DECARBONISATION THROUGH DIGITALISATION: HOW CAN DIGITALISATION ACCELERATE THE DECARBONISATION OF THE FUTURE OF AVIATION?
ADS is the UK trade association for aerospace, defence, security and space. ADS’ more than 1,100 strong membership includes companies from across the value chain who are at the forefront of developing the future. Overcoming the challenges and opportunities of the future of aerospace is the day-to-day operations of the UK aerospace industry, and the optimism and drive of the ADS membership will decarbonise aviation on the global stage.

ROLAND BERGER is a global consultancy with offices in all major markets and industries, providing expertise on major strategic topics. Roland Berger is a leader in Aerospace & Defence, delivering measurable results for clients across the value chain from OEMs to suppliers to MRO providers. Roland Berger is also a leader in how the aerospace and aviation ecosystem will undergo the sustainability transition to net-zero and to true zero. Driven by our values of entrepreneurship, excellence and empathy, we at Roland Berger are convinced that the world needs a new sustainable paradigm that takes the entire value cycle into account and enables us to meet the profound challenges of today and tomorrow.

Dassault Systèmes, the 3DEXPERIENCE® Company, is a catalyst for human progress. We provide business and people with collaborative virtual environments to imagine sustainable innovations. By creating ‘virtual experience twins’ of the real world with our 3DEXPERIENCE platform and applications, our customers push the boundaries of innovation, learning and production. Dassault Systèmes’ 20,000 employees are bringing value to more than 270,000 customers of all sizes, in all industries, in more than 140 countries.

Note from Contributors:
ADS, Roland Berger, and Dassault Systemes have come together to develop this report to bring attention to an important issue: digitalisation as a driver for decarbonisation in the aerospace sector. Not only will digitalisation be essential to enable the change, but it can be a major accelerant: to help ensure safety, accountability and add pace to the transition to a sustainable future. As contributors to this report, ADS brings a broad understanding of the industry landscape, Roland Berger brings its industry-leading perspective on how the aerospace and aviation sectors will decarbonise, and Dassault Systemes are leaders in sustainability with over 40 years of extensive industry expertise in delivering cutting-edge solutions.
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Aviation needs to accelerate its decarbonisation if it is to meet its net zero by 2050 commitments. If commitments are to stay on track, it is clear that disruption will play a significant role in expediting those decarbonisation efforts. In April 2020, airline capacity reduced by 75% due to the global coronavirus pandemic, a crisis which led aviation experts to outline structural changes that could rebuild the industry and materialise their long-time low-carbon aspirations. However, emission reduction targets were nothing new, having already been established in 2000 through the ACARE (Advisory Council for Aviation Research and Innovation) vision 2020 goals (which has now become the ACARE Flightpath 2050).

Beyond the ‘what’ and the ‘why’, the inevitable question the industry needs to answer today is the ‘how’. Digitalisation, that’s how. It may not be the entire answer, but digitalisation will clearly be an accelerator and key enabler for the decarbonisation of the industry as it searches for that sustainable model.”

-Professor Rab Scott
Director of Industrial Digitalisation
University of Sheffield
Advanced Manufacturing Research Centre (AMRC)
Decarbonising aviation is now on the agenda of every executive in the aerospace industry. The pandemic and related disruptions have led aviation experts to outline structural changes that could rebuild the industry enable their low-carbon aspirations.

That said, decarbonising the future of flight is easier said than done. Without a proper ecosystem to address and implement end-to-end low-carbon operations and infrastructure, the industry’s revenue models could be at risk.

While there are many possible technological levers today such as green hydrogen or electric aircraft, the industry is now focusing on building the right expertise around the industrialisation of these new technologies and building the right ecosystem of partners to deliver them at scale.

This report focuses on how digitalisation can help accelerate decarbonisation and aims to offer tangible recommendations to translate current efforts into consistent zero-carbon precision for aircraft.

### THE SKY’S THE LIMIT FOR AVIATION DECARBONISATION

Decarbonising aviation can be complex and challenging – but it does not have to be. In fact, as seen below, low carbon possibilities are endless with the right solutions.

<table>
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<tr>
<th>Year</th>
<th>eVTOL</th>
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Credit: Dassault Systèmes
3. WHY IS DIGITALISATION CRUCIAL FOR THE DECARBONISATION OF FLIGHT?

KEY HEADLINE INDICATORS

The aerospace industry is on the precipice of one of the most dramatic evolutions of the way we fly in the century since humans first took flight.

As the need to take action to protect the climate becomes clearer and clearer, industry is responding with the same dedication that has driven substantial improvements in safety and efficiency over the past century.

New propulsion systems, whether electric, hybrid, or hydrogen, will represent the biggest shift in aviation technology since Frank Whittle’s jet engine. Aircraft profiles may soon look unfamiliar, with innovative new concepts such as a blended wing body and a transonic truss-braced wings. These kinds of developments will make the conventional aircraft of the future stand out not only visually, but from a sustainability perspective too, reshaping aviation’s environmental image.

ECOSYSTEMS & BUSINESS MODELS

While the aircraft that take us between London and New York will look and behave very differently in the future, there is a wider revolution about to unfold, as automotive-inspired advancements in batteries and electric motors comes to the world of aerospace.

Investments in novel technologies will unlock entirely new business models, markets, and industries, driving new ideas of how the skies above us could be used to better connect us all. The new world of Advanced Air Mobility (AAM) covers everything from flying taxis to delivery drones, taking advantage of evolving battery technology and the promise of a decentralised aviation network, unlocking new and unheard-of routes.

With innovative ideas and technologies will come new methods of manufacturing and producing aircraft at higher production volumes, requiring supply chains to be more resilient. Globally, there is a renewed need to invest in supply chains, to support future technology needs and for regulators to keep pace with developments to bring goods to market.

INVESTING IN INFRASTRUCTURE

In order to supporting future flying capabilities and technologies, there needs to be investment in the required infrastructure that will support the future of both aerospace and aviation across the globe. Global standards will be a minimum for the propulsion systems of the future: a zero-carbon hydrogen flight will require standardised infrastructure at departure and arrival airports.

Looking ahead, airports are considering how new aircraft shapes can fit into gates and stands designed for conventional tube-and-wing aircraft, and what this may mean for investment in ground infrastructure over the coming decades.

For regional and intra city flights, which will mostly likely be electric, a whole new type of infrastructure will be required. New vertiports, small, city-based hubs for take-off and landing, could sit alongside pre-existing general aviation airfields to create a comprehensive, deeply connected aviation ecosystem. Digitalisation will aid the progress of infrastructure development with a more streamlined, though no less secure, approach to security, boarding and the wider experience of getting on a flight.
Despite the ongoing repercussions of the COVID pandemic, supply chain challenges, and an ever increasing need to get the right skills, this is an exciting moment for aviation. In order to deliver on the potential of the future of flight, industry, and policy makers to take some big decisions now, to ensure the new, sustainable, connected vision of aerospace becomes a reality.

In the UK, the aerospace industry is worth £8bn to the economy in terms of value add. Businesses turnover around £22.4bn and the sector is one of high value that employees 111,000 people in the UK alone. UK aerospace saw £2.7bn in private sector investment made in 2020, and £1.7bn spent on R&D in the UK alone by businesses in the sector. For this high value, highly competitive sector to be world leading in the future of flight, the UK must work together as industry, government, and stakeholders to create the right environment to develop capabilities and technologies to tackle decarbonisation. The UK’s approach must not be just UK centric. Instead, a focus on a global scale on R&D, regulation & certification, training & education, and creating a positive investment environment will serve as a keystone for the future of flight, while a clear certification process will be critical to the entry-into-service of exciting new innovations.

Advancements in research will not become reality without an exciting and innovative R&D pipeline, attracting the brightest and best skills of the future. A globally enticing investment environment will give policy makers and regulators the confidence that industry will take the next steps towards the future.

With the right policy environment, a long-term skills plan and an inspiring level of ambition, digitalisation will be the catalyst for the future of flight. In the same way that the spirit of going ever faster and further was central to the early days of flight a century ago, digitalisation will be at the core of everything that aviation can and will offer to improve the productivity, connectivity and sustainability of society at large in the future. The question of what and how, however, are still to be settled.

**UK AEROSPACE SECTOR**

- £15.2 BN EXPORTS
- £8 BN VALUE ADDED
- 111K DIRECT EMPLOYEES
- 5.5K APPRENTICES
- £22.4 BN TURNOVER

Credit: ADS Facts & Figures Report 2022
4. DECONSTRUCTING THE ROADMAPS – WHAT ARE THE LEVERS TO ENABLE DIGITALISATION?

There are a number of decarbonisation roadmaps addressing aviation, all agreeing on the levers, but with different perspectives on their relative impact.

Decarbonisation roadmaps overview

<table>
<thead>
<tr>
<th>Primary decarbonization levers</th>
<th>“Art of the probable” roadmaps</th>
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<tbody>
<tr>
<td>Operational and infrastructure</td>
<td>show realistic pathways to reduce</td>
</tr>
<tr>
<td>improvements</td>
<td>aviation emissions significantly</td>
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<tr>
<td>Aircraft technology development</td>
<td>“Art of the possible” roadmaps serve to lay out different radical</td>
</tr>
<tr>
<td>(incl. electric, hydrogen)</td>
<td>strategies that lead to a substantial</td>
</tr>
<tr>
<td>Sustainable Aviation Fuel (SAF)</td>
<td>contribution of the aviation industry to combating climate change</td>
</tr>
<tr>
<td>Market based measures (incl. offsetting)</td>
<td>Dramatic ramp-up of at least one decarbonization lever is necessary</td>
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Credit Roland Berger

The aviation decarbonisation problem is complex and lacks an “easy” solution. Neither is there a technological “silver bullet” today (indeed, no current technology exists to fully decarbonise aviation), nor do any planned future technologies have an easy path to commercial viability today.

Still, there are many roadmaps to decarbonise aviation in public discourse today – all roadmaps ultimately call on 4 levers to decarbonise:

- Operational and infrastructure improvements
- Aircraft technology development (incl. electric, hydrogen)
- Sustainable Aviation Fuel (SAF)
- Market based measures (incl. offsetting)

However, they differ in their approaches. There are “art of the probable” roadmaps which show realistic pathways to reduce aviation emissions significantly, however their realism typically leaves a large share of emissions unaddressed in the long-term.

Conversely, “art of the possible” roadmaps serve to lay out different radical strategies that lead to a substantial contribution of the aviation industry to combatting climate change, where a dramatic ramp-up of at least one decarbonisation lever (e.g., SAF uplift or novel aircraft technology penetration) is necessary.
Most “art of probable” (a.k.a “realistic”) roadmaps lead to a flattening of net CO₂ emissions, typically by ~2040. For example, relative to 2019 levels, ICAO’s IS1 roadmap forecasts growth in emissions, by about 60% into 2050 at a global level.

Roland Berger’s post-COVID Baseline scenario forecasts that emissions growth will flatten by the early 2040s as SAF uplift and new aircraft ramp-up picks up. ATAG’s Waypoint S0 roadmap shows emissions peaking in the mid-2030s and returning to approximately 2019 levels by 2050.

To be clear: all these roadmaps forecast growth in air travel demand and industry capacity, so a flattening of emissions while revenue passenger kilometres grow is already extraordinary, and potentially the first time the aviation sector can forecast something like this to occur realistically.

However, this is still not enough to meet global targets to decarbonise – 40-65% of emissions are expected to remain unmitigated by 2050 in each of these “realistic” / “art of the probable” roadmaps.
By contrast, "art of the possible" roadmaps all arrive at nearly net-zero by 2050. ICAO’s IS3 and ATAG Waypoint’s S1/S2/S3 roadmaps call for very significant SAF uplift to reduce emission by 85-95% by 2050.

At the extreme, Roland Berger’s very bullish "Roadmap to True Zero" estimates that 90-100% reduction is feasible if fleet replacement can be ramped up and if the development and certification of novel aircraft technologies (electric for short haul, hybrid-electric and hydrogen for medium range and SAFs for long haul) can be accelerated so they enter the fleet rapidly.

At the European level, both Destination 2050 and Transport & Environment call for half of emissions reduction through technology and operations, and half through SAFs. Thus, net-zero by 2050 is feasible, but it is hard.
Thus, to take on this challenge, all levers employed have to be looked at not just through the lens of technological feasibility, but also commercial viability.

At the same time, most current roadmaps fail to consider non-CO$_2$ effects, with Roland Berger’s Roadmap to True Zero the only current roadmap explicitly bringing these effects to light and aiming to reduce them to zero in parallel with CO$_2$ reduction. In absence of considering these effects, we may optimise incorrectly and risk worsening non-CO$_2$ effects while decarbonising. Solutions we take on thus must consider the whole problem, not just the CO$_2$ portion.

To meet Paris Agreement targets and to genuinely give the world a chance to beat climate change, we do not have the luxury to wait. So, not only must we develop new aviation technologies, but new solutions to accelerate our path to these new technologies.

“’The path to net-zero will be complex and remains uncertain - but digitalisation in design, manufacturing, and throughout aircraft operation will be crucial to accelerate the production and use of sustainable technologies in aviation”

– Manfred Hader, Senior Partner and Head of Aerospace & Defence, Roland Berger
5. WHY IS DIGITALISATION IMPORTANT?

Each of the 4 levers will require solutions that go beyond just the physical hardware: potential roles for digitalisation exist for each of the levers (non-exhaustive)

OPERATIONAL AND INFRASTRUCTURE IMPROVEMENTS:

• Fine-tuning of operations will require more capable planning, real-time monitoring and in-flight flexible navigation.
• Ground infrastructure will require connectivity, e.g., to ensure correct blending of SAFs and constant safety monitoring for airport-based hydrogen infrastructure.

AIRCRAFT TECHNOLOGY DEVELOPMENT (INCL. ELECTRIC, HYDROGEN):

• New aircraft technology development is perhaps the field which will need the most in digital solutions.
• Faster design and development is critical to getting novel aircraft to the market on time – but faster EIS must always come without risking safety concerns with novel technologies. Digital solutions will be key to speed up design, testing and validation for development and certification while maintaining the extremely high safety standards that we require in aviation.

Finally, even as we decarbonise, monitoring and measuring non-CO$_2$ effects will be key. As an industry, it is essential that we grow our scientific understanding of these effects. But we also need to step-up the discourse from just improving understanding to focus on mitigating non-CO$_2$ effects in parallel with CO$_2$ reduction. On non-CO$_2$, digital solutions will help with, inter alia:

• Engine monitoring to develop better understanding of exhaust gases and particulates.
• Aviation network tracking and systems to make real-time adjustments to minimise contrail production without causing undue additional fuel burn.
• Atmospheric monitoring to track contrails and contrail cirrus, and systems to link them back to actions taken by airlines to mitigate these effects.
• Aircraft and propulsion design optimisation tools to take all CO$_2$ and non-CO$_2$ effects into account so that new technologies do not inadvertently worsen non-CO$_2$ effects even as carbon emissions are reduced.

SUSTAINABLE AVIATION FUEL (SAF):

• SAF delivery, monitoring and uplift will all need to be tightly controlled – not just for commercial reasons, but to ensure that companies fulfil their commitments and governments can ensure that mandates are being met.
• Specifically, book-and-claim systems will be fundamental, especially in the early days when SAFs will only represent a share of global fuel supply – digitalisation will be crucial to enable these systems.
• Digital solutions to ensure traceability and transparency in SAF delivery and uplift will be key.

MARKET BASED MEASURES (INCL. OFFSETTING):

• Much as for SAFs, appropriate monitoring and transparency are key for market based measures (such as ETS) and offsetting.
• As the market grows, new technologies such as SAFs (and eventually novel aircraft) come into the mix, and more airlines take on offsetting, accurate and airline-specific monitoring will be essential – digital solutions can help.
6. HOW DO WE DECARBONISE AND VIRTUALISE THE FUTURE OF AVIATION?

Digitalisation and the adoption of virtual technologies will spur companies to continuously optimise their air transport value chains, accelerate fuel technology innovation and plane designs to achieve a carbon-neutral future through:

Virtual Twins: The Virtual Twin Experience can help the industry’s decarbonisation, providing the digital expression of a product or industrial system’s full definition in the way that it is shaped as well as the way it behaves and interacts with other systems. It starts from the earliest planning and design stages of its lifecycle all the way through to manufacturing, operations, sustainment and disposal. Virtual Twins enable aviation companies to explore scenarios in a collaborative manner, predict future behaviours and deliver the right solution, at scale, from the very first time.

The Virtual Twin Experience capability can accelerate aircraft prototype testing. By simulating advanced 3D designs based on real-life scenarios, stakeholders can virtually test, validate and accurately predict an aircraft feature’s performance well before production. This way, they can easily obtain critical validation right at the design stage while reducing emissions, costs, waste and use of resources.

- **Multiscale, multiphysical models for hydrogen sub-systems:** Depending on the chosen architecture, hydrogen powered aircraft involve four major components: a storage system for gaseous or liquid hydrogen, cryogenic pipes for the fuel distribution, fuel cells to convert hydrogen to electricity (as propulsive or non-propulsive source of energy), and either electrical or conventional thermal engines (thus fueled by hydrogen). Developing these new systems requires physics-based multiscale models that accurately describe the phenomena occurring from the lower scales to the product level. Producers can leverage these multiscale models, to optimize the full system. This enables them to improve storage, fuel cell or engine performance and manage any energy loss.

- **Systemic compatibility:** Hydrogen can optimally power-up fuel cells in hybrid and electric aircraft, particularly those in the vertical take-off and landing (VTOL) and light commuters segment. Fuel cells utilize the electrochemical reaction between stored hydrogen and ambient air. As long as a fuel source is available, they can continuously produce electricity, which is why they don’t have to be periodically recharged like batteries. In this sense, fuel cells are an efficient and quiet source of power for aircrafts as they allow these planes to cover greater distance with minimal carbon emissions. Virtual Twins enable companies to develop, test and optimize fuel cell development including its material properties from nanoscale to macro scale. The same solution can help companies safely measure and validate the integration between, fuel cells and its related components such as hydrogen storage, battery cells systems and electric engines development. With single-source data models and virtual twin-powered digital continuity, companies can easily streamline their plans from fuel-electric systems research and testing to aircraft deployment and maintenance.
• **Value chain management:** By simulating real-life scenarios, companies can optimize infrastructure features such as airport and aircraft storage capacities, and on-ground and up-in-the-air engineering systems. This way, they can choose the best and safest storage options more easily. With the Virtual Twin Experience-based scenario planning, companies can also build and optimize hydrogen storage and logistical infrastructures more effectively. These infrastructures are critical for hydrogen success and overall market growth. At the same time, companies can utilize the Virtual Twin Experience to eliminate logistical issues around hydrogen fuel transportation. Using planning solution backed by real-time data insights, they can optimize their delivery plans and routes, and simulate the best transportation scenarios while factoring in suggested safety metrics gathered from real-time data around stored hydrogen stocks. This practice guides them to improve their decision-making more easily and choose the most optimal delivery outcomes while using less CO₂ during the derivative production of hydrogen. By simulating real-life scenarios, companies can optimize infrastructure features such as airport and aircraft storage capacities, and on-ground and up-in-the-air engineering systems. This way, they can choose the best and safest storage options more easily.

• **Safety first:** To minimize the risk of an accident, companies can use Virtual Twins to provide a digital environment where process control and operational solutions are tested and designed before being applied in real time. This way, they can optimize life cycle assessment, deploy these solutions online more quickly and upskill operators in the safest way possible, before trying them in the real world.

“Digital twin technology will help us to develop and share the critical steps of requirements, ensure we’re developing the aircraft according to those requirements, do validation and also manage the certification of the aircraft with the authorities. It’s a one-stop shop and single source of truth for Vertical Aerospace and our business partners that allows us to work concurrently wherever we are in the world.”

– Eric Samson, Head of Engineering at Vertical Aerospace
7. HOW TO ACHIEVE A FULLY SUSTAINABLE VALUE CHAIN FROM CRADLE TO CRADLE?

- **Greener production:** On the platform, companies can leverage digital continuity powered by the Virtual Twin Experience and 5G-IIoT to observe data carbon levels used during production in real time. The same solutions can also accurately monitor the use of other energy resources such as water and electricity.

- **Remanufacturing existing aircraft** is also a great way to integrate recycling practices into production. It can also curtail production-wide carbon levels and beyond. With digital continuity powered by the Virtual Twin Experience and 5G-IIoT-backed sensors, manufacturers can easily plan and validate complex manufacturing processes before the start of production. For instance, 3D nesting tools make it possible to automatically maximize the number of parts which can be produced in a single job while still ensuring their quality.

- **Maintenance:** Original equipment manufacturers (OEMs) can leverage the same digital continuity technologies used to optimize their remanufacturing strategy to monitor the states of machine parts in real time and predict their deterioration rate in advance.

- **Seamless feedback systems:** On an integrated platform, OEM stakeholders and strategic innovation partners can make the most of total value network visibility and single-source data models to ensure crucial information in relation to R&D. Updates relating to safety and efficiency progress are consistently streamlined, accessible and verifiable.
• **Prototyping testing:** By simulating advanced 3D designs based on real-life scenarios, stakeholders can virtually test, validate and accurately predict the performance of an aircraft feature well before production. This way, they can easily attain critical validations required right at the design stage while reducing emissions, costs, waste and use of resources.

• **Certification:** With end-to-end visibility on the platform, all stakeholders involved in the certification process can solve important pain points such as time, resources and workforce availability. As such, they can optimize their certification strategy more efficiently. When stakeholders digitally platformize the certification process, they not only pave the way for future systems-based optimization efforts via key data-captured information, but they can also achieve more stringent certification.

• **Infrastructure optimization:** On top of optimizing hydrogen storage facilities and planned deliveries, stakeholders can leverage integrated platforms for collaborations backed by real-time data insights in order to monitor and reduce onsite carbon levels. With access to single-source data models and optimized feedback loops on the platform, they can improve their carbon capture and reuse strategy and execution.

• **Decommissioning and recycling:** Aircraft decommissioning and recycling is a multidisciplinary process that relies on many environmental, operational, safety and economic aspects. Efficient collaboration can help stakeholders capitalize on the EU directive End-of-Life Vehicle (ELV), which stipulates that reuse and recovery must utilize a minimum of 95% by average weight per vehicle. Acting on the directive thus enables the aviation industry to optimally prepare for undoubted future regulations.
Digitalisation affects every part of the decarbonisation process. This fact is truly roadmap agnostic and features in every lever regardless of which path is taken. Some of our recommendations include:

• Tackle sustainability and innovation together
• Improve understanding of how digital tools can accelerate transformation (tech, economic challenges and opportunities)
• Focus on systems based and disruptive change
• Rally your value network (ecosystem / supply chain) and secure infrastructure support

“Aviation sustainability is no longer a question of ‘if’ but a question of ‘how’ and ‘when.’ While there are many technologies and innovators exploring the realm of the possible, stakeholders must now build a comprehensive strategy to integrate these new actors into their value network seamlessly,”

– David Ziegler, Vice President, Aerospace & Defense at Dassault Systèmes
9. CONTRIBUTORS

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<tr>
<th>Name</th>
<th>Role</th>
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Our 3DEXPERIENCE® platform powers our brand applications, serving 11 industries, and provides a rich portfolio of industry solution experiences.

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