Capgemini engineering

SUSTAINABLE AVIATION: THE JOURNEY TO NET ZERO

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Sustainable aviation: The journey to net zero

The future of flight will look very different from today, and hopefully much more sustainable.

For planes, kerosene will eventually give way to other propulsion sources, whether electric, hydrogen fuel cells, or sustainably produced fuels. Meanwhile, the nature of flight itself will be transformed, as new airborne transport modes, such as air taxis - which will have sustainability designed in from the start - pass certification and hit the market.

This will all have far-reaching effects. New propulsion mechanisms may open up more efficient plane designs, which may radically alter the 100-year-old aviation template. Innovations in materials science and recycling may also be revolutionary for aircraft designs. On both new and old designs, new sensors and data will incrementally optimize everything - from airflow over the wings to flight routes - in order to squeeze further energy efficiency gains. All of this will have an unprecedented impact on global supply chains for fuel, materials and manufacturing.

This cannot happen soon enough. Aviation is responsible for at least 2% of global carbon dioxide emissions according to the International Energy Agency (IEA), though the release of these emissions at high altitudes (eg. nitrogen oxides that increase ozone formation, and water vapour that traps heat through contrail formation) means they have an outsized effect on global warming.

Addressing this in every sector is increasingly urgent. The global average temperature has already risen by about 1.1C above pre-industrial levels, according to the Intergovernmental Panel on Climate Change (IPCC), approaching the limit of 1.5C, which the Paris Agreement hopes to keep to.

Aviation has committed to being part of the solution, and the global aviation industry has agreed to net-zero emissions by 2050.

The big impact will come from sustainable fuels – with a variety of approaches being explored. For example, Airbus aims to field a zero-emission aircraft by 2035, and is investigating hydrogen combustion and fuel cells. Boeing, Airbus and others are exploring sustainable aviation fuels (SAFs). Various start-ups are exploring fully electric and hydrogen-powered aircraft - and have recently demonstrated that success is possible.

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However, other changes are also needed to reduce emissions and energy required – from aerodynamic designs and lighter materials, to more efficient computer-aided flights and route planning.

Supply must also change, replacing dirty raw materials and polluting factories with clean biomaterials, recycling (the 'circular economy'), and suppliers running on renewable energy.

Yet, all of this must happen in a period of aerospace growth, fuelled by new demand (especially in Asia), and increased fleet sizes. An evaluation by Boeing and Airbus reckons the number of aircraft will double in the next 20 years. But, to meet a carbon budget compatible with the Paris Agreement, this increase in air traffic volume must be balanced with emissions reductions - and will likely be part of a growing debate in the near future, with airlines, airports, consumers and governments all exerting pressure.

Sustainable aviation is a complex challenge that must be tackled in various ways. We are now at a key moment in aviation history. We require a massive, coordinated effort, and a reanimation of the passion of aviation pioneers. We must reignite this spirit of innovation, driven by a sense of urgency, because failure is not an option, and the clock is ticking. Below, we cover how this must be done.

So, how do we make aviation part of the solution?

In each piece in this series, we will cover various ways to decarbonize aviation.

1. REDESIGNING AIRCRAFT FOR NEW ENERGY SOURCES

Decarbonizing aircraft propulsion

The biggest and most important lever for decarbonizing aviation is finding green sources of propulsion. Burning aviation fuel – which currently is mostly oil-derived kerosene – represents an estimated 99% of aviation emissions – the so-called 'Scope 3' downstream emissions (ie. emissions from products in use).

Sustainable Aviation Fuel is one option, and has the benefit of working with most existing engine designs. But entirely new propulsion systems, eg hydrogen and electric, require whole new designs for the aircraft's powertrain, from engines to fuel tanks and transport, and power transmission to propellers. And in some cases, it may require a wholesale redesign of the plane.

This will not be easy. The companies who have started on this path see many years of work before they can get green planes into regular flight. There is an engineering challenge ahead on a scale and urgency the likes of which aviation has never seen. Nonetheless, companies large and small are taking on the challenge.

Time is of the essence, not only because the clock is ticking on climate change, but also because the companies that get there first will have a significant advantage. This doesn't just mean fielding new aircraft, but also retrofitting existing fleets for sustainability. For example, just a year's jump on competitors could mean many orders, before others catch up.

So, how can companies accelerate this Engineering R&D process?

The challenge ahead

Decarbonizing propulsion comes with a series of options, each with its own challenges. We will summarize the opportunities and challenges of each, before discussing solutions.

Sustainable aviation fuel

The easiest and most promising short-term solution is sustainable aviation fuel (SAF), a category of fuels derived from biomass or from carbon capture, which remove CO2 from the air or emissions and chemically process it into precursors of kerosene. According to the International Air Transport Association (IATA), SAF could contribute contribute around 65% of the reduction in emissions needed by aviation to reach net-zero in 2050.

In terms of redesigns, SAF is the easy option. SAF can 'drop in' - which means that it can be blended with conventional jet fuel and, in some cases (…more in future), replace conventional jet fuel entirely. This means that SAF requires little to no redesign. Airbus already has commercial and military aircraft capable of flying with up to a 50% blend of SAF, and aims for 100% by 2030. The UK MOD has begun accepting up to 50% drop in from its fuel suppliers and has already demonstrated a 100% SAF flight.

SAF, it should also be noted, can be produced in a carbon neutral way, but take CO2 out at ground level and return it at altitude – so, whilst a good deal better than kerosene, and an excellent transition fuel, SAF is not a completely green solution.

It's worth mentioning that the production pathway of SAF (and thus its scalability) is an important factor. For example, it's important to ensure that SAF created from biological sources (like forestry residues) does not compete with other sectors that need to use those same resides, like the paper industry. The EU and US are pursuing different approaches to this challenge. You can read more about the importance of sustainable supply chains in Article 4.

Hydrogen

As a fuel source, hydrogen can be directly combusted, or used in a hydrogen fuel cell to produce electricity.

Due to a later start, hydrogen has a shorter timeline and is likely to start seeing major aviation deployment in the 2030s. When combusted, hydrogen reacts with oxygen to create energy and water vapour, and so has no carbon emissions. If the hydrogen is produced from green sources, flights could, in theory, be carbon neutral (though it is unlikely we will completely eliminate emissions from hydrogen's production, storage and transport infrastructure).

The energy density of hydrogen, by mass, is three times greater than kerosene, which makes hydrogen very attractive as an energy carrier. However, it has less energy by volume than kerosene: six times less for gas at high pressure (700 bars) and three times less for liquid (which requires it to be cooled to -253°C). So liquid hydrogen is more viable but will still require more space for storage than fuel, which will challenge aircraft shape and architecture.

As such, it will likely require planes to be redesigned to accommodate larger fuel tanks. This, for example, could create an opportunity to improve aircraft by moving the fuel storage - for example, taking it out of the wings. The wings could then be made thinner, generating less drag and increasing fuel efficiency. It also creates complex challenges around the design, engineering and materials choices for hydrogen storage tanks, fuel injection, and the engine itself - which would need to be modified to deal with this new fuel source.

H2 (whether combusted or used in fuel cells) also produces contrails/water vapour, the dispersion of such clouds (contrail cirrus clouds) can trap heat that radiates from the earth below, increasing warming. Combusting it also produces nitrogen oxides ('NOx') which could be a cause of smog, acid rain, and respiratory problems in humans, though it produces less of these than kerosene.

Hydrogen could also be used to power fuel cells, which drive an electric powertrain, and which have no waste emissions. A few recent test flights, including from startups ZeroAvia and Universal Hydrogen, are promising. Major primes are betting on the technology too; Airbus wants to deploy its hydrogen fuel cell-powered engine at a major scale by 2035. It is worth mentioning, however, that the weight of these fuel cells may limit them to single-aisle planes, and medium ranges.

Electric propulsion

As with electric vehicles (EVs), batteries could power engines and be charged at airports in-between operations. The main constraint is the batteries themselves, which are heavy. This decreases flight efficiency and – thanks to the laws of physics - places an upper limit on how much energy can be stored before any given plane is too heavy to fly.

Nonetheless, electrical propulsion has already demonstrated promise in smaller aircraft. Pipistrel claims to be the first company to get certification for an electric aircraft (the Velis Electro), back in 2020.

More recently, in September 2022, US-based Eviation Aircraft demonstrated what it claims to be 'the world's first all-electric passenger craft', with a predicted service date of 2027, and a plan for commuter and cargo flights between 150-250 miles.

The primary engineering challenge then will be squeezing optimal efficiencies out of battery storage and efficiency, as well as making them lighter weight, to extend the range of electric planes. Progress may come from new battery chemistries that are lighter and more powerful, like lithium sulphur. There is also much improvement to be gained from better thermal management, which can also help to prolong battery life.

Electric powertrains

The secondary challenge of electrification will be redesigning plane subsystems and control surfaces with electric motors and transmission lines to replace hydraulic ones. These have differing operating considerations to existing hydraulic controls and major work will need to be done to retrofit them to existing aircraft.

This may nonetheless be viable. 'Electrification' can be used on an aircraft with any kind of engine (eg. conventional, SAF, H2), provides potential weight savings compared with conventional hydraulics and potentially draws less energy from the aircraft's power plant, as well as being simpler to install and maintain (due to fewer moving parts) whilst arguably offering more precise control.

Hybrid electric

Hybrid electric propulsion (in which a vehicle uses electric power combined with other propulsion sources) has already proven itself in the automotive sector. An aircraft could use an electric drive for better energy management, for example, during taxiing, or in conjunction with the aircraft's other engines to provide assistance during take-off and ascent.

Airbus claims that hybrid electric propulsion could reduce fuel consumption by 5% per flight. It could also be invaluable when combined with other kinds of power sources that lack the peak power output of kerosene.

Digital enablers: getting there faster

The challenges above will clearly take energy and research. Given the safety-critical nature of aerospace, they will also take a lot of testing before passengers are allowed anywhere near them. Some of this just has to be done, but some elements can be sped up through new digital engineering approaches.

Digital design tools can help scope design and architecture, engineering, as well as the electrical, mechanical systems and physical domains, and how they should join up. Modelling – when designed by aerospace entering experts - can help optimize and define the most effective configuration for fuselages, tanks and wings, predict the best materials choices, and design the integration of electrical, electronic, and mechanical components. Even Artificial Intelligence (AI) can help propose optimal designs if provided with clear input criteria, reducing the number of false starts, and the need to produce early physical prototypes.

Simulations and physics-based systems modelling can be used for understanding important properties, like thermal management, which will be critical for the safety and efficiency of designs of battery packs, and engines using new fuel sources stored at different pressures and temperatures.

Software design will also be increasingly important for system management, as powertrains are electrified and systems need to be monitored and held at particular states throughout the flight.

Model-based system engineering (MBSE) - 'the application of modeling to support system requirements, design, analysis, verification and validation (V&V) activities' – allows designers to take a holistic view; analyzing the aircraft system as a whole throughout its entire lifecyle, and identify the interactions between its components. The digital approach can help to accelerate projects, hastening the Validation & Verification (V&V) certification process, for example, by allowing more of the test and evaluation work to be done digitally.

AI can also be used to translate flight data into scenarios for simulated testing from the component level up to virtual flight tests in varied and challenging conditions. This helps spot challenges early, reducing risk in costly real-life flight tests – though these, of course, must be done eventually. Once they are, detailed data collection, post-processing and visualization can help understand risks and improvements - which can be fed back into the digital model in order to improve the design.

Airbus' Digital Design Manufacturing and Services (DDMS) program is a good example of 'digital-first' in action. It has been used to help develop the Future Combat Air System and the A321XLR, which Airbus claims burns 30% less fuel than previous generation aircraft.

No silver bullets, but many choices

The commercial aviation community agrees on a mixture of propulsion solutions, but there are no ‘silver bullets’.

In the near future, SAF-powered aircraft will likely predominate, as SAF requires no modification to airframes and is an improvement on conventional fuel from a sustainability perspective. SAF alone won’t get us to Net Zero, however.

This leaves us with hydrogen and electricity. Electricity is always likely to be limited to short distance flights due to the weight of batteries. Green hydrogen will likely be the eventual solution for commercial flights, due to its highly sustainable credentials and ability to be stored on board as a liquid fuel. Nonetheless, hydrogen will add storage and weight to current aircraft compared to kerosene, and so SAF is likely to be the best option for long-distance flights, at least in the medium term.

Neither electric nor hydrogen propulsion is anywhere near ready to meet the full needs of commercial aviation, but both are progressing rapidly. Both will require major redesigns of aircraft, followed by endless optimization and rigorous testing. Those that get through this process first will have a significant competitive advantage. Digital engineering will likely determine the winners.

2. MAKING AIRCRAFT MORE ENERGY-EFFICIENT

Caveat: incremental but important

We begin with a caveat. The majority of CO_2 savings in aviation will be made by transitioning aircraft to new fuel and propulsion sources, like sustainable aviation fuels (SAFs) or hydrogen.

In comparison, increasing the energy efficiency of aircraft airframes is likely to yield savings of 10-20%, which may be thought of as a marginal gain. However, even 10% is still significant considering the criticality of the challenge. Increased efficiency also scales pretty quickly for aircraft operators looking at cost and carbon savings - and it means a lot, if progress on green fuels stalls.

Savings of **10-20%**

by increasing the energy efficency of aircraft airframes

Change is necessary, and change is coming

As aircraft become more fuel-efficient, their fuel consumption per passenger mile continues to fall, but, as the total flight volume increases, total greenhouse gas (GHG) emissions continue to rise. This has been described as the 'rebound effect'.

Broadly speaking, there has been continuous iterative progress over the last few decades on the aircraft configuration layout. Increasingly efficient, the design adopted on the majority of aircraft in commercial aviation has been optimised for both safety and performance. It sets a clear separation between the major functions of the aircraft and its major physical components, lift and fuel storage (wings), propulsion (engine), passengers or freight carrying (fuselage) and control (empennage).

The stability of this configuration over recent decades, the countless hours of flight test data and the longstanding collaborative culture among the aviation community have allowed us to reach an unprecedented and outstanding level of safety. The success of civil aviation can be seen, partly, in the confidence of airline passengers in the aircraft that transport them, including a familiarity with its general configuration layout. Might this confidence be affected by significant airframe redesigns? Possibly. But change is coming anyway.

For example, new energy sources are very likely to induce important changes in airframe architectures, at least for hydrogen-powered craft. SAF will not necessitate a redesign, which partly contributes to its use as a near-term solution (you can read more about the redesign of aircraft for new energy sources in our previous article). But even where there is no critical need for redesign, there are still plenty of improvements to be made to the airframe itself.

Energy efficiency: alternative approaches

There are a number of possibilities to improve current aircraft to squeeze out those extra percentages of efficiency. We will look at some here.

Improved aerodynamics and 'smart wings'

Currently, the adaptation of aircraft's wing shape to its external conditions and flight phase is very limited. It relies on the slow and discontinuous motions of parts (slats and flaps), which makes it very far from the ideal motion of a bird, which can morph its wing shape and orientation in a highly efficient way.

An aircraft wing that could respond to airflow in a fashion similar to those seen in nature would be significantly more effective, but would require a fundamental redesign. This is the premise of a 'smart wing' - which could combine smart sensors all over the outside of the aircraft (to detect local airflow changes) and smart actuators that can react very quickly to these changes, driven by a control system capable of rapidly determining the optimum reaction in a very short timescale.

The collected sensor data could also feed back into the digital model of the airframe, and be used to improve it. Rethinking the traditional wing model in the manner described above increases opportunities to re-engineer the aircraft further.

Partial/full electrification

As discussed in the previous article, replacing hydraulics with electric control surfaces is a power-source agnostic way to reduce aircraft weight and increase efficiency. Electrification is also not a new idea, it began with the introduction of electrical flight control systems decades ago. Today, the trend is towards a growing number of electrical components - taking over more and more key flight functions. The refinement of battery technology is a major driver here, but we still have a long way to go.

New and improved materials

Weight is a massive driver of efficiency in aerospace. As such, any reduction in weight has huge value. Structural improvements include lightweight materials, like carbon fiber composites, that can be used, not only in the airframe, but eventually on aircraft's subsystems. Other promising material groups include bio-composites, which are derived from biological and mineral-based sources, and graphene, which was only discovered in 2004.

The challenge here is scaling promising new materials to the point where they are cheap and plentiful; enough to be used at the scale required by the commercial aviation industry. And of course, successfully passing the rigorous certification process set by international authorities.

Instead of completely overhauling what major aircraft components are made from, we're more likely to see an incremental approach, with the replacement of aircraft parts over time with lighter, carbon-fibre equivalents.

Additive manufacturing (AM)/3D printing

AM is promising. General Electric describes it as the potential of "Better performance from fewer parts". It can, in theory, simplify designs (and manufacturing) - creating cost savings. Fewer parts mean a lighter airframe, and less fuel consumption. It also promises increased durability, as fewer welded joints and connected parts offer fewer points of potential failure.

Whilst not directly linked to in service efficiency, additive manufacturing nevertheless offers the potential of reduced waste: by avoiding overproduction (as components can be printed on demand limiting also storage), and the expenditure of energy and loss of material in milling and forming.

However, given aerospace's Safety Assurance requirements, additive manufacturing is not yet suitable for all of an aircraft's parts (and certainly not yet a 3D-printed major component). Other shortcomings include size limitations, production speed/scalability, a limited range of materials available, and the challenge of creating parts made from multiple materials. Again, an incremental approach is likely to be adopted.

Propellers

The physical configuration of aircraft is driven partly by its speed in the cruise phase. The current design aims to be as fast as possible, whilst remaining subsonic (as supersonic conditions create additional design constraints and performance issues).

However, if we prioritize efficiency over speed and slow down further, we create further opportunities for slower aircraft for shorter distances. In fact, we see this already in the success of turboprop designs, which tend to serve shorter routes and can outperform jets at lower speeds and altitudes. In fact, it's worth mentioning that most efforts involving hydrogen-electric powerplants (eg. ZeroAvia, Universal Hydrogen) are being trialled on propeller platforms.

Moreover, and following a common vision from GE and Safran through their joint venture, CFM International, significant effort is being invested into a similar design - 'open rotor engines' or 'propfans'. This propulsion technology uses counter rotating ranges of unducted and twisted blades, and allows aircraft to reach higher speeds than pure propeller designs, while presenting significant gains in terms of fuel consumption and emissions. Although these designs introduce additional difficulties around certification and acoustic performance, they have reached a level of maturity in recent years that makes them a serious and hopeful option.

What should companies do now?

Integrate Life Cycle Assessment and the Circular Economy into designs and redesigns

Making aircraft energy efficient isn't just about how these aircraft perform when they fly - it's also about ensuring that the plane itself (and by extension all of its constituent parts) are sourced in the most energy/carbon efficient way possible. For example, can recycled (and recyclable) materials be used? This requires a nuanced understanding of the supply chain for every part of the aircraft.

Build links with research institutions, academia and start-ups

The technologies that will help make the aircraft of tomorrow more energy efficient are (probably) already in their nascent forms in the lab. Startups with bold ideas and nimble processes may be able to develop new valuable technologies faster than in-house teams. Ergo, it is important to perform horizon scanning and build partner ecosystems so you know which labs, startups and institutions have the technology and IP to improve your designs.

Push for open standards and interoperability

There is also a pronounced need to develop (and support) non-proprietary digital engineering standards and interfaces, this will help to ensure that the advantages of digital engineering can be shared in complex, multi-vendor projects.

Learn from innovators in the automotive business

Aerospace could learn a few things from other sectors, particularly the automotive industry. For example, Tesla was able to create rapid and disruptive innovations by working in a cloud-based PLM, which was directly updated with vehicle sensor and test data. This provided real-time insight, and allowed them to use AI on that data to gather insights and build simulations. The variety of electrification problems overcome by Electric Vehicle (EV) manufacturers is also a highly valuable source of innovation for aeronautics.

Go as digital as you can

Most aviation players possess some level of digital engineering capability, but this may be an area in which 'more is almost certainly always better'.

For example, the digital thread creates the opportunity for digital continuity between design, manufacturing and operation. After all, there is a 60-70 years aircraft lifecycle to consider, with a strict need to manage and maintain aircraft. This presents an ample timeframe to gather data. Such data can be fed back into the digital thread from operational and maintenance data to further optimise aircraft designs.

60-70

years aircraft lifecycle to consider, with a strict need to manage and maintain aircraft

As previously stated, digital infrastructure is mature in major aerospace primes. The most advanced manufacturers (eg. Airbus and Boeing) have set up complex simulation infrastructures and fully virtual test environment ecosystems. This is done, for example, during the design phase, through the extensive use of advanced physics simulation, which allows manufacturers to understand, predict and validate complex physical behaviour in aerodynamics, structural dynamics, thermodynamics and acoustics with high fidelity.

This process can also be fully engaged in the Verification & Validation phase - from the complete aircraft down to the individual component level, allowing much of the work to be done before 'steel is cut', drastically reducing costs and flight testing required. This is both safer and cheaper. The smart combination of data from virtual simulation, ground testing and flight testing can be used to optimize and accelerate the certification journey.

3. SUSTAINABLE IN-SERVICE OPERATIONS

As well as aircraft design, the other area where the aerospace industry can directly improve their sustainability is in optimizing operations. This can include flight paths, ground operations, and maintenance, all of which have clear opportunities for emissions reductions.

How can we optimise flight paths?

Optimizing flight paths has long been of interest to flight operators, partly because it combines improving sustainability with saving fuel, and thus money. Yet various studies show there is still plenty of room for reducing fuel use by flying more optimized paths. A 2021 study, for example, suggested New York to London flights could be up to 16.4% shorter. And distance is not the whole story; altitude, latitude, and atmospheric conditions all affect not just fuel use, but the impact that emissions have on the environment.

Whilst new propulsion and plane designs will take time, optimizing flight paths is something we can do right now. And the better we do it, the more time we buy for the net zero transition.

But even in a post-kerosene world, optimised flight plans will still matters. SAF planes will still produce high-altitude emissions. And it is hard to imagine completely carbon neutral hydrogen/electricity for a while, so the less energy needed, the better.

The low hanging fruit is to add environmental impact metrics into route planning and route tracking, to give a CO2 equivalent figure. Taking all flights in an airspace together, we can then look to minimise CO2 as well as flight times, delay risks, etc. We could then plan more effectively using this metric, and then retrospectively use the actual flight data to assess our effectiveness, to feed back into ever better planning. All the data we need to make a start on this exists today; we can do this now, with a few modifications to current systems.

As more data is collected, new sophisticated AI could be built to perform more complex analyses and fine tune routing algorithms to reduce impact further.

That would allow air traffic operators to choose the most sustainable route. A further step up would be for operators to collaborate on shared models to optimise for the whole flight, rather than just individual geographic airspaces.

Good route models will also help us make important future decisions. During the transition, which may be a decade or more, we will have a mix of clean and dirty planes in the sky. We will need to make complex decisions about routes – should we put the fossil fuel planes on the shortest paths to reduce their impact, or the clean planes on the shortest paths to incentivise their use? The exact mix will be a political decision, but good models help inform decisions and help airlines build business cases.

Predictive maintenance

Another operational area for improving sustainability is maintenance of aircraft.

Predictive maintenance, already widely used, can ensure maintenance is scheduled at a convenient time and place, rather than having to divert planes, or fly out engineers. This is usually driven by cost saving and reducing downtime. But, as airlines look to reduce their emissions across the board, they should add ‘emissions reductions’ as a consideration shaping their predictive maintenance strategy.

Doing so may help them see things in new ways. For example, it may encourage them to explore the optimal global maintenance locations to reduce their overall footprint. Or to look at how technology can reduce emissions – for example our ons – for example our Andy3D platform let’s any technician put on VR headset and connect to a relevant expert anywhere in the world, who can guide them through the solution, thus removing the need to constantly fly a limited pool of specialists across the globe.

Airlines can also use predictive maintenance data to reduce their materials footprint. Many replacement schedules are based on historic data, with limited feedback loops. Parts designed to last 10,000 hours may be replaced after 1,000 to give suitable confidence levels. But with modern analysis techniques we can continually update models of lifetime failure with in-service data. This allows us to identify parts that can be swapped out less frequently without impacting confidence levels. A reduction in parts has a direct impact on the materials and energy required to produce service spares.

To make data-driven decisions about maintenance schedules which ensure optimal sustainability, we will need validated predictive maintenance tools, analysis of in-service maintenance data, and ongoing feedback loops. We need to be certain of what the data is telling us, and that it poses no compromise to safety. But once we are, there are big materials, transport, and personnel savings to be made.

Ground operations

A final area ripe for improvement is ground operations. Airports are a microcosm of modern small cities, with lots of vehicles scurrying around carrying bags, fuel, food and people. These vehicles are making short, stop-start journeys, so burn a lot of fuel. Most never leave the airfield.

This is a perfect use case for electrification. Vehicles could be electrified. Renewable generation – especially solar - could be deployed on rooftops and other open areas. There are hundreds of marginal gains that would quickly add up, for which all the necessary technology already exists. Many airports are making these moves. Airport Carbon Accreditation – an emissions reduction accreditation scheme - claims its 64 signed-up airports reduced their combined CO2 emissions by 1.7 million tonnes over the decade to 2019.

But progress is often ad hoc. A more cohesive transition plan would be better – which includes modelling energy needs, making renewable technology selections aligned to predicted demand, and designing charging schedules to take advantage electricity produced directly from airport solar, or cheap electricity at night. This would be helped by emissions monitoring tools, data analysis, and collaboration between airports, airlines, ground handlers, and air traffic controllers, all of whom can help drive these changes.

Conclusion

Operations may not provide the big bang transformation of fuel transitions. But it provides many opportunities for optimisations that – if pursued at scale – will deliver meaningful emissions reductions, and cost savings. Importantly, many of these can be realized relatively quickly and without huge investment, leading to an impact now, and buying time for full decarbonisation of air travel.

These are all opportunities that are firmly within air traffic management providers, airlines, and airports control. They will therefore be easier to implement that the much talked of supply chain emissions reductions. Though these are also important, and we shall turn to these next.

4. SUSTAINABLE SUPPLY CHAINS

Large aerospace companies rely on suppliers for up to 80% of the finished product. So, achieving a sustainable aviation industry must involve creating a sustainable supply chain.

The supply chain presents two challenges. The first is the need to recalibrate it with new suppliers, as companies design and build the next generation of green aircraft. The second is to ensure suppliers, new and old, are as sustainable as possible.

New suppliers for sustainable planes

Start with the first challenge. Building electric, SAF, and hydrogen planes will need new suppliers for new engine parts and fuels, as well as new storage in the case of hydrogen. It may need new suppliers of greener materials, and suppliers to recycle parts. If it does not build this supply chain, it will miss milestones on the net zero transition, and fall behind competitors.

Hydrogen provides a particularly thorny example of the challenges of integrating new suppliers. Hydrogen is straightforward to produce, but capacity to produce green hydrogen is limited, so aerospace manufacturers pursuing hydrogen will need to find ways to encourage scale up and secure supplies.

The more technical challenge is storage; in transit, at the airport and – especially – on the plane. Hydrogen has different properties to kerosene and needs to be stored at higher pressures and very low temperatures, so tank designs will need to overcome thermal management challenges handle this, even as planes experience external temperatures from 50 degrees at some airports to -50 at cruising altitude (we discuss these challenges further here). Existing kerosene tank specialists may not be able to easily pivot, whilst hydrogen specialists may not be familiar with the strict rules of aviation.

Bringing new suppliers onboard

Aerospace will therefore need to work closely with new suppliers to solve problems. They will need to identify those with the technical capabilities to deliver. And they will need to work closely to explain the specific constraints of aerospace – the design, the tests it must undergo, and the data needed to get approval from the regulators who govern global airspace (e.g. Part21).

This world may be new to many suppliers. Aerospace will need to take time to explain the rules and provide the suppliers with all the information they need to do a good job – including specifications, measurement approaches, tolerances, data standards and so on. And they will need to setup systems to ensure quality and consistency throughout the supply chain.

A good model is the Advanced Product Quality Planning (APQP) framework, a set of processes widely used in automotive for designing and communicating specifications to all stakeholders. Capgemini is sufficiently impressed by this approach that we have developed a set of methodologies adjusted on it to support aerospace customers to onboard and manage suppliers.

This must all be kept as simple as possible. Because aerospace is complex and highly regulated, there can be a tendency to design systems so complex that no one will use them unless they have to. In a finite world where many suppliers will have a choice of customers, there is a need to shift from systems designed around the complexity of the product, to systems built for user experience (whilst of course ensuring technical and safety criteria are met).

Competing to be at the front of the queue

This point about finite supplies and suppliers is an important one, and a key challenge to overcome. It is no good having a brilliant onboarding and management process if there is no supplier to onboard.

Depending on how supply and demand evolve, green hydrogen may be in short supply and high demand, at least in the short term, though recent progress here gives cause for optimism that hydrogen will be a common commodity by the time hydrogen planes take off en masse. In the meantime, aluminium, as well as lithium and other battery materials are also at bottlenecks. For aluminium and batteries, aerospace competes with automotive, which has higher production volumes and can tempt finite suppliers with higher volume orders. Furthermore, suppliers with a choice may be put off working with aerospace because of the complexity of regulations, and the reputational risk if a plane using their product goes wrong mid-flight.

Aerospace needs to recognise and plan for this challenge. There are no easy solutions. For immediate needs, they may consider long-term commitments to suppliers in the hope of jumping the queue. Though this comes with its own risks: if a better alternative comes along or demand for planes drops, they may be left with a year's supply of material they can't use.

For longer term requirements like hydrogen, there will need to work collaboratively with energy companies, electrolyser companies, other hydrogen users, regulators and governments to ensure adequate supply chains are built. Plenty is happening in this space, but it needs to move fast, so everyone needs to be working together towards a shared goal. Aerospace could also create more confidence amongst suppliers and investors by being more vocal about its future needs, and publicly committing to transition roadmaps with clarity on the suppliers they will need.

Aerospace has always been a collaborative industry. It will need to build on this heritage and get used to communicating its needs to a wider range of suppliers and stakeholders to ensure its future needs are met.

Airbus has over **8,000**

direct and 18,000 indirect suppliers

Greening the supply chain's emissions

Whether suppliers are new or old, there is a need to ensure they are as sustainable as possible. A hydrogen engine that is made by pumping CO2 into air and pollutants into rivers may not win over the flight shamers, even if the engine itself addresses the bulk of the problem. To be truly green, aviation therefore needs to audit its supply chains emissions (known as upstream Scope 3 emissions), select sustainable suppliers, and support/incentivise suppliers to go greener.

The basis of this is proper emissions accounting. That is hard because there are lots of suppliers - Airbus has over 8,000 direct and 18,000 indirect suppliers in over 100 countries – and they are a mixed group, from major global companies, to specialist SMEs with no knowledge of how to track emissions. Some may be three or four steps down the supply chain. And there is no industry agreed approach to emissions accounting, so even when suppliers are tracking emissions, there is no guarantee their approach will work for you.

The big picture need is for the industry to come together and agree what platform and standards they will use. An industry-led project in automotive, Catena-X, provides a good model for sharing data across a supply chain. Aerospace needs its own such initiatives.

Shorter term, there is a need to do something that works for your ecosystem. Setting clear and reasonable rules for what suppliers should report, how they should report it, and providing a cloud-based platform for them to report into is a good start. Setting consistent policies for data collection and formats in your own organisation is also a wise move if it has not already been done.

If suppliers are unable to meet your requirements, a variety of solutions could help, from software that can translate supplier data formats into your system's format, to deploying sensors at supplier sites, to workshops and training.If real-world data is not available, the International Aerospace Environmental Group (IAEG) has an easy-to-use Excel-based Scope 3 emissions calculator which enables initial assessments.

Using data to make decisions

Having clear data on your supply chain lets you make informed Scope 3 emissions-reduction decisions. For example, you may find that a local supplier is greener overall due to reduced transport, even if their process is less green. Such outcomes often come as a surprise, which is why a rigorous data-driven approach is so important both to making decisions and proving their effectiveness to customers and investors.

You can then set informed continuous improvement policies to drive down supply chain emissions. These may include targets, green procurement processes, and incentives or support for suppliers. You can focus efforts on the highest emitters to deliver the biggest bang for your buck. As suppliers report more comprehensive data, you can incorporate more diverse and evidence-based strategies.

But you can only do this well if you have the data that tells you what you are looking at.

5. NEXT GENERATION AVIATION

In this series we have discussed how today's planes could be reinvented and refined to become more sustainable. But planes are not the only game in town. A new generation of flying machines are emerging. These may rip up the rules of aviation, but equally, they may prove a breeding ground for the skills and mindsets needed to transform the wider aviation industry.

What is next generation aviation?

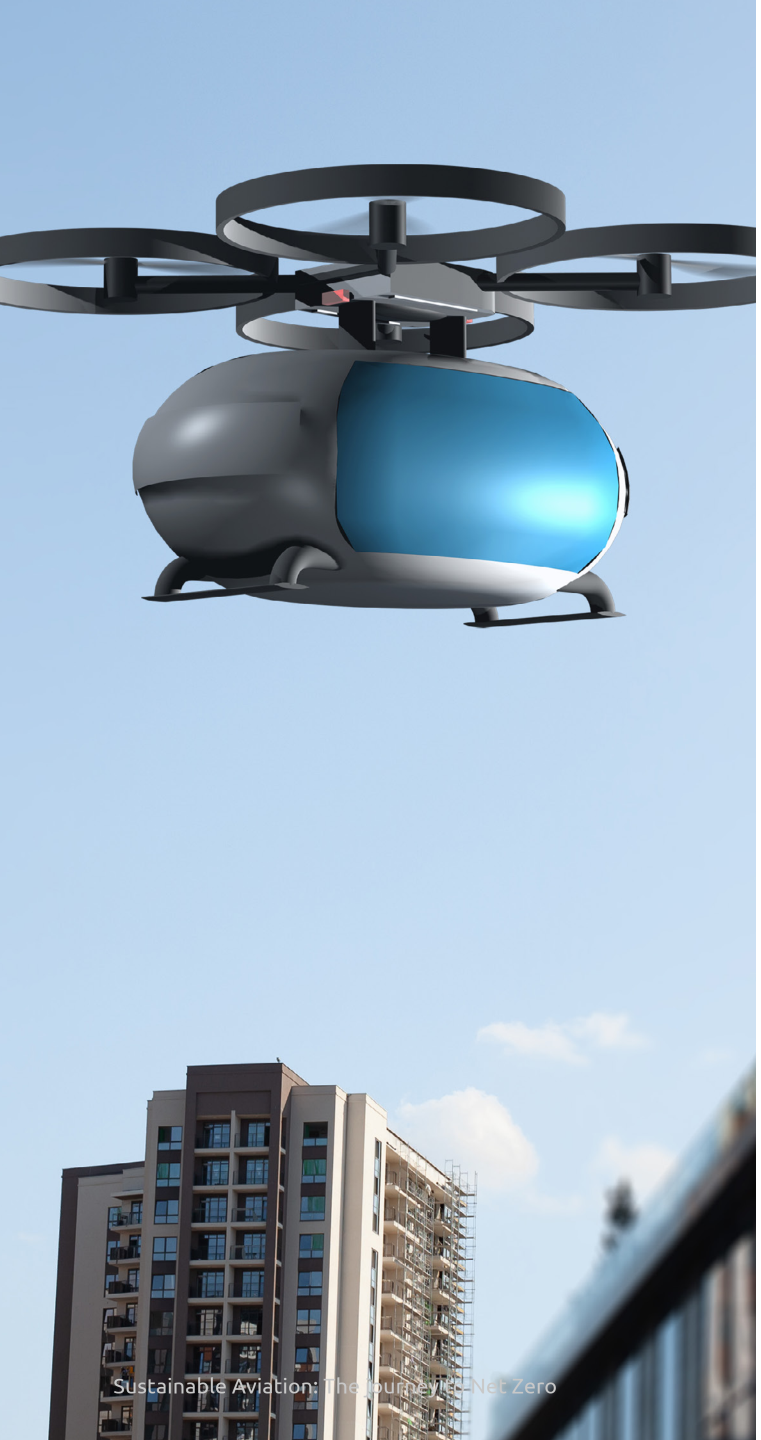
While next-gen aviation encompasses various innovations in the industry, electric vertical take-off and landing, (eVTOL) technology stands out in particular. This technology, powered by batteries or fuel cells, drives a distributed set of electric powertrains with tilting propellers, enabling almost silent, cheap and zero-emission vertical flight.

Not only does eVTOL represent a fundamental step towards fully sustainable aviation, it also holds significant potential to disrupt regional ecosystems. If charged with renewable energy, these eVTOL craft will help to alleviate city congestion, and provide faster and cheaper commutes.

This new crop of aircraft is not a replacement for long-distance planes, but rather a whole new mode of air travel, with a range of new use cases. Drones using VTOL techniques are already commonplace for surveillance, inspection and military applications. Larger eVTOLs – some of which may eventually be automated – are already in advanced development and plan to transport passengers or cargo across and between urban areas.

Even as early VTOLs start to find commercial use cases, yet more innovative approaches are being explored. Jetoptera, for example, uses electric compressors to create an air pressure differential within the centre of a ring (picture a Dyson Airblade) which pushes air through at high speeds, generating thrust. It claims its approach could be up to 50% more fuel efficient than a propellor. This is an area rife with innovation.

What is notable is that – being created from scratch in the 21st Century – these new innovations have sustainable propulsion at their heart, and most are built around intelligent software and digital engineering. They are therefore interesting, both in how they will shape the future of aviation, but also in what they can teach some of the incumbent aerospace companies.



The challenges of next gen aviation

Getting an entirely new mode of transport off the ground - especially one that may hover above densely packed urban areas - is fraught with engineering challenges.

Take Ascendance Technologies, an innovative future mobility startup, to which Capgemini is a partner. It has developed a new hybrid propulsion system called STERNA, an electric system powered that can be powered by fuel and/or batteries, which is installed in its ATEA VTOL, but has the potential to be installed in any small/medium range flying vehicle. Success with eVTOL requires a variety of challenges to be solved. For example, developing such technology required a completely new electrical architecture and complex thermal management to transform energy into thrust, with new wing and propeller designs to optimize flight physics and reduce noise. And all of this needed to be done within the strict constraints of safety regulations. You can read more about Ascendance Flight Technologies' work here.

For electric propulsion, **battery optimization** is perhaps the most pressing challenge. Small flying vehicles require high energy density, high power densities and long-life cycles; and they will eventually need to be manufactured at high-volumes and low costs if they are to have a viable business model. Air taxis will also need fast charging speeds to enable them to be constantly shuttling passengers about – every minute grounded while charging is lost revenue.

Electric drivetrains will need to be optimised for power conversion from the battery to the motor. And the **power-to-weight ratio** – whilst not the use-case killer that it is for large electric aircraft – must be brought down through efficient design and materials choices, to get the most out of battery power.

Designing for user acceptance is another challenge, and one that may be new to aviation, where planes have historically existed mostly outside of people's sight and hearing. But filling city skies with flying machines will not be everyone's cup of tea and eVTOLs may face fierce resistance. Whilst this is partly a communications challenge, such aircraft will need to be designed and engineered to be minimally intrusive. **Noise** is a particular challenge. Drone propellers are – according to Nasa – one of the most annoying sounds imaginable. Engineering quieter vehicles, especially for takeoff and landing, may be decisive in user acceptance.

And, of course, all this must be done without compromising safety.

A call for the best engineering brains to solve the most difficult challenges

Across this series of articles on sustainable aviation, the emerging theme has been the need for high quality engineering, backed by cutting edge digital tools and the use of software and data, to overcome thorny challenges. Next gen aviation is certainly no exception.

Deploying battery expertise and modeling capability into eVTOL companies will be critical. Batteries have an optimal temperature range, and thermal management is key to their optimization. But this is highly use case dependent – ambient temperatures and heat dispersion are different in the air than on the ground. Experts in thermal management will be needed to understand airborne batteries and – using physics-based models and simulations - design heat transfer systems to optimize performance and ensure safety.

Similarly, digital engineering enables engineers to simulate and analyze the behavior of other key components, including flight handling qualities and operational scaling, in a virtual environment. This allows them to identify design flaws and optimize performance before manufacturing begins. Bespoke software will also need to be written to optimise the whole product in use, from battery management systems (BMS), to flight controls and handling qualities.

Once testing begins, data captured from simulations, and then from onboard sensors, can feed back into an iterative process to further optimize design. This allows engineers to make ever more informed decisions about component design, material selection, and system architecture.

A digital engineering approach, backed by real engineering expertise, can also help rapidly test new concepts. For example, a team at MIT have been investigating using toroidal propellers to reduce noise. The team put together digital models, 3D-printed their prototypes, and collected usage data to iterate design.

As a final point, whilst we are focusing here on sustainable aviation, it is worth noting that there are other challenges facing next gen aviation, from automation, to communications protocols, to air traffic management, to pilot training. Whilst these are not strictly sustainability issues, these will need to be overcome in order to get this sustainable mode of transport in the air. These too will all benefit from digital, data, and software expertise.

A new certification challenge

Once a new aircraft has been created, it must also be certified. Getting certified requires ground testing, simulations, in-flight data acquisition, critical software testing, and detailed data collection and reporting, in order to meet European Union Aviation Safety Agency (EASA)/Federal Aviation Administration (FAA) airworthiness requirements. This is the most expensive and challenging task prior to market entry. It is a particular challenge for a new transport mode with no certification precedent.

Digital technologies can help speed and optimise complex processes, whilst offering a degree of rigor that will help assure regulators, who are themselves still working out this new industry. Opportunities here include automating data capture across tests to speed the process; applying AI to that data to create simulated test scenarios; and using cross-sector data to develop anomaly detection algorithms that can automate critical elements of testing (see here for a deeper dive on eVTOL certification).

A platform for innovation

Next gen aviation is a minefield, but a minefield where lots of companies compete. It remains unclear who will emerge as the winner, but whoever it is will need teams of skilled people with expertise in engineering, digital engineering, software, and certification.

Next gen aviation may seem an obvious business for today's aerospace companies. They know the world of flight, aerospace engineering, and certification. Aviation companies may also feel more trustworthy than others when it comes to keeping people safe in the air.

But the lessons from Electric vehicles (EVs) also put automakers in a strong position to help manufacture electric aircraft. Stellantis recently agreed a partnership with Archer Aviation, through which it will exclusively manufacture its Midnight eVTOL, as part of a partnership that provides capital, manufacturing capability, and supply chain access. Toyota, Porsche, Hyundai and Daimler, amongst others, all have collaborations with next gen aviation companies (Joby, Eve, Supernal and Volocopter respectively).

Equally, electric transport is increasingly seen as a software-driven industry – since the moving parts in electric vehicles are actually quite simple, and it is the control systems, connectivity and digital optimization where the real value lies. That puts the tech giants in a good place. And of course, former employees of all of the above may decide to build their own businesses, as many already have.

In short, it is a tough and competitive market with lots of risks. Innovators in this field will need to work hard to optimise efficiency and noise levels, keep costs low, and ensure rigorous attention to safety.

However, another interpretation is that next gen aviation will be part of a collaborative transformation which supports the whole industry. We already see hints that people are leaving big aerospace companies to create eVTOL companies with a 'digital startup' mentality, doing rapid innovation, then collaborating or being acquired by former employers, who help them with scale and certification.

This collaborative approach not only advances next gen innovation towards commercialisation more quickly, but also brings the much-needed learnings of innovative startups into established companies. That helps create the culture that aerospace companies will need in order to transform more broadly. And it is culture that we shall turn to in our final article in this series.

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6. A CULTURE FOR SUSTAINABLE AEROSPACE INNOVATION

A cultural problem disguised as a technological problem

The message is loud and clear; go green or become irrelevant.

And the message has been received. Large aerospace primes are well aware of the need to be more sustainable. Environmental, social, and governance (ESG) rules, changing international legislation and increasing shareholder activism are all factors. Business models are having to change, in order to support the decarbonisation of aviation. Companies that don't make the change will be unable to operate and, will, by extension, not make it through.

But changing the trajectory of aviation is not like adjusting the course of an airliner. It's more like turning a supertanker; gaining momentum takes time - but time is not a thing we have a lot of, considering the traditional development timeframes of commercial aviation capabilities.

So, how can progress be accelerated? It's a cultural challenge as well as a tooling one - the rapid innovation needed to decarbonise aviation requires a cultural shift. Companies, large and small, will need to work faster than before, and work together in ways they may not be entirely comfortable with, whilst maintaining the extremely high safety standards of aerospace certification.

It is technology that will largely help us solve the problem of sustainable aviation. But technology (eg. what technologies to use and how to use them) is created by humans and largely determined by human decisions. And culture is made up of people - which means that innovating the technology we need is, at least partly, a cultural challenge.

‘Digital first’ for digital firsts

According to instant messaging giant and tech success story, Slack: “*Building a digital-first culture involves more than just integrating the latest technologies. Digital-first means creating an agile organization where* ***technology and corporate culture work together*** *to improve processes, maximize efficiencies and offer unparalleled customer experience.”*

Many look to the rapid ‘fail fast’ approach of tech companies, like Slack, as an example to emulate - but few would disagree that aerospace companies face far more serious consequences for failure.

We can consider SpaceX, arguably the best known aerospace company, as an example of a company that is digital first and that takes a rapid innovation approach. It even frames the high-profile explosions of its rockets as ‘successful failures’, taking the opportunity to gather data from the launch (and crash) to quickly understand and remedy issues for the next launch. Of course, none of these craft are crewed, so no lives are lost - but it is still a bold stance, considering the sheer costs of a lost rocket.

So, how might this rapid, tech-driven approach be adapted to such a traditionally slow moving and safety-critical aerospace environment? What must change in company culture?

1. A vision and a plan to achieve it

As the old business cliche goes, ‘start with why’.

Digital transformation (or ‘digitalization’) doesn’t happen ‘by accident’. Companies that wish to create a more innovative culture should establish a clear vision and an innovation strategy. Why does the company want to be innovative? What does success look like? How will progress be measured? What will inspire employees to want to get involved (…and not see innovation as something that is ‘being done to them’)? And, how can the company’s goals and values be aligned with innovation and creativity?

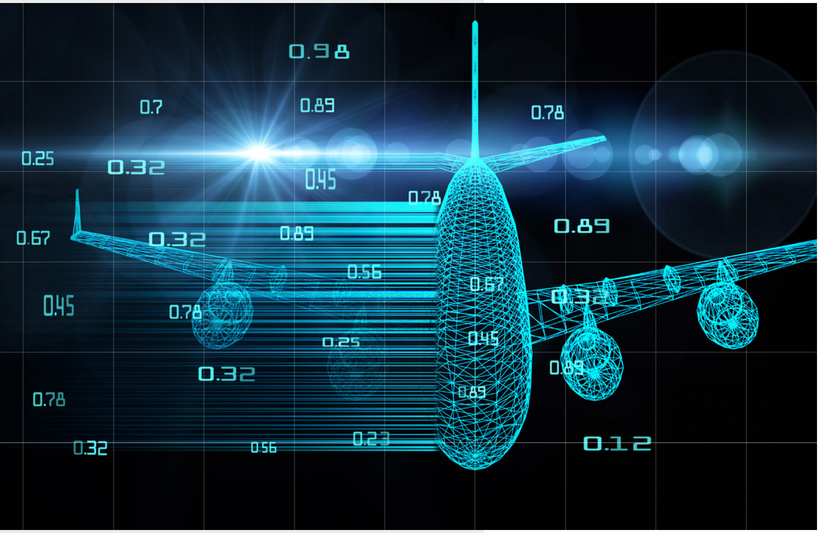
2. New ways of thinking and working

To succeed, the movement will need to be ‘bottom up’ and ‘top down’ - individuals within companies, no matter how junior, must understand that they also have a part to play and should feel able to challenge unsuited or unsustainable practices. Employees should be encouraged to experiment, learn from failures, and continuously improve their skills and knowledge. They should be given the necessary resources, including time, tools, and training. ‘Flattening’ the organisational structure might be too much of an ask, but staff must feel free to challenge the status quo, when the status quo is not the best option.

This brings us to communication and hierarchy. Instead of seniority being a trump card, innovation favours ‘what’s right, not who’s right’. Data-driven decision-making should prevail here; with data collection and analytics used to inform decision-making and to measure the success of initiatives.

Risk tolerance is another factor. A culture of experimentation and innovation takes experimentation as a given, not as a risk, and accepts that failure is inevitable, but can be properly managed. This is understandably more difficult with strict safety procedures and fiduciary responsibilities to shareholders, but an ability to be more flexible with project expectations and milestones may pay dividends in scoping (and working on) complex aerospace technology projects. This is where digital, iterative ways of working and project management, like DevOps, DevSecOps or Agile (which are synonymous with tech) tend to win out against more traditional and inflexible project styles, like PRINCE2 or Waterfall.

Geographically distributed teams allow access to a greater talent pool, plus potential labor and carbon cost savings. For example, consider the case in which a specialist engineer/expert can work remotely, for example, using extended reality (XR) technology



(virtual reality (VR), Augmented Reality (AR) and Mixed Reality (MR)), to help local staff troubleshoot a technical problem, instead of having to travel to the site.

Remote working also offers the promise of an improved work-life balance that supports recruitment with the promise of a happier workforce. In fact, a happier workforce is another competitive advantage - companies that wish to create an innovative culture and attract the right staff should give thought to creating an environment that prioritizes employee wellbeing.

3. Leadership and an example to follow

Speaking of hierarchy (or the lack thereof) - a supportive leadership is also essential.

Leaders play a critical role in setting the tone and expectations for innovation. They must be supportive of new ideas, willing to take risks, and provide resources to support innovation among their subordinates. They should emphasize the value of feedback and encourage employees to learn from failures and mistakes. And, as always, they must lead through their example - innovative leaders make for an innovative culture.

4. The right tech stack

Having spoken at some length about culture, we'd be remiss not to cover some of the technologies that can support aerospace innovation.

As we've covered in previous articles, the ability to do a significant amount of engineering digitally is a huge cost and time saver and a significant source of competitive advantage. As such, it's not a matter of kind, but a matter of degree - how much more digital can an organisation become, in order to increase collaboration, and speed of innovation – whilst also driving down the need to travel and test physically, plus the associated environmental costs? And what tech can support this?

At the high level, this requires a robust cloud-based infrastructure to enable distributed teams, collaboration, and scalability. It also means AI, ML and big data analytics tools that can make sense of the plethora of test and operations data, and drive data-driven decisions. And of course, it also means robust cybersecurity to protect all of this invaluable infrastructure.

Succeed together, fail alone

Aerospace startups can clearly be more 'nimble' than many longstanding incumbents, but, this doesn't mean startups are more digitally capable than established primes, who have ample resources to invest in the best-in-class tech. However, startups are often able to operate without the constraints imposed by the bureaucracy or legacy systems of large organisations, and they do not have the problem of getting traditional engineers who have been with the company for decades to work with new sustainability and software teams, who have different ways of working.

In fact, many major aviation players are quite far advanced in the use of digital thread and digital engineering. For example, Rolls Royce has used digital twins for its engine designs for some years now, and Northrop Grumman's sixth-generation stealth bomber, the B-21 Raider, was built using the latest suite of digital engineering techniques. This puts them in a good position to innovate, but digital technologies and huge R&D budgets alone do not create revolutionary ideas – culture is a major factor.

The real lesson from startups is not so much around the use of advanced digital technology. It is, instead, to adopt the fail fast mentality that lets these startups rapidly experiment to solve big challenges, and quickly move from proof of concept to prototype to minimum viable product and beyond - learning and iterating through simulation and testing, whilst also having appropriate stage-gated checks to ensure good ideas progress and duds are quickly stopped. Can we combine the pace of a startup with the industrial capacity of an aerospace prime?

Considering that many major primes are actually quite advanced in digital technologies, their next focus should be putting these digital tools to use in new areas, for example, bringing in specialization and nurturing innovative mindsets within parts of the business (without cannibalizing profitable existing approaches). This can be done by partnering with smaller companies that have specialist technical expertise (eg. hydrogen fuel cells or autonomous navigation algorithms), or by building teams of in-house innovators with high degrees of specialist expertise in novel areas, and setting frameworks to encourage experimentation.

None of this needs to be done alone, and does not require aerospace companies to see everyone as a competitor. Value chains aren't independent – they operate in a regulatory framework and are made up of a network of specialist companies, all competing and cooperating in different measures. To truly transform, cultures must move to a collaborative mentality, using digital collaboration tools to securely work with partners, suppliers, academics, startups, software companies, hyperscalers, consultants, and, sometimes, even competitors.

This too, is something of a cultural challenge. Solving sustainable aviation is partly a coordination problem: thought must be given to how newer players and incumbents will work together. Incentives and efforts must be aligned - it can't work otherwise. This may require a cultural shift, moving away from a natural possessiveness around IP and data, to the realization that partnerships between aerospace generalists (with scale and experience), and tech specialists (with deep domain expertise) are likely the fastest and most efficient way to get us to Net Zero 50.

As with many other historic challenges, we succeed if we work together, and we fail if we don't.

CONCLUSION

How Capgemini can help aviation reach Net Zero?

Demand for air travel is set to rise, despite growing environmental concerns. As we have seen in this series, the global aviation industry must take significant steps to make its technology, fuels, and operations more sustainable if it is to achieve its goal of net zero carbon emissions by 2050. Some of this will be incremental engineering and operational improvements, some will be radical redesigns and rethinking of the nature of flight.

Capgemini can help on this journey. We are a recognized leader in sustainability technology, with strong partnerships worldwide, and three decades experience in aeronautics, as well as in related industries such as automotive and energy which offer valuable learnings for aviation.

We have deep expertise in the full range of areas needed to support aerospace to decarbonise, including: digital engineering, model-based system engineering, feasibility studies, simulation, software and AI, Verification & Validation, Life Cycle Assessment, supply chain optimisation, air traffic management, route optimisation, predictive maintenance and airport operations planning.

As such, we can provides a streamlined approach, acting as a single strategic partner, and working with experts and partners around the world to develop, test and deploy the sustainable technologies and engineering advances that will support aviation on its journey to net zero.

To discuss how we can help, please contact Mylène Thiéry, Next Generation & Sustainable A&D Offer Leader, Capgemini Engineering: mylene.thiery@capgemini.com

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Also available on this blog article: https://www.capgemini.com/insights/expert-perspectives/ensuring-aerospace-defense-supplier-resilience-sustainability-in-a-volatile-world/

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About Capgemini Engineering

World leader in engineering and R&D services, Capgemini Engineering combines its broad industry knowledge and cutting-edge technologies in digital and software to support the convergence of the physical and digital worlds. Coupled with the capabilities of the rest of the Group, it helps clients to accelerate their journey towards Intelligent Industry. Capgemini Engineering has more than 55,000 engineer and scientist team members in over 30 countries across sectors including Aeronautics, Space, Defense, Naval, Automotive, Rail, Infrastructure & Transportation, Energy, Utilities & Chemicals, Life Sciences, Communications, Semiconductor & Electronics, Industrial & Consumer, Software & Internet.

Capgemini Engineering is an integral part of the Capgemini Group, a global leader in partnering with companies to transform and manage their business by harnessing the power of technology. The Group is guided every day by its purpose of unleashing human energy through technology for an inclusive and sustainable future. It is a responsible and diverse organization of over 340,000 team members in more than 50 countries. With its strong 55-year heritage and deep industry expertise, Capgemini is trusted by its clients to address the entire breadth of their business needs, from strategy and design to operations, fueled by the fast evolving and innovative world of cloud, data, AI, connectivity, software, digital engineering and platforms. The Group reported in 2022 global revenues of €22 billion.

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