

# Research on Traditional Aircraft and Electric Aircraft from Environmental and Technological Aspects

Yanchen Wang \*

College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen 518000, China

\* Corresponding author: 2015211131@smail.jsut.edu.cn

**Abstract.** People frequently underestimate how much aviation contributes to climate change—3.5% of warming. Compared to other mainstream industries, its current share of emissions is quite tiny. However, the question is that air travel cannot be decarbonized yet through present technologies. Environmental pollution problem is getting worse and worse on account of greenhouse and harmful gas emissions. On the other side, the interest in full or more electric aircraft is stimulated by the electric vehicle industry during the last couple of years. This paper mainly focuses on the system in more electric aircraft (MEA) and the difference between MEA and traditional aircraft design. The present goal of more electric aircraft is that most of the important systems that currently use non-electric power should be replaced such as engine start, taxiing and propulsion system to improve air contamination issue and a number of aircraft characteristics. Besides, NASA's electric propulsion idea on reduce emissions, improve fuel efficiency and its system structure are all worth considering.

**Keywords:** Aviation, decarbonize, gas emissions, MEA, traditional aircraft.

## 1. Introduction

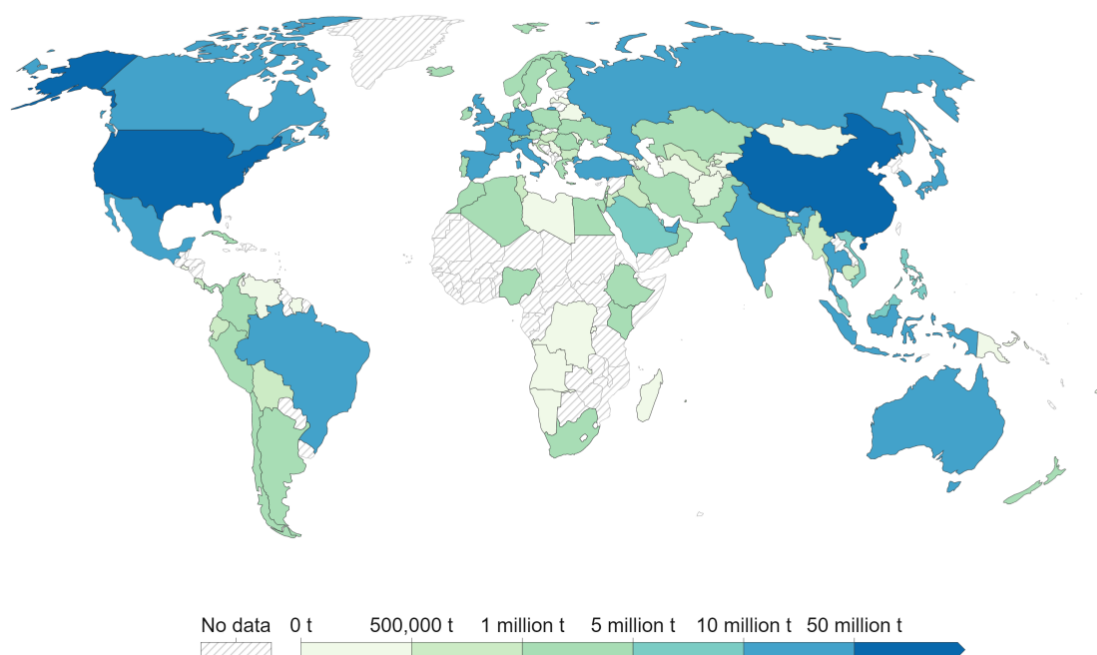
Greenhouse gas emission problem has existed for a long time though it did not draw much attention in previous development. For hundreds of years, liquid hydrocarbons have been a main component of commercial aviation because of their high energy density, simple handling, widespread availability, and affordable price [1, 2]. However, over-reliance on petroleum products comes at the expense of the environment. In 2015, 7% of global oil products were consumed by the global aircraft fleet which was totally 276 million tonnes of fuel [3]. Additionally, it is believed that aviation's non-CO<sub>2</sub> warming effects are just as significant as its CO<sub>2</sub> emissions, nearly doubling the industry's influence on global warming [4-6]. For example, NO<sub>x</sub>, as one of the aviation combustion emissions, can seriously affect air quality. A significant rise in NO<sub>x</sub> could raise the estimated 16000 premature deaths annually caused by aviation emissions worldwide. There is also mounting proof that noise from airplanes has a negative influence on people's health and increases their risk of early death [7, 8]. Thus, it is inadvisable to ignore environmental impacts from aviation. All direct combustion emissions, and as a result, all direct effects of non-CO<sub>2</sub> global warming and all direct air pollutants, would be avoided with fully electric aircraft, while lifecycle CO<sub>2</sub> emissions of full electric aircraft based on the power generating mix. Currently, numerous new energy industries are boosting, such as land transportation system which has been operating practically in daily life. However, the design of electric aircraft still faces many issues such as technology aspects, costs, energy efficiency and so on. In traditional aircraft, hydraulic, electrical, pneumatic, and mechanical energy are just a few of the types of energy that can be used by various of systems [9]. However, each energy source has its own disadvantages, such as the loss of overall engine efficiency when a specific energy is harvested, as in the case of hydraulic and pneumatic systems. The major change in aircraft is the use of electrical technology in functions that were previously driven by pneumatic or hydraulic sources. The challenges and difficulties can be presented through analyzing examples of typical system design in traditional aircraft and electrical technology in MEA. The increase in electrical energy use has resulted in a demand for new technology development. In electric aviation, it has two mainstream trajectories. The first trajectory builds upon the jet engines' gradual electrification [2]. As opposed to turbo-electric aircraft, this category of hybrid-electric aircraft concepts lacks batteries. Advantage and

disadvantage of Gas-Electric Hybrid Propulsion Aircraft system from NASA’s idea (a hybrid wing body (HWB) aircraft with a turbo-electric distributed propulsion system (TeDP)) will be analyzed. The other approach is the Hybrid-electric aircraft with batteries. At limited specific operating conditions, additional power or regeneration will be provided by batteries. The final design in aviation is a full electric airplane, which would have no emissions from direct combustion and, depending on the source of the power, might possibly minimize CO<sub>2</sub> emissions and eliminate aviation-specific non-CO<sub>2</sub> consequences [2]. Hence, to make electric aircraft come true, it is necessary to develop more efficient propulsion system, E-motor, and battery technologies. Electrical systems are thought to have a far greater potential for energy efficiency advancement in the future than traditional ones. In this article, the differences between traditional aircraft and more electric aircraft design are researched. Besides, new ideas or design in more electric aircraft and the situation of global CO<sub>2</sub> emissions will be introduced.

## 2. Emission Situation

### CO<sub>2</sub> emissions from aviation, 2018

Aviation emissions include both domestic and international flights. International aviation emissions are here allocated to the country of departure of each flight.



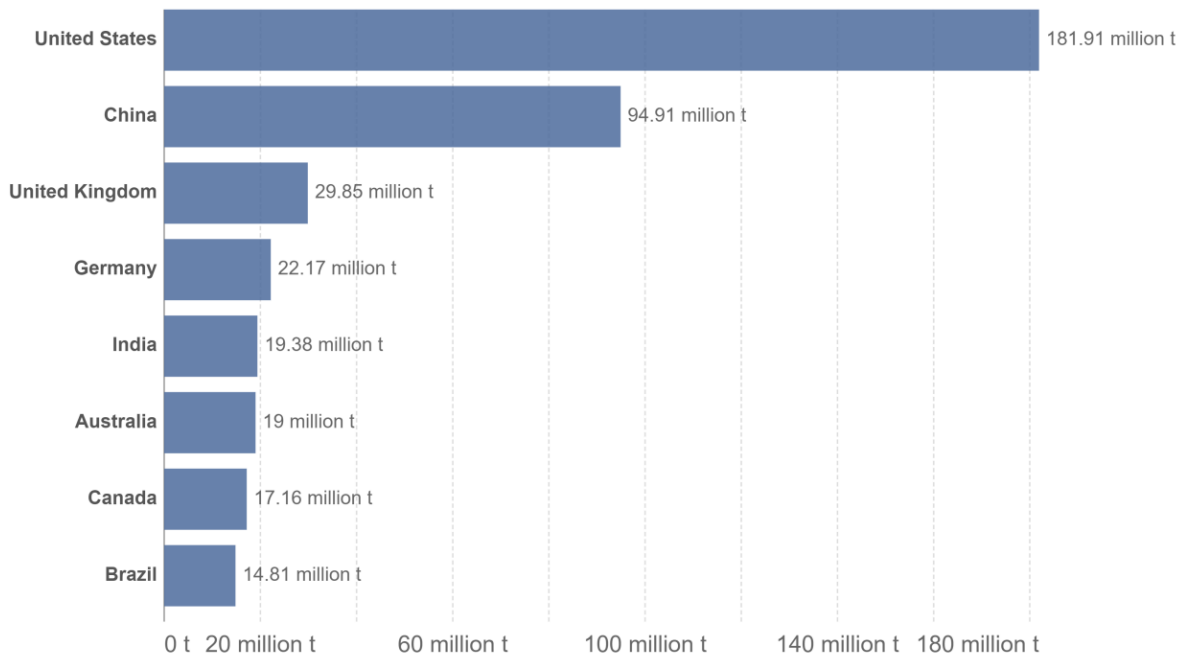
Source: Graver, Zhang & Rutherford (2019). International Council of Clean Transportation (ICCT).

CC BY

**Figure 1.** CO<sub>2</sub> emissions in aviation of every country in 2018, including both domestic and international flights [10]

### CO<sub>2</sub> emissions from aviation, 2018

Aviation emissions include both domestic and international flights. International aviation emissions are here allocated to the country of departure of each flight.



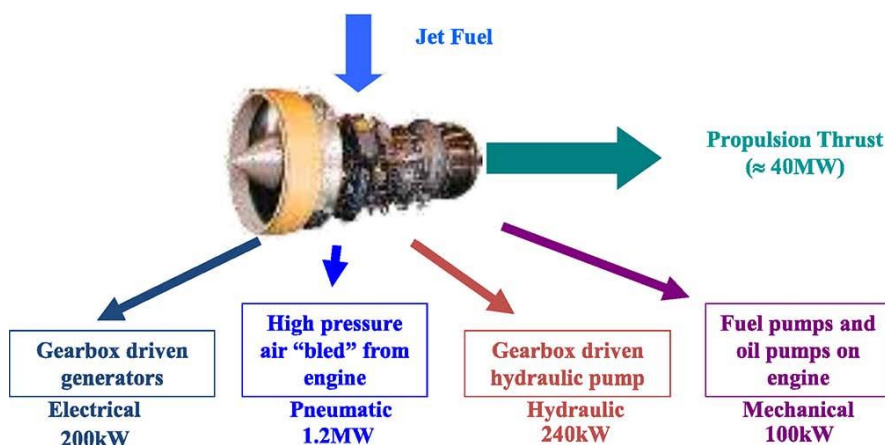
Source: Graver, Zhang & Rutherford (2019). International Council of Clean Transportation (ICCT).

CC BY

**Figure 2.** From aviation, the main CO<sub>2</sub> emissions countries in the world [10]

From Fig. 1 and Fig. 2, the USA and China were the main CO<sub>2</sub> emissions country in aviation all over the world. Furthermore, the data shows that 918 million metric tons of CO<sub>2</sub> were released from all commercial activities in 2019. About 85% of emissions came from passenger travel. Hence, aviation CO<sub>2</sub> emissions is indeed a serious problem which people ignored in the past and the passenger transport is the main part of aviation. A study found that 20% of CO<sub>2</sub> emissions from commercial aircraft in 2019 came from first and business class passenger travel as opposed to transporting freight. Depending on the kind of aircraft, in premium class, one passenger emits 2.5 to 4.5 times more CO<sub>2</sub> per kilometer than in the economy class. The mainly reason is the space. In premium class, passenger do have more personal space than in the economy class. Besides, premium class means more services are supplied to passenger. Although it is impossible to make everyone choose economy class in any situations, passengers should try to choose economy class as far as possible.

### 3. Traditional Aircraft Design



**Figure 3.** Power system on a typical large civilian aircraft

As shown in Fig. 3, the gas turbine engines provide the main source of power for the sub-systems on typical large aircraft. The thrust for the flight of a traditional aircraft and the power sources required for all the other loads on the plane are all provided by the gas turbines. However, the gas turbines are mainly used to supply the propulsion thrust. Fig. 3 displays the loads and power sources for a typical big aircraft power system. In a traditional, large, civil airplane, typically, the engines provide power from four sources: electrical, pneumatic, mechanical, and hydraulic [11].

I. The pneumatic system

The pneumatic system acts as the engine's air output, providing loads such as air conditioning, cabin pressurization, and wing ice protection.

II. The electrical system

The avionics systems, entertainment systems, lighting system in a plane are all powered by the electrical system.

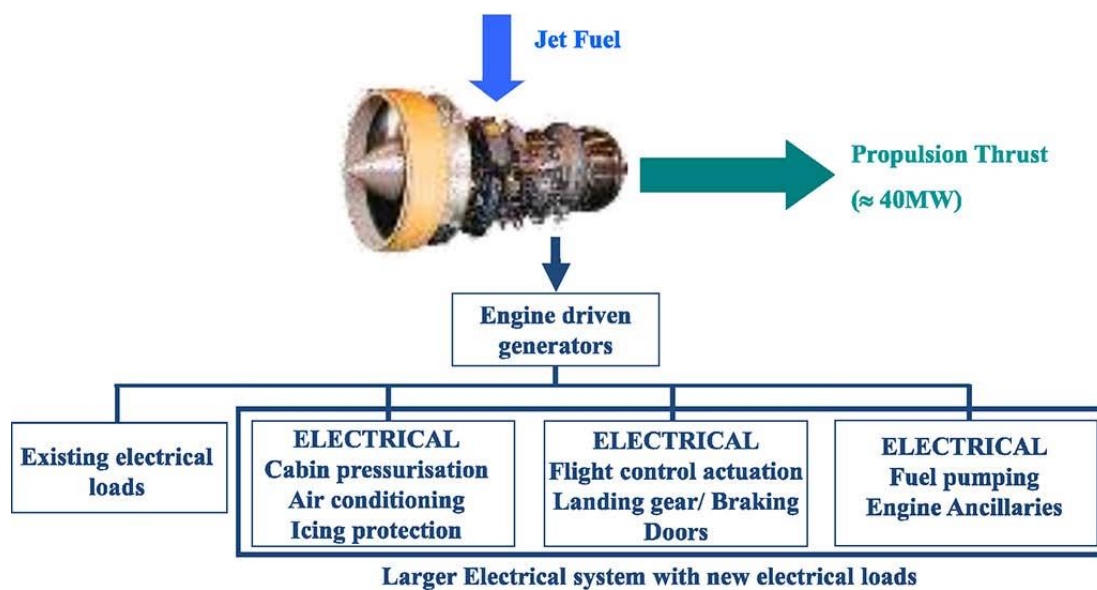
III. The hydraulic system and the mechanical system.

The majority of an aircraft's actuation systems are hydraulic in nature.

The mechanical system is utilized to pump oil and fuel, primarily in an area close to the engine.

Both are responsible for the flight control systems and auxiliary systems. These systems often have a combined maximum power output of over 1MW, making them a sizable power system for a relatively tiny platform [11].

#### 4. MEA Concept



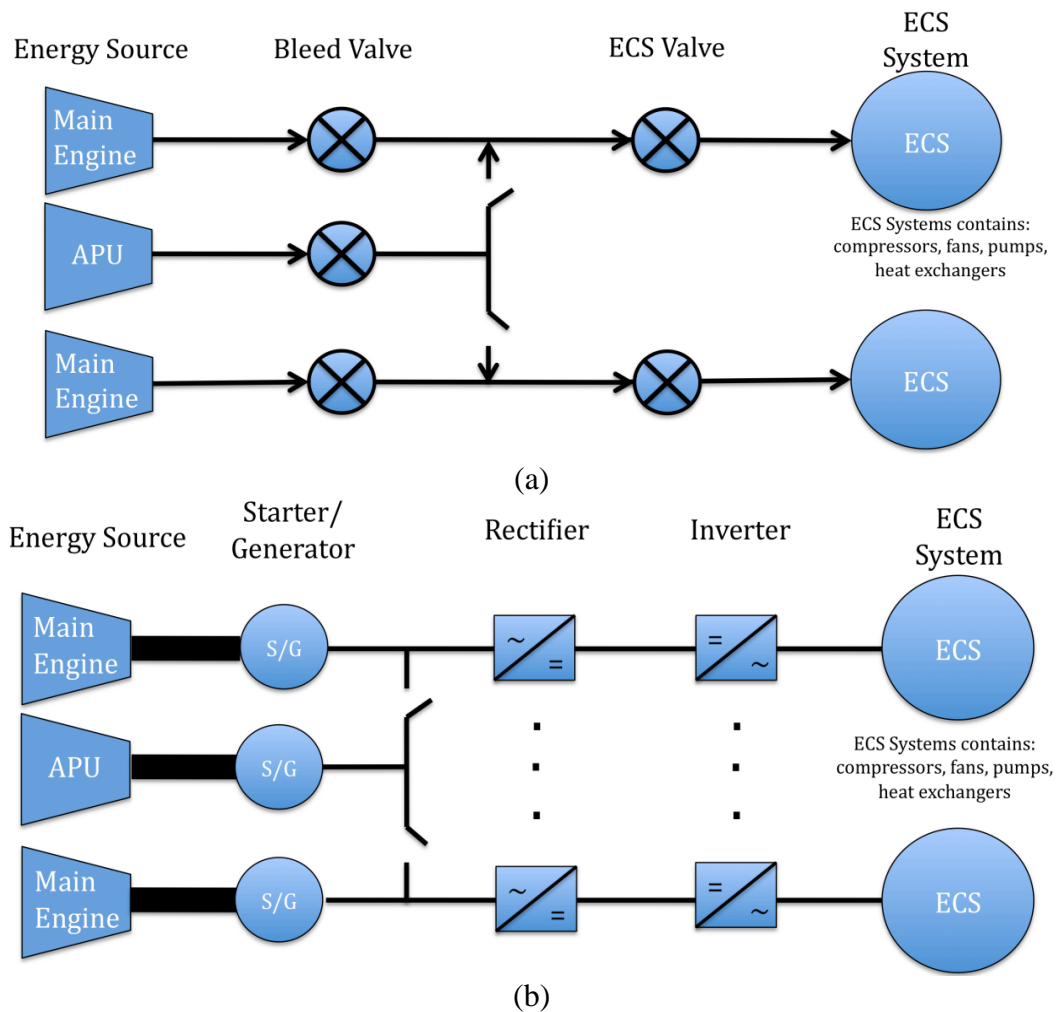
**Figure 4.** Concept of the power sources on a more electric aircraft

In traditional aircraft, four independent power systems are designed in human history so that each system is appropriate for their dedicate loads. However, when the airplane is viewed as a whole, it is possible to make the efficiency gain if all systems only use one power source. Electrical power is used as this power source because of its versatility and wide range of uses. Fig. 4 shows a possible power system concept for the MEA, and the propulsion thrust is approximately the same as the power system on a large civil aircraft which is about 40MW. The goal of this concept is that all onboard loads can be provided power from an electrical system. Without pneumatic systems means no need for a bleed air system on the gas turbine which might result in a significant efficiency improvement of the turbine. This change is also related to the Environmental Control system (ECS) which would be discussed below. Removing the mechanical and hydraulic systems may reduce overall weight of aircraft, but if battery pack is installed in the aircraft in the future all electric aircraft, the weight of battery also needs to be considered. The aim of this system in MEA is to improve energy efficiency, reduce maintaining and operating costs, decrease fuel consumption and the most important one is to

eliminate the environment impact from aviation in the future. In addition, electrical systems provide many new options such as advanced prognostic and diagnostic systems which means these systems could help to reduce unscheduled maintenance costs and improve the availability of aircraft. Through these systems, it is possible to use equipment to monitor aircraft’s use and environmental conditions practically rather than do preventive maintenance depending on age or flying hours [11]. For achieving these technologies, power electronics' dependability, the size and weight of electrical machines and apparatus, as well as the storage and movement of electrical energy are all need to be enhanced and developed.

**5. Environmental Control System on the Typical Aircraft and MEA.**

Through removing the use of bleed air in the ECS, electrical systems have been applied widely. Environmental Control systems manage the cabin temperature and air pressure to achieve passenger comfort. Generally, the main engine's compressor stages were used to supply bleed air [12]. The ECS of the Airbus A350 is depended on a bleed air configuration. However, the pneumatic system and air ducts from the engine have been removed for this system in the Boeing 787 because it employs a set of compressors powered by electricity to manage the pressure and temperature in the cabin rather than drawing bleed air from the engine [9].



**Figure 5.** (a) ECS with bleed air; (b)ECS without bleed air

Fig. 5(a) (b) simply shows the structure difference between the ECS system with bleed air and electric systems without bleed air. This simplified figure shows that compressors, fans, pumps, valves, pipes, and heat exchangers are all contained in Environmental Control systems.

The major component of the ECS systems are the fans which can ventilate the aircraft. To keep the air circulating in the cockpit, cabin, and cargo space, there would be numerous fans. Besides, ventilation of the cockpit and electronic equipment are provided by avionics ventilation.

The compressors, fans, and pumps of all these high-voltage, variable-frequency aircraft need to convert electricity in DC to AC and AC to DC to drive their respective E- motors. The energy loss in these processes is considerable, which means that energy efficiency needs to be calculated and energy conversion efficiency needs to be improved.

The problems are as follows. The electric power calculation for all stages of the flight and the size of the whole system is one of the challenges of the ECS. The compressors are powered by the biggest motors and power electronic converters.

Other two necessary considerations of the ECS are the reliability and redundancy which conduce to the design of the whole electric power system structure.

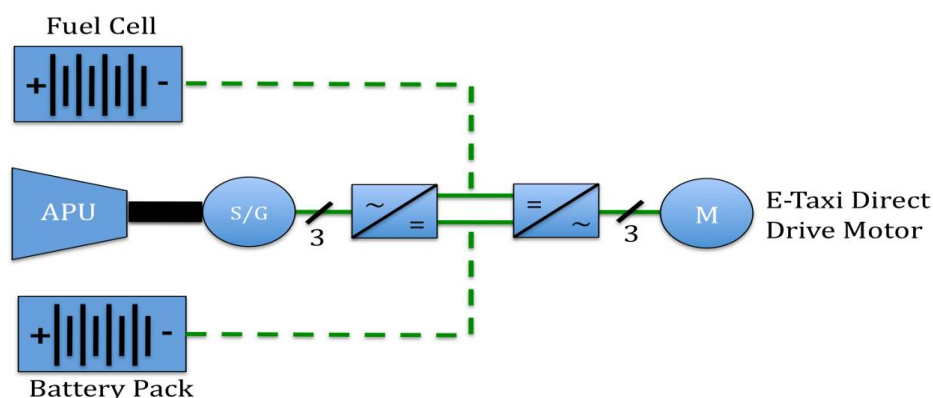
## 6. Typical Taxiing System and the Advantage of Future Electric Taxiing System

The electric taxiing capability is one of the more practical and useful technologies for MEA in the future.

As things stand now, the airplane is moved from the terminal gate to the tarmac by a tug vehicle which would burn a great deal of fuel because in this period, the main engine provides the main power to navigate to the runways of the airport.

Without a doubt, the engine is not operating at its best when it is taxiing. Taxiing involves traveling a considerable distance and taking a lot of time because of the magnitude and volume of traffic at some of the larger airports. It has been suggested as a solution to this issue to use E-motors built into the aircraft's primary gears and/or nose wheel to enable taxiing. As a result, the main engines may be shut off until just before departure. These direct-drive electric motors would make it possible to turn off the main engines after landing and conduct an electric taxi to the gate. E- motor, controls, power electronic converter, cockpit communication, and Auxiliary Power Unit (APU) power are required for electric taxiing. The structure is shown in Fig. 6 [9]. Dashed lines mean possible extra energy sources.

The term "Electric-taxi" is often used to describe this aircraft technology.



**Figure 6.** Electric taxi architecture

Besides, if fuel cells are utilized instead of the APU for electric taxiing, completely solving emissions problem while the aircraft is taxiing, this technology can be advanced even further. Powerful and dependable motors that may be installed inside the aircraft wheels are needed for this new method. Numerous system-level and safety-critical requirements, including as dependability, cost, efficiency, fault tolerance, volume, and weight, must be considered for this notion to become a reality [9].

The capacity to achieve reduced emissions, minimize fuel use, and boost operating capabilities are advantages of this growing subsystem. The removal of tug cars from airports and the streamlining of

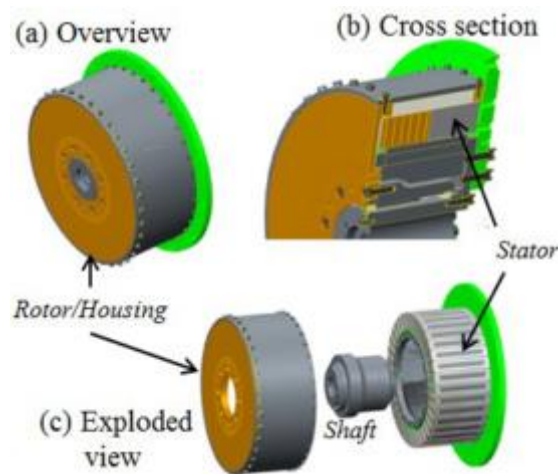
airport logistics and operations are further advantages that will ultimately lower the danger of accidents. A quantitative comparison of the traditional and electric taxi methods is presented in Table 1.

**Table 1.** Benefits of E-taxiing [9]

	E-taxiing
CO emissions*	40% reduction
CO2 emissions*	25% reduction
NO2 emissions*	50% reduction
Fuel consumption	4% savings of the total fuel

Note: \*indicates savings opposed to tug method

This is an example of structure and demonstration (Fig. 7 and Fig. 8) of a direct drive wheel with a permanent magnet motor physical implementation of the Airbus A320 power system.



**Figure 7.** Direct drive PM machine for electric taxiing [13]



**Figure 8.** The demonstration of electric taxiing [9]

## 7. NASA’s Idea (HWB with TeDP System)

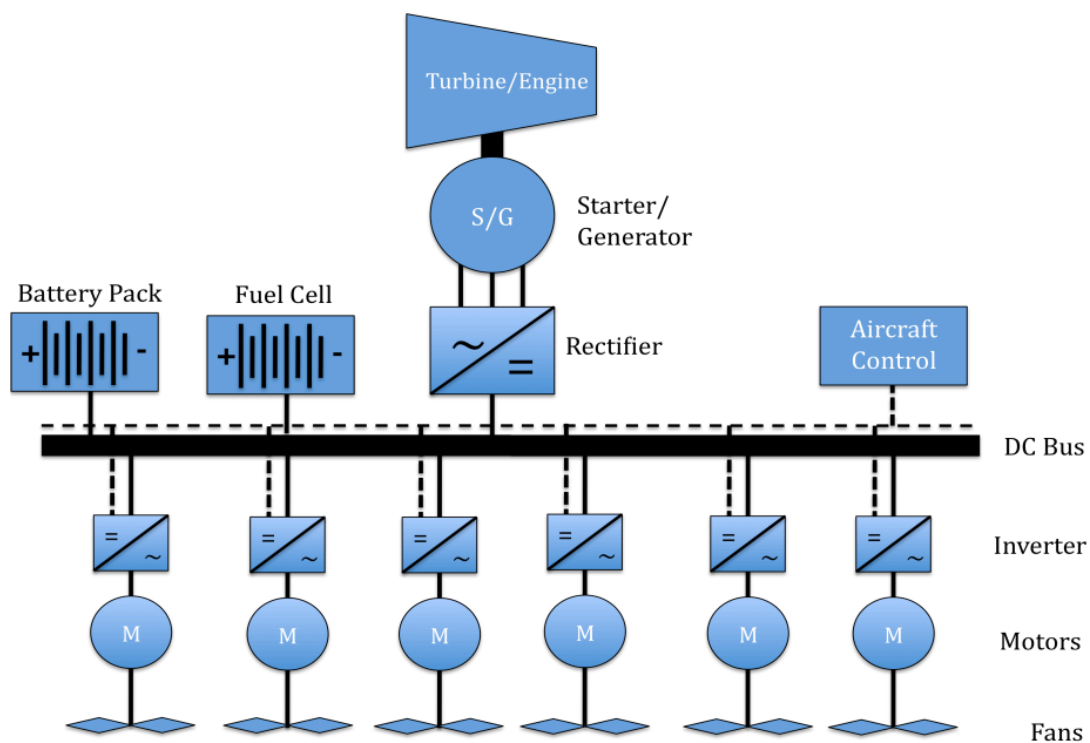
NASA has established objectives for the next generation of subsonic fixed-wing aircraft, including lower levels of NOx emissions, audible noise and also improve fuel or energy efficiency [9].

In order to achieve these goals, hybrid wing body aircraft with a distributed turbo-electric propulsion concept are two necessary structural considerations.

As shown in Fig. 9 and Fig. 10, two gas turbine engines with massive generators (22.4 MVA each side) are used in this design to generate electricity. The aircraft is propelled by a total of 15 propulsor 2-3 MW motors, which are powered by the generated electric energy. Due to its decoupling for maximum efficiency, the fan shafts and gas turbine are operated at their maximum speed [9].



**Figure 9.** A hybrid aircraft's distributed turbo-electric propulsion system



**Figure 10.** TeDP system structure for hybrid electric propulsion aircraft

The problems of this concept are energy loss and limited efficiency. It can be seen from Fig. 10, the process is that rectifier converts AC into DC at the beginning, so electric power can be stored in battery pack. Then, the electric power coming from the battery pack is converted into AC again by the inverters to drive the motors. Therefore, through this whole process, this system does lose some power.

## 8. Conclusion

More and more efforts and research were made in electric aircraft industry. Hence, it is believed that electric aircraft will have a bright future and it will contribute to environmental protection. The use of all-electric aircraft could result in the elimination of direct CO<sub>2</sub> emissions as well as direct non-

CO<sub>2</sub> consequences. The problem of Greenhouse gases emissions both in land and aviation must be solve in the future. Electric energy is an ideal energy type, but it will not be environmentally friendly if it is not ensured that the process of generating electricity is green. Compared to conventional aircraft, in MEA concept, the aircraft is considered as a whole, so it is can theoretically improve energy efficiency by only using one power type. However, in view of the process of the conversion between AC and DC, how to improve electric energy conversion efficiency is quite a problem. For full or more electric aircraft, researching more efficient propulsion system and electric-motor is as important as the development of battery technologies. Both Hybrid gas-electric propulsion system and electric taxiing technology for electric aircraft are good idea, but when it comes to practical using, there still have many problems need to be solved, such as the operating costs, energy using efficiency and suitable devices and materials.

## References

- [1] Climate change and flying: what share of global CO<sub>2</sub> emissions come from aviation? - Our World in Data
- [2] Schäfer A W, Barrett S R H, Doyme K, et al. Technological, economic, and environmental prospects of all-electric aircraft [J]. *Nature Energy*, 2019, 4 (2): 160 - 166.
- [3] International Energy Agency World Energy Statistics 2017 (IEA, 2017).
- [4] Lee, D. S. et al. Aviation and global climate change in the 21st century. *Atmos. Environ.* 43, 3520–3537 (2009).
- [5] Dorbian, C. S., Wolfe, P. J. & Waitz, I. A. Estimating the climate and air quality benefits of aviation fuel and emissions reductions. *Atmos. Environ.* 45, 2750 – 2759 (2011).
- [6] Brasseur, G. P. et al. Impact of aviation on climate: FAA’s Aviation Climate Change Research Initiative (ACCRI) phase II. *Bull. Am. Meteorol. Soc.* 97, 561 – 583 (2016).
- [7] Yim S H L, Lee G L, Lee I H, et al. Global, regional, and local health impacts of civil aviation emissions [J]. *Environmental Research Letters*, 2015, 10 (3): 034001.
- [8] Wolfe P J, Kramer J L, Barrett S R H. Current, and future noise impacts of the UK hub airport [J]. *Journal of Air Transport Management*, 2017, 58: 91 - 99.
- [9] Sarlioglu B, Morris C T. More electric aircraft: Review, challenges, and opportunities for commercial transport aircraft [J]. *IEEE transactions on Transportation Electrification*, 2015, 1 (1): 54 - 64.
- [10] CO<sub>2</sub> emissions from aviation, 2018 (ourworldindata.org).
- [11] Wheeler P. Technology for the more and all electric aircraft of the future [C]//2016 IEEE International Conference on Automatica (ICA-ACCA). IEEE, 2016: 1 - 5.
- [12] Cronin M J. All electric environmental control system for advanced transport aircraft: U.S. Patent 4, 523, 517 [P]. 1985 - 6 - 18.
- [13] Xu Z, Tighe C, Galea M, et al. Thermal design of a permanent magnetic motor for direct drive wheel actuator [C]//2014 International Conference on Electrical Machines (ICEM). IEEE, 2014: 2186 - 2192.