The Journal of Young Researchers

Analysis on the Feasibility of Electric Aircraft:

Current Status and Future Development

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Abstract

Electric aircraft are expected to play an essential role in future transportation, considering that global warming has become a serious problem. In such a context, the aim of this article is to explore the feasibility of electric aircraft currently and in a decade. The history of electric aircraft is introduced first, then some limitations and advantages of electric aircraft are listed to demonstrate the necessity in developing electric aircraft. Here we judge the feasibility by calculating the maximum take-off mass of electric aircraft under different application scenarios and analyze the results. Based on the results, it is found that at present electric aircraft can be used in some light-duty fields such as private aircrafts, while it is unrealistic to utilize electric aircraft in other applications. In a decade, electric aircraft will be extensively used with battery specific energy reaching 600 Wh/kg, which demonstrates the importance of battery technology to electric aviation industry.

Keywords

Electric aircraft; Feasibility; Battery specific energy

Introduction

Nowadays, environmental pollution has attracted global attention. As technology drives forward, global warming, which is caused by the emission of Greenhouse Gas (GHG), becomes a serious problem. In 1950, about 6 billion tons of CO_2 was emitted, while when it came to 2020, global CO_2 emissions reached 34 billion tons, having grown almost six times. Many sectors are concerned about this matter, trying to reduce GHG emissions significantly in several decades. An example is that vehicles have been rapidly electrified in recent years and achieved great success. Apart from automotive industry, another sector being valued by people is the aviation industry. Actually, in 2006, industry-wide GHG emission reduction measures have already been discussed for the aviation industry, aiming to reduce the GHG emissions to 50% of those in 2005. In this sense, the development of electric aircraft is expected

Citation: Yuhao Yue. (2022) Analysis on the Feasibility of Electric Aircraft: Current Status and Future Development. The Journal of Young Researchers 4(7): e20220528

Received on May 5, 2022; Accepted on May 10, 2022; Published on May 28, 2022

to be a key solution to achieving this goal.

The aviation industry has already devoted to the investigation of electric aircraft for many years, and some previous attempt has already been made in the past few decades. However, due to technological limitations (e.g., the battery specific energy is rather low and the cost is still at a relatively high level), it was infeasible to invent an electric aircraft that can be put into use for aviation industry. Today, with advancements in battery and other related technologies, it becomes possible to invent electric aircraft. For example, a solar-powered airplane called 'Solar Impulse' from Switzerland made its first successful test flight on April 7, 2010. Besides, just few months ago on November 1, 2021, a pilot named Gary Freedman successfully flew an electric plane across New Zealand's Cook Strait.

Given all this, the aim of this study is to discuss the importance of electric aircraft and investigate the possibility of making an electric aircraft, which can contain 1-19 passengers, from the perspective of current technology status and future technology development. Analysis on the feasibility of electric aircraft is based on their maximum takeoff mass, which is calculated by component sizing model and flying process model.

The study is going to be presented in seven sections. The first one is Introduction, which gives a general illustration on the importance and inevitability of the invention of electric aircraft. The second section is Literature Review, which aims to show the advantages and impediments to electric aircraft. The next section is Methods, which contains mainly calculations to design my own plane, followed by the Results section showing my calculation results. Then the feasibility of electric aircraft will be discussed based on the chart which shows the relationship of the maximum takeoff mass with designed range and number of passengers. Results with the context of improved battery specific energy in a decade will also be shown and discussed to investigate the role that battery technology plays in the development of electric aircraft. Ways to further improve the feasibility of electric aircraft will be provided. In the last two sections (i.e., Conclusion and Self-reflection), the whole process of the program will be summarized and I will review and judge myself in the end.

Electric Manned Aircraft's Technology Development

As early as in 1940, Fred Militky has tried to use electric motors to drive the model plane. However, due to technical limitations, the battery (lead-acid battery) and electric motors are not advanced or light enough to be used in a manned aircraft. Until 1960, he successfully launched a small model electric aircraft to the market using an electric motor with higher efficiency, whereas not so reliable as the battery is still lead-acid battery. Later Ni-Cd battery came out and it had a much higher battery energy density. With the help of Ni-Cd battery, Fred Militky made manned flight using electric aircraft a reality in 1972. Even though the aircraft only flew for 15 minutes, it demonstrated the feasibility of electric manned aircraft.

In recent years, electric manned aircraft technology has proliferated. Electric aircraft can mainly be divided into battery electric aircraft, fuel cell aircraft and hybrid aircraft. In 2014, Airbus launched the world's first electric aircraft: E-Fan 2.0, which will be used in the general aviation training market and is the world's first full-speed mass-production electric aircraft. E-Fan 2.0 produces zero direct GHG emission and zero noise, which are considered to be one of the advantages of electric aircraft. It is constructed by all carbon fiber composite, which is a low weight material, and hence, the total weight is only half a ton. This revolutionary aircraft has lithium-ion polymer batteries on its 31-foot-long wings and twin motors with a total power of 60 kW. The maximum speed of this aircraft is 218 km/h, with up to one hour of flying time.

After 2019, China has invented an electric aircraft which could contain up to four passengers, named RX4E. The aircraft has a wingspan of 13.5 m, a length of 8.4 m, a takeoff mass of 1200 kg, and a cruising speed of 200 km/h. The endurance of this plane is 1.5 hours and the range is 300 km. Similarly, RX4E also uses Carbon Fiber Reinforced Polymer (CFRP) as the material to build up its structure for its low mass and high intensity. It has the technical characteristics of small and light structure. In the future, this plane may be used in various applications, for instance, training and short-distance transport. Even though we have achieved a breakthrough in the past few years, battery electric manned aircraft is still at the beginning stage now, with a huge room for improvement.

Advantages of Electric Aircraft

Electric aircraft use electric propulsion systems instead of internal combustion engines, thus gaining many advantages and unique qualities. Considering that the aviation industry is one of the major contributors to GHG emissions and global warming, electric aircraft are expected to play an important role in solving this problem as it has a prominent advantage (i.e., high energy efficiency), and great potential in protecting environment with zero direct GHG emissions. Therefore, it is regarded as a kind of environmentally friendly product. Liu et al. (Liu et al., 2022) calculated the GHG emissions of small aircraft with different propulsion systems (e.g., battery electric system and internal combustion engine), finding that in a 100-km trip, battery electric aircraft can have 30% less emissions in comparison with internal combustion engine aircraft. Schäfer et al. (2018) suggested that an all-electric aircraft with battery specific energy of 800 Wh/kg and a range up to more than 1100 km can reduce NO_x at airport by 40%, fuel use and CO_2 emissions both by 15%. An electric aircraft with stronger endurance which is able to fly for more than 2200 km can mitigate NO_x by over 60%, fuel use and CO_2 both by about 40%. Moreover, according to the research of Kasliwal et al. (2019), the base-case emission intensity (kg-CO_2e VKT^{-1}, VKT stands for vehicle-kilometer traveled) of Internal Combustion Engine Vehicles (ICEVs) and Battery Electric Vehicles (BEVs) over a range of point-to-point distance from 5 km to 250 km is about 0.20 and 0.10 kg-CO_2e VKT^{-1}, respectively. However, the emission intensity of an electric Vertical Takeoff and Landing aircraft (e-VTOL) is about 0.59 kg-CO_2e VKT^{-1} at 5 km and decreases continuously over the range, reaching 0.14 kg-CO_2e VKT^{-1} for a 250-km trip. The GHG emissions of e-VTOLs are 35% lower but 28% higher than those of ICEVs and BEVs. This shows that for a medium range trip, VTOLs have less emissions than ICEVs and acceptably more emissions than BEVs. Besides, the popularization of e-VTOLs can reduce the traffic jam on the ground and hence reduce the emission of the whole traffic system.

Another apparent advantage of electric aircraft compared to conventional aircraft is their low noise. The noise of airplanes is mainly produced by their motors, including turbine propellers, turbojet engines and turbofan engines. During the flight, the motor is continuously working, especially in the process of accelerating. As for electric aircraft, electric motors, which use permanent magnets to convert electrical energy into mechanical energy without combustion, are utilized. Besides, a feature of electric energy is that it can be converted into other kinds of energy, including mechanical energy, with high efficiency. Considering that the noise is mainly from friction sound inside rotor material and the sound from brush conversion, these sounds can be eliminated to background sound as long as the material of the motor is sufficiently sophisticated. Schäfer et al. (2018) pointed out that aircraft noise during takeoff is mainly determined by the thrust of the engines needed. With a lower fan pressure ratios and the absence of combustion noise, there will be over 50% reduction in takeoff noise for electric aircraft. The improvement in battery energy density will also lead to an improved noise performance of all-electric aircraft. Besides, Jeff Holden and Nikhil Goel (Uber, 2016) estimated the noise level of an e-VTOL, finding that the noise would be about 87 dB at 250 ft altitude, which is half as loud as the smallest four-seater helicopter, the Robinson R44. This further illustrated that electric motors will generate less noise than conventional motors.

Disadvantages of Electric Aircraft

There are many challenges encountered by the electric aircraft. An obvious one is the limitation in the performance of battery technology. In order to succeed in market, the plane has to fly far enough. However, the flying range of battery electric aircraft has been widely concerned by people. As an electric aircraft, there is no change in the mass of the aircraft during the voyage because there is no reduction in fuels. Huang et al. (2016) calculated the relationship between range and battery specific energy with different L/D (Lift-to-Drag ratio), finding that battery specific energy has the greatest influence on range, indicating the great challenge encountered by aviation industry considering that current battery specific energy is still at a low level and the range cannot meet market demand with current battery technology. Stolaroff et al. (2018) investigated the impact of battery mass on the range of an electric drone, finding that with a 5-kg battery at current technology level, the drone can only fly a maximum range of 5 km. What's worse, the range will not increase any more when the mass of the battery increases beyond a certain value. Similar as an electric drone, for an electric aircraft, which is also driven by battery, long flight distance can only be achieved with a battery far beyond the trust abilities of the models.

Another problem, or which can be considered as the disadvantage of the electric aircraft, is its high cost. Compared with a fossil-fueled aircraft, which has a high energy use cost caused by the high aviation fuel price, an electric aircraft is costly in its manufacturing process due to high-cost batteries. More importantly, batteries have to be replaced frequently and motors have to be overhauled. To be more specific, a battery can only go through about 2000 cycles before its State of Health (SOH) drops below 80%. For an electric aircraft, which has much higher requirements on the SOH of batteries and is planned to be used for about

20 years with several missions per day, the battery has to be replaced for around 10 times. This is going to induce an extremely high cost. From Pratt & Whitney Canada (2021), Light plane turboprop engines (less than 1 MW) is required to be overhauled every few thousand flights, costing around \$30-90 per flight hour or cycle. From Aircraft Commerce 70, it will cost about \$350-550 per flight cycle for a 42-MWh battery of a single-aisle airliner.

Safety is also a severe problem. For an electric aircraft, battery can be a dangerous part as sometimes spontaneous combustion will occur. According to the reporter of United Airlines, an airliner caught on fire on December 12, 2021, for a lithium battery which was placed in a thermal containment bag was heated up and exploded while flying. For another example, a lithium battery was discovered overheating and releasing smoke within the aircraft cabin on November 2, 2021 of United Airlines. A cargo aircraft of FEDEX on October 27, 2021 also had a similar event. During the aviation cargo sortation process, a package carrying nineteen Lithium-ion batteries was discovered emitting smoke. These accidents all happened in just two months, indicating that battery safety will definitely be a major concern (US Federal Aviation Authority).

There are some other disadvantages. For instance, the long charging time leads to low operation efficiency of electric aircrafts as most of their time is spent in charging batteries on the ground, thus they are considered to be less profitable. In order to solve battery charging time problems, airlines may decide to spend more money in building battery swapping stations which, however, increase the cost again. Besides, an electric aircraft may require larger space to place batteries so that there is less room for passengers. This means consumers will be less comfortable in electric aircraft. Besides, electric aircraft hold less passengers than conventional aircraft, which reduces the profits of airlines.

Power Demand

During the flying process of an aircraft, normally it can be divided into five phases: taxiing, climbing, cruising, descending and landing. Each has different kinematic and dynamic characteristics, with different equations for calculating power demand and energy consumption.

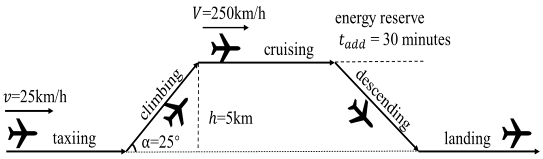

Figure 1. Flying process of aircraft

For taxiing and landing, they have the same equation of calculating power demand if we assume the acceleration and deceleration have same magnitude. Therefore, we can rewrite the power demand of these two phases as a mean power demand for taxiing and landing to simplify the calculation. The mean power demand of both phases is calculated based on Eq. (1), which relates mean power demand to the takeoff mass of the aircraft, take-off or landing speed, air density, coefficient of friction, wing area, drag coefficient, lift coefficient, and propulsion system efficiency.

$$P_1 = \frac{mfgv + \frac{\rho v^3 S\left(C_x - fC_g\right)}{2}}{\eta_{battery} \times \eta_{motor} \times \eta_{trans}} \tag{1}$$

where,

P_1 is the mean power demand of the electric

aircraft while taxing and landing (kW);
m is the takeoff mass of the airplane (kg);
v is the speed (m/s);
ρ is the air density (kg/m^3);
f is the coefficient of friction between aircraft and ground;
C_x is the drag coefficient;
C_g is the lift coefficient;
η_{motor} is motor efficiency;
η_{trans} is efficiency of transmission system.
$\eta_{battery}$ is efficiency of transmission system.

Considering climbing and descending, we assume the Rate of Climb (ROC) is the same as rate of descend and the Angle of Attack (AOA) is the same as well. For an electric airplane there is no change in mass during the trip, thus they can be calculated in the same way, as shown in Eq. (2), which relates the power demand of the two phases to the maximum takeoff mass, AOA, ROC and L/D while climbing.

$$P_2 = \frac{\left(\frac{mgROC\cot\alpha}{L/D_{climb}} + mgROC\right)}{\eta_{battery} \times \eta_{motor} \times \eta_{trans}} \qquad (2)$$

where,
P_2 is the mean power demand during climbing and descending (kW);
ROC is the rate of climb or descend (m/s);
α is the angle of attack in degree;
L/D_{climb} is the lift-to-drag ratio while climbing.

Since there is no loss of fuel mass, hence, no change in total mass, we considered takeoff mass m in this equation the same as the takeoff mass m in other equations. The power demand while cruising is obtained by dividing the product of weight and cruising speed by the product of lift-to-drag ratio while climbing and propulsion system efficiency (Eq. 3).

$$P_3 = \frac{\frac{mg}{L/D_{cruise}} \times V}{\eta_{battery} \times \eta_{motor} \times \eta_{trans}} \qquad (3)$$

where,
P_3 is the power demand while cruising (kW);
m is the maximum takeoff mass of plane (kg);
L/D_{cruise} is the lift-to-drag ratio while cruising;
V is the cruising speed (m/s).

Energy Requirements

In order to find total energy required, we need to find both the energy consumption and energy reserve, as shown by Eq. (4). Energy consumption is calculated by multiplying the power demand of each phase with the duration separately and adding them up (Eq. 5). Energy reserve should meet the demand of flying at cruising speed for additional cruising time, as shown by Eq. (6). The duration of time while climbing is calculated by dividing the height of flight by ROC, as shown by Eq. (7). The duration of cruising is calculated by dividing the range of trip by cruising speed (Eq. 8). Here we assume the time for taxiing is fixed, not affected by other factors.

$$E_{total} = E_c + E_r \qquad (4)$$

$$E_r = P_{cruise} \times t_{add} \qquad (5)$$

$$E_c = 2P_1 \times t_{taxi} + 2P_2 \times t_{climb} + P_3 \times t_{cruise} \qquad (6)$$

$$t_{climb} = \frac{h}{ROC} \quad (7)$$

$$t_{cruise} = \frac{R_{cruise}}{V} \quad (8)$$

where,

E_{total} is the total energy required (J);

E_c is the energy consumption during the trip (J);

E_r is the energy reserve (J);

t_{climb}, t_{taxi} and t_{cruise} are the durations for each of these phase (s);

h is the height of flight (m);

R_{cruise} is the range of cruising (m);

t_{add} is the additional cruising time (s).

Mass of each component

An electric aircraft can mainly be divided into four parts, which are payload, structure, batteries, and motors, therefore, the maximum takeoff mass is the sum of each part's mass, as shown in Eq. (9). Mass of batteries is calculated by dividing total energy required by battery specific energy, as shown by Eq. (10). Mass of motors is calculated by dividing the maximum power demand by motor power density (Eq. 11). Mass of payload is calculated by average mass of each passenger times total number of passengers, as shown by Eq. (12). Mass of structure is assumed to be proportional to the takeoff mass (Eq. 13). The relationship between wing area and maximum takeoff mass is shown by Eq. (14).

It is notable that for the whole trip, normally the maximum power demand is power demand during climbing process. Therefore, the power of electric motors is considered to be the power demand while climbing. While after calculation, it is necessary to substitute the result into equations of each phase to check whether it is maximum among all five phases.

$$m = m_b + m_m + m_s + m_p \quad (9)$$

$$m_b = \frac{E_{total}}{\rho_b} \quad (10)$$

$$m_m = \frac{P_{max}}{\rho_m} \quad (11)$$

$$m_p = n \times m_x \quad (12)$$

$$m_s = \mu \times m \quad (13)$$

$$S = 0.0022m + 9.1993 \quad (14)$$

where,

m_b is the mass of battery (kg);

m_m is the mass of motor (kg);

m_p is the total mass of passengers (kg);

m_x is the mass of each passenger (kg);

m_s is the mass of structure (kg);

n is the number of passengers;

ρ_b is battery specific energy (Wh/kg);

ρ_m is motor power density (kW/kg).

After calculation according to the equations, each part of the aircraft can be written into an expression containing m. Then, we substitute the expressions of all parameters into Eq. (9) to get an equation that only contains m. In this way, we can figure out the numerical value of m, which can be used to further calculate the mass of the components in the aircraft.

Then we use different values of battery specific energy, which is a key factor affecting the modelling of the aircraft to calculate the mass of it with different number of passengers; obtain a graph showing the relationship between mass and passenger number; and judge the feasibility currently and in the next decade.

Data Assumption

Table 1 shows all the parameters used in calculation. Noticed that the ratio of lift coefficient to drag coefficient is equal to the lift-drag ratio when climbing, we assume the drag coefficient to be around 0.05 which is around the ideal value. By calculating, the lift coefficient is found to be 0.75, which is acceptable. For business jets, the cruising altitude is around 7000–12000 m, thus the altitude for electric aircraft is set as around 5000 m, considering that currently the battery technology cannot enable it to fly as high as a fossil-fueled airplane.

Table1. Data assumption

Parameter	Notation	Value	Unit	References
Air density	ρ	1.29	kg/m^3	(*Engineering Toolbox*, 2018)
Cruising speed	V	250	km/h	
Angle of attack	α	25	degree	
L/D while cruising	L/D_{cruise}	20		(Uber, 2016)
L/D while climbing	L/D_{climb}	15		(Uber, 2016)
Rate of climb	ROC	8	m/s	(Stoll & Mikic, 2016)
Rate of descent	ROD	8	m/s	(Stoll & Mikic, 2016)
Battery efficiency	$\eta_{battery}$	90%		
Motor efficiency	η_{motor}	92%		(Fan et al., 2019)
Transmission system efficiency	η_{trans}	98%		
Height of flight	h	5000	m	
Lift coefficient	C_g	0.75		
Drag coefficient	C_x	0.05		
Battery specific energy	ρ_b	200 (2020) 600 (2030)	Wh/kg	(Bacchini & Cestino, 2019; Zhang et al., 2020)
Motor power density	ρ_m	4	kW/kg	(Naru & German, 2018)
Taxiing time	t_{taxi}	30	s	
Taxiing speed	v	25	km/h	
m_s to m ratio	μ	44%		
Gravitational acceleration	g	9.81	m/s^2	Constant
Additional cruising time	t_{add}	0.5	h	(Huang & Yang, 2016)
Coefficient of friction	f	0.5		
Average m ass of passengers	m_x	75	kg	

Maximum Takeoff Mass with Prevailing Technology

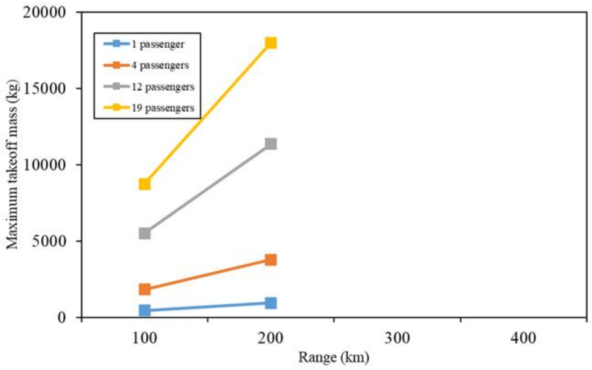

Figure 2. Maximum takeoff mass of electric aircraft with 200 Wh/kg battery specific energy

It shows the maximum takeoff mass of an electric aircraft with prevailing technology (battery specific energy: 200 Wh/kg) at different range and number of passenger settings. With increased number of passengers, the maximum takeoff mass increases much more significantly with range. From calculation based on methodology, if the aircraft carries 1 passenger, the maximum takeoff mass is calculated to be 460 and 945 kg for 100 and 200 km, respectively, where there is merely a 485-kg increment over a range of 100 km. For a 12-passenger electric aircraft, the mass is more than 5500 kg under 100 km and 11350 kg under 200 km, where the mass increment is around 5900 kg, much greater than that of 4-passenger aircraft. For those carry 19 passengers, the maximum takeoff mass soars to almost 18000 kg at 200 km and its mass increment from 100 km to 200 km is around 9300 kg, which is almost twice as large as the mass increment of 12-passenger aircraft. Besides, at the same range, the increment of mass becomes greater when number of passengers increases. For 12-passenger electric aircraft, which is normally considered to be similar to a private plane, the takeoff mass is 11350 kg under 200 km. As for the 4-passenger electric aircraft, the takeoff mass under this range is only 3780 kg, which is 7570 kg lower. While comparing the takeoff mass of 4-passenger aircraft with those only carry 1 passenger, the mass difference is only 2830 kg, much lower than the 7570-kg difference above. What's more, for a battery specific energy of 200 Wh/kg, the percentage increase in mass over a range from 100 km to 200 km is 52%, independent of number of passengers.

Maximum Takeoff Mass with Future Technology

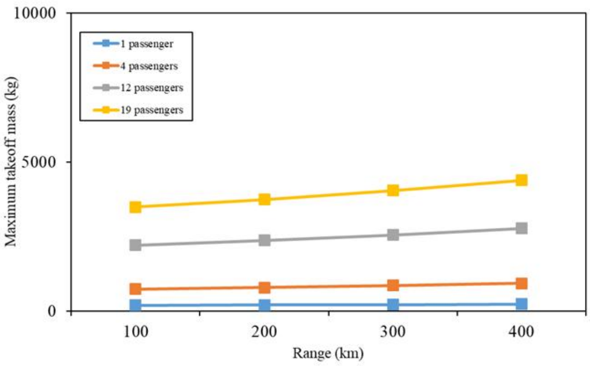

Figure 3. Maximum takeoff mass of electric aircraft with 600 Wh/kg battery specific energy

It shows the relationship between range of an electric aircraft with future technology (battery specific energy: 600 Wh/kg). It is notable that there is a small difference in maximum takeoff mass over range from 100 km to 400 km. For a 1-passenger aircraft, the maximum takeoff mass is calculated to be 180 kg under 100 km and 230 kg under 400 km, with the difference being only 50 kg. In order to carry 4 passengers, the takeoff mass is calculated to be 730 and 920 kg for 100 and 400 km, respectively, with a 90-kg difference. For 12 passengers, the electric aircraft should be designed with a takeoff mass of 2200 kg for 100 km and about 2800 kg for 400 km. The increment in takeoff mass is around 600 kg in this circumstance. For 19 passengers, the maximum takeoff mass rises from 3480 kg to 4380 kg with the range increasing from 100 to 400 km. By comparing these differences, we can find that the difference between masses increases with increased number of passengers. The percentage increment over ranges for different number of passengers is 21% in this context.

Comparison Between Current and Future

In contrast, the takeoff mass of the electric aircraft with 600 Wh/kg battery is far less than that of the electric aircraft with 200 Wh/kg. With 12 passengers, in order to fly for 200 km, the takeoff mass is 11350 kg with current battery technology, whereas the mass decreases sharply to just 2360 kg with 600 Wh/kg battery specific energy. Compared with the first figure, carrying a certain number of passengers, the percentage increment in mass over ranges from 100 to 200 km is far greater for aircraft with a battery specific energy of 200 Wh/kg (52%) than that with a battery specific energy of 600 Wh/kg (21%), over twice as large. Changes in takeoff mass are also considerably different with different battery specific energy settings. For instance, for a 19-passenger electric aircraft, the increment in takeoff mass from 100 km to 200 km is 9300 kg if the battery specific energy is 200 Wh/kg, while this increment decreases to only 260 kg with 600 Wh/kg battery specific energy, about 35 times lower. This means the maximum takeoff mass increases much faster under low battery specific energy condition. Therefore, current electric aircraft has a range limit, which indicates that the aircraft cannot fly for a longer distance because of tremendous increment in takeoff mass over ranges. While in the future the aircraft can fly for a much longer range than the range limit of current aircraft. Changes in takeoff mass with different number of passenger settings at the same range differs a lot as well. When travelling a range of 200 km, the takeoff mass increases by about 6650 kg from 12 passengers to 19 passengers with a battery specific energy of 200 Wh/kg and about 1380 kg with a battery specific energy of 600 Wh/kg. Again, this is a huge difference.

Current Application of Electric Aircraft and Limitation

Under current battery technology, electric aircraft show relatively low technical feasibility, with limited potential in short-range and low-capacity applications. With current battery technology, i.e., battery specific energy of 200 Wh/kg, the takeoff mass increases significantly with designed range increasing, for electric aircraft under all payload scenarios. Electric aircraft with current battery technology have a range limit of 200 km, which substantially demonstrates the overall low feasibility of electric aircraft currently. For low-capacity electric aircraft, which carry 1 or 4 passengers, the takeoff mass is in a variation range of 400-4000 kg for 100-200 km ranges, which is feasible within reasonable limits, showing the probability of the utilization of electric aircraft in low-capacity applications such as private airplane. However, for a high-capacity electric aircraft, which carry 12 or 19 passengers, the takeoff mass rises significantly over ranges. For example, for a 19-passenger aircraft to fly 200 km, the takeoff mass comes to almost 20 tons, which is far beyond the general mass of aircraft with the same size currently. Such heavy electric aircraft require battery systems with tremendous weight, which shows extremely low feasibility. Besides, a large number of batteries has to be packed together, which is dangerous as batteries show much lower reliability as shown in literature review. This also makes it hard for the battery management system to work, indicating that repairing them will be fairly costly, hence, they are not economical as well. In conclusion, electric aviation can only be put into use in private airplane field with current battery technology, while the feasibility of medium and large electric aircraft is too low to come into commercialization.

Future Application of Electric Aircraft and Limitation

Although electric aircraft are currently only able to meet short-distance transportation, future development of battery technology could help improve their utilization in long-distance scenarios. In the following decade, we assume the battery technology is going to develop to a specific energy of 600 Wh/kg. This is found to have significant impacts on the feasibility of electric aircraft. The maximum takeoff mass will decrease with the changes in either range or the number of passengers. The electric aircraft can travel more than 400 km with much lower takeoff mass than that of aircraft with a battery specific energy of 200 Wh/kg. For a 19-passenger aircraft, the maximum takeoff mass is below 5 tons when travelling 400 km, and it has a tendency to extend its range to over 400 km; hence, its range could be further broadened to satisfy the demand of long-range transportation. For example, in 2030, the electric aircraft may be capable to carry 20 passengers from London to

Liverpool (approximately 350 km), or even from London to Edinburgh (approximately 650 km), indicating high potential of electric aircraft in large-scale deployment. What's more, the electric aircraft can be designed to more than 20 people as the increment in takeoff mass with increased number of passengers is less steep compared with that with battery of 200 Wh/kg, therefore, electric aircraft can be more widely used in the aviation industry. However, the 600 Wh/kg battery is just our assumption and expectation. The development of battery technology has a high degree of uncertainty. Current battery cathode materials are nickel, cobalt and manganese and it is calculated that the maximum specific energy of this kind of battery is only 400 Wh/kg. Therefore, next-generation battery technology such as solid-state battery is required in order to achieve 600 Wh/kg battery specific energy. However, it is notable that this solid-state battery has much higher uncertainty, for example, even though the battery specific energy can be higher than that of current lithium-ion battery, it might have low power density, which might be impediments to the development of electric aircraft. Besides, the battery life may be low for solid-state battery and its safety also has high indeterminacy.

Battery Improvement

One way to increase the feasibility of electric aircraft is to, obviously, develop battery technology. From battery specific energy of 200 Wh/kg to 600 Wh/kg, there is a huge decrement in takeoff mass. With such an improvement in battery technology, the technical feasibility of electric aircraft is significantly increased. However, there are lots of challenges in front of the aviation industry to develop battery technology. In this case, the government is suggested to pay more attention to electric aircraft, such as lowering taxes, providing subsidy on investigation of battery technology and setting threshold in entering the market. For example, only electric aircraft can be used in the future so that aviation-related companies are forced to put much more efforts in developing battery technology. Additionally, aviation-related companies are encouraged to cooperate in researching and developing battery technology and share information and ideas to achieve rapid development of electric aircraft.

Other Ways in Encouraging Green Aviation

Adopting other technologies instead of battery technology would also be a good way to increase the feasibility of electric aircraft. For instance, fuel cells can be used in electric aircraft for its stable power and technical characteristics, while there are also limitations for fuel cell technology. It cannot achieve both high power and high efficiency at the same time so when providing high power, the energy consumption might be relatively high. A hydrogen tank that occupies great volume and space has to be carried with the aircraft and is quite dangerous for hydrogen is stored at high pressure. In addition, the high cost of fuel cell will also impede its utilization in electric aircraft. In order to decrease its cost, scale of fuel cell production has to be improved by improving its performances, which calls for supports from the government such as promoting the construction of hydrogen refueling stations. Aside from fuel cell, low emission in aviation industry can also be achieved even with internal combustion engine, using sustainable aviation fuels instead of current aviation fuels. Although sustainable aviation fuel is environmentally friendly, it is too expensive that no aviation company would like to use it since they usually care more about how to maximize their profits. If sustainable energy such as wind power and hydropower generation can be widely applied, with their cost being further reduced, the cost of sustainable aviation fuel will have the possibility to become lower but this also requires much more efforts.

Conclusion

This article mainly evaluated the feasibility of electric aircraft from the perspective of current status and future development, based on the functional component sizing model established according to the design requirements of electric aircrafts and the analysis of the flying process of electric aircraft. By calculating the energy demand and power demand, the maximum takeoff mass can be found under different ranges with different application scenarios. The results demonstrate that battery specific energy has a decisive impact on the maximum takeoff mass of electric aircraft. Development of battery technology from 200 Wh/kg specific energy to 600 Wh/kg could reduce the takeoff mass of a high-capacity aircraft by almost 5 times at 200 km and it extends the range limit. Based on the results, discussion on the feasibility of electric aircraft currently and in the coming decade has been made, i.e., at present electric aircraft can only be applied in low-capacity applications. With improvements in battery technology in 10 years, electric aircraft are likely to be more widely used in high-capacity and long-range applications. Some recommendations on how to improve the feasibility have been made according to the discussion on battery technology such as cooperation in R&D of battery technology, government support (lower taxes and more subsidies), and some other factors that may have impacts on it, for example, using fuel cells instead of batteries or using sustainable aviation fuel rather than conventional aviation fuel. The feasibility of these alternatives has also been discussed as above.

Conflict of Interests: the author has claimed that no conflict of interests exists.

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