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Common – Emerging technologies/Aviation – Gas emissions: In search of alternative propulsion systems for aircraft: Airbus prepares tests with hydrogen propulsion for aircraft

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【概要：Summary】

Considering the targets of achieving a net-zero GHG emissions in the EU by 2050 and to reduce the transport sector's GHG emissions by 90% by that time, the aviation sector is the most difficult sector to achieve a GHG emission reduction due to the problems to replacing combustion engines with environmentally friendlier propulsion systems. The aviation sector lacks of alternatives to currently used propulsion systems or the wide utilisation of sustainable aviation fuels for significantly reducing CO2 emissions. Contrary to the road transport sector and the possibility to switch to electric vehicles, there are no zero-emission aircraft available yet, and options to decarbonise aviation are limited. The development of a low to zero emission propulsion systems for aircraft is still the most challenging of all sectors.

The aviation industry will have to develop radically new technologies regarding aviation fuels and propulsion systems. For the near future, sustainable aviation fuels (SAF) like synthetic fuel (synfuel) will have to be scaled up temporarily and to use carbon offsets in large quantities to reduce the CO_2 emissions from aviation. Furthermore, different new propulsion systems will have to be developed from electric hybrid, over electric, to H_2 propulsion, among others. Regarding the feasibility and economy of hydrogen-based propulsion systems for aircraft, hydrogen propulsion systems could play a major role in aviation's future technology mix.

Airbus started is new hydrogen-based aircraft project in September 2020 and presented three ZEROe hydrogen-fuelled concepts, aiming for commercial service by 2035. These concepts for hydrogen powered aircraft each represent a different approach to achieving zero-emission aircraft, exploring various technology pathways and aerodynamic configurations. On 22 February 2022, Airbus announced the arrival of a demonstration of a liquid hydrogen-fuelled Turbofan prototype. The A380 MSN1 test aircraft called the ZEROe Demonstrator will have the task to examine how hydrogen combustion can be used to power turbofan jet engines to deploy the world's first zero-emission commercial aircraft by 2035.

【記事：Article】

1. Background: The need to reduce GHG emissions of aircraft

In 2017, direct emissions from aviation in the EU accounted for 3.8% of total CO_2 emissions and for 13.9% of the emissions from transport. This makes aviation the second biggest source of transport GHG emissions after road transport. Before the COVID-19 crisis, the International Civil Aviation Organization (ICAO) estimated that by 2050 international aviation emissions could triple compared with 2015 (European Commission n.y.).

Furthermore, the aviation sector is particularly difficult to decarbonise due to its exclusive reliance on fossil energy and there are only limited technological options available for reducing its CO_2 emissions. Currently, more than 99% of jet fuel used in the EU in 2018 was fossil kerosene (SWD(2021) 633 final).

In 2019, aviation emissions covered by the EU-ETS amounted to 68.2 Mt Coe, representing an increase of 1.0% compared to 2018 (European Commission 2021a). According to Clean Sky 2 JU and FCH 2 JU (2020), assuming a growth of the aviation industry of 3% to 4% (p.a.) and efficiency improvement of 2% p.a., emissions would more than double by 2050 (Clean Sky 2 JU and FCH 2 JU 2020).

Since 2021, those airlines covered under the ICAO's CORSIA pilot phase need to offset the growth in CO_2 emissions from the routes between states, which have volunteered to participate.

The European Green Deal (COM/2019/640 final) sets an overall 2050 net-zero carbon emission target, also including a call to reduce the transport sector's GHG emissions by 90% by 2050. The mid-term target of reducing GHG emissions is set at 55% to be met by 2030. This also puts the aviation sector under pressure to find solutions for its CO_2 emission problem. Accordingly, the European Commission's "Fit for 55" package of 14 July 2021 also includes the ReFuelEU Aviation proposal (COM (2021) 561 final), which will oblige fuel suppliers to blend increasing levels of sustainable aviation fuels (SAFs) into jet fuel at EU airports.

2. The utilisation of SAF in aviation

Contrary to the electric vehicles in the road transport sector, zero emission aircraft are not yet available and options to decarbonise aviation are limited. In short to mid-term, the means to reduce CO_2 emissions in aviation mainly focus on the utilisation of sustainable aviation fuels (SAF). According to IATA (n.y.), sustainable aviation fuels (SAF) have most potential to cut the aviation sector's carbon footprint by up to 80% and therefore they could significantly contribute to the decarbonisation of aviation (EPRS 2020).

The ReFuelEU Aviation proposal will oblige fuel suppliers to blend increasing levels of sustainable aviation fuels into jet fuel at EU airports, including synthetic low carbon fuels (e-fuels). The gradual introduction of the blending mandate will start with a 2% SAF requirement in 2025, followed by 5% in 2030, 20% in 2035, 32% in 2040, and 63% in 2050 (COM (2021) 561 final). The fact that SAFs can be mixed with kerosene up to around 50%, without any changes to the aircraft engine is an advantage for the beginning of a wider introduction of SAF in aviation. The ReFuelEU Aviation (COM (2021) 561 final) is expected to boost SAF production and their uptake already in the short-term by ensuring that increasing levels of SAFs will be available at EU airports.

Meanwhile, the aircraft manufacturers including Airbus are developing new propulsion systems for aircraft.

3. New propulsion system options of aircraft

The need to reduce GHG emissions of aircraft and to make them more environmentally friendly has also led to considerations to develop new propulsion systems for aircraft. There are attempts to develop electric propulsion systems for aircraft and start-up companies as well as established aircraft manufacturers intend to launch hybrid or all-electric commercial passenger jets, capable of flying passengers on short-haul routes within a decade. In the same way as electric cars and road vehicles, also electric aircraft could get their propulsion energy from on-board batteries. Electrically driven aircraft are considered being especially beneficial for the environment as electricity could be generated by completely renewable sources. There already exist promising new programmes and around 130 projects worldwide for developing all-electric or hybrid-electric propulsion aircraft concepts. Currently, electric propulsion is only realistic for very small aircraft, which gives the urban mobility electric aircraft and urban air taxis deployment a promising prospective. For larger aircraft, the development of regional and larger commercial aircraft concepts with hybrid-electric propulsion could become feasible in medium term (Greenaironline 2018a).

In its non-extensive lists of projects, ICAO currently lists six ongoing projects of business and regional aircraft projects, out of which four are full electric aircraft and 2 hybrid aircraft projects for electric passenger jets of 9-18 passengers' capacity (ICAO 2022a). Regarding large commercial aircraft, ICAO lists three ongoing projects, out of which two are hybrid and one is full electric. (ICAO 2022a). The three ongoing projects for large electric commercial aircraft, ICAO lists EAG Hybrid Electric Regional Aircraft (HERA), a hybrid electric aircraft, with 70 passengers' capacity. Wright Electric/Easy Jet, which develop a full electric aircraft with 186 passengers' capacity and Boeing Sugar VOLT are developing a hybrid electric aircraft with 135 passengers' capacity (ICAO 2022b).

The fourth ICAO listed project of Airbus/Siemens/Rolls Royce/E-Fan X for a hybrid electric aircraft seating 100 passengers has been cancelled in April 2020 amid the COVID-19 pandemic (Wikipedia 2022a, ICAO 2022b). However, Airbus has meanwhile come up with a new project on electric aircraft. Airbus prepares for EcoPulse flight test of high-voltage battery technology. EcoPulse is a distributed hybrid-propulsion aircraft demonstrator developed in partnership with Daher and Safran with the support of France's CORAC and DGAC (Airbus 2022a). The standard engine and propeller systems are augmented by six wing-mounted propellers, each of which is driven by 50-kW ENGINeUS™ electric motors and powered by batteries (Airbus 2022a). Airbus is providing the high-energy-density battery technology and overseeing aerodynamic modelling of the distributed-propulsion system and the development of a Flight Control computer system (Airbus n.y.). The EcoPulse demonstrator's high-voltage Lithium-Ion main battery system is developed by Airbus Defence and Space in Toulouse (Airbus 2022a).

By understanding high voltage battery behaviour based on this testing, Airbus will develop competence for future aircraft, to optimise power/energy management of non-propulsive functions such as air conditioning, auto flight, and flight controls, among others (Airbus 2022a).

The development projects of electric aircraft in recent years even led to a plan of the Norwegian government to replace kerosene propelled aircraft with electric aircraft on short-haul flights within Norway and neighbouring countries by 2040 (Greenaironline 2018b). Meanwhile, engine manufacturer Rolls-Royce and aircraft designer Tecnam teamed up with Norwegian regional airline Widerøe to deploy an all-electric 9-seater passenger aircraft by 2026 (Hampel 2021).

Before the pandemic, Airbus intended to develop electric aircraft for shorter-range aircraft. However, the current level of technology limits the use of electric propulsion to very small aircraft and the challenge remains how to power the large aircraft sector in future.

In the meantime, the aviation sector will have to rely on alternative fuels to reduce its CO_2 emissions. A hybrid-powered aircraft is more likely to be available sooner than a full electric aircraft.

4. Development of hydrogen propulsion solutions for commercial aircraft

While the electric propulsion is not mature enough for being applied in larger commercial aircraft, the aviation industry has to find other ways of developing carbon-neutral new propulsion technologies. In this context, hydrogen (H_2) propulsion is considered being one of the more promising future propulsion technologies that might be applicable in larger commercial aircraft. The development of H_2 combustion engines and fuel cell powered propulsion could offer a solution also for aircraft.

Hydrogen is already safely used in automobiles and trains, and it is the aviation industry's challenge now to adapt this potentially zero-emission energy carrier to the commercial aviation's needs. Concluded in 2002, the EU's research project CRYOPLANE with Airbus and 34 other partner companies assessed the technical feasibility, safety, environmental impact, and economic viability of using liquid hydrogen as an aviation fuel (Wikipedia 2022c). According to the Clean Sky 2 JU and FCH 2 JU report (2020), hydrogen propulsion has the potential to be a major part of the future propulsion technology mix. However, it will require significant research and development, investments, and accompanying regulation to ensure safe, economic H_2 aircraft and infrastructure. H_2 propulsion in aircraft could significantly reduce climate impact if hydrogen is produced from renewable energies. According to the Clean Sky 2 JU and FCH 2 JU report (2020), the latest estimates show that H_2 propulsion systems could reduce the climate impact in flights by 50% to 75%, and fuel-cell propulsion even by 75% to 90%, compared to about 30% to 60% for synfuels (Clean Sky 2 JU and FCH 2 JU 2020).

However, to reach a mature level of H_2 aircraft and infrastructure, several technological steps need to be taken, including enhancing the overall efficiency with lighter tanks and fuel cell systems, liquid hydrogen (LH2) distribution within the aircraft, turbines capable of burning hydrogen with low-NOx emissions, and the development of efficient refuelling technologies enabling flow rates comparable to kerosene (Clean Sky 2 JU and FCH 2 JU 2020).

Assuming these technical developments, H_2 propulsion-based aircraft could enter service within the next eight to fifteen years (Clean Sky 2 JU and FCH 2 JU 2020). Instead, long-range aircraft with hydrogen propulsion will require new aircraft designs. H_2 is technically feasible but less suitable for long-range aircraft designs from an economic perspective. The hydrogen tanks would increase airframe length and energy demand, resulting in 40% to 50% higher costs per PAX. Synfuel is likely the more cost-effective decarbonization solution for long-range aircraft. New aircraft designs (e.g., blended-wing-body) could change this but they are at least 20 years away from entry into service, according to Clean Sky 2 JU and FCH 2 JU (2020).

Feasibility and economic analyses show hydrogen could be a major part of aviation's future technology mix, if H_2 powered aircraft are deployed in segments where they are the most cost-efficient means of decarbonization. They could account for 40% of all aircraft by 2050, with this share further increasing after 2050 (Clean Sky 2 JU and FCH 2 JU 2020).

However, bold steps need to be taken urgently to initiate a path towards decarbonization through hydrogen, as the aviation industry needs to develop solutions now, with the commercialization and certification of aircraft probably taking more than 10 years and substantial fleet replacement would take another 10 years (Clean Sky 2 JU and FCH 2 JU 2020).

5. Airbus ZEROe hydrogen-fuelled concepts

Airbus started a new hydrogen-based aircraft project in September 2020 and presented three ZEROe hydrogen-fuelled concepts aiming for commercial service by 2035. This includes a 100-passenger turboprop, a 200-passenger turbofan, and a futuristic design based around a blended wing body (Airbus 2020, Wikipedia 2022c).

The first ZEROe hydrogen-fuelled concept is a turbofan design (120-200 passengers) with a range of 2,000+ nautical miles, capable of operating trans-continentally and powered by a modified gas-turbine engine running on hydrogen, through combustion. The liquid hydrogen will be stored and distributed via tanks located behind the rear pressure bulkhead (Airbus 2020).

The second concept is an aircraft design for up to 100 passengers, using a turboprop engine instead of a turbofan. It is powered by hydrogen combustion in modified gas-turbine engines, which would be capable of traveling more than 1,000 nautical miles, making it a perfect option for short-haul trips.

The third concept is a "blended-wing body" design concept for up to 200 passengers in which the wings merge with the main body of the aircraft. The exceptionally wide fuselage opens multiple options for hydrogen storage and distribution, and for the cabin layout (Airbus 2020).

These Airbus concepts for hydrogen powered aircraft each represent a different approach to achieving zero-emission flight and use various technology and aerodynamic configurations to decarbonise future Airbus aircraft (Airbus 2020). Airbus expects to decide on the best hydrogen technologies by 2025 and to develop a zero-emission commercial aircraft by 2035.

On 22 February 2022, Airbus announced the arrival of a demonstration of a liquid hydrogen-fuelled Turbofan prototype. The A380 MSN1 test aircraft is earmarked for the new role to take the lead on testing the technologies towards developing the world's first zero-emission aircraft to market by 2035. This new testing of the hydrogen combustion engine in the A380 platform builds on the results of the EU's Cryoplane research project (2000-2002).

The A380 MSN1 functions as a flight laboratory platform for testing the new hydrogen technologies. The platform can comfortably accommodate the large flight test instrumentation that will be needed to analyse the performance of the hydrogen propulsion system.

The demonstration will use the very first Airbus A380 - MSN 1 - as a flying testbed equipped with liquid hydrogen tanks prepared at Airbus facilities in France and Germany (Pilling 2022). A380 flying testbed called the ZEROe Demonstrator has the objective to examine how hydrogen combustion can be used to power turbofan jet engines. Airbus will define the hydrogen propulsion system requirements, oversee flight testing, and provide the A380 platform to test the hydrogen combustion engine in cruise phase, as well as measure condensation trails. The A380 platform can comfortably accommodate the large flight test instrumentation that will be needed to analyse the performance of the hydrogen in the hydrogen-propulsion system. The multi-year demonstrator programme has officially been launched with the objective to test a variety of hydrogen technologies both on the ground and in the air (Airbus 2022b).

Airbus will partner with CFM International, a 50/50 joint venture between General Electric Co. and Safran Aircraft Engines to develop a hydrogen-fuelled aircraft engine that should be put into operation in zero-emission aircraft by 2035 (Pilling 2022). Airbus will set the hydrogen propulsion system requirements and oversee flight testing while CFM International develops the hydrogen combustion engine and prepares it for testing. Specifically, the company will modify the combustor, fuel system and control system of a GE PassportTM turbofan to run on hydrogen. The engine was selected due to its physical size, advanced turbo machinery, and fuel flow capability (Airbus 2022b).

The new engine will not be powering the A380, which will use its conventional engines. Instead, the hydrogen engine will be mounted on the rear fuselage toward the stern on a stub support. This will allow the engineers to monitor the emissions of the hydrogen engine including contrails, separately from those of the main engines powering the aircraft (Mandel 2022). During the flight test phase, data will be gathered on the condensation trails produced by the engine in different atmospheric conditions (Airbus 2022b). CFM will undertake an extensive ground test programme ahead of the A380 flight test. Each technology component - the hydrogen tanks, hydrogen combustion engine and liquid hydrogen distribution system - will be tested individually on the ground. Then, the complete system will be tested first on the ground and then subsequently in flight. The first flight is expected to take place in the next five years and the entry-into-service of a zero-emission aircraft is planned to take place in 2035 (Airbus 2022b).

Since hydrogen is also more voluminous than kerosene, more space on the aircraft must be dedicated to fuel storage. The A380 will be fitted with four hermetically sealed liquid hydrogen fuel tanks in the rear of the fuselage delivered from the Airbus Zero Emissions Development Centres, which are working on metallic hydrogen tanks (Mandel 2022). The fuel load will consist of 400kg of liquid hydrogen. Furthermore, to remain in a liquid form, hydrogen must be kept at an extremely low temperature - around -252 degrees Celsius - which requires cryogenic storage. Therefore, a new cryogenic fuel distribution system, including a new pump, seals and pipes will be required for this engine with the liquid hydrogen converted into a gas before combustion. There will also be cockpit modifications to monitor and manage the propulsion system (Airbus 2022b).

Now, Airbus and CFM International are working on a demonstrator for a hydrogen jet engine that is expected to fly in the next few years and could lead to the introduction of a zero-emission aircraft by 2035. However, it can be expected that it will still take decades until hydrogen powered aircraft will enter the wider aircraft market.

6. Conclusion

The need to reduce GHG emissions and other emissions from aircraft has led to considerations to introduce SAF and to develop alternative propulsion systems. Encouraging the take-up of sustainable aviation fuels is seen as an important element in the short-to mid-term efforts to reduce GHG emissions in aviation. The ReFuelEU Aviation proposal (COM (2021) 561 final) targets might not be sufficient and calls for raising the percentage of SAF. Other elements include market-based measures, the streamlining of air traffic management as well as the development of alternative propulsion technologies and aircraft may contribute in the long-term. In the past years several electric or hybrid-electric commercial aircraft projects have been made public. These projects are all based on the general concept that electric aircraft can significantly reduce the negative environmental impact of the aviation industry. However, technologies like electric and hydrogen propulsion for aircraft have not yet matured sufficiently and it still might take decades until commercial use of these technologies can be reached. Regarding the feasibility and economy of hydrogen-based propulsion systems for aircraft, hydrogen can be a major part of aviation’s future technology mix, if H_2 powered aircraft are deployed in segments where they are the most cost-efficient means of decarbonization and if their technology is based on renewable energy sources. From an environmental point of view, hydrogen seems to be a suitable alternative to substitute conventional jet aviation fuel. However, it will still take decades that hydrogen propulsion of aircraft will become ready for the market, as the planes will have to be adapted to withstand the specific needs of hydrogen storage and combustion. Many companies are working on the decarbonisation of aviation and the Airbus projects are an example for these worldwide efforts to fundamentally change the aircraft's propulsion systems.

However, with hydrogen and electric aircraft still being decades away from widespread usage, both, the aviation industry, and the European Commission will only have the option to increase the use of sustainable aviation fuels (SAF) as the currently only feasible way to reduce GHG emissions from aviation in the short-term.

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