Mapping Midlands Universities: Advancing Space Industry Research and Innovation

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1. Introduction

This report aims to comprehensively assess the assets and research strengths within Midlands universities relevant to both the upstream and downstream sectors of the space industry. The intention is to provide a clear overview of existing capabilities and facilities that can foster potential knowledge transfer and industrial partnerships, specifically in support of the Midlands Space Cluster. The report aims to highlight promising avenues for collaboration, targeted investments, and the overall advancement of space research in the Midlands. The report focuses on key research capabilities within areas such as space science, spaceflight operations, space domain awareness, AI and data science, advanced materials and manufacturing, and energy. The identification of current university research related to both upstream and downstream space activities aims to highlight expertise that could bolster the overall competitiveness and sustainability of the Midlands' space cluster.

The findings show that the Midlands region stands as a hub of excellence in space-related research and innovation, driven by its world-class universities at the forefront of cutting-edge exploration and technology development. The report underscores strengths spanning astrophysics, planetary science, materials, propulsion, robotics, autonomy, power systems, and more. Universities like Leicester, Birmingham, Warwick, Loughborough, and Nottingham are pioneering breakthroughs in diverse fields, from asteroid exploration to AI-enabled spacecraft, space-qualified batteries to combustion research for rocket propulsion, and gravitational wave astronomy to recycling technologies for space sustainability. Their cross-disciplinary competencies, state-of-the-art facilities, and history of impactful discoveries highlight their capacity to drive innovation tailored to space applications. Their research not only expands scientific frontiers but also fosters tangible technological capabilities, enhancing the efficiency, reliability, and cost-effectiveness of space missions.

The strengths of space-related research across Midlands Universities are relevant to the expansion and competitiveness of the Midlands' space cluster for several reasons. Firstly, the investment in public R&D within universities has a proven positive spillover effect on private R&D investment within the UK. For every £1 increase in public R&D funding allocated to universities, there is a substantial long-term increase of £2.29 to £2.46 in private R&D investment (ERC, 2017). This finding underscores the critical role universities play as catalysts for innovation and technological advancement, thereby directly benefiting private sector entities, including space sector companies. Furthermore, the proximity to universities is a crucial factor in maximizing the spillover effects of R&D investment. Studies have shown that the positive impacts of public R&D funding on private investment tend to diminish beyond a 15-mile radius from universities. This highlights the importance of geographical proximity and collaboration between universities and businesses, particularly for industries such as the space sector, where cutting-edge research and innovation are paramount. Moreover, direct collaboration between businesses and regional universities has been demonstrated to significantly enhance the likelihood of new product innovations. On average, such collaborations increase the probability of new product innovations by 5.2% (ERC, 2017). This statistic underscores the tangible benefits that arise from partnerships between academia and industry, particularly in sectors requiring high levels of technical expertise and research, such as space-related industries. Therefore, the strengths of space-related research across Midlands Universities offer a unique opportunity for Midlands-based space sector companies to

leverage the expertise, resources, and collaborative potential present within the regional academic landscape. By capitalising on these research strengths and developing closer partnerships with universities, Midlands companies can potentially access cutting-edge knowledge and innovative concepts, helping to propel their own research, development, and commercialisation opportunities.

Despite the considerable strengths of the region's academic landscape, the Midlands falls short of the UK average in terms of research funding and the production of high-impact outputs. This disparity underscores the need for targeted interventions to enhance the region's research and innovation capabilities. Evidence suggests that local academic-industry collaborations in the Midlands are less extensive compared to other regions, indicating untapped potential for synergy between academia and industry. To address these challenges, it is imperative to strengthen large-scale Research, Development, and Innovation (RD&I) collaborations between regional Higher Education Institutions (HEIs) and firms. Such collaborations can catalyse innovation initiatives, driving economic growth and competitiveness in the long term. However, realising this potential requires substantial funding and concerted efforts in consortium-building to facilitate meaningful partnerships and collaboration frameworks. Reports like the present one, which identify and delineate research specialisms, play a pivotal role in guiding strategic endeavours aimed at reinforcing innovation ecosystems. By providing insights into existing strengths and areas for improvement, these reports inform decision-making processes and help align resources and initiatives to maximise impact. Ultimately, fostering robust RD&I collaborations and leveraging regional research expertise are crucial steps toward building a vibrant innovation ecosystem that drives sustainable growth and competitiveness in the Midlands' economy.

The structure of the report is divided into seven sections, which aligns with the following research strengths and capabilities:

- **Space Science**: This section provides an overview of the research strengths and capabilities related to fundamental space science disciplines such as astrophysics, planetary science, and cosmology. This includes research on observational astronomy, space exploration missions, and theoretical astrophysics.
- **Spaceflight and Space Operations**: Here, the report examines the expertise and facilities pertaining to the engineering and operational aspects of spaceflight. This includes spacecraft design, propulsion systems, launch operations, mission control, and space mission planning.
- **Space Domain Awareness**: This section distinguishes between ground-based and space-based Space Domain Awareness (SDA). It explores the capabilities for monitoring and tracking objects in space, detecting potential threats, and ensuring the safety and security of space assets. Ground-based SDA focuses on surveillance and tracking from Earth, while space-based SDA involves satellite-based systems for monitoring activities in orbit.
- **Advanced Materials and Manufacturing**: This section examines the research capabilities in advanced materials science and manufacturing technologies relevant to the space industry. It includes research relating to lightweight materials, additive manufacturing, nanotechnology, and composite materials used in spacecraft construction and equipment fabrication.
- **Space Applications:** This section has a broad range of research and development in the space domain, with strengths across the Midlands found in global navigation satellite systems (GNSS) and Earth Observation.
- **Artificial Intelligence / Machine Learning and Data Science**: This part highlights research strengths in AI, machine learning, and data science as applied to space-related applications. It discusses how these technologies are utilized for data analysis, pattern recognition, predictive modelling, and decision-making in space missions and exploration.
- **Energy:** The final section explores research strengths in energy-related technologies applicable to space missions and infrastructure. This includes renewable energy systems for spacecraft power generation, energy storage solutions, and propulsion systems powered by alternative energy sources.

The research focused on the Midlands region of the UK, encompassing the traditional East and West Midlands areas. The boundaries however are not hard; the Midlands Innovation Space Group currently work with the South East Midlands Local Enterprise Partnership (SEMLEP) which includes Cranfield University. Therefore, we included Cranfield in our list. The priority universities were as follows:

West Midlands	East Midlands
• Aston University, Birmingham • Birmingham City University • University of Birmingham • Coventry University • Keele University • Newman University, Birmingham • Staffordshire University • University of Warwick • University of Wolverhampton • University of Worcester	• University of Derby • University of Leicester • University of Lincoln • Loughborough University • University of Northampton • University of Nottingham • Nottingham Trent University • Cranfield University

2. Recommendations

The research strengths and capabilities outlined in this report present significant opportunities for collaboration and growth within the Midlands Space Cluster. Through strategic emphasis on the region's academic strength, this report lays the groundwork for expanded collaboration, innovation, and economic growth within the Midlands Space Cluster. The following recommendations highlights – in our view – the most promising collaboration / growth opportunities

1. **Fostering Collaborations in Space Science Missions:**

   Establishing formal partnerships between Midlands universities and space agencies or organisations to leverage expertise in astrophysics, planetary science, and space exploration for collaborative missions. Options include joint research projects, data and facilities sharing agreements, or student and researcher exchange programmes to facilitate knowledge transfer. More established researchers could be funded to go on strategic international visits as well - this has the potential to bring in multi-national funding for projects.

2. **Driving Innovation in Spacecraft Technology:**

   Encouraging interdisciplinary research initiatives that bring together experts in advanced materials, additive manufacturing, and energy systems to develop next-generation spacecraft components. Options could include a research workshop series to develop project ideas, and seed funding opportunities (by the UKSA for example) specifically targeted at projects aiming to revolutionise spacecraft design, construction techniques, and propulsion systems. These projects could then feed into the proposal by the Space Academic Network (SPAN) to establish a SmallSats programme.

3. **Utilising AI and Data Science for Space Applications:**

   Establishing dedicated research centres or institutes within Midlands universities focused on AI/machine learning and data science applications for space exploration, with support from the national Alan Turing Institute. These centres could facilitate collaborations between researchers from different disciplines to develop algorithms for data analysis, decision-making processes, and autonomous operations in space missions.

4. **Investing in Research Infrastructure:**

Allocating resources to expand research infrastructure and facilities in strategic areas relevant to space exploration, such as satellite engineering, space domain awareness, and Earth observation. This could involve investing in state-of-the-art laboratories, test facilities, and equipment to support cutting-edge research projects and attract top talent to the region. While some universities in the Midlands region have established strengths in certain academic areas and facilities, it's crucial to promote a balanced distribution of resources across institutions. Efforts should be made to redress potential imbalances by strategically investing in complementary or supplementary facilities at universities that may currently them. This approach not only nurtures a collaborative academic ecosystem but also drives innovation and knowledge-sharing, ultimately benefiting the entire Midlands academic community.

Overall, these recommendations aim to leverage the Midlands' academic strengths and foster collaboration between academia, industry, and government to drive innovation, economic growth, and establish the region as a key player in the global space industry.

3. Space Science

This section examines the space science (including astrophysics, astronomy, planetary science) research being pursued across universities identified in the Midlands space cluster, including Cranfield University, the University of Birmingham, Keele University, the University of Warwick, the University of Leicester, and the University of Nottingham. The research covers various domains relevant to the space sector, including astrophysics, planetary science, gravitational wave astronomy, extrasolar planets, cosmology, and space environment modelling.

Key strengths:

- Cranfield University is engaged in innovative asteroid exploration mission planning and planetary defence research. This can enable cost-effective trajectory design and inform future asteroid missions.
- The University of Birmingham is advancing our understanding of the cosmos through astrophysics research and contributions to gravitational wave astronomy. Their expertise in precision quantum sensors has applications in space exploration.
- Keele University's studies on stellar and planetary system formation and evolution aligns with interests in space resource utilization and exploration target selection. Their stellar astrophysics research aids exoplanet characterization.
- Warwick's discoveries in exoplanet science and involvement in major space telescope projects demonstrates capabilities in space mission development. Their planet formation insights can inform exoplanet exploration missions.
- Leicester has strengths in planetary science, space plasma physics, transient astrophysics, and stellar dynamics relevant to space mission planning, instrumentation, and data analysis.
- Nottingham leverages simulations, gravitational lensing, extragalactic astronomy, and galaxy evolution research to expand cosmological knowledge and enable space technology advances.

The universities showcase a breadth of research and expertise valuable for advancing space science and exploration. Investing in these research activities can yield practical benefits for space missions, instrumentation, target selection, and technology development. Collaboration opportunities exist across instrumentation, mission planning, theoretical studies, and more.

Cranfield University

Cranfield University is actively involved in significant projects in the space exploration domain. One notable endeavor is the CASTPath project, conducted in collaboration with the UK Space Agency. This initiative focuses on designing trajectory opportunities for the future CASTAway (Comet and Asteroid Space Telescope Away in the asteroid belt) mission, an upcoming European Space Agency (ESA) endeavour aimed at studying asteroids in the asteroid belt. The research enables the planning and trajectory design of multiple asteroid fly-bys from 2029 onward, supporting ambitious scientific objectives while ensuring mission efficiency and effectiveness. The expertise gained from this project holds broader relevance to asteroid exploration missions, offering insights into solar system formation and evolution. Additionally, the demonstration of cost-effective fly-by trajectories underscores innovation in mission planning, potentially inspiring similar approaches in the space sector.

Cranfield University is also active in a 'Dynamical Studies of Asteroids Collisions' Project, aiming to understand how asteroids interact in the solar system, particularly concerning close approaches and collisions. The research analysed asteroid trajectories affected by these events to refine solar system models and estimate asteroid masses. This project holds significance for planetary defense by improving our ability to track and mitigate potential asteroid impacts on Earth. Understanding asteroid dynamics contributes to a deeper comprehension of the solar system's evolution, benefiting planetary science missions and research across celestial bodies. The project's innovative method of detecting asteroid collisions or near misses through trajectory analysis offers a valuable approach applicable to various space research domains. Its findings, including identifying dynamical anomalies and proposing methods for asteroid orbit determination, have broad implications for the space research community, aiding researchers and agencies involved in asteroid studies.

https://www.cranfield.ac.uk/research-projects/castpath
https://www.cranfield.ac.uk/research-projects/dynamical-studies-of-asteroids-collisions

University of Birmingham

The University of Birmingham conducts diverse research in astrophysics, quantum technology, and materials science, with direct implications for the space sector. Their work not only enhances our understanding of the cosmos but also contributes to vital technologies and methodologies for space exploration and scientific discovery. In astrophysics, the university's research lays the groundwork for understanding celestial objects such as stars, galaxies, and black holes. This knowledge informs the design and operation of space telescopes and spacecraft, the interpretation of mission data, and the planning of exploration missions. Their involvement in the Institute for Gravitational Wave Astronomy supports the development of gravitational-wave detectors, crucial for observing cosmic events like black hole mergers and neutron star collisions. The university's contributions to projects like the Advanced LIGO UK Project and the LIGO Scientific Collaboration drive advancements in gravitational wave astronomy, enhancing detector precision for space-based missions. Research in macroscopic quantum opto-mechanics and the search for axion dark matter within the Quantum Interferometry collaboration aligns with improving precision measurements, crucial for space exploration. Quantum technology, such as quantum amplifiers, can boost instrument sensitivity for missions observing gravitational waves and searching for dark matter. Studying position sensors in cryogenic environments is relevant for operating gravitational wave detectors at low temperatures, vital for future space-based observatories. Research on ultracold quantum gases, quantum technology, and atomic quantum devices not only advances fundamental physics but also holds promise for developing advanced sensors and instruments for space missions.

https://www.birmingham.ac.uk/research/heroes/gravitational-waves.aspx
https://www.birmingham.ac.uk/research/activity/gravity/quantum-sensors.aspx
https://www.sr.bham.ac.uk/qi/

https://www.birmingham.ac.uk/research/activity/physics/quantum/index.aspx
https://more.bham.ac.uk/theoretical-physics/research/#:~:text=Ultracold%20atoms&text=The%20resulting%20quantum%20gas%20is,area%20of%20rotating%20Bose%20condensates.

University of Keele

The University of Keele is pursuing a range of research with direct implications for investment decisions in the space sector. This research will inform strategies for space exploration, the selection of targets for missions, and the development of technologies and models crucial for the success of space missions and observatories. Accurate understanding of stellar and planetary systems is central to achieving the goals of various space-related investments. Ongoing research is investigating the formation of planets and stars. Understanding these processes is critical for investment in space exploration and resource utilisation. It informs us about the conditions under which celestial bodies are born, helping us identify potential targets for resource extraction, colonisation, or scientific study. Knowledge gained from studying the Large and Small Magellanic Clouds, which resemble conditions during early galaxy assembly, can guide investment decisions related to interstellar travel and resource prospecting. Insights into star formation in metal-poor environments could influence plans for exploiting resources in similar regions.

There is also work on high-precision stellar astrophysics. In the context of investment in space missions and observatories like Kepler, TESS, and GAIA, accurate stellar models and atmospheric parameters are indispensable. These models are crucial for interpreting data collected from stars and planets throughout the Galaxy. Investments in space missions heavily rely on the accuracy of these models. Precision measurements of stars in binary systems contribute to the calibration of next-generation stellar models. For investors in space missions involving exoplanet discovery or characterization, the reliability of these models is fundamental in understanding planetary systems. The study's focus on accurately measuring the masses, sizes, luminosity, and composition of stars in binary systems aligns with investment interests in characterising exoplanets and their host stars. These measurements can impact mission planning and instrument development.

https://eprints.keele.ac.uk/id/eprint/11463/
https://www.keele.ac.uk/research/researchnews/2020/january/galaxies-collision/milky-way-study.php
https://eprints.keele.ac.uk/10984/6/stac957.pdf
https://www.keele.ac.uk/research/ourresearch/chemicalandphysicalsciences/astrophysicsanddatascience/#galaxies,-star-clusters,-associations-and-the-interstellar-medium

University of Warwick

The University of Warwick's Astronomy and Astrophysics group is engaged in a wide-ranging exploration of the cosmos, covering various scales across the Universe, from planetary systems to galaxies. Their research is both observational and theoretical, and they use a diverse array of ground-based and space-based telescopes, including some of the world's most advanced observatories like ESO's Very Large Telescope (VLT), the Atacama Large Millimetre Array (ALMA), NASA's Chandra and ESA's XMM-Newton X-ray observatories, and the Hubble Space Telescope.

The group's track record of making significant discoveries, such as the recent finding of a white dwarf pulsar and a novel method of planet formation, underscores their contributions to advancing our understanding of the cosmos. Their active involvement in the development of space missions, including ESA's Exoplanet

missions like PLATO, demonstrates their capability in contributing to the design and execution of space projects. This can be of interest to investors looking to support or collaborate on space missions.

Their research on planet formation, including the "sandwiched planet formation" concept, can have implications for understanding the formation of planets in our solar system and beyond. Investments in missions targeting exoplanet exploration and characterization may find their insights valuable.

https://warwick.ac.uk/fac/sci/physics/research/astro/
https://warwick.ac.uk/newsandevents/pressreleases/?newsItem=8a1785d78906717a01891b0f6ac21afa
https://warwick.ac.uk/newsandevents/pressreleases/?newsItem=8a17841a8895e8e30188bf9533d5041e

University of Leicester

The University of Leicester School of Physics and Astronomy has been a leader in high-energy astrophysics since the 1960s. Today, its research has diversified, offering opportunities for investors seeking collaboration with top experts in the field. With expertise in space-related research, instrument development, and data analysis, the university is a valuable partner in advancing space exploration and scientific discovery. The Planetary Science group at Leicester is actively studying planetary environments, including magnetospheres, ionospheres, atmospheres, and surface conditions. This research involves developing instruments for planetary missions and space telescopes, presenting collaboration opportunities for investors interested in planetary exploration and technology development. Understanding planetary materials through meteorites and mission data analysis informs future space missions and studies on celestial body evolution. Research on planetary atmospheres and dynamics is vital for spacecraft design and climate modelling, offering collaboration prospects for investors in atmospheric research. Stellar dynamics research aids in understanding dark matter distribution and galaxy evolution, relevant for galaxy formation projects and dark matter studies. Leicester's work in transient astrophysics, focusing on gamma-ray bursts and gravitational wave events, aligns with multi-messenger astrophysics. Investment opportunities exist in observatory facilities, data analysis, and coordinated studies of transient events. Similarly, research on cataclysmic variables, like white dwarfs and recurrent novae, sheds light on explosive astrophysical phenomena, potentially benefiting investors in X-ray observatories and high-energy astrophysics instrumentation.

https://le.ac.uk/planetary-science
https://le.ac.uk/planetary-science/planetary-magnetospheres-and-ionospheres#:~:text=We%20at%20Leicester%20have%20played,telescopes%2C%20and%20via%20theoretical%20and
https://le.ac.uk/astrophysics/stellar-dynamics-and-dark-matter
https://le.ac.uk/astrophysics/cataclysmic-variables#:~:text=Novae%20erupt%20when%20the%20accreted,around%20a%20hundred%20million%20degrees).

University of Nottingham

The University of Nottingham uses numerical simulations to model astrophysical and cosmological phenomena. These simulations are invaluable for mission planning, spacecraft design, and data analysis in the space sector. They contribute to understanding the behaviour of matter and energy in the universe, aiding space exploration and technology development. Additionally, research on gravitational lensing, a phenomenon predicted by Einstein's theory of general relativity, offers practical applications in cosmology and astrophysics. It enables astronomers to study the distribution of matter in the universe, providing insights into the nature of dark matter and dark energy. This knowledge can have direct implications for space-related

projects and missions. Understanding objects beyond our Milky Way galaxy is essential for space research. Extragalactic astronomy contributes to the study of distant galaxies, black holes, and celestial objects, which can inform space mission objectives and target selection. This research aids in expanding our understanding of the universe. Furthermore, knowledge of how galaxies form and evolve is vital for both cosmological studies and mission planning in the space sector. The complex processes governing galaxies' properties and appearance are studied through observations and computer simulations, helping researchers better understand these objects. Similarly, the study of nearby galaxies provides insights into physical processes and environments relevant to space missions. This knowledge can be applied to spacecraft design and mission planning, ensuring that missions are well-prepared for various encountered conditions.

https://www.nottingham.ac.uk/astronomy/research.php

4. Space Domain Awareness

Over the past six decades, a population of orbital debris has accumulated in near-Earth space. Abandoned spacecraft, rocket bodies and fragments from explosions and collisions coexist in orbit with the active satellites we rely on. With large constellations of satellites licensed for launch, and vast quantities of debris still invisible to the current generation of surveillance networks, the challenges facing Space Domain Awareness (SDA) are numerous.

Two regions are of particular concern. Low Earth orbit (LEO) plays host to the most densely populated orbital bands, as well as the International Space Station. Certain parts of the LEO region are thought to be on the cusp of triggering the so-called "Kessler Syndrome", a runaway process whereby a collision generates fragments that seed further collisions, and so on. The geosynchronous (GSO) region, situated at a much higher altitude above the Equator, has a limited number of orbital slots, and is known to contain a population of faint, poorly characterised debris.

https://warwick.ac.uk/fac/sci/physics/research/astro/csda/

University of Warwick

The Centre for Space Domain Awareness (CSDA) draws from the experience and expertise of a wide range of research groups at the University of Warwick to tackle issues relating to the safety and sustainability of satellite operations in the space domain. Research activities within the CSDA aim to address a variety of SDA problems, including:

- the timely acquisition of precise datasets to detect, track and/or characterise objects in orbit;
- the fusion of physical and human-based information for improved object tracking;
- the modelling and prediction of space weather, and the quantification of associated risk.

University of Birmingham

The University of Birmingham is undertaking specific research regarding radar, remote sensing and signal processing through the Microwave Integrated Systems Laboratory (MISL) which was founded in 2003 and stands today as the largest academic research team in the UK working in radar, remote sensing and signal processing. A large focus of this is improved Space Domain Awareness, and they are currently developing new space domain capability based on Inverse Synthetic Aperture Radar (ISAR) operating at extremely high frequencies (W-band and above), to obtain high resolution imagery to characterise all space residents (other satellites and debris) from in-orbit.

5. Spaceflight / Space Operations

This section examines the research activities related to spaceflight and space operations across several UK universities, including Leicester, Loughborough, Keele, and Warwick. The research covers areas like satellite systems, propulsion, communications, instrumentation, and wildlife tracking from space. It also research on space weather as part of 'space operations'.

Key strengths:

- Leicester has expertise in fault tolerance, self-healing systems, and optics for space missions. They collaborate with ESA and industry, presenting investment opportunities in robust satellite systems.
- Loughborough conducts research in rocket propulsion efficiency, spacecraft cooling, and antenna arrays for satellite communications. This can enable optimized space systems.
- Keele studies advanced materials for space applications like sensors, data storage, computing, and optics. This provides avenues for enhanced spacecraft technology.
- Warwick leads development of an innovative CubeSat for space-based wildlife tracking in collaboration with space agencies and research institutes. This enables streamlined wildlife monitoring from orbit.

The universities showcase specialised capabilities valuable for advancing spaceflight systems and operations through projects across fault tolerance, propulsion, materials, communications and observation. Collaboration and investment opportunities exist to accelerate the development of optimised and robust space technologies.

University of Leicester

The university collaborates with the European Space Agency and Airbus Defence and Space on a novel approach to enhance the reliability of distributed failure detection systems in space. This technology addresses critical concerns about system failures and can significantly improve the robustness of space missions, making it an attractive investment for companies seeking to ensure the success of their satellite-based projects.

The university's research team has proposed a self-healing inter-satellite computing model that supports fault-tolerant distributed data processing among satellite nodes. This innovative approach ensures the continuous operation of satellite constellations by detecting and autonomously recovering from node failures. This technology can be a game-changer for satellite-based data processing, particularly for applications that rely on artificial intelligence and machine learning techniques, presenting investment opportunities for those interested in advanced space-based data processing capabilities.

The University of Leicester has a strong focus on detector systems for instruments and optical system design, with a track record of contributing to major space missions. Their expertise in X-ray optics is particularly noteworthy, as they have provided telescopes for missions like BepiColombo, SVOM, and SMILE. This optical and instrument expertise opens up investment avenues for companies involved in space mission instrumentation and optics technology.

The university boasts a diverse range of expertise across disciplines such as engineering, computer science, mathematics, and business. This interdisciplinary approach allows for comprehensive support in the design

and development of space systems, instruments, and payloads. This wide-ranging expertise includes radiation-hard embedded systems, advanced manufacturing techniques, materials modelling, software engineering, and the use of artificial intelligence.

Furthermore, The Earth Observation Science Group is a world-leader in interpreting cutting-edge observations that allow us to understand and predict changes to our weather and climate systems.

Their activities range from developing complex physical retrieval techniques to infer atmospheric concentrations of important greenhouse gases to detailed process studies of cloud physics using satellite radars. In their work they cooperate with many international space agencies (UK Space Agency, ESA, NASA, JAXA, etc) in order to propose, develop and evaluate current and future Earth Observation satellite missions. Through our research we contribute to programmes such as the ESA Climate Change Initiative and the EU Copernicus Climate Change Service, where the data we generate is widely distributed to the scientific community and ultimately used to inform policymakers in making climate-related decisions.

Satellite Observations of Climate and Weather | Earth Observation Science | University of Leicester
https://le.ac.uk/planetary-science

University of Loughborough

The University of Loughborough excels in applied aerodynamics, and is currently undertaking research in a range of relevant areas. Much of this is centred around greater efficiency of propulsion and compulsion. For example, high-speed nozzle and plume studies. This research can help optimise rocket propulsion systems, ensuring efficient and stable thrust in the vacuum of space. Similarly, there is extensive research into combustion system aerodynamics and fuel injector and two-phase flows which will improve combustion processes in rocket engines and render them more efficient and reliable.There is also efficiency research that aims to reduce energy loss regarding aeroacoustics, and heat transfer and cooling. Aeroacoustic studies can help in the design of quieter spacecraft and launch systems while managing heat is critical in spacecraft to prevent overheating of onboard systems and components. The University of Loughborough is also undertaking research in RF (radio frequency) antennas is crucial for satellite communication systems. Traditionally, complex phase shifters feeding antenna arrays are used to beamform radiation patterns in different directions. However, these are cumbersome and are not ideal for small installations as is necessary in spacecraft construction. This work is looking into developing more cost-efficient and compact active antenna array systems for electronic beam-steering at 28GHz.

https://www.lboro.ac.uk/departments/aae/research/applied-aerodynamics/

https://www.lboro.ac.uk/departments/aae/research/applied-aerodynamics/#:~:text=The%20Aeroacoustics%20research%20group%20is,by%20EPSRC%2C%20ATI%20and%20ARCHER.

https://www.lboro.ac.uk/departments/meme/research/research-projects/activemm-waveantennaarray/

Keele University

Within Keele University the Computational Materials Physics group led by Dr. Juliana Morbec holds particular interest in the space sector. Within this project there is research into spintronics and optoelectronics. Spintronics, which involves manipulating the intrinsic spin of electrons in addition to their fundamental electronic charge, is a promising area for space technology. It can be applied in advanced sensors, data storage, and computing systems used in space missions. Furthermore, research on hybrid organic/inorganic

materials for optoelectronic applications can have relevance in space-based optical systems and communication technology.

https://www.keele.ac.uk/research/ourresearch/chemicalandphysicalsciences/materialsscienceandrenewableenergy/#computational-materials-physics-(dr-juliana-morbec)

University of Warwick

The University of Warwick is at the forefront of the WUSAT project (Warwick University Satellite Project). This initiative is currently developing WUSAT-3, a 3U CubeSat, with the primary aim of showcasing an innovative direction-finding capability. This capability is intended for wildlife monitoring and is designed to be deployed from the International Space Station. This student-driven project is in collaboration with the Icarus Initiative, a partnership involving animal scientists and space agencies from Germany, Europe, and Russia. The Max Planck Institute for Ornithology leads this initiative, which seeks to establish a robust infrastructure for wildlife observation.

Traditionally, wildlife tracking systems rely on satellites to remotely sense or physically record signals from tracking tags, often involving GPS technology, which can be labour-intensive. The research within this project aims to streamline this process, potentially extending the range of species that can be effectively monitored. It represents an exciting development in the field of wildlife observation from space.

This project also offers low-cost in-orbit test/demonstration opportunities for research or industrial development payloads that require validation in a Space environment.

https://warwick.ac.uk/fac/sci/eng/meng/wusat/

https://warwick.ac.uk/fac/sci/eng/meng/wusat/projects/wusat-3/

University of Birmingham

The Space Environment Research Group (SERENE) at University of Birmingham develops statistical, physics-based, and data assimilation models to study the Sun's influence on Earth's ionosphere and space weather phenomena. Some of their key models are E-CHAIM, A-CHAIM, AENeAS, and AIDA, which are widely utilized across academia, government, and industry in over 30 countries.

SERENE conducts research to understand the likelihood and potential impacts of rare, high-consequence solar superstorms on technology and infrastructure. This focuses on using advanced mathematical techniques to estimate the occurrence of extreme space weather events. Additionally, SERENE investigates how high-amplitude electromagnetic waves can energise particles in the magnetosphere faster than previously thought. Incorporating this knowledge into space weather models aims to improve forecasting for satellite safety and reliability.

SERENE has developed a networked over-the-horizon radar (NOTHR) system to overcome limitations of conventional OTHRs. The NOTHR system enables detection and tracking of low-velocity targets, determines target velocities within a wide search area, and simultaneously monitors multiple targets. Utilizing the powerful Low-Frequency Array (LOFAR) radio telescope, SERENE also investigates small-scale ionospheric structures, refines phase screen modeling, and examines the coupling between the mesosphere and ionosphere. LOFAR's high sensitivity and wide-field imaging capabilities allow SERENE to detect and classify

intricate ionospheric structures. Furthermore, the AENeAS thermosphere model, developed by SERENE and deployed at the UK Met Office, provides accurate satellite drag forecasts. This helps better predict satellite orbits and prevent collisions in low Earth orbit, ensuring the safety and longevity of satellite assets.

https://spaceweather.bham.ac.uk/group/topics/

6. Advanced manufacturing and materials

This section examines the research on advanced manufacturing techniques and materials being conducted at several UK universities, including Birmingham, Derby, Loughborough, Nottingham, and Warwick. The research aims to develop more efficient production processes and advanced materials to meet the demands of the space industry.

Key strengths:

- Birmingham has expertise in micro manufacturing, laser processing, and recycling technologies to improve manufacturing efficiency, reduce costs, and enable sustainability for space missions.
- Derby demonstrated metal 3D printing can reduce costs and lead times for complex components by over 50% with environmental benefits, advantages for aerospace and space applications.
- Loughborough studies high-temperature materials, superalloys, composites, and coatings to withstand space conditions and advanced characterization techniques.
- Nottingham develops sensors, coatings, and simulations tailored to space applications like life support systems, thermal protection, and electromagnetic design.
- Warwick's research on producing silicon carbide will enable this valuable material for spacecraft construction, solar arrays, electronics, and radiation resistance.

The universities exhibit specialized capabilities in manufacturing techniques and advanced materials that can significantly benefit the space sector. Opportunities exist for collaboration to develop optimized and cost-effective solutions. Targeted investments could accelerate innovations in space-qualified materials, efficient production, and sustainability.

University of Birmingham

The University has strategically invested in Advanced Manufacturing, resulting in the establishment of a leading research group in micro manufacturing. Supported by a grant from Advantage West Midlands, the group assists numerous small and medium manufacturing companies in the region. Their research focuses on:

- Examining micro-machining capabilities of materials like aerospace alloys and mold/die steels.
- Developing micro tool-making and replication techniques crucial for scaling up micro manufacturing processes.
- Integrating micro machining technologies such as micro milling and laser ablation to meet specific product requirements.
- Conducting feasibility studies for new micro manufacturing platforms tailored to emerging applications.

These processes aim to streamline manufacturing, making it more efficient and profitable. The lab boasts state-of-the-art micro machining facilities, including a Matsuura LX-1 High-Speed Machining Centre and an Agie-Charmilles Vertex Twin-Spool Wire EDM.

The University of Birmingham's Advanced Manufacturing Centre conducts Laser Processing research on advanced engineering materials such as aerospace alloys and stainless steel. Understanding laser-material interactions is crucial for developing stronger and more resilient materials for space applications. The group utilizes state-of-the-art laser micro machining and characterization equipment, including a Lasea Multi-Axis Laser Micro Machining Centre and Alicona G4 InfiniteFocus system. Superconducting and metamaterials research is essential for spacecraft component design and development of optical materials for space technology. Understanding these materials' performance in extreme space environments optimises radar, remote sensing, and signal processing systems.

The University also leads the 'Recycling and Reuse' project (ReLiB) with partners like the Faraday Institute and the University of Leicester. This project aims to improve and scale recycling technologies to recover valuable materials from waste streams efficiently. Efficient recycling reduces the need for launching additional resources from Earth, making space missions more sustainable and cost-effective.

https://www.birmingham.ac.uk/research/activity/mechanical-engineering/advanced-manufacturing/index.aspx
https://www.birmingham.ac.uk/research/activity/mechanical-engineering/advanced-manufacturing/micro-manufacturing.aspx
https://www.birmingham.ac.uk/research/activity/mechanical-engineering/advanced-manufacturing/laser-processing.aspx
https://wmgrowth.com/article/nasa-scientists-impressed-by-mtc-capability
https://www.birmingham.ac.uk/research/activity/physics/quantum/metamaterials/index.aspx

http://www.faraday.ac.uk/six-projects-reshaping/
https://relib1.relib.org.uk/

University of Derby

The University of Derby, in collaboration with its Institute for Innovation in Sustainable Engineering (IISE), has conducted research on the potential of metal 3D printing (3DP) to transform manufacturing processes and offer a competitive advantage to various industries. This research project addresses a unique challenge in the utilities sector by applying a metal 3DP workflow to remanufacture obsolete parts for the UK's gas transmission grid, as well as tackling how cost-intensive traditional methods of replacing asset parts in the gas pipeline system was. The IISE team developed alternative approaches, resulting in significant cost and time savings (over 50%) when producing complex components. Environmental benefits of 3DP were evident, as the research demonstrated that metal powder stock used in 3DP generates only 5% of CO2 emissions and less than 10% of waste compared to traditional solid stock manufacturing methods.

While the primary focus of the research may not be space-related applications, the advancements in metal 3D printing technology, cost savings, environmental benefits, and knowledge sharing have the potential to benefit the space sector by improving manufacturing processes, reducing costs, and contributing to sustainability goals in space exploration and satellite manufacturing. For example, metal 3D printing is increasingly used in aerospace for manufacturing complex components, including engine parts and structural elements. The research's success in fabricating complex aircraft engine components in a cost-effective and time-efficient manner could directly apply to the space sector. Spacecraft, satellites, and launch vehicle components can benefit from 3D printing technologies to reduce costs and lead times. Additionally, the ability to quickly and cost-effectively manufacture parts using 3D printing can be advantageous for space exploration and research. Researchers and engineers in the space sector often require custom-designed components and prototypes for testing and experimentation. 3D printing allows for rapid prototyping and iterative design processes.

https://www.sciencedirect.com/science/article/abs/pii/S0093641320300963?via%3Dihub
https://www.derby.ac.uk/research/showcase/metal-3d-printing-additive-manufacturing/#:~:text=Effect%20of%20powder%20bed%20fusion%20laser%20melting%20process%20parameters%2C%20build%20orientation%20and%20strut%20thickness%20on%20porosity%2C%20accuracy%20and%20tensile%20properties%20of%20an%20auxetic%20structure%20in%20IN718%20alloy
https://www.mdpi.com/1996-1944/12/24/4203

University of Loughborough

The University of Loughborough has conducted extensive research on advanced materials, particularly focusing on their performance under extreme conditions. For instance, they have explored high-temperature materials suitable for spacecraft, satellites, and propulsion systems, which must endure extreme heat during launch, re-entry, and space travel. Understanding factors like oxidation resistance is vital for selecting materials for such applications. Additionally, research includes superalloys, steels, alloys, and composites, commonly used in aerospace components like engines and turbines due to their ability to withstand high temperatures and mechanical stress. The microstructural changes these materials undergo during high-temperature service affect their performance in space. Advanced materials such as nano-quasicrystalline and nano-fibril alloys and composites offer lightweight and high-strength properties, ideal for spacecraft construction, cost reduction, and enhanced efficiency.

Furthermore, research encompasses various production techniques, including additive manufacturing, which is increasingly vital in the space sector for creating intricate components. Understanding the microstructure of materials produced through additive manufacturing is crucial for ensuring their reliability in space. Additionally, research focuses on hydrophobic/icephobic coatings essential for spacecraft and equipment to prevent ice buildup under extreme space conditions. Much of this research takes place at the Loughborough Materials Characterisation Centre's research facilities. The centre offers crystallographic analysis using FEGSEMs equipped with Electron Backscatter Diffraction (EBSD) cameras, allowing for the analysis of crystallographic orientation in vacuum-compatible, crystalline samples. Moreover, the centre provides X-ray diffraction (XRD) for analysing polycrystalline materials, aiding in phase identification, crystallinity determination, and structural investigations.

https://www.lboro.ac.uk/research/lmcc/facilities/
https://www.lboro.ac.uk/departments/materials/research/advanced-materials/
https://www.lboro.ac.uk/departments/aae/research/utc/

University of Nottingham

The University of Nottingham conducts substantial research in materials and manufacturing directly relevant to space exploration. As part of the Gateway Earth Development Group, research focuses on testing materials and space-manufacturing methods, including electrochemical simulations, high-temperature corrosion, thermal barrier coatings, and laser alloying. One key area of research is the development of lightweight fluorescent sensors for real-time monitoring of bioprocesses in space environments. These sensors are crucial for ensuring astronauts' health and well-being during long-duration space missions and for the success of biologically-based experiments in space. Additionally, Nottingham leads research into electromagnetic design for space applications. This includes GGI_TLM & UTLM for full field 3D electromagnetic simulation across all frequencies and SACAMOS for developing cable models for satellite applications.

https://www.nottingham.ac.uk/engineering/departments/m3/people/katy.voisey

https://www.nottingham.ac.uk/aerospace/research/space/index.aspx
https://www.nottingham.ac.uk/research/groups/cam/index.aspx
https://www.nottingham.ac.uk/utc/research/advanced-manufacturing-processes/advanced-manufacturing-processes.aspx

Birmingham City University

Birmingham City University is currently conducting a project funded by the National Science Centre (NCN) to explore the evolution of nano crystallised, highly-reactive multi-layered metal structures. Spacecraft and satellites endure significant temperature fluctuations in space. By researching the thermomechanical processes and their impact on nanocrystalline structures, we aim to understand how materials can withstand these stresses. Additionally, investigating the formation of oxide scale clusters is crucial for enhancing material durability in space. These findings have the potential to advance the development of more resilient and dependable materials for space missions and technologies.

https://www.bcu.ac.uk/engineering/research/advanced-materials-and-manufacturing/research-projects/reactive-multi-layered-metal-structures#:~:text=of%20nanocrysta...-,Evolution%20of%20nanocrystallised%2C%20highly%2Dreactive%20multi%2Dlayered%20metal%20structures,clusters%20and%20micro%2Dstructural%20features.

Coventry University

The Coventry University project 'KTP with the National Physical Laboratory' has developed a novel process to ‘functionalise fibres within fabric’, enabling them to be coated with metallic nanoparticles for selective metallisation. This innovation could yield composite materials with enhanced properties, potentially beneficial for spacecraft construction, satellite components, and space suits. Spacesuits require durable materials offering thermal and radiation protection. Advances in fabric functionalisation and nanoparticle coatings could lead to improved space suit materials, enhancing astronaut safety during spacewalks and missions. Additionally, Coventry university research involves the development and application of neutron transmission imaging for strain mapping in aerospace applications, in collaboration with the ISIS Neutron and Muon Facility. Neutron Bragg edge strain analysis provides insights into internal stress and strain within materials critical for understanding aerospace material behaviour under various conditions encountered in space. The development of novel analysis methods can enhance the characterisation of aerospace materials, leading to improved materials design and performance.

University of Warwick

There is extensive research underway on silicon carbide, a next-gen semiconductor material similar to silicon but much more efficient, saving space, weight, and reducing heat loss. However, its high cost remains a challenge, making Warwick's research into its production crucial. Silicon carbide boasts unique properties like radiation resistance, thermal stability, lightweight strength, and precise optics, making it valuable in space technology. It improves spacecraft, instruments, and other space tech in terms of performance, reliability, and longevity. Warwick's Faculty of Science aims to tackle challenges in silicon carbide production, particularly the uniform oxide layer needed for higher temperature applications. This research holds broad applications, especially in the space sector. Silicon carbide's exceptional radiation resistance is crucial for space missions where ionizing radiation levels are high, enduring without degradation. It's also ideal for constructing space solar arrays, enduring harsh radiation and temperature shifts typical in space environments. Moreover, space conditions range from freezing cold in deep space to scorching heat during re-entry. SiC's high thermal conductivity and temperature resilience make it perfect for spacecraft thermal

protection systems and components. Advanced ion thrusters for spacecraft propulsion use SiC components for their durability and electrical properties, benefiting from its ability to withstand high temperatures.

https://warwick.ac.uk/fac/cross_fac/sciencecity/programmes/internal/themes/energyefficiency/power_electronics/
https://pubmed.ncbi.nlm.nih.gov/34640228/

7. Space Applications

This section has a broad range of research and development in the space domain, with strengths across the Midlands found in global navigation satellite systems (GNSS) and Earth Observation.

The University of Nottingham conducts research on space applications through its Nottingham Geospatial Institute (NGI). Key areas include:

- Earth Observation - Developing technologies for environmental monitoring, natural hazards, etc. using satellite/drone data.
- Positioning and Navigation - Research on satellite navigation systems, ubiquitous positioning technologies, applications like autonomous driving.
- Geospatial Science - Open-source geospatial technologies, location-based services, data interoperability.
- GNSS Propagation Effects - Studying atmospheric influences on GNSS signals, modelling/mitigating impacts.

The University of Leicester's Earth Observation Science group works on the entire Earth observation technology cycle - from lab spectroscopy to satellite missions. Activities include atmospheric trace gas measurement, sensor development for greenhouse gases/air pollution, and contributing to missions like GOSAT.

University of Birmingham research also involves space-based applications, which includes the International Clock and Oscillator Network (ICON) project and a new generation of gravity sensors based on quantum technology.

Finally, Cranfield’s space system applications research includes Earth observation (EO), communications, and position / navigation / timing (PNT).

All universities aim to advance space applications and address scientific/societal challenges through their complementary research efforts.

University of Nottingham

The University of Nottingham's research on Space Applications is conducted through the Nottingham Geospatial Institute (NGI). NGI undertakes research on many key aspects that impact and integrate with geospatial engineering and science. This research utilises a diverse range of scientific disciplines including geodesy, remote sensing, engineering surveying, and Geographic Information Systems (GIS). By combining expertise from these various disciplines, NGI aims to advance the field of geospatial technologies and applications.

In addition to its research activities, NGI operates a knowledge transfer and business engagement unit called GRACE (Geospatial Research and Commercialization Centre for Excellence). The focus of GRACE is to assist organisations, businesses, start-ups, and entrepreneurs in taking advantage of satellite navigation technologies and applications. Through this unit, NGI facilitates the commercialization and practical implementation of its research findings in the domain of satellite navigation and geospatial sciences.

Space Research - The University of Nottingham

Earth Observation

The University of Nottingham conducts research focused on improving the potential of technology and its applications related to Earth observations. This research activity involves algorithm development, creating novel methodologies, and optimizing system performance to solve scientific and engineering challenges. With strong links outside the university, application projects are also undertaken to transfer the knowledge and expertise from Earth observation research into industry applications.

The Earth observation research at Nottingham involves the use of data acquired from satellites and drones. This data is applied to address a range of environmental challenges, including natural hazards such as landslides and flooding. Recent Earth observation-based projects conducted at the university encompass various areas. These include bridge monitoring, highway surveying, flood risk asset management, monitoring of tide gauges and land movement (such as subsidence and landslides), digital surface modelling for flood inundation modelling, 3D urban modelling, and laboratory engineering model monitoring.

Through these research efforts, the University of Nottingham aims to develop cutting-edge technologies, methodologies, and applications that leverage Earth observation data to solve complex scientific and engineering problems. The strong industry links ensure that the knowledge and expertise gained from this research can be effectively transferred and utilized in practical applications, particularly in the domain of environmental monitoring and natural hazard management.

Engineering surveying and remote measurement - The University of Nottingham

Positioning and Navigation Technologies

The core of the Institute's research activity in the area of positioning and navigation has traditionally focused on satellite navigation and positioning systems. More recently, this has expanded with research and development into ubiquitous positioning and navigation technologies. These technologies utilise different grades of inertial sensors, signals of opportunity such as pseudolites, GSM/GPRS, Wi-Fi, DAB, DTV, IMES, and computer vision systems.

The current research at the Institute ranges from fundamental science to wider engineering and environmental applications, with an ever-increasing diversity. It includes network-based GNSS RTK, Precise Point Positioning, software receiver engineering, mobile phone applications, imagery-based positioning and navigation, and communications-based positioning and navigation.

The Institute's current application areas of interest for positioning and navigation research include intelligent transport systems and services, particularly autonomous driving. Additionally, location-based services and precision agriculture are areas of focus for applying the Institute's research in positioning and navigation technologies.

Through this wide range of research activities, the Institute aims to advance the field of positioning and navigation by exploring novel technologies, techniques, and applications. The expansion into ubiquitous positioning and navigation systems, combined with the Institute's traditional expertise in satellite navigation, positions them at the forefront of this rapidly evolving domain.

Positioning and Navigation Technologies - The University of Nottingham

Geospatial Science

The Geospatial Science group at the University of Nottingham engages in research across all areas of geoinformatics, resulting in collaborations with many disciplines and institutions. Their research efforts address both long-term fundamental challenges as well as shorter-term application-oriented issues.

The Nottingham Geospatial Institute (NGI) leads the UK Open-Source Geospatial domain and is actively involved in multiple Open-Source geospatial initiatives. NGI holds the position of Chair for the International

Cartographic Association (ICA) Commission on Open-Source Geospatial Technologies. Additionally, they co-chair the Open-Source GIS Conference series and are a founder member of the Erasmus IP Summer school in Open-Source GIS. NGI plays a key role in establishing and supporting Open-Source Geospatial Foundation (OSGeo) activities in the UK, including the Open-Source Geospatial Lab, which is crucial for the development of open-source geospatial software technologies, training, and expertise in the country.

Furthermore, NGI maintains an active role on several associated committees and boards, including the ICA Commission for Open-Source Geospatial Technologies, the Scientific Committee for Free and Open-Source Software for Geospatial (FOSS4G), and the GIS Research Community for The Open Source Observatory and Repository for European public administrations (OSOR).

A significant area of research focus at NGI is Location-Based Services (LBS), which are applications that register facilities and services relevant to a user's location and context, particularly those accessed by smart phones. In the early 21st century, the LBS market failed to develop fully due to factors such as the high cost of GPS-enabled mobile devices, inadequate positioning accuracy, and a lack of user-oriented data sets. However, this situation is changing, and NGI is at the forefront of LBS research.

The data required for LBS come from different sources, which have traditionally not collaborated to ensure the compatibility and interoperability of their data sets. For several LBS propositions, there are no current dependable commercial sources. While ad-hoc consumer-driven data capture approaches have evolved, they still leave issues of compatibility, completeness, and integrity.

NGI's research focuses on addressing challenges related to generalisation/schematisation/visualisation, interoperability, middleware architectures, positioning and tracking, data, and semantics. The institute collaborates with other disciplines within NGI on topics such as ubiquitous positioning technologies based on a combination of positioning inputs, improved and interoperable datasets, better usability for small screens, and semantic interoperability to enable the effective use of crowd-sourced data.

The overarching goal of NGI's research is to develop new frameworks in which location-based services can flourish, addressing the limitations and challenges that have hindered the full development of the LBS market.

Geospatial Science - The University of Nottingham

Propagation effects on GNSS

This research theme considers external influences on GNSS signal propagation before reaching a receiver on or near Earth, including the receiver's local environment and the atmosphere. The atmosphere remains the dominant error source in GNSS applications, leading to performance degradation. Therefore, the main focus is on studying the atmosphere's impact on GNSS.

From an atmospheric scientist's perspective, GNSS observational systems provide a unique platform to study the Earth's atmosphere. This synergy creates an opportunity for cross-disciplinary research and collaboration between GNSS and atmospheric sciences.

At the Nottingham Geospatial Institute (NGI), the focus is on GNSS atmospheric research to model, monitor, forecast, and mitigate the impact on end-users. Topics include monitoring water vapor in the lower neutral atmosphere (led by Richard Bingley) and studying the behaviour of disturbances in the upper charged atmosphere (ionosphere) plasma.

Regarding the neutral atmosphere, NGI has been developing near real-time (NRT) GPS processing systems since 2002, providing hourly updated estimates of atmospheric water vapor to the UK Met Office. These estimates have been included in the Network of European Meteorological Services E-GVAP project and assimilated into the Met Office's operational numerical weather prediction model. Both regional and global hourly processing systems have been developed, utilizing data from various station networks.

The latest development is a European regional sub-hourly NRT processing system, cycling every 15 minutes to reduce output latency. This allows the estimates to be used for specific weather events, such as severe thunderstorms, in addition to numerical weather prediction runs. Ongoing research is also conducted through the NERC British Isles continuous GNSS Facility (BIGF).

Regarding the upper atmosphere (ionosphere), significant research effort has been concentrated on monitoring and studying the effects of ionospheric disturbances, such as irregularities causing signal scintillation. Scintillation causes amplitude and phase fluctuations in GNSS signals, degrading positioning accuracy or causing complete signal loss.

NGI has collaborated with other experts to tackle this problem through developing detection, forecasting, and mitigation techniques. These include new algorithms for implementation in GNSS receiver firmware and improved receiver tracking models for increased robustness against ionospheric disturbances.

In-depth studies have been conducted on GNSS receiver tracking loop performance under scintillation conditions, utilising simulated and real data from high and low latitude monitoring networks, where ionospheric scintillation is most prominent. Long-term data analysis is performed to study local environment effects at individual stations and isolate multipath from ionospheric effects.

Propagation effects on GNSS - The University of Nottingham

University of Leicester

Earth observation at Leicester has a wide-ranging portfolio including, sea surface temperature measurement providing one of the primary datasets for monitoring climate change. There are also strong programmes in atmospheric chemistry, monitoring pollution, and land-use, including forestry and the effect of forest fires and the loss of peat in ecosystems.

The Earth Observation Science (EOS) group at the University of Leicester contributes to the entire cycle of Earth Observation (EO) technology development. Their work spans from fundamental laboratory-based spectroscopy research and sensor development to mission concepts, airborne demonstrators, and satellite missions. The EOS group collaborates closely with a wide range of scientific, industrial, and space agency partners to shape the future of EO and drive novel technology towards providing new data and understanding to address scientific and societal needs.

A significant part of the group's work involves laboratory-based activities to underpin their measurement science in atmospheric trace gases. In addition to evaluating the performance of new sensor technologies, they perform infrared molecular spectroscopic measurements required for the interpretation of remote-sensing data and the modelling of radiation transfer through the atmosphere. The group focuses on a wide range of molecular species, including volatile organic compounds, halogenated species like chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HFCs), and greenhouse gases such as carbon dioxide. These data are provided to international molecular spectroscopy databases like HITRAN and GEISA.

The EOS group contributes to major current and future missions, including GOSAT and Earthcare. Their flagship technology projects include the GHOST carbon dioxide and methane spectrometer, which has flown on the Global Hawk, and a range of compact nitrogen dioxide sensors, such as CompAQS and HAPI.

The group's work in this theme encompasses lab-based infrared spectroscopy and laboratory analysis of atmospheric composition, spectrometer development for atmospheric sensing of greenhouse gases and air pollution, miniaturized satellite missions, and the development of in situ and ground-based remote sensors and networks (gas sensors, radiometers, and lidars).

Earth Observation Technology, Missions, and Laboratory-based spectroscopy | Earth Observation Science | University of Leicester

GNSS Probe

The University of Leicester conducts research on Global Navigation Satellite System (GNSS) probes. These probes are designed to gather atmospheric data by tracking signals from navigation satellites as they pass through the Earth's atmosphere. The study focuses on improving the accuracy of atmospheric measurements by combining data from multiple GNSS probes. By doing so, researchers are able to gain insights into atmospheric phenomena such as temperature, pressure, and humidity. This research contributes to a better understanding of the Earth's atmosphere and has potential applications in weather forecasting and climate research.

GNSS Probe | The Centre for Landscape and Climate Research | University of Leicester

University of Birmingham

The UK Quantum Technology Hub Sensors and Timing (led by the University of Birmingham) is one of four Hubs within the UK National Quantum Technologies Programme. The Hub brings together experts from across the university, and other academic and industrial partners. Since 2014, the Hub has over 200 projects, valued at over £170 million, and has 26 patent applications. Research which involves space-based applications include the International Clock and Oscillator Network (ICON) project which brings together the best international transportable optical clocks and optical link space infrastructure to explore the limits of precision time transfer. Birmingham also has a world leading research programme that is building a new generation of gravity sensors based on quantum technology. Future spacebased versions will enable high-definition gravity maps that provide data for earth observation, environmental monitoring and navigation.

Quantum technologies (birmingham.ac.uk)

University of Cranfield

Cranfield's space system applications research includes Earth observation (EO), communications, and position / navigation / timing (PNT). In each of these domains it is the application of science and technology to solve real-world problems which is at the core of our research. Agriculture yield estimates using EO have been a long-term strength at Cranfield, developed in the UK, Europe and globally – with commercial, environmental and security applications. For communications and PNT it is the integration of these services in other systems (for example autonomous vehicles) which has been Cranfield's forte, and we have access to world-class test facilities including our airport to support this research. Cranfield's contributions to space science draw on our engineering expertise. In EO, Cranfield led the Hydroterra proposal for the European Space Agency (ESA) and provided the astrodynamics lead for ESA's Comet Interceptor mission. They are a leading UK centre for the application of biosensors and biotechnology to space missions (building on sensor development for the ExoMars rover).

Space Systems (cranfield.ac.uk)

8. Artificial Intelligence

This section examines AI research projects at Cranfield University, Loughborough University, University of Birmingham, and Staffordshire University that have applications in autonomous spacecraft, robotics, communications, and signal processing for space missions.

Key strengths:

- Cranfield's work on energy-efficient deep learning, robotic inspection, and 5G connectivity has applications in autonomous spacecraft, structural monitoring, and space communications.
- Loughborough develops autonomous vehicle algorithms adaptable for spacecraft landing and rendezvous procedures, enhancing mission safety and precision. Their robust decision-making algorithms can assist space missions.

- Birmingham's projects in robotic grasping and multi-agent collaboration are relevant for on-orbit satellite servicing, assembly, and autonomous mission coordination.
- Staffordshire's research on efficient direction-of-arrival estimation algorithms implemented in FPGAs can enhance satellite communications, space-based radar, and remote sensing applications.

The universities showcase specialized expertise in AI and signal processing with tangible benefits for autonomous space systems, robotics, communications, and navigation. Targeted investments in these research areas could accelerate AI adoption to reduce risks, lower costs, and unlock new capabilities for the space sector.

AI (Artificial Intelligence) plays a significant role in the space sector and can have a profound impact on various aspects of space investment. AI is crucial for autonomous operations of spacecraft. It enables autonomous navigation, collision avoidance, and decision-making, reducing the need for continuous human intervention. Investors can benefit from reduced mission risks and operational costs. Furthermore, space investments come with inherent risks. AI can help assess and mitigate these risks by modelling various scenarios, predicting potential failures, and optimising insurance coverage. Investors can make more informed decisions about their investments when they have accurate risk assessments.

Cranfield University

AI is rapidly increasing its energy consumption, posing a challenge globally. Cranfield University's Green Machine Learning for 5G and Beyond Resource Optimization project stands out as it aims to create energy-efficient deep learning architectures, combating this issue. Additionally, their MultiAct project, a collaboration between the UK and Canada, focuses on developing an unmanned aerial system (UAS) using active thermography to detect and locate defects in aircraft structures. This technology, applicable to spacecraft, satellites, and other space equipment, ensures thorough inspection without physical contact. Detecting flaws in spacecraft structures is crucial for mission safety and success. Furthermore, the DfT-FASS (Digital Aviation Connectivity and Security) project emphasises digital connectivity's role in evolving air travel needs and aviation industry demands, especially through the 5G Aviation Connectivity and Security project. While targeting aviation, the project's advancements in 5G technology and cybersecurity are relevant to space systems and satellite communications. Enhanced connectivity and cybersecurity are pivotal for space exploration, satellite operations, and communication with space assets. Thus, the project's outcomes could greatly benefit the space sector, improving space communication and security.

https://www.cranfield.ac.uk/research-projects/green-machine-learning-for-5g-and-beyond-resource-optimisation
https://www.cranfield.ac.uk/research-projects/green-machine-learning-for-5g-and-beyond-resource-optimisation
https://www.cranfield.ac.uk/research-projects/multiact
https://www.cranfield.ac.uk/research-projects/dft-fass-digital-aviation-connectivity-and-security

Loughborough University

Robust decision-making algorithms developed by Loughborough University can assist space missions in making critical decisions, such as course corrections or resource allocation. The research on safety assurance can help ensure the safe operation of autonomous spacecraft, reducing the risks associated with space exploration and satellite operations. One such example published in 2021 presents an optimization-based control framework for the autonomous forced landing of fixed-wing Unmanned Aircraft (UA), which could find useful application in the space sector, particularly in autonomous space vehicles and landers. This may have a range of potential applications. For example, The hierarchical MPC framework developed in this research can potentially be adapted for the autonomous landing of space vehicles, including landers, rovers,

or spacecraft returning to Earth or other celestial bodies. It allows for precise control of the landing trajectory while responding to real-time dynamics and disturbances, which is critical for ensuring safe and controlled landings in space exploration missions. Similarly, regarding spacecraft rendezvous and docking, the development of autonomous control strategies will be significant, especially in scenarios when human intervention is limited. The principles of hierarchical MPC could be applied to optimise the approach, alignment, and docking phases of spacecraft docking procedures. Given the increasing interest in Mars exploration, the research's approach to autonomous control and landing could be valuable for future missions involving Mars landers or sample return missions. Precise control during the descent and landing phases is crucial for mission success.

https://www.lboro.ac.uk/research/safe-smart-mobility/applicationareas/cavengineeringandoperations/
https://www.lboro.ac.uk/departments/compsci/research/research-themes/vahc/
https://repository.lboro.ac.uk/articles/journal_contribution/Economic_model-predictive_control_for_aircraft_forced_landing_Framework_and_two-level_implementation/17069801

University of Birmingham

The University of Birmingham's Computer Science department ranks 3rd in the UK for top research and hosts the Intelligent Robotics Lab (IRLab). One notable project, 'BURG: Benchmarks for Understanding Grasping,' aims to enhance object manipulation through detailed grasping models. This research is crucial for space exploration, where robotics handle tasks like satellite maintenance and assembly. Understanding grasping is vital for developing robotic arms and tools used in space. Investors keen on space robotics and satellite technology could benefit from projects like BURG. Another project focuses on 'Explainable Reasoning, Learning, and Ad Hoc Multi-Agent Collaboration.' It develops algorithms for long-duration autonomy in teams of different agents without prior coordination. This research is relevant to the space sector, where autonomous missions involve diverse agents operating in complex environments. Advancements in reasoning and collaboration algorithms can greatly improve space mission efficiency. Investors interested in enhancing space mission autonomy and coordination may find investing in this research area valuable.

https://www.birmingham.ac.uk/schools/computer-science/index.aspx
https://research.birmingham.ac.uk/en/projects/burg-benchmarks-for-understanding-grasping
https://www.birmingham.ac.uk/research/activity/computer-science/artificial-intelligence/intelligent-robotics-lab/projects.aspx

Staffordshire University

The University of Staffordshire's Centre for Smart Systems, AI, and Cybersecurity (SSAICS) is researching 'FPGA Hardware Implementation and Experimental Validation of Efficient DOA Estimation Algorithms.' This project focuses on developing efficient algorithms to estimate the direction of arrival (DOA) of radio frequency (RF) signals. These algorithms will be implemented on field programmable gate arrays (FPGAs) for real-time validation. DOA estimation of RF signals has wide applications in civilian and military fields, including sonar, radar, MIMO systems, and smart antenna arrays for mobile communication. The project aims to efficiently implement DOA estimation algorithms in hardware by focusing on those with lower computational complexity. This research has applications in the space sector, including satellite communication, remote sensing, and space-based radar systems. Efficient DOA estimation is vital in satellite communication systems for optimizing signal reception from Earth stations or terminals. Implementing these algorithms on FPGAs can enhance satellite communication reliability and performance, making it an attractive investment for satellite technology companies.

For remote sensing, space-based platforms with RF sensors rely on DOA estimation to identify and track RF sources on Earth's surface. Real-time implementation of these algorithms on FPGAs can improve geolocation accuracy and target tracking in remote sensing applications, appealing to investors in Earth observation and remote sensing technology. Space-based radar systems used for Earth observation, environmental monitoring, and defence applications benefit from DOA estimation for locating and tracking objects on Earth. Implementing efficient DOA estimation algorithms on FPGAs can enhance radar system capabilities, making it appealing for investors in space-based radar technology.

https://www.staffs.ac.uk/research/projects/fpga-hardware-implementation-and-experimental-validation-of-efficient-doa-estimation-algorithms

9. Data science analytics

This section examines data science research projects at the University of Birmingham, University of Warwick, University of Lincoln, Loughborough University, and Keele University that leverage advanced analytics and AI for space applications.

Key strengths:

- Birmingham provides high-performance computing infrastructure through BlueBEAR, BEAR AI, and Baskerville to empower space research and data analysis.
- Warwick focuses on AI for automation, systems reliability, Bayesian inference, and model selection, advancing autonomous systems, mission planning, and data analysis for space.
- Lincoln conducts research in automation, computer vision, HCI, and machine learning to enhance spacecraft operations, training, and space data analysis.
- Loughborough specializes in intelligent automation, lifelong learning, and manufacturing algorithms to streamline and add resilience to space manufacturing processes.
- Keele's astrophysics and galaxy research involving large datasets helps understand stellar clusters and galactic activities to inform space missions and analysis.

Universities excel in using data science and AI to extract insights from space data, benefiting space missions. Investing in these research areas can spur innovation in autonomous space systems, data analytics, and manufacturing efficiency. Data science involves using statistics, computing, and algorithms to glean insights from various data types. It's crucial for the space sector due to its interdisciplinary nature and scalability requirements. Machine learning and data mining techniques, part of data science, are vital for analysing vast amounts of space mission data, especially in satellite remote sensing and Earth observation tasks.

University of Birmingham

The University of Birmingham collaborates with the Alan Turing Research Institute and offers cutting-edge data science infrastructure through the Birmingham Environment for Academic Research (BEAR). BlueBEAR, the university's supercomputer, is designed for high-performance and energy-efficient computing, utilizing direct on-chip water cooling. It's available to all researchers at no cost. BEAR AI, an IBM POWER9 AI cluster, is one of the largest in the UK and supports advanced data science projects, including those related to space research. Baskerville, another resource, funded by the Engineering and Physical Sciences Research Council, aids modelling and data analysis with 208 GPUs, 52 Compute Nodes, and 5400 terabytes of storage. These resources enable advanced computing and data analysis at Birmingham University, benefiting space-related research, simulations, and data analysis. They support spacecraft design, remote sensing data analysis, and other aspects of space exploration and technology development.

https://intranet.birmingham.ac.uk/it/teams/infrastructure/research/bear/bluebear/index.aspx
https://intranet.birmingham.ac.uk/it/teams/infrastructure/research/bear/bluebear/index.aspx
https://intranet.birmingham.ac.uk/it/teams/infrastructure/research/bear/about-bear.aspx
https://www.baskerville.ac.uk/

University of Warwick

The University of Warwick is also a partner with the Alan Turing Research Institute and supports various AI projects that could benefit the space sector:

1. AI for Automation: Developing advanced AI, including deep reinforcement learning algorithms, for complex tasks. In space, autonomous systems are crucial for spacecraft control, navigation, and planetary exploration rovers. Advanced AI like deep reinforcement learning can improve the autonomy of space systems, making them more adaptable to challenging environments.
2. Analysing reliability in engineering systems: Studying the reliability of complex engineering systems, crucial for space missions with many components. Optimising system reliability ensures mission success and astronaut safety. Computational techniques from this research could assess spacecraft reliability.
3. Designing New Self-Tuning MCMC Algorithms: Developing self-tuning Markov Chain Monte Carlo (MCMC) algorithms for reliable Bayesian inference. Bayesian inference is used in space applications like remote sensing data analysis and spacecraft trajectory optimization. Self-tuning MCMC algorithms can improve efficiency and reliability in space research and engineering.
4. Controlled thermodynamic integral: Introducing the "controlled thermodynamic integral" approach for accurate model evidence estimation in Bayesian model comparison. Model comparison is vital in spacecraft design and mission planning. Accurate model selection is crucial for informed decisions in space-related applications.

Furthermore, ongoing research focuses on high-speed data acquisition methods, essential for monitoring rapidly changing celestial entities. This expertise is crucial for missions requiring immediate data processing, like observing transient events or studying rapidly evolving phenomena in space.

https://warwick.ac.uk/fac/sci/wmg/research/digital/datascience/
https://warwick.ac.uk/research/turing/researchimpact/improvingreliability/
https://warwick.ac.uk/research/turing/researchimpact/mcmcalgorithms/#:~:text=Adaptive%20MCMC%20is%20an%20approach,inference%20in%20these%20important%20applications.

University of Lincoln

The University of Lincoln's research in data science spans various areas, offering potential benefits for the space sector:

1. Industrial Automation and Optimisation (L-CAS): Research focuses on human-robot collaboration and autonomous systems, beneficial for industrial automation. These advancements can also apply to space exploration and robotic spacecraft operations, improving efficiency and safety.
2. Laboratory of Vision Engineering (LoVE): Specializes in image and data processing applicable to space missions, satellite imagery, and remote sensing.
3. Interactive Technologies Lab (intLab): Focuses on Human-Computer Interaction (HCI), useful for designing user-friendly interfaces in spacecraft control systems and astronaut training. Their work in immersive technologies can enhance astronaut training experiences.
4. Machine Learning Group (MLEARN): Emphasizes machine learning, data science, and AI, applicable to space data analysis, autonomous spacecraft navigation, and predictive modeling for space missions.

https://www.visioneng.org.uk/
https://www.lboro.ac.uk/departments/meme/research/research-groups/intelligent-automation/
https://www.lincoln.ac.uk/socs/research/intlab/
https://mlearn.lincoln.ac.uk/

Loughborough University

Loughborough University is deeply involved in AI research with broad applications across different sectors, including space exploration. Their research includes:

1. **Intelligent Automation**: Loughborough is a leader in developing intelligent manufacturing systems that can operate alongside humans safely. This technology can improve manufacturing processes for spacecraft and space equipment, making production more flexible and resilient.
2. **Lifelong Learning for Autonomous Systems**: As part of the STELLAR project, the university is involved in teaching AI systems to learn new tasks while retaining previous knowledge. This innovation could lead to more adaptable and intelligent robotic systems for space exploration and maintenance.
3. **Reconfigurable Robotics for Responsive Manufacture**: Loughborough collaborates on a project exploring new methods for manufacturing resilience. This includes developing algorithms to automate program and configuration data generation, reducing the need for human intervention. In the context of space, this technology can streamline equipment manufacturing processes.

Loughborough's expertise in AI, data mining, and autonomous systems has potential applications in the space sector, including satellite remote sensing, mission planning, and computer vision. Investors in space-related ventures may find value in leveraging Loughborough's research to advance space technology and exploration.

https://www.lboro.ac.uk/departments/meme/research/research-groups/intelligent-automation/
https://www.lboro.ac.uk/departments/compsci/news/2021/project-ai-systems-to-learn-from-each-other/
https://www.lboro.ac.uk/research/internationally-recognised/high-value-manufacturing/digital-manufacturing/#:~:text=Reconfigurable%20robotics%20for%20responsive%20manufacture&text=Together%20with%20industrial%20partners%20we,need%20for%20significant%20human%20input.

Keele

Keele University conducts data science research with relevance to the space sector, especially in astrophysics and galaxy studies. Their research includes:

1. **Stellar Cluster and Association Studies**: Keele investigates the formation and dynamics of star clusters and associations, vital in understanding star and planet formation. They analyze data from telescopes like Gaia, providing precise observations of celestial structures.
2. **Active Galaxies Research**: Keele explores how galactic activity influences galaxy evolution and the Universe's reionization. They examine data from various surveys across different spectra, such as ultraviolet, optical, infrared, and radio.

https://www.keele.ac.uk/about/news/2022/july/keele-galaxies/astronomers-keele-map.php#:~:text=Now%20the%20data%20is%20being,National%20Astronomy%20Meeting%202022%20conference.
https://www.keele.ac.uk/research/ourresearch/chemicalandphysicalsciences/astrophysicsanddatascience/#!

10. Energy

This section examines energy research across Cranfield University, University of Warwick, Loughborough University, University of Nottingham, Keele University, and University of Wolverhampton covering areas like propulsion, power generation, storage, and sustainability.

Key strengths:

- Cranfield's gas turbine and engine inlet research can enhance spacecraft propulsion efficiency and performance.
- Warwick focuses on batteries and power electronics for applications like EV wireless charging relevant for spacecraft power systems.
- Loughborough specializes in combustion and aerothermal research to optimize rocket engine and spacecraft design. Their solar cell advances improve spacecraft power generation.
- Nottingham develops batteries suited for space use, like lithium-sulfur batteries that are lighter than lithium-ion. This aids weight-sensitive space tech.
- Keele improves electrocatalysis for sustainable fuel generation from waste, helping reduce space sector's carbon footprint.
- Wolverhampton works on energy harvesting, conversion, and storage technologies to enable sustainable power for remote space missions.

The universities exhibit capabilities to advance space propulsion, power, and sustainability through specialized energy research. Collaboration and investment opportunities exist to drive forward energy innovations tailored for space applications.

The Midlands region is a leading hub for the energy sector, employing a significant portion of the industry's workforce and contributing billions to the UK's economy annually. The region's robust research efforts drive innovation across various energy-related fields, including applications and storage solutions. The energy-intensive nature of the space sector relies heavily on advancements in energy technologies, making the Midlands' expertise crucial for space sector investments. The region offers abundant expertise that can be further developed to attract effective investments. In addition to university research, the Midlands hosts established research clusters like the Energy Research Accelerator (ERA). This collaborative hub involves several universities and research institutions, including Aston University, the University of Birmingham, the British Geological Survey, Leicester University, Loughborough University, the University of Nottingham, and the University of Warwick. ERA focuses on diverse research areas such as new battery chemistries, electro-mechanical behaviour, second-life applications, supercapacitors, and high-rate chemistries.

Cranfield University

The SINATRA project, led by Cranfield University and funded by the EU's Horizon 2020 program, aims to advance non-intrusive inlet flow distortion measurements for modern civil aero-engines. Traditional methods struggle to accurately assess engine stability due to unsteady distortions, which can harm performance. Current intrusive techniques, like seeding the inlet flow, are costly and complex. The project addresses these issues by developing non-intrusive measurement techniques, crucial for airborne testing. SINATRA could transform distortion measurements in aero-engine development, offering a cutting-edge testing facility. This will help researchers optimize engine performance in new aircraft designs, potentially leading to more efficient and eco-friendly propulsion systems for the aerospace and space sectors. The outcomes may also benefit military aviation and space exploration. Similarly, the NIFTI project, also by Cranfield University and funded by the EU's Horizon 2020 program, focuses on non-intrusive inlet flow distortion measurements for civil aero-engines. It aims to overcome limitations of intrusive pressure measurements by developing a non-intrusive technique using Particle Image Velocimetry (PIV). This could enhance understanding of flow distortions,

benefiting spacecraft propulsion and aerospace research. The high spatial resolution of these techniques could be valuable for studying aerodynamics in space-related applications like spaceplanes and re-entry vehicles.

https://www.sciencedirect.com/science/article/pii/S0376042122000057
https://www.sciencedirect.com/science/article/pii/S0376042122000057
https://www.cranfield.ac.uk/research-projects/sinatra
https://www.cranfield.ac.uk/research-projects/nifti

University of Warwick

Within the Energy Research Accelerator (ERA), the University of Warwick hosts the Energy Innovation Centre, dedicated to leading Midlands-based research in battery storage technologies. With a substantial £20 million funding, the centre has broadened its research scope to encompass electrochemical materials and the development of customized power electronic converters for various applications, such as EV wireless charging, V2X, and battery systems. In collaboration with the Faraday Institution, WMG (formerly Warwick Manufacturing Group) at the University of Warwick has secured a portion of £29 million in funding to advance insights into electrochemical energy storage. The three WMG research projects focus on Extending Battery Life, Battery Modelling, and Battery Safety. Recent investigations have particularly explored batteries in extreme conditions, including storage post-freezing.

- https://warwick.ac.uk/fac/sci/wmg/about/facilities/energyinnovationcentre
- https://warwick.ac.uk/newsandevents/pressreleases/?newsItem=8a1785d88747430f01874b843e280940
- https://wrap.warwick.ac.uk/170794/

Loughborough University

The National Centre for Combustion Aerothermal Technology (NCCAT) at Loughborough Science and Enterprise Park, funded by a partnership including the Aerospace Technology Institute, Department for Business, Energy & Industrial Strategy, and Rolls-Royce, boasts cutting-edge facilities for researching gas turbine combustion systems:

- The centre features an 850m2 purpose-built laboratory with eight new test cells.
- It houses specialized equipment for single-phase and two-phase, non-reacting and reacting flow experiments under various conditions, including sub-atmospheric, atmospheric, and elevated pressures and temperatures.
- Accessible instrumentation includes standard aerothermal measurement techniques, advanced laser diagnostics, fuel injector evaluation techniques, and gas sampling/analysis systems.
- Additionally, there's a 100m2 workshop with manufacturing equipment to service the test cells.

The research conducted by NCCAT spans fluid mechanics, combustion, and aerodynamics. Areas of expertise include low emission combustor designs, fuel injector technology, aeroacoustics, combustion instabilities, and cooling technologies. These insights directly contribute to the development of advanced rocket engines and thrusters for space propulsion. Furthermore, NCCAT's understanding of aerodynamics and heat transfer is vital for spacecraft design, ensuring safety during launch and re-entry, and optimizing launch vehicle efficiency. In summary, NCCAT's research capabilities hold promise for enhancing propulsion systems and spacecraft performance in the space sector.

Loughborough University also conducts significant research in solar energy, particularly focusing on solar hydrogen generation and advancing thin film photovoltaic devices. Their goal is to make solar energy more cost-effective and efficient by improving thin film solar cell technology, manufacturing processes, and coatings. This research contributes to renewable energy efforts and finds application in space missions where solar panels power spacecraft systems. Notable achievements include setting world records for solar cell efficiency, insights into improving device performance, and advancements in manufacturing methods and coatings. These efforts aim to enhance solar-generated energy and address issues with current solar panels, ultimately advancing solar technology for space exploration and beyond.

https://www.lboro.ac.uk/research/crest/research/groups/pv-materials-devices/
https://www.lboro.ac.uk/research/nccat/
https://www.lboro.ac.uk/research/nccat/capabilities/
https://www.lboro.ac.uk/research/crest/research/groups/pv-materials-devices/
https://www.lboro.ac.uk/departments/aae/research/electric-vehicles-advanced-propulsion/

University of Nottingham

The University of Nottingham's research initiatives, funded through ERA and the Faraday Institute, are pivotal in advancing energy storage technologies uniquely suited to the rigours of space exploration. These efforts not only enhance the capabilities of space missions but also offer broader benefits, including reduced resource dependencies and heightened efficiency across various sectors, including aerospace.

This research has been awarded £20m as part of the ERA programme, which has significantly expanded these facilities. Additionally, earlier this year the university research was awarded a further £5 million funding for its research within the Faraday Institute, specifically the Faraday Institution's LiSTAR (Lithium-Sulfur Technology Accelerator) project. One aspect of this funding will be used to expand the University of Nottingham's work within Li-S batteries, using lighter materials than in conventional Li-ion batteries, making it promising for weight-sensitive technologies such as the space sector. This also has the added benefit of working to reduce the UK's dependence on some of the critical elements used in Li-ion batteries, such as Cobalt.

https://www.nottingham.ac.uk/news/next-generation-battery-research-strengthened-with-5m-funding
http://www.faraday.ac.uk/six-projects-reshaping/

Keele University

Keele University has been working on improving a system of sustainable electrocatalysis in order to generate fuels and chemicals from greenhouse gases and waste streams using electrolysers to increase production with reduced costs, through implementing novel catalysts for electrocatalytic conversions. By developing a more efficient electrocatalytic system, the research helps reduce greenhouse gas emissions. This is critical for sustainability as the space sector aims to minimise its carbon footprint, especially during rocket launches and spacecraft operations. This research will ensure greater fuel efficiency for sustainable practice within the space sector, as it can lead to more environmentally friendly and cost-effective space exploration, ultimately contributing to the long-term sustainability of space activities. Sustainable practices ensure the long-term viability of space exploration. By reducing waste and emissions, and by optimizing fuel efficiency, space missions become more sustainable and can continue to advance without depleting resources or causing excessive harm to the environment.

https://www.keele.ac.uk/research/ourresearch/chemicalandphysicalsciences/materialsscienceandrenewableenergy/#sustainable-electrocatalysis-(charlie-creissen)

University of Wolverhampton

The University of Wolverhampton's Centre for Engineering, Innovation and Research is currently researching GreenTech, including but not limited to energy storage and batteries; Energy harvesting/conversion and biofuel production; hydrogen and solid oxide fuel cells. Advancements in these technologies can enhance the capabilities and sustainability of space missions, making them more cost-effective and reliable. For example, space missions often operate in remote and extreme environments where traditional power sources may be limited. Energy harvesting and conversion technologies can be used to harness energy from sources like solar radiation, kinetic energy, or thermal gradients, providing sustainable power sources for space missions. Compact, lightweight, and long-lasting batteries are crucial for powering space probes, spacecraft, and scientific instruments. Research in battery technology can contribute to the development of high-performance batteries for space applications.

https://www.wlv.ac.uk/research/research-centres/centre-for-engineering-innovation-and-research/energy-and-green-technology-group/