene based materials in aeronautical structures for de-icing [5].

Swedish defence and security manufacturer SAAB filed a patent application in February 2013 detailing a de-icing process with graphene at its core. In a project funded by Vinnova – Sweden's Innovation Agency, SAAB also co-ordinated the development of multifunctional paint with enhanced conductivity by adding graphene for lightning strike protection and de-icing systems of the aircrafts.

Australia's national science agency, CSIRO, has created a patented technology, GraphON [6], new conductive form of graphitic material with the potential to offer industries like aerospace and defence an innovative new way to conduct heat or electricity through a surface coating or composite structure for applications such as de-icing .

Signet International Holdings, Inc.'s subsidiary, SGT, announced in 2019 [7], execution of a contract with Florida International University to further the development and commercialization of a new de-icing technology enhanced by graphene. The graphene foam–polymer composite has superior de-icing efficiency and strength and is expected to have a major impact on the aircraft de-icing market.

[1] Alemour, B., Badran, O. & Hassan, M. R. A Review of Using Conductive Composite, 1–23, (2019).
[2] Blanco, T. et al. Grafeno para Anti-hielo Graphene for Anti-icing, 3, 22–27 (2019).
[3] Graphene Flagship, Airbus-Backed European Project Could Produce Safer Aircrafts, Viewed on 01 June 2020, <https://graphene-flagship.eu/project/spearhead/Pages/GICE.aspx> (2020).
[4] AZO Materials. The Graphene Flagship Project : The Key Developments in Aviation. (2020)
[5] GRAPHICING Project, Viewed on 01 June 2020, <https://cordis.europa.eu/project/id/886376?WT.mc_id=RSS-Feed&WT.rss_f=project&WT.rss_a=228385&WT.rss_ev=a.>
[6] CSIRO. GraphON : Conductive coatings & materials. Viewed on 01 June 2020, <https://www.csiro.au/en/News/News-releases/2019/GraphON-conductive-coatings-materials> (2020).
[7] Signet Int. Holdings. 3D Graphene – Polymer Composite to Deice Aircraft. Viewed on 01 June 2020, <http://www.signetinternationalholdings.com/graphene-3/>, (2020).

Graphene's Role in the Electrification of Aircraft

Copper wires are one of the most commonly used elements for communication cables and circuits of electronic devices. However, the native oxide layer generated on the copper at low temperature (< 100°C) can be detrimental to the multi-functional performance and limit its applications such as light-weight cables and thermal-resistant electronic circuits [1].

Recently, Versarien announced [2], following an open innovation call, multinational engineering company Rolls-Royce has selected to work with The University of Manchester's Graphene Engineering Innovation Centre (GEIC) (pictured top-right) and Tier 1 partner 2-DTech Ltd.

The initial programme of work will use the state-of-the-art chemical vapour deposition (CVD) equipment located within the GEIC to explore, understand and create technological advances surrounding the use of graphene and other 2d materials used in wiring for next-generation aerospace engine systems.

This project will explore the optimization of copper wires, firstly to remove the native oxide layer and grow GRM layers layer directly on the wire surface. This solution is expected to reduce the weight of the wires (It is predicted that removal of a typical 100nm thick copper oxide layer on a 25um diameter wire will result in a ca. 1% weight reduction), along with improvement of electrical conductivity and also resistance to corrosion.

Overall, the programme aims to present potential economic benefits, through the possibility of significant cost reductions, and global environmental benefits, through the reduction of energy use and lower emissions from electrification.

Neill Ricketts, Chief Executive of Versarien commented:
"The pursuit of sustainability has become an important goal for many companies in recent years. Rolls-Royce is one of the world's leading industrial technology companies and today, the size and impact of the markets its serves makes this task more urgent than ever. Taking advantage of advanced materials such as graphene, has the potential to revolutionise these markets and add real benefit...the partnership with Rolls-Royce is a significant endorsement to 2-DTech's work over the years and we are delighted it has been chosen by such a renowned business and look forward to working together."

Dr Alexis Lambourne, Materials Specialist at Rolls-Royce, commented:
"Partnering with the GEIC and its members makes perfect sense to Rolls-Royce as we explore the opportunities and properties of a new class of 2d materials. Using the unique capabilities of 2-DTech and the GEIC we hope to address some of the challenges facing materials in the global aerospace industry, as we pioneer the electrification of future aircraft."

James Baker, Graphene@Manchester CEO, commented:
"The GEIC is intended to act as an accelerator for graphene commercialisation, market penetration and in the creation of the material supply chain of graphene and 2d materials. It's great to see a company like Rolls-Royce partner with us and our other Tier 1 member, 2-DTech, to capitalise on our world-leading expertise and experience, along with specialist equipment, which will accelerate the product and process development and market entry."

[1] L.-W. Jang, L. Zhang, M. Menghini, H. Cho, J. Y. Hwang, D. I. Son, J.-P. Locquet, J. W. Seo., Carbon, 139, 666-671 (2018)
[2] Versarien plc RNS Announcement, viewed 01 June 2020, <https://www.voxmarkets.co.uk/xsrns/00e505ce-1c6d-48b4-b5c4-7a73e0185766/>

Summary

This report has highlighted a number of key case studies where graphene is enabling the realization of multifunctional components for the aerospace sector. Several other application areas that are being developed with graphene also exist including energy storage technologies (supercapacitors, batteries), energy harvesting (solar, wind), thermal management (cooling for satellites), military focused applications (radar absorption and camouflage) and unmanned aerial vehicles (UAVs) to name a few.

Graphene will no doubt play a pivotal role in the next-generation of aircraft, underpinned by significant funding from the UK government and the EC. Competition from other regions will increase, in particular from China who is witnessing the fast development of its aerospace and aviation industry, on track to become the world's largest aviation market.

However, with the world's most highly regarded centres of excellence for graphene research (NGI and CGC) and the ability to now accelerate development through the GEIC, there is a serious case to be put forward for UK-centred projects to build on these strong foundations. Rolls Royce are one particular company to have taken the initiative to partner with the GEIC and its partners. Other GEIC advisory panel partners with activities in aerospace include Airbus, AkzoNobel, BAE Systems, GKN Aerospace, Siemens, Tata Steel and Thales, would seem prime candidates with which to develop graphene-related research and commercialisation focused projects.

Acknowledgements

Versarien would like to thank the Graphene Flagship for providing additional information and images for this report.

Glossary

2d	Two-dimensional
AEROGrAFT	Next-Generation Aerospace Filtration
AM	Additive manufacturing
ATI	The Aerospace Technology Institute
CF	Carbon Fibre
CFRP	Carbon Fibre Reinforced Polymer
CVD	Chemical Vapour Deposition
EC	European Council
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
FDM	Fused Deposition Modelling
GF	Graphene Flagship
GICE	Graphene-based thermoelectric ice protection system
GNP	Graphene Nanoplatelet
GRMs	Graphene and Related Materials
hBN	Hexagonal Boron Nitride
LSP	Lightning Strike Protection
MWCNT	Multiwalled Carbon Nanotube
NGI	National Graphene Institute
PAEK	Polyaryletherketone
PEEK	Polyetheretherketone
SLS	Selective Laser Sintering
TRL	Technology Readiness Level
UAV	Unmanned aerial vehicle
UV	Ultraviolet

Disclaimer

Versarien plc
Unit 1A-1D
Longhope Business Park
Longhope
Gloucestershire
GL17 0QZ

www.versarien.com