Electric, Hybrid, and Hydrogen Aircraft – State of Play

By ICAO Secretariat

INTRODUCTION

The aviation industry has noted a consistent increase in the electrification of aircraft systems, research on electrical propulsion, and investments in electric or hybrid aircraft designs. Projects are also ongoing on liquid hydrogen research for civil aviation purposes. Electric, hybrid and hydrogen aircraft may help ICAO meet its major environmental goals on climate change, local air quality, and noise. This article describes the possible environmental benefits that may result from these new technologies, and provides an overview of the current status of their development and implementation in aircraft.

POTENTIAL ENVIRONMENTAL BENEFITS FROM ELECTRIC, HYBRID AND HYDROGEN AIRCRAFT

Climate change

Substituting jet fuel with electricity or hydrogen can have a notable impact on the climate change impacts of aviation, as the operation of electric or hydrogen aircraft will not be associated with CO_2 emissions from fuel combustion. However, it is important to note that such CO_2 benefits need to be considered on a life cycle basis, and will only occur if the electric energy or hydrogen is obtained from lower carbon sources. For example, as of 2015, 98 airports around the world had installed solar power projects[1], and this number has continued to grow in the years since. The continued expansion of renewable energy capacity and availability at airports could provide an opportunity for hybrid or electric aircraft to recharge in such a way that CO_2 benefits could be achieved. Similarly, such renewable energy could be used to produce hydrogen with a low CO_2 impact on a life cycle basis.

The climate benefits of electric aviation may come not only from its reduced CO_2 emissions, but also from the elimination of contrails - the long, thin clouds that form in the wake of jet engines[2]. Although no scientific consensus exist on the radiative forcing effect of contrails, some studies point out that they may have further warming impacts on the global climate.

Beyond electric and hydrogen propulsion, it should be noted that there are various ways to use electricity and hydrogen in aircraft operations. One example is electric taxiing (E-taxi), which could save almost 33kg of CO_2 per minute of use, according to ICAO's Rules of Thumb[3]. Hybrid aircraft can also help to reduce fuel consumption and contrail generation by using electric motors as a supplementary thrust source during the takeoff phase, which allows the use of smaller and more efficient jet engines during the cruise phase of flight. Airports around the world have also demonstrated the feasibility of hydrogen for ground support/transport vehicles. For example, initiatives in Heathrow[4], Berlin[5] and Los Angeles[6] installed hydrogen fuelling stations that produce hydrogen onsite from renewable energy sources, using the electrolysis process.

1 ATAG. 2015. Aviation Climate Solutions. Air Transport Action Group. September 2015.
2 https://climate.nasa.gov/news/2482/electric-airplanes-batteries-included/
3 ICAO. 2016. ICAO Doc 9988, Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities.
4 https://hydrogeneurope.eu/project/hylift-europe
5 https://www.sciencedirect.com/science/article/pii/S1464285914701221
6 http://www.calstatela.edu/ecst/h2station

Local air quality

Full electric aircraft promise significant benefits for local air quality, as the pollutants emitted on the fuel combustion process are avoided. Hybrid-electric aircraft may similarly help improve local air quality impacts of aviation due to its lower fuel burn. However, while looking at air pollution impacts from all types of aircrafts including electric ones, brake abrasion, in addition to tire abrasion and road surface erosion still needs to be considered as these factors are a source of particulate matter emissions. In addition, similarly to the CO_2 emissions, the source of the electricity should be considered when assessing the local air quality impacts of electrification, since different processes of electricity production may still be associated with air pollution.

Other factors also need to be considered when looking at overall trends. While becoming more fuel efficient, aircraft tend to increase in size and weight, carrying more passengers and more fuel. This increase in carried fuel could offset the fuel reduction achieved through energy efficiency improvements thanks to hybrid systems. Therefore, it is clear that hybrid-electric aircraft help reduce air pollutant emissions when looking at the per-passenger figures, but not necessarily when looking at total figures. Moreover, most hybrid-electric aircrafts are equipped with batteries for electricity storage and supply. Due to battery energy density and the required power supply, these batteries are currently very heavy, thus can substantially increase the weight of aircraft.

A Life cycle approach to electric aircraft could be useful to assess the overall impact of electric aircraft on the environment and its sustainability benefits. This approach goes from inception of an aircraft to its end-of-life, and helps to avoid environmental and social risks. **Batteries** used in electric aircraft are currently made of mostly lithium. Air pollutants emitted during processes associated with the production of lithium batteries may affect air quality and health. Moreover, the lifetime of batteries is still short and induces battery waste containing toxic or corrosive materials such as lithium. This hazardous waste could pose threats to health and the environment if improperly disposed. Nevertheless, there are opportunities for improvements in the batteries' life-cycles that will reduce possible impacts to the environment and health, as their use increases. Sustainable alternatives to lithium batteries are also being developed.

Noise

Electric propulsion may also result in lower aircraft noise levels, since electric engines will not have some of the noise sources associated with jet or piston engines, such as combustor and turbine noise. Depending on the design of the aircraft, jet noise may be also reduced substantially due to the lower jet speeds required for aircraft operation. The lower noise levels associated with electric aircraft may facilitate its use in densely populated areas. For example, the low noise of the Pipistrel Alpha Electro is being used to justify its use by flight schools in urban areas[7], and the Uber Elevate project is aiming at a 15 dB noise reduction when compared with typical helicopter of similar weight[8].

CURRENTLY ONGOING ELECTRIC AND HYBRID AIRCRAFT PROJECTS

The ICAO Secretariat is currently following the industry developments in electric and hybrid aircraft designs by means of the Electric and Hybrid Aircraft Platform for Innovation (E-HAPI)[9]. This website is being maintained with a non-extensive list of projects that have been identified globally, ranging from general aviation or recreational aircraft; business and regional aircraft; large commercial aircraft; and vertical take-off and landing (VTOL) aircraft (also called electric urban air-taxis). Most of them target an entry-in-service date between 2020 and 2030, and some are already commercially available. Four of the projects had their first flights in 2019 (Lilium, City Airbus, Boeing Aurora eVTOL, and Bye Aerospace Sun Flyer 2).

Currently there are no specific ICAO environmental standards in Annex 16 to cover such aircraft types. ICAO is monitoring the developments around these new entrants, and the need for SARPs and guidance.

7 https://www.pipistrel-usa.com/newsletter-115-may-2019/
8 https://s3.amazonaws.com/uber-static/elevate/Summary+Mission+and+Requirements.pdf
9 The most up-to-date version of this table is available at: https://www.icao.int/environmental-protection/Pages/electric-aircraft.aspx

TABLE 1: ICAO Electric and Hybrid Aircraft Platform for Innovation (E-HAPI)

Project	Type	Category	MTOW (KG)	Pax	Target Entry in Service	Cruise altitude (FT)	Cruise Speed (kt)	Payload (KG)	Range (KM)	Engine power (kW)
Airbus/ Siemens/ Rolls Royce E-Fan X	Hybrid-electric	Large commercial aircraft	N.A.	100	2030	N.A.	N.A.	6650	N.A.	2000
NASA X-57 Maxwell	Electric	General Aviation/ recreational aircraft	N.A.	2	2020-2021	9000	149.464	N.A.	160	60 +10
Zunum Aero ZA10	Hybrid-electric	business aircraft	5216.3	12	2020	max. 25,000	295	1134	1127	1000+500
Uber Elevate	Electric	VTOL	N.A.	up to 4	2023	1,000 - 2,000	130	498.96	97	N.A.
Lilium	Electric	VTOL	639.6	5	2025	3300	160	200	300	320
Pipistrel Alpha Electro	Electric	General Aviation/ recreational aircraft	549.8	2	2018	N.A.	85	200	600	60
Kitty Hawk Cora	Electric	VTOL	N.A.	2	2022	up to 3000	95	N.A.	100	N.A.
Kitty Hawk Flyer	Electric	VTOL	N.A.	1		10	17	N.A.	10.7	
Airbus (A^3) Vahana	Electric	VTOL	725.7	1	2020	N.A.	95	113	100	360
Airbus City Airbus	Electric	VTOL	2199.2	4	2023	N.A.	59	N.A.	96	8*100
Airbus/Audi Pop up	Electric	VTOL	N.A.	2	N.A.	N.A.	N.A.	N.A.	130	N.A.
Boeing Aurora eVTOL	Electric	VTOL	798.3	2	2020	N.A.	48.6	N.A.	N.A.	N.A.
Ehang 184	Electric	VTOL	N.A.	1	N.A.	9843	54	100	16	106
Volocopter 2X	Electric	VTOL	450	2	2018	6562	27	160	27	N.A.
Eviation Alice	Electric	business aircraft	6349.8	9	2021	32 808	240	1250	1046	N.A.
Wright Electric/Easy Jet	Electric	Large commercial aircraft	N.A.	at least 120	2027	N.A.	N.A.	N.A.	539	3*260
Extra aircraft/ Siemens Extra 330LE	Electric	General Aviation/ recreational aircraft	1000.1	2	2016	9843	184 (top)	N.A.	N.A.	260
Magnus Aircraft/ Siemens eFusion	hybrid diesel-electric	General Aviation/ recreational aircraft	600.1	2	N.A.	N.A.	100-130	N.A.	1100	60

Solar Impulse 2	Electric	General Aviation/ recreational aircraft	N.A.	1	N.A.	27887	38	N.A.	N.A.	N.A.
Bye Aerospace Sun Flyer 2	Electric	General Aviation/ recreational aircraft	861.8	2	N.A.	N.A.	55-135	363	N.A.	90
Ampaire TailWind	Electric	business aircraft	N.A.	9	N.A.	N.A.	N.A.	N.A.	161	N.A.
Embraer Dreammaker	Electric	VTOL	N.A.	N.A.	2024	2,600-3,300	N.A.	N.A.	N.A.	N.A.
Bell Nexus	Electric	VTOL	N.A.	4	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Boeing Sugar VOLT	Hybrid-electric	Large commercial aircraft	N.A.	135	2030-2050	N.A.	N.A.	N.A.	6482	N.A.
DigiSky SkySpark	Electric	General Aviation/ recreational aircraft	N.A.	2	N.A.	N.A.	162 (top)	N.A.	500	65
Hamilton aEro	Electric	General Aviation/ recreational aircraft	420	1	2017	N.A.	92	N.A.	160	80
Dufour aEro 2	Electric	VTOL	N.A.	2	N.A.	N.A.	173	N.A.	120	N.A.
PC Aero Elektra One Solar	Electric	General Aviation/ recreational aircraft	300	1	N.A.	19600	76	100	600	32
PC Aero Elektra Two Solar	Electric	General Aviation/ recreational aircraft	450	2	N.A.	65616	37.8	200	almost unlimited	23
PC Aero Elektra Solar Trainer	Electric	General Aviation/ recreational aircraft	600	2	N.A.		76.6	260	400	32
Volta Volare DaVinci	Hybrid-electric	General Aviation/ recreational aircraft	N.A.	2+2	2017	24 000	160	N.A.	N.A.	N.A.
Yuneec International E430	Electric	General Aviation/ recreational aircraft	430	2	N.A.	9840	52	N.A.	N.A.	N.A.

Pipistrel Alpha Electro

The Pipistrel Alpha Electro is a 2-seat trainer with an endurance of one hour+30 minute reserve. It is the first certified all-electric aeroplane, with about 60 aircraft currently in operation over the world. Energy-cost associated with its operation is around 1 Euro per hour, which makes it suitable for use by flight schools.

The general aviation/recreational aircraft group consists of aircraft with MTOW from 300 to 1000 kg. These are mostly electric powered aircraft with a seat capacity of two. This category includes aircraft which are already produced and certified, for example the Pipistrel Alpha Electro.

The aircraft under the business and regional aircraft category claims longer flight range close to 1000 km with increased seat capacity (around ten). A full scale prototype of the Eviation Alice was displayed at the Le Bourget Air Show in Paris. Flight testing is expected to start by the end of the year[10].

Significant progress has also been made on the VTOL category over recent years, with seat capacities from one to five, MTOWs between 450 and 2200 kg and projected flight ranges from 16 to 300 km. These aircraft projects are only electric powered and aim to enter into service in the period of 2020-2025.

The large commercial aircraft category includes Airbus and Boeing initiatives focused on hybrid-electric, single-aisle aircraft with seat capacities of 100-135 and targeted entry into service after 2030.

Eviation Alice

The Eviation Alice is being designed to take 9 passengers + 2 pilots up to 650 miles at a cruise speed of 240 knots. It is powered by three 260 kW (350 hp) electric motors developed by the Siemens eAircraft business, which was recently acquired by Rolls-Royce. At 3,700kg, the battery accounts for 60% of the aircraft take-off weight. Eviation announced that U.S regional airline Cape Air is to buy the Eviation Alice, which has a list price of around $4 million each. Eviation expects to receive certification by late 2021, with deliveries predicted for 2022.

References

https://www.wingsmagazine.com/rolls-royce-to-acquire-siemens-electric-propulsion-business/

https://www.cnbc.com/2019/06/18/all-electric-jet-firm-eviation-announces-us-airline-as-first-customer.html

PROSPECTS ON HYDROGEN PROPULSION

Hydrogen powered aircraft were successfully flown in the past. The Tupolev 155 (Tu-155) was tested in the late 1980s powered by cryogenic hydrogen and liquefied natural gas. This aircraft had a number of fundamental differences from the original version (Tu-154), such as a cryogenic fuel tank along with the fuel supply system and an experimental turbofan engine which operated together with the kerosene engines. The cryogenic complex on the plane was operated using several innovative systems, such as a helium control system for the power plant and a nitrogen system to replace the air in the compartments with the risk of cryogenic fuel leakage. To allow that, nitrogen and helium tanks were installed in the cargo compartment

10 https://www.cnbc.com/2019/06/14/in-pictures-the-stars-of-the-2019-international-paris-air-show.html

Airbus E-Fan X

The E-Fan X is an Airbus project, in partnership with Siemens and Rolls-Royce, which is developing a flight demonstrator testing a 2MW hybrid-electric propulsion system. The project aims is to replace one of four gas turbines on a British Aerospace RJ100 with a 2 MW electric motor. Flight testing is expected to start in 2020. With the E-Fan X, Airbus intends to investigate the thermal effects, electric thrust management, altitude and dynamic effects on electric systems, and electromagnetic compatibility issues, as well as facilitate the establishment of certification requirements for electrically powered aircraft.

Lilium Jet

The Lilium Jet is a tilt-jet aircraft with 36 electric motors mounted on its flaps. It will be capable of traveling up to 300 km in 60 minutes, carrying 4 passengers + one pilot. The ducted design of the electric motors is expected to provide noise benefits when compared with traditional helicopter designs. The Lilium Jet completed its maiden flight in May 2019, and is expected to be fully operational in various cities around the world by 2025.

Reference
https://lilium.com/

and cabin area. In the late 1990s, the initiative to create Tu-156 as a serial aircraft was proposed but the project hasn't been completed. However, the Tu-155 flight tests confirmed the possibility of safe operation of the aircraft powered by cryogenic fuel.

To date, several factors still hinder a possible use of hydrogen in commercial flights, such as on-board storage, safety concerns, the high cost of producing the fuel and the need for dedicated infrastructure at airports. Research projects are ongoing to demonstrate the feasibility of hydrogen propulsion and to overcome these challenges, in support of longer term environmental objectives for civil aviation.

One of these projects is the ENABLEH_2 (ENABLing CryogEnic Hydrogen-Based CO_2-free Air Transport)[11], a recently launched project funded by the European Union and led by Cranfield University. This project aims to revitalise enthusiasm for liquid hydrogen (LH_2) research for civil aviation, demonstrate its feasibility, and the need for more R&D into advanced airframes, propulsion systems and air transport operations as part of an LH2 future. The project will include experimental and numerical work for two key enabling technologies: H_2 micromix combustion (for ultra-low NOx emissions), and fuel system heat management (to exploit the heat sink potential of LH_2 to facilitate advanced turboelectric propulsion technologies). These technologies will be evaluated and analysed for competing aircraft scenarios; for advanced short to medium range aircraft and for long range aircraft, both featuring distributed turbo-electric propulsion systems. The study will include mission energy efficiency and life cycle CO_2 and economic viability studies of the technologies under various fuel price and emissions taxation scenarios. ENABLEH_2 will also deliver a comprehensive safety audit characterising and mitigating

11 https://www.enableh2.eu/

hazards in order to support integration and acceptance of LH_2. The project will provide a roadmap to develop the key enabling technologies and the integrated aircraft and propulsion systems to TRL 6 in the 2030-2035 timeframe.

CONCLUSION

New innovative technologies and energy sources for aviation are under development in a fast pace. ICAO is closely following up these developments and its possible benefits in terms of the ICAO Environmental Goals. Much work by ICAO will be required to keep pace with the timely environmental certification of such new technologies, as appropriate.