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The green light for air transport: sustainable aviation at present

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Abstract
In the nearly 120 years of aviation history, the industry and technology have evolved with the world. In the early decades, the focus was on preparing aircraft for passenger transport, and gradually the industry developed different areas such as airports, navigation, in-flight services and air traffic control. The aviation industry has faced quite many challenges in different periods. At the beginning of the JET era, the first very controversial factor, noise pollution, was already apparent. The gas turbines of the time were much less efficient than today', and although the technology worked, some factors were less considered by developers, such as the noise and environmental impact mentioned above. As we moved into more modern times, the focus shifted more and more to the pollutants emitted by aircraft, which has become one of the most studied factors to date. This research examines the sustainability of aviation, past, present and future, in the light of global warming. It presents technologies that already work in the present, but their possible spread only points to the near or even distant future.
Keywords
Sustainability, sustainable aviation, hydrogen. electric propulsion

1. Why is aviation important to the environment?

Our research is based on a study of the amount of CO_2 emitted by humans, gas in the atmosphere in concentrations that make it the most greenhouse gas. *Figure 1* shows that, according to the Air Transport Action Group (ATAG), the amount of CO_2 emitted by aviation accounts for 2 % of the CO_2 emitted by human activity globally. On a global scale, aviation is responsible for 12 % of CO_2 pollution from transport, while 74 % stems from road transport and 14 % from other forms of transport. It is important to note that approximately 80 % of the CO_2 emitted by aviation comes from flights of more than 1,500 km, where no practical alternative travel mode can be envisaged (*Čokorilo, Ivković, Kaplanović, 2019*). On a per-passenger-kilometre basis, rail transport results in lower carbon emissions, but it is also essential to consider the social and economic impacts of the development of the rail network. Flights less than 500 km represent only 1-2 % of all European air travel. Constructing railway lines is highly environmentally damaging, but the negative impact on wildlife is also significant (*Oxera, 2023*).

Aircraft are essential tools for landscape protection (*Bakó et al., 2021*). Aerial monitoring is a scientific, well-documented, verifiable method that enables continuous mapping and verifying the accuracy of data gained from other sources. For example, due to the rapidly spreading invasive species, vegetation can drastically change between preparing two environmental management plans. These fast changes can be monitored efficiently from above. When analysing the changes in grassland dynamics or mapping the upper canopy level of forests, the results turn out to be much more accurate (patch size and accuracy of boundaries of 20–50 cm) than it is feasible using GPS devices, total stations, field-work and investing the same amount of time. Field-work supported by aerial remote sensing with a few centimetres of spatial resolution range allows for more frequent, more accurate data collected from a wider area. This way, interpretive evidence and decision-support information can be obtained, and a periodic landscape change becomes widely understood and considered. It should be noted that in addition to the consequences of strong anthropogenic impacts, monitoring certain natural processes – in which human

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influence is not evident or moderate – may also be an important task from a nature conservation point of view. Surveys applying airborne and unmanned aerial systems (UAS) are increasingly crucial for controlling invasive plant species and infestations for forestry and conservation (*Müllerová et al., 2017; da Silva et al., 2023*).

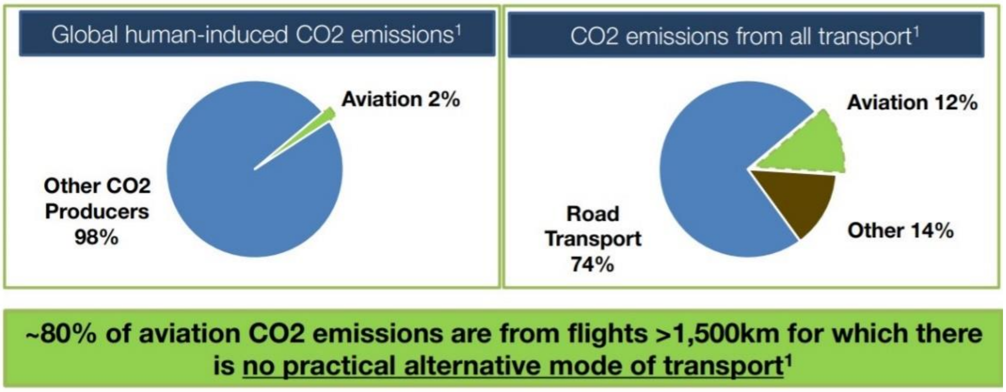

Figure 1. The role of aviation in carbon dioxide emissions (ATAG, 2023)

In 2020, the pandemic reduced the industry's CO_2 emissions by almost a third compared to the previous year, equivalent to 1997 levels. Compared to 2019, annual passenger numbers fell by 60 % by 2020 and 49 % by 2021. Carbon dioxide emissions have risen again as aviation industry indicators are rising in passenger and flight numbers. In 2019, the industry emitted 914 million tonnes of CO_2 out of 43 billion tonnes of CO_2 emitted globally each year, as shown in *Figure 2* (*ICAO, 2023a*). Natural carbon sinks can remove approximately 9-10 Gt of carbon from the atmosphere yearly, with CO_2 emissions reaching 36 Gt in 2019 (*Edgar, 2021*). At the International Air Transport Association 2022 conference, airlines agreed to commit to achieving climate neutrality by 2050. This implies the need to introduce technologies that can significantly positively contribute to reducing emissions.

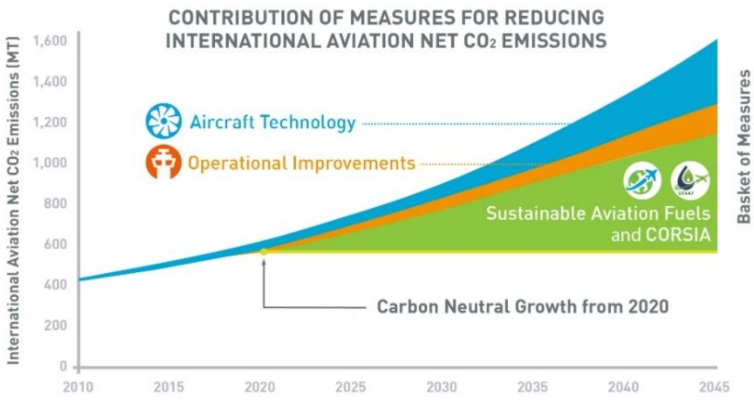

Figure 2. Aviation CO_2 emissions by year (*ICAO, 2023a*)

Today's aircraft have 80% better fuel efficiency per passenger kilometre than the types introduced in the 1950s at the dawn of the JET era. In 2019, the immediate year before the epidemic, 4.5 billion passengers used air transport, of which 1.9 billion were international and 2.6 billion were domestic. The figures (*Figures 1. and 2.*) show that the sustainability of air transport is an important issue. This research presents the possible alternatives to traditional fuel, such as electric propulsion, sustainable aviation fuel (SAF), and hydrogen operations, which are future technologies. It also compares with conventional JET fuel, i.e. kerosene, in terms of emissions.

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3. Technological enhancement in aviation

This chapter presents state-of-the-art research results in this field, focusing on the most important technical characteristics.

3.1. Electric propulsion

The growing attention paid to electric propulsion is no longer just a novelty: it is the technology that market players expect to bring the most significant reductions in emissions, noise and operating costs once the barriers are broken (*Ficzere, 2021*). However, significant hurdles must be overcome to achieve zero CO_2 emissions by 2050. More than 300 electric aircraft projects and nearly 200 start-ups were launched between 2016 and 2022 (*Ying, 2022*).

3.1.1. The economics of electric aircraft

Experience with the operation of pure electric aircraft has been very positive. The energy cost of a two-seater Pipistrel electric-powered aircraft is about $1 per hour, while a conventional two-seater Cessna C152 with an internal combustion piston engine costs about $34, according to pre-Russian–Ukrainian war estimates. Moreover, the total operating cost per hour estimate for a fossil-fuelled aircraft is 3.6:1 for a modern electric-powered aircraft. It can therefore be concluded that for these models, the energy cost per hour of operation of an electric aircraft is thirty-fourths of that of a conventional aircraft, but even when the total operating cost is compared to a fossil fuel-powered aircraft, it is almost a quarter of that (*Ying, 2022*).

3.1.2. Range and payload

Physical characteristics, such as payload, cruising speed and range, are significant difficulties for the spread of zero-emission systems. Today's advanced lithium batteries are about 50 times heavier than aviation fuel under given conditions. Even then, if the weight of JET engines is substituted for that of electric motors, the excess is 25 times greater (*Ying, 2022*). These are the difficulties electric aircraft developers face, and their results are as follows.

A prototype of a shoulder-winged composite plane with a twin-bladed propeller from the Liaoning General Aviation Research Institute in Senjang was analysed. Developed from an earlier two-seat model, the RX4E has a maximum take-off weight of 1200 kg and a wingspan of 13.5 m. It can fly for an hour and a half on a single charge and has a maximum speed of 200 km/h. The maximum distance it has flown from Senjang is 300 km. The battery capacity required is almost 70 kWh (*Asia Times, 2019*).

The ACCEL (Accelerating the Electrification of Flight) programme has developed a more advanced aircraft battery than ever before, which will enable the Rolls Royce – Spirit of Innovation aerobatic aircraft to fly a London to Paris route, which is around 345 km (*Rolls-Royce, 2021*).

The Alice twin-engine twin-jet from Eviation, an Israeli-based company based in the Seattle area, is a six to nine-passenger business jet with a payload of 1200 kg. This load will have a range of 815 kilometres at a speed of more than 400 km/h. These figures can be achieved by charging the aircraft for about thirty minutes (*DHL Group, 2021; Villamizar, 2022*).

3.1.3. Top speed of electric aircraft

The Rolls-Royce – Spirit of Innovation (*Figure 3*) aerobatic aircraft is part of the ACCEL (Accelerating the Electrification of Flight) programme. The development, supported by a government grant from the UK Government's Department for Innovation, involved two other smaller UK companies that are partners of Rolls-Royce. The aircraft's high-performance, ultra-lightweight electric propulsion system delivers 400 kW (500+ hp) of power, which has helped the aircraft set three new world records. These are still under review by the Fédération Aéronautique Internationale (*FAI*).

At 15:45 GMT on 16 Nov 2021, the aircraft reached a top speed of 555.9 km/h over 3 kilometres, beating the previous record by 213.04 km/h. In subsequent runs at the UK Ministry of Defence's Boscombe Down experimental aircraft test range, the Spirit of Innovation achieved a speed of 532.1 km/h over 15 kilometres, 292.8 km/h, faster than the previous best, and reduced the fastest time to climb to 3,000 metres to 202 seconds,

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beating the previous record by 60 seconds. During the record-breaking final runs, the aircraft reached a top speed of 623 km/h. The FAI has not yet validated these results (*Rolls-Royce, 2021*).

Figure 3. Spirit of Innovation electric aircraft (*Rolls-Royce, 2021*)

3.1.4.Approach to the objective

It can be concluded that technology development requires either a significant reduction in the electricity consumption of electric traction motors for a given power output or a significant increase (at least by one order of magnitude) in the capacity-to-weight ratio of batteries. For example, there are significant developments in solid-state batteries (SSB), which promise four times higher energy density than Li-ion batteries. *Table 1* shows the current energy density values of energy sources. These will become commercially available for electric vehicles in the next decade. Until this happens, the use of electric propulsion in aviation is severely limited. However, electric propulsion can already be considered a cost- and emission-reducing auxiliary propulsion system. An optimised hybrid electric aircraft in parallel operation using sustainable aviation fuels (SAF, 50% blend) can achieve a 90% reduction in emissions (*Ying, 2022*).

Table 1. The energy density of energy sources (*Tran et al., 2018*)

Fuel	**Energy Density ($MJ\ L^{-1}$)**	**Energy Density ($MJ\ kg^{-1}$)**
JP-8 JET fuel	34.5	43.4
Diesel	36.2	42.5
Gasoline	32	44
Hydrogen (liquid)	120	8
Methanol	15.6	19.7
Lithium-ion battery	N/A	0.6

3.2. Sustainable Aviation Fuel (SAF)

Sustainable Aviation Fuel (SAF) can play a significant role in the relatively rapid emissions reduction. SAF is an alternative fuel that can be produced from wood waste, algae, alcohol, sugar cane, cooking oil, etc. The carbon in the fuel is derived from biomass, and the engine releases CO_2 extracted by vegetation back into the atmosphere. Sustainability can be achieved if the biomass comes from sustainable farming. If this can be achieved, it can reduce the entire life cycle measured CO_2 emissions by 80-90% compared to kerosene (*Khadilkar, 2021*). The target blend rate with kerosene is 1–5% by 2025, rising to 15% by 2030. In the summer of 2022, the world's first 100% SAF fuel aircraft, operated by BRA, completed its first flight (*CO_2 Value Europe, 2022*).

On 1 Dec 2021, United Airlines became the first airline in the US to carry passengers using 100% SAF fuel in one of its engines. The Boeing 737 MAX 8 aircraft departed from Chicago and was destined for Washington DC, with over 100 passengers on board. The other engine was conventional kerosene. During the flight, it was found that

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there was no difference in the operation of the two engines using different types of fuel. Replacing kerosene with SAF could result in an approximate 80% reduction in carbon dioxide emitted by the aviation industry from the fuel when considering the entire life cycle shown in *Figure 4* (*Levingston, 2022*):

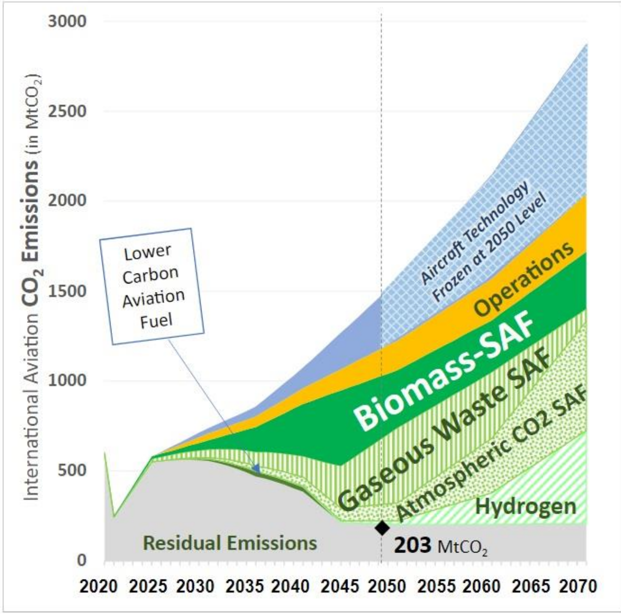

Figure 4. The future of aviation CO_2 emissions according to ICAO estimates (ICAO, 2023b)

In practice, SAF blending up to 50% can be observed when blended with conventional JET A or JET A-1 fuel. SAF fuel is fully interchangeable with kerosene without any engine modification. Currently, alternative fuels can be produced at 3 to 6 times the cost of traditional kerosene. Through continuous development and commercialisation, the technology will become cheaper and more affordable in small steps. It is already available at more than 60 airports, but it is currently impossible to produce sufficient quantities of sustainable fuels from plant derivatives, and synthetic production is needed. By 2050, SAF fuel could account for approximately 15% of total aviation fuel consumption (*Gül et al., 2021*).

3.3.Hydrogen-powered aircraft

Hydrogen can play a significant role in meeting the energy needs of aviation. Experts consider it essential to focus on using renewable energy to produce hydrogen produced by water decomposition. According to ICAO, the use of hydrogen in propulsion will not have a significant impact on carbon dioxide reduction until 2050. It is estimated to account for approximately 1.9% of the energy mix. These figures could increase significantly after 2050 (*ICAO Committee on Aviation Environmental Protection Report, 2022*).

3.3.1. Hydrogen-fueled gas turbines

The industry needs time to build airport infrastructure and hydrogen transport, but some aircraft manufacturers, such as Airbus, prioritise this type of technology as a long-term carbon reduction option. According to the manufacturer, the first hydrogen-powered passenger aircraft could operate scheduled flights by 2035, with up to 200 passengers on board and a maximum range of 3,500 km. The storage of liquid hydrogen faces many obstacles. Designing and integrating fuel tanks in aircraft is one of the most critical processes for testing aircraft with new technology. Airbus plans to test hydrogen tanks stored at extremely low temperatures of around -252 degrees Celsius by 2025 (*Airbus, 2021*).

3.3.2.Hydrogen fuel cell propulsion

Hydrogen can be used not only as a fuel for gas turbines, where the combustion products exiting the engine are used to provide some thrust but also for fuel cell engines of propeller rotation design that the green fuel can power. In fuel cells, an electrochemical reaction converts hydrogen into electrical energy to turn a propeller by an electric

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motor. The converted A380, which Airbus is testing hydrogen technologies on, is being used for various tests to monitor the engines' operating parameters and the liquid hydrogen distribution and storage systems. The technology does not emit carbon dioxide in its combustion products, its main by-product being water. Fuel cell technology has the advantage of zero nitrogen oxide emissions and no contrails. Airbus expects to launch the ZEROe programme in the late 2020s. The fuel cell aircraft to be developed in this programme are expected to have a range of nearly 2000 km, carrying approximately 100 passengers. Using a propeller has limitations compared to JET technologies: lower cruising speed and altitude.

4. Conclusion

The technologies described above are based on the benchmarks of today's well-established forms of aviation, such as conventional kerosene-fuelled gas turbines or internal combustion engines fuelled by AVGAS or diesel. Fossil fuel-burning aircraft have a high emission and environmental impact but have become a safe and widespread form of air transport, flying at relatively high altitudes, high speeds and long distances, carrying hundreds of passengers or many tonnes of cargo. The future technology aims to reduce emissions by orders of magnitude, focusing on carbon dioxide gas, without compromising these flight characteristics. The challenge for practitioners and policymakers is to develop a roadmap for implementing mature technologies in aviation over the coming decades so that the industry can reach the realistic emission levels we are now setting ourselves in the name of sustainability.

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