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Maximising value from UK academic research – the UK-Aerospace Research Consortium theme approach

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Abstract

The UK-Aerospace Research Consortium of UK universities has set up 6 research theme groups that are analysing research state-of-the-art, needs and capabilities. These themes address technology, fuels, and system/operational challenges to deliver zero carbon aviation. Narratives are informing future research following consultation with UK and international experts in industry and government.

Keywords: universities, research, collaboration, sustainability, impact

1. Introduction

As aviation transitions to new technologies to address its climate change impacts, the need to leverage the lower TRL research capabilities of universities has never been greater.

Aviation accounts for around 2.5% of global carbon dioxide (CO2) emissions as well as being a contributor to other non-CO2 emissions and these impacts will grow unless concerted action is taken. The value to society generated through air transport is under threat if new low and zero carbon technologies are not implemented rapidly. The UK-Aerospace Research Consortium (UK-ARC) [1] is taking a whole system approach to understanding the optimal research strategies for evolutionary and revolutionary technology development and adoption. The UK-ARC has initiated a number of research theme groups that look at needs and challenges in the areas of:

- More Fuel / Energy Efficient Aircraft
- Electrification
- Hydrogen
- Sustainable Alternative Fuels
- Materials and Manufacturing and
- Air Transport

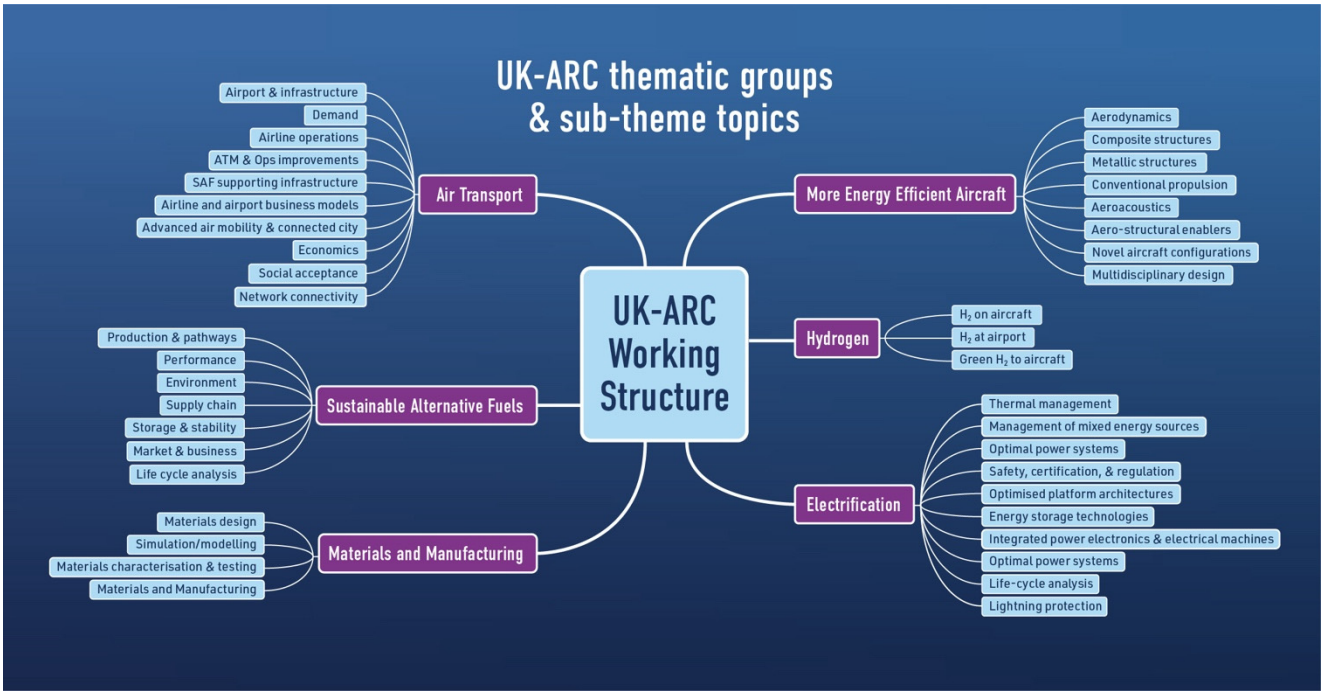
Research narratives in each of these areas are being developed during 2022, drawing upon UK-ARC academic expertise and that of other contributing UK universities that are part of the wider network. These narratives which will examine the UK-ARC university knowledge base and account for sector roadmaps will then be explored with the industry and operators, with government and organisations such as the Aerospace Technology Institute (ATI) [2]. These baseline positions will also be used in discussions with international collaborators. The goal is then to define, prioritise and undertake collaborative value-added and impact-driven research that assists and accelerates the aviation sector's journey towards net zero operations. This paper sets out some of the developmental thinking in these six theme areas.

2. UK-ARC Theme Groups

2.1 Theme Group Structure

Following initial discussions with the theme groups, a broad structure for investigation has been

determined. This captures the current six themes and sets out a number of sub-themes as shown in the figure below:



2.2 More Fuel / Energy Efficient Aircraft MFEEA) theme

At the integration level, the **More Fuel / Energy Efficient Aircraft (MFEEA) theme** is focused on the development of technologies to enable more fuel / energy efficient aircraft through improved aerodynamics, reduced structural weight, better conventional powerplant and exploitation of the interactions between these three disciplines. Even with the move towards electric / hydrogen powered aircraft, using less energy will be a very desirable goal regardless of the form of propulsion.

This theme is concentrating upon technologies that enable less environmental impact through a number of specific design and structural research areas including development of better high and low fidelity aerodynamic modelling methods and improved designs to enable higher lift / drag ratios. Development of novel composite and metallic materials to enable lighter aircraft structures combined with better manufacturing / design processes to enable better structures also features within this theme though it also connects with the Materials and Manufacturing theme.

Also captured under the MFEEA theme development of structural enablers/concepts to enable improved performance through technologies such as morphing, laminar flow, flow control, loads alleviation, aeroelastic tailoring and flutter suppression. That is in addition to consideration of development and evaluation of non-traditional aircraft configurations e.g., blended wing bodies, high aspect ratio wings, forward swept wings, joined wings, etc. Linked to design/structural developments is improved designs of conventional aircraft powerplants – e.g., higher By-Pass ratios and better propellers – and this angle is being addressed related to conventional gas turbine engines, aside from consideration being given in other theme groups to the electrification and hydrogen. Of course, noise remains a challenge for all designs and configurations so development of more accurate aero-acoustic prediction software and mechanisms to control noise generation and levels is part of the theme. A linked topic is development of on-board systems that use less energy (heating, food, entertainment etc.).

Development of improved multi-disciplinary design capabilities to exploit the above individual topics in a synergistic way, either between two research topics or the combination of several. At the final level, the inclusion of all the topics needs to be combined in some way to influence designs from the start, rather than as an add on at the end of the design process. This final item

would not only bring together all of the topics in this theme, but also reach out and interact with the other UKARC themes.

Whilst discussions in the group are ongoing, a number of priority areas are emerging:

Topic	Top 3 research priorities
Aerodynamics	Aerodynamic testing and correlation with numerical models High and low fidelity aerodynamic modelling methods Aerodynamic shape optimisation
Structural Enablers	Alternative fuel storage Morphing and multifunctional structures Composites for aeroelastic tailoring
Propulsion	Hybrid Powered aircraft All-electric aircraft Hydrogen fuel cells
Novel configurations	Fast evaluation of different concepts at conceptual stage Distributed propulsion designs Pathways to certification for novel configurations

2.3 Hydrogen theme

The New design and aero-structural developments will certainly feature in the **Hydrogen theme group** which aims to expedite entry into service of H_2 fuelled aircraft. Based upon an analysis of factors influencing attainment of this goal and liaison with stakeholders addressing the hydrogen adoption challenge for other sectors, the UK-ARC Hydrogen theme group aims to identify and deliver world-leading research and innovation, ranging from fundamental numerical analyses to low and high TRL experimental studies. This theme is broken down into three sub-theme areas:

1. *H_2 in the aircraft:* This comprises H_2 aircraft design and performance analyses, H_2 propulsion system design integration and performance analyses, Low NOx H_2 combustion research, LH_2 tank design, manufacturing, and aircraft integration, LH_2 tank fluid movement modelling, sensors and gauging, thermal management, and control. Advanced materials and manufacturing will also be a key focus with links to the UK-ARC Material and Manufacturing theme. The research will also extend to technoeconomic environmental risk analyses of LH_2 aircraft at both mission level and over the life cycle (including contrail assessments).
2. *H_2 in the airport:* This sub-theme covers assessments related to H_2 aircraft ground operations and airport infrastructure as well as H_2 safety at aircraft, airport (storage and refuelling) and operational level.
3. *H_2 to the airport:* This will comprise H_2 production and liquefaction including seawater electrolysis to protect freshwater supplies as well as broader outreach to other sectors e.g., automotive, marine, nuclear and stationary gas turbines given the potential for knowledge transfer on the hydrogen topic.

The sub-are area making greatest progress is ‘H2 in the aircraft’ sub-theme for which discussions are focused in the areas of H2 propulsion system design, integration, and performance analysis (gas turbines (including advanced cycles – intercooling, recuperation, pressure rise combustion etc.), fuel cells, hybrid, and turboelectric and distributed propulsion). H2 storage is also a significant topic where tank design, tank fluid movement, thermal management and solid-state storage are all being considered. This aspect also relates to the work being undertaken within the Materials and Manufacturing theme group. Additional topics where research is anticipated are low NOx H2 combustion and contrail modelling/aircraft trajectory modelling and also certification.

Hydrogen storage also appears in the ‘H2 at the airport’ sub-theme where it is linked to safety discussions that include refuelling and infrastructure support and operations.

2.4 Electrification theme

The Aerospace Electrification is an important option in reducing the overall environmental impact associated with air travel and freight transport in the future through the development of both fully- and hybrid-electric propulsion configurations, along with a move to more-electric aircraft with the potential for weight saving and therefore a reduction in fuel consumption.

The **UK-ARC Electrification theme group** is working to bring together the leading UK Aerospace Electrification research institutions and has linked with ATI developed research roadmaps that bear upon electrification. Whilst the work of the group is ongoing, workshop discussions have defined a number of sub-theme topics upon which consideration is focused:

- Thermal management
- Management of mixed energy sources
- Optimal power systems
- Safety, certification, and regulation
- Optimised platform architectures
- Energy storage technologies
- Integrated power electronics and electrical machines
- Optimal power systems
- Life-cycle analysis
- Lightning protection

UK-ARC universities have set out in some detail the areas of research in which they are engaged that relate to electrification to build up a map of topics where complementary work is appropriate and that feed into a broader understanding of challenges and potential solutions. A number of issues that are part of enabling electrification are being considered including different metrics for electric aircraft, such as aircraft level life-cycle analysis and identifying assessment requirements for component-level, system-level, and aircraft-level technology. As well as looking at the research challenges, the UK-ARC Electrification theme group is identifying the current UK aerospace electrification research capabilities and test facilities and examining the trajectory for academic research in the context of both the national and international aerospace electrification landscape. An intended outcome of the work of the group is to link beyond the UK and raise awareness of UK academic capability globally.

Significant challenges to be addressed to enable widespread adoption of electrification technologies, include an increase in power density for electrical machines and associated power electronics, while an increase in capacity and energy density for storage options is required to increase range and reduce overall system weight. There is potential for advancement in many areas to support this including sub-system, system and platform integration, thermal management, manufacturing, and materials, which highlights the importance of linkages and synergy with other UK-ARC theme groups.

The electrification theme is led by the University of Nottingham which is also championing a separate independent activity on aviation electrification. This is the Solutions for Aerospace Electrification Leadership (SAEL) [3] initiative which is addressing largely similar challenges but involving industry and regulators in the UK and beyond. Two UK-ARC universities are supporting SAEL and the expertise they contribute to SAEL also helps bring strong UK capability to the UK-ARC theme group.

2.5 Sustainable Alternative Fuels theme

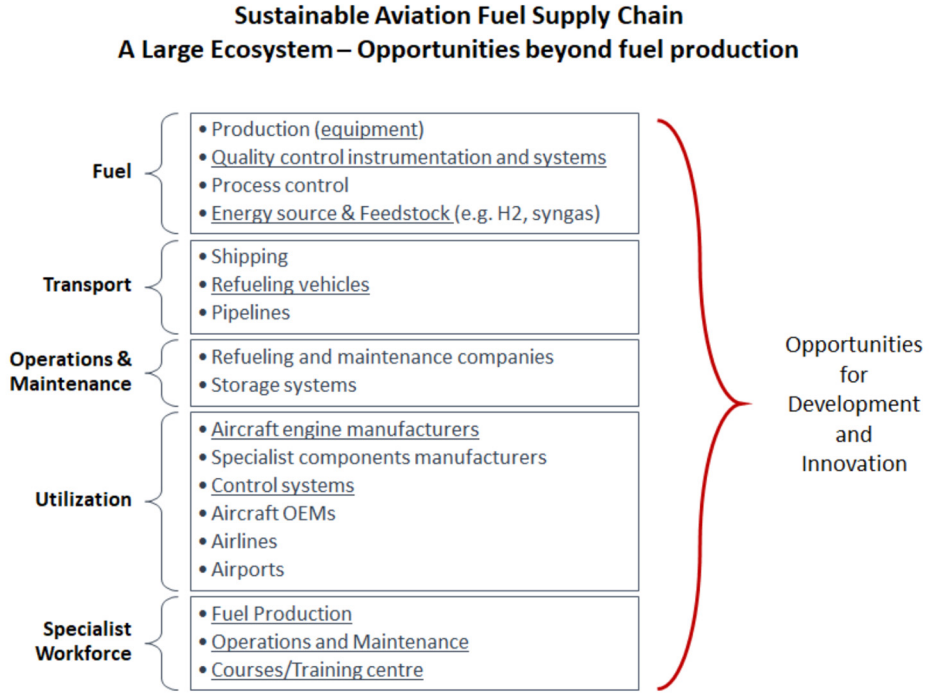
Sustainable alternative fuels (SAF), like hydrogen and electrification is part of the strategy

towards net zero aviation. The **UK-ARC Sustainable Alternative Fuels theme** has several strands of activity that largely reflect the way that the UK government is examining the feasibility of SAF roll-out. At the technical level, the theme is looking at production pathways for bio- and e-fuels, their composition, and their operational performance. Emissions characteristics are also being considered for different fuels to understand NOx, particulate matter (PM) and contrail/induced cirrus formation. Feedstock availability, supply chain logistics and transportation and storage/stability also form part of this analysis.

Important non-technical analysis and research also form part of the feasibility work towards SAF adoption in meaningful quantities. The theme group also has within its scope, issues of market constraints, business models, competition with other users of SAF, economics linked to production costs, pricing and market incentives that will support transition from fossil fuels. The role of policy and regulation is a key factor in this transition phase so forms part of the group's consideration. The theme addresses research needs related to the importance of lifecycle carbon analysis which is essential to ensure the desired reduction in carbon emissions is achieved.

Any new fuel must undergo significant 'fit for purpose' testing with increasing cost and fuel volumes through a four-tier process. Any future fuels research is therefore dependent upon well-equipped campus laboratories. The UK-ARC SAF has therefore set up a virtual fuel centre comprising expertise and facilities from leading institutions. This includes access to pilot-scale state-of -the-art validation/certification of SAF to support researchers and stakeholders through the early stages of fuel testing.

The industrial areas related to SAF were divided as such: end-users, production and refining, raw material, technologies, infrastructure, design and build, fuel testing and certification. A visual representation is provided below to highlight the areas within the supply chain being examined by the ARC-SAF theme:



The significance of the work of the UK-ARC SAF theme is emphasised by the profile being given to SAF by the UK government through the Jet Zero Council initiative to establish technological, operational and SAF pathways to achieving net zero aviation by 2050. UK-ARC SAF experts are contributing this activity and the scope of research areas, as illustrated above, shows the importance of innovation in delivering advances in this theme area. Discussions are ongoing

within the SAF group.

2.6 Materials and Manufacturing theme

The **Materials and Manufacturing UK-ARC theme** has been assessing existing UK-ARC capabilities and expertise in order to establish strategic priorities for future research, investment and capability development required to enable the move towards new structures, electrification, and hydrogen propulsion systems in aviation. Existing capabilities have been grouped in four key areas: materials characterization and testing; material design; simulation and modelling; and manufacturing as shown in Figure 1.

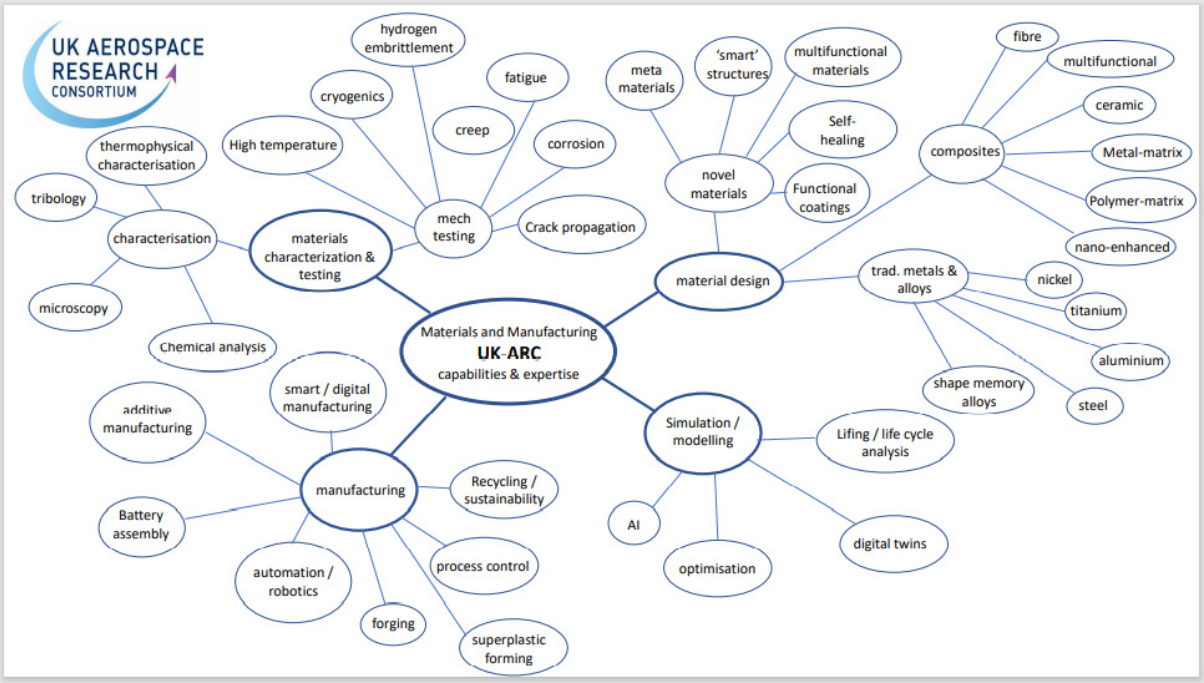


Figure 1 – Existing capabilities and expertise in materials and manufacturing across the UK-ARC network

As an example, key areas that will require an expansion of expertise and capability in the future to meet the needs of the development of hydrogen propulsion systems include hydrogen embrittlement and permeation modelling and materials characterization and behavior under cryogenic conditions on and off aircraft. Further facilities will be required to enable cryogenic materials testing. The group has also determined that further research will be required in relation to composite/multi-materials solutions to liquid hydrogen storage and the same applies to metallics but such work is hampered by the lack of materials data representative of in-service conditions.

The move towards electrification also opens up materials issues associated with the possibility of novel dry wind designs and the development of thinner wings and morphing technologies. The group is also considering materials issues linked to light weight motors such as aluminum windings and insulation. Materials questions also arise in relation to passenger comfort and noise/vibration by addressing potential of materials science to deal with damping and absorption.

The materials and manufacturing theme group is also exploring research needs linked to materials design. This falls into a number of subtheme areas. On sustainable (bio-based/and natural) materials weight saving potential exists though use of natural fibres is thermoset/thermoplastic composites for secondary structures. Such fibres can also be exploited on account of positive vibro-acoustic properties. Opportunities also exist in relation to bio-based materials to achieve anti-scratch, damping and antimicrobial/antiviral properties. Smart/meta materials can assist with transition to hydrogen or electrified aircraft on account of

structural load and electro-chemical energy storage potential. Additive manufacture will continue to be a strong fucus for research linked to some of the issues noted above and there is growing interest in graphene nanocomposites which offer the prospect of enhanced materials characteristics and performance.

An important facet of materials science development is life cycle analysis. From raw materials to supply chains and recycling, research is required to determine the integrated impact of materials developments under consideration. The same applies in relation to manufacturing techniques and approaches. The Materials and Manufacturing theme has made good progress in laying out the broad landscape and the challenges on a range of topics and is progressively defining the right research projects strategy to support the sector.

2.7 Air Transport theme

Realising the benefits of aerospace technology advancements is dependent upon the global aviation system being ready to implement sometimes dramatic changes. That means airport infrastructure, business models and operational practices are likely to be altered and there are socio-economic impacts that need consideration. The **Air Transport UK-ARC theme** focuses on these system and operational enablers for rolling out new platforms and practices into the sector. It also addresses changes in aviation economics and business models, the regulatory environments that the sector operates in, and also demand side behaviour.

Based upon an analysis of research needs and current activity/capability, the network of researchers within this theme group aim to develop compelling and impactful projects that would enable lower climate impacts through operational, policy, and behavioural changes. The first stage is information gathering and the production of a research needs narrative in consort with government, industry, the wider academic community to help research prioritising. A key UK development in this respect is the establishment of the Jet Zero Council [4] which seeks to strengthen the academic research link into addressing the aviation climate challenge. Universities are working to identify the optimal response pathways to bridge the gap between fundamental technological developments, industry application and system implementation.

As alternative fuels become available, airport logistics and infrastructures will need adjustment and optimisation. Airline business models will change to reflect different cost environments, and operations will need further optimisation. The demand environment for airline services will also evolve as passenger purchasing become more environmentally informed, the air cargo business changes to reflect changes in global demand and purchasing behaviours. An important new dynamic is the advent of Advanced Air Mobility (AAM) which encompasses a number of research challenges new to air transport. Summarising the scope of research needs, capability, and future project plans of this air transport theme, it is addressing:

- Airport and infrastructure
- Demand
- Airline operations
- Air Traffic Management modernisation and operational improvements
- The infrastructure and logistics in widespread adoption of SAFs
- Airline and Airport business models
- Advanced Air Mobility and the connected city
- Economics
- Social acceptance of change including new technologies

This group started work sometime after the other groups so this activity is still at a developmental stage.

3. Discussion and conclusions

Benefits of broad analytical approach

There are strong connections between all these themes which jointly comprise the system for delivery of cleaner aviation in the future. Accordingly, there will progressively be stronger interaction between the themes to ensure complementarity, connection, and avoidance of duplication. The resulting output will represent a 'blueprint' for research that will accelerate adoption of net zero technologies and support industry ambitions.

It is important to note that the scope of the UK-ARC theme group activity is not set as additional theme may fall out of what is being done at present to give some sub-themes greater profile, to build linkage with the atmospheric science community and to account for the connections beyond the UK-ARC community into sectors which are addressing similar issues. This paper therefore summarises the current focus of the UK-ARC theme groups but it is likely that additional topics will be added. This work will be matured during the first half of 2022. On account of the growing importance of non-CO2 emissions, as noted above, it is important to forge effective links to the science community, primarily those seeking to understand the upper atmospheric impacts of aviation but also with experts who are looking at the implications of change upon local air quality and health impacts.

These UK-ARC initiatives are intended to ensure an inclusive and comprehensive set of theme narratives and an overarching integrated viewpoint that can be discussed with the sector and government to ensure aligned research agendas. The key output is new research projects that serve sector advancement with reduced adverse impacts – projects are being discussed as the dialogue matures. The engagement aspect of research theme development relates not only to engagement within the UK but also internationally where there will be similar programmes of research needs analysis. The UK-ARC will engage internationally to help promote coordination and maximise the potential for joint research activity. The maturing UK-ARC research narratives will therefore be used to help build cross-community consensus on the way forward.

The strong contributions of the UK-ARC universities, especially the theme leads, is duly recognised in the work of these groups so far. It is also important to acknowledge the contributions of other UK universities to the theme groups as these universities are also addressing research in the same areas and they have notable expertise to contribute to the solutions needed to enable sustainable aviation. UK-ARC seeks to draw in such expertise to widen the network.

The founding UK-ARC universities are:

References

[1] https://www.ukarc.ac.uk/

[2] https://www.ati.org.uk/

[3] University of Nottingham Solutions for Aerospace Electrification Leadership (SAEL) https://www.nottingham.ac.uk/aerospace/projects/sael-initiative/index.aspx

[4] https://www.gov.uk/government/groups/jet-zero-council
