Lithium Batteries in Transforming Aircraft Energy Systems by Replacing Traditional Fuels

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Abstract. The increasing reliance on gasoline and fossil fuels has led to significant environmental challenges, including global warming and air quality degradation, which affect all aspects of human life. Aviation, a major contributor to air pollution, is now under pressure to adopt cleaner energy alternatives. Lithium batteries (LiBs) have emerged as a promising solution, offering a potential pathway for replacing traditional jet fuels in aircraft energy systems. This paper examines the feasibility of using LiBs in aviation, focusing on their advantages, such as rechargeability, higher energy density, and lack of memory effect when compared to conventional fuels. Furthermore, the study investigates the performance of lithium-powered aircraft, analyzing both power system efficiency and flight dynamics. By transitioning to LiBs, the aviation industry could achieve significant environmental benefits, including reduced emissions and improved sustainability. This paper highlights the key challenges and opportunities of integrating LiBs into aircraft, offering insights into the future of clean aviation.

Keywords: New energy; Li battery; aircraft; power system performance; flight performance.

1. Introduction

In people's daily lives, energy and sustainability are two hot topics. People are constantly discovering new ways to innovate and generate electricity to sustain our growing population. Batteries play a vital role in this process, powering our electronic devices, powering electric vehicles, and providing off-grid and backup power to our homes.

The first Li-ion battery discovered was a prototype Li-ion battery whose development was carried out by Akira Yoshino in 1985 which was based on research that John Goodenough, M first carried out. Stanley Whittingham, Rachid Yazami, and Koichi Mizushima in the early 1970s and 1980s. Afterward, a commercial Li-ion battery came into existence in 1991 by a team led by Yoshio Nishi. These batteries are most commonly used for portable electronics as well as electric vehicles and are showing massive growth in aerospace applications [1].

Unmanned aerial vehicles (UAVs) currently in the design of new energy applications include: first, the formation of topographic maps by drone aerial photography. Large UAV devices can measure a wide range of topographic maps; small UAV devices can complete the topography of a small area; all depend on the use of Li batteries. Then, through the drone complete the outdoor site reconnaissance work [2].

2. Comparison between Li Battery Power and Traditional Power

Over several centuries, people have always lived on fossil fuels, including coal, petroleum and natural gas. These three energies meet people's almost 80% need for energy [3]. Although fossil fuel has greatly promoted the development of economic society, it causes serious risks to our future. Increasing emissions of CO_2, water quality problems, rising number of endangered animals are all warnings sent from the Earth. Despite these, the limitation of fuel resources is, in fact, the most urgent problem. So, all the countries are devoting themselves to finding new energy resources, such as wind energy and sun energy, which slowly displace the traditional ones these years. What attracts people's attention most is the electricity energy, especially Li battery power.

There are lots of reasons for people to choose Li battery power instead of traditional power. First is the one mentioned just now, which has relatively fewer side effects on the environment. Nearly zero global warming gas will be emitted while producing batteries. The reuse problem of Li batteries is solved properly as well. For example, AI-powered sorting systems can identify battery types and categorize them with high levels of accuracy [4]. This makes the recycling process a lot easier, ensuring that batteries with similar components are disposed of and recycled properly.

In addition, the energy storage capacity of batteries is much greater than that of fossil fuel energy. This is because battery storage helps relieve stress on the grid in order to save electricity as much as possible. Batteries can easily integrate with existing networks. Then, they release that power when needed. For instance, in the winter, the demand of using electricity to heat their homes. Batteries will also smooth our transition into a carbon-neutral future. So, electrical utilities are increasingly pivoting their systems to carbon-free alternatives. Studies have found that people can reduce carbon emissions by between 50% and 80% by transitioning to solar and wind sources coupled with proper storage, such as Li batteries [5].

Moreover, by comparing Figs. 1 and 2, it also has benefits on profitability [6,7]. Initially, lithium batteries were expensive, but in recent years, the cost has dropped dramatically due to research, development, and widespread adoption. As battery technology continues to improve and mass production increases, lithium batteries are expected to become more cost-effective.

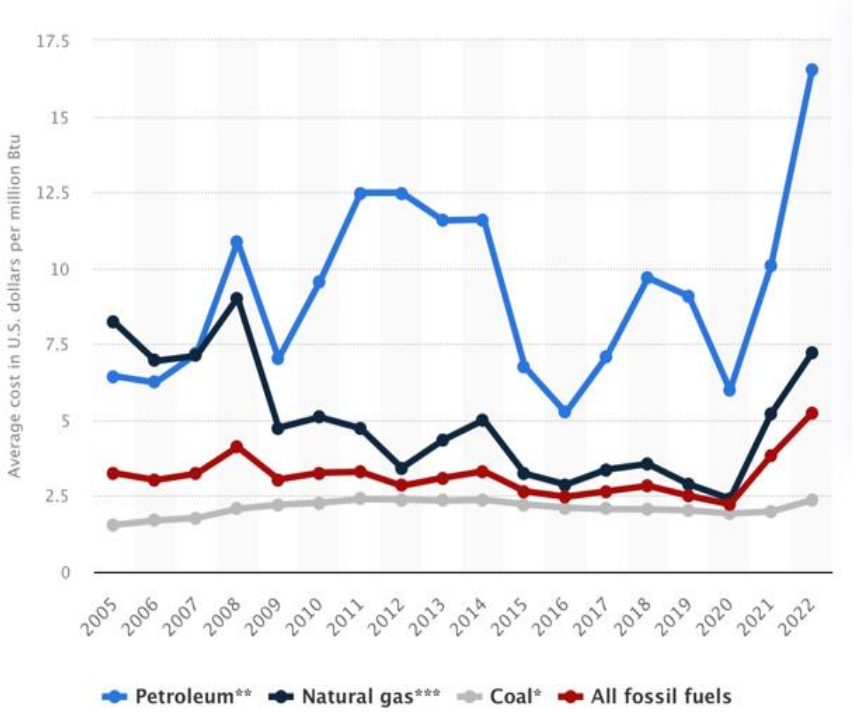


Fig. 1 Changes in prices of different kinds of fossil fuel in 1005-2022 [6].

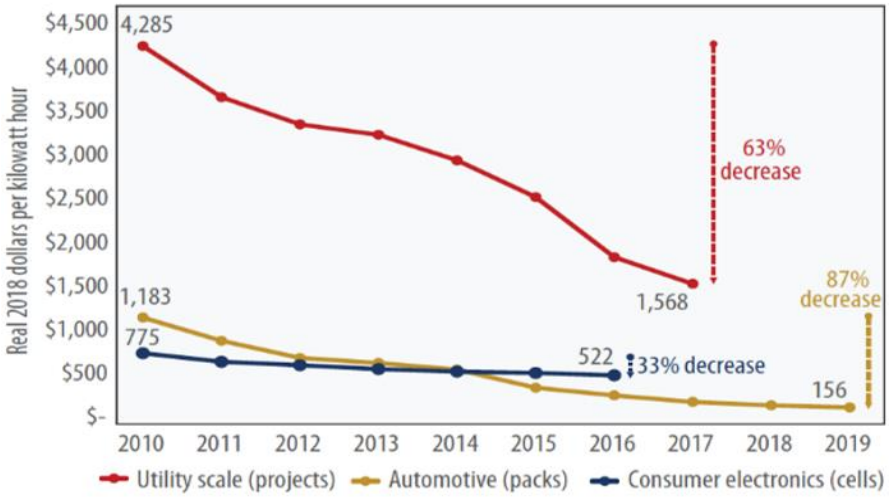


Fig. 2 Declining prices of lithium-ion batteries in 2010-2019 [7].

3. Feasibility and Application Principle of Using Li Battery in Aircraft

The basic principle of lithium batteries is to use the migration of lithium ions between the positive and negative electrodes to achieve the conversion of electrical energy. The main components of lithium batteries are positive, negative, diaphragm and electrolyte.

The positive electrode is the positive electrode material of lithium batteries, generally made of metal oxide or phosphate-containing lithium. Releasing lithium ions during discharge and providing electrons are the main roles of the positive electrode. During the charging process, the function is the opposite. It absorbs lithium ions, receives electrons, and restores the charge. Then, the negative electrode is usually made from a metal or carbon material that can be inserted and extracted from lithium ions, such as Li, C, Si, and so on. The function of the negative electrode is to embed lithium ions during discharge, release electrons, and form an electric current. The lithium ions are removed during the charging process, the electrons are received, and the charge is restored.

The diaphragm is an important part of the battery, which is the isolation layer of lithium batteries. Commercially available lithium battery separators are made from polyolefins such as polypropylene (PP) and polyethylene (PE) [8]. The function of the diaphragm is to isolate the positive and negative electrodes and prevent short circuits. At the same time, it allows lithium ions to pass through to ensure electrolyte connectivity. An electrolyte is the conductive medium of a lithium battery, usually an organic solution or solid substance containing lithium salt, such as $LiPF_6$, $LiClO_4$, etc. The role of the electrolyte is to provide a carrier for lithium ions and realize the migration of lithium ions between the positive and negative electrodes.

4. Li Battery Performance Analysis and Challenge

This work analyzed the performance parameters of all the DJ-Innovations (DJI) drones on sale and only took the parameters that are related to the dynamic maneuverability of the drone.

This analysis takes Takeoff Weight as “g”, takes Battery Capacity as “mAh”, takes Max Flight Time as “minute”, takes Max Hovering Time as “minute”, takes Battery voltage as “Voltage,” and takes Battery volume as Wh, which is equal to Battery Volume*Battery Capacity/1000, takes Rated Power as W, which is equal to Battery Volume/Max Hovering Time, as shown in Table 1.

Table 1. Performance parameters of DJI drones on sale [9]

SN	Takeoff Weight (g)	Battery Capacity (mAh)	Max Flight Time (minute)	Max Hovering Time (minute)
Mini 4K	246	2250	31	-
Mini 4 Pro Standard	249	2590	34	30
Mini 4 Pro Long	292	3850	45	39
Mini 2E	246	2250	31	-
Mini 3 Standard	248	2453	38	33
Mini 3 Long	290	3850	51	44
Air 3	720	4241	46	42
Mini 4 Pro Standard	249	2590	34	30
Mini 4 Pro Long	292	3850	45	39
Mavic 3 Pro	958	5000	43	37
Mavic 3 Pro Cine	963	5000	43	37
Mavic 3	895	5000	46	40
Mavic 3 Cine	899	5000	46	40
Mavic 3 Classic	895	5000	46	40
Mini 2	249	2250	31	29
Mini 3 Pro Standard	249	2453	34	30
Mini 3 Pro Long	292	3850	47	40
Mini SE	249	2250	30	-
Air 2	595	3750	31	30
Mavic Air 2	570	3500	34	33
Mavic 2 Pro	907	3850	31	29
Mavic 2 Zoom	905	3850	31	29
Inspire 3	3995	4280	28	25
Inspire 2	3440	4280	27	-
Avata 2	377	2150	23	21
Avata	410	2420	20	18
FPV	795	2000	20	16

4.1. Power System Performance Analysis

Because different drones use different series of brushless motors, this paper only takes several classic types for analysis. After several rounds of power system analysis, the research can understand the logic of how the engineers select different batteries for different drones. Also, the paper concluded that these drones are designed with proper battery volume for the designed flight/hovering time.

Mavic 2 Pro uses motor type 2008-KV 1400, detail parameters are as below. Based on the below analysis, we can get the conclusion that the battery volume is suitable for 30 minutes flighting time for the Mavic 2 Pro, as shown in Table 2.

Table 2. Mavic 2 Pro detail parameters [9]

SN	Takeoff Weight (g)	Battery Capacity (mAh)	Max Flight Time (minute)	Max Hovering Time (minute)	Battery Voltage (V)	Battery Volume (Wh)	Rated Power (W)
Mavic 2 Pro	907	3850	31	29	14.76	56.8	117.6

The motor-rated voltage is 11.1 V, which is below the battery voltage (14.76 V). There is a voltage adjustment function in the controller to provide a stable voltage to the motor. The rated current is 2.1 A. The rated power/single motor is 23.3 W. Rated power/4 motors is 93.2 W. The rated Power/whole drone is 117.6 W, which also includes the controller and sensor system power, etc. The power of these sensors and control systems is about 20 W. The battery value is 57 Wh, which can provide 29 minutes of hovering time.

Mini 3 pro use motor type: 1503. Detailed parameters are as below. Based on the below analysis, we can get the conclusion that the battery volume is suitable for 30 minutes flighting time for Mini 3 Pro, as shown in Table 3.

Table 3. Mini 3 Pro detail parameters [9]

SN	Takeoff Weight (g)	Battery Capacity (mAh)	Max Flight Time (minute)	Max Hovering Time (minute)	Battery Voltage (V)	Battery Volume (Wh)	Rated Power (W)
Mini 3 prolong	292	3850	47	40	14.76	56.8	85.2

The motor-rated voltage is 7.4 V, which is below the battery voltage (14.76 V). There is a voltage adjustment function in the controller to provide a stable voltage to the motor. The rated current is 2.1 A. Rated power/single motor is 17 W. Rated power/4 motors is 68 W. Rated power/whole drone is 85.2 W, which also includes the controller and sensor. The power of this sensor and control system is about 20 W. The battery volume is 56.8 Wh, which can provide 40 minutes of hovering time.

4.2. Flight Maneuverability Performance Analysis

This paper also takes the same 2 drone types for detailed flight performance analysis: Mavic 2 Pro and Mini 3 Pro. This analysis can help understand the logic of how the engineers select different motors for different drones. Moreover, the research concluded that these drones are designed with proper motors for the designed flight performance like max acceleration.

Table 4. Mavic 2 Pro detail parameters [9]

SN	Takeoff Weight (g)	Battery Capacity (mAh)	Max Flight Time (minute)	Max Hovering Time (minute)	Battery Voltage (V)	Battery Volume (Wh)	Rated Power (W)
Mavic 2 Pro	907	3850	31	29	14.76	56.8	117.6

Mavic 2 Pro use motor type is 2008-KV 1400. Rating lift power/single motor is 227 g. Rating lift power/4 motors is 908 g, which can help the drone make the hovering. The max lift power/single motor is 530 g, and the max lift power/4 motors is 2120 g, which can provide 1.34 g acceleration, as shown in Table 4.

Table 5. Mini 3 Pro detail parameters [9]

SN	Takeoff Weight (g)	Battery Capacity (mAh)	Max Flight Time (minute)	Max Hovering Time (minute)	Battery Voltage (V)	Battery Volume (Wh)	Rated Power (W)
Mini 3 prolong	292	3850	47	40	14.76	56.8	85.2

Mini 3 Pro use motor type is 1503. Rating lift power/single motor is 73 g. Rating lift power/4 motors is 292 g, which can help the drone make the hovering. The max lift power/single motor is 175 g, and the max lift power/4 motors is 700 g, which can provide 1.4 g acceleration, as shown in Table 5.

4.3. Flight Endurance Analysis

This paper makes a detailed analysis of the max flight time, battery capacity and takeoff weight to find out the relationship between these three parameters [10].

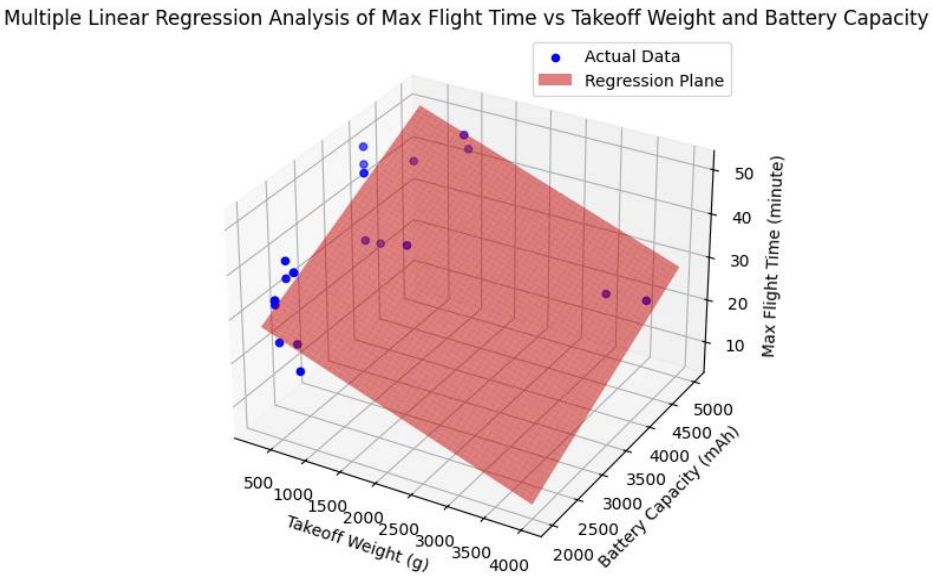


Fig. 3 The relationship between takeoff weight, battery capacity and max flight time [9].

The 3D plot in Fig. 3 illustrates the relationship between the maximum flight time and the two other parameters: takeoff weight and battery capacity. The blue points represent the actual data, while the red surface represents the regression plane fitted to the data.

i) Takeoff Weight: The coefficient for takeoff weight is approximately -0.00577. This suggests that by holding other parameters constant (here, we can hold the battery capacity), for every 1-gram

increase in takeoff weight, the maximum flight time is expected to decrease by approximately 0.00577 minutes.

ii) Battery Capacity: The coefficient for battery capacity is approximately 0.00757. This indicates that holding other variables constant (which hold the takeoff weight), for every 1 mAh increase in battery capacity, the maximum flight time is expected to increase by approximately 0.00757 minutes.

iii) R-squared Value: The R-squared value of 0.7101 indicates that approximately 71.01% of the variability in the maximum flight time can be explained by the combined effect of takeoff weight and battery capacity. This suggests a strong relationship between max flight time and the combined effect of takeoff weight and battery capacity.

5. Conclusion

In conclusion, the paper compares Li battery and traditional power, and research shows that Li battery has many benefits against fossil fuel as fuel for aircraft, including environmentally friendly working process, energy storage capacity and profitability. Also, the paper analyses the performance of using Li battery technology in aircraft. The author finally found that Li battery is suitable for the drones which are about 30 to 60 minutes flight time. Current motor technology can provide a proper motor for the designed maneuverability. The drone engineers mainly work on the takeoff weight and the battery capacity to find out the best combination of these variations for the best max flight time performance. Both takeoff weight and battery capacity have a significant impact on the maximum flight time, with battery capacity having a more significant effect on coefficient 0.007 VS 0.005.

In a word, despite the challenges, the future of electric aircraft is still promising. People have reason to believe that our electric aircraft will become an important part of the future aviation industry, ushering in the era of green flight. Moreover, the author thinks the Li battery power will displace traditional power step by step. There is only one earth, so people should try their best to protect it. These warning words always remind people to cherish the earth, this only home, and green flight is to protect this home and work hard.

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