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Research in the Past, Present and Future Solar Electric Aircraft

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ABSTRACT

Due to the increased use in vehicles that are operated by internal combustion (IC) engines, several challenges associated with climate change and global warming have appeared. The best alternative to face with those challenges is to use the vehicles which do not require fuels and IC engines. Electric vehicles are being well-designed, developed and produced to be more effective every day. In the field of aviation, new aircraft which run on full-electric-energy are being developed which is expected to change the conventional travel way. Those aircraft use batteries, ultra-capacitors, fuel-cells to drive motors which are connected to propellers. With the proper development in the field of electric aviation, the aforementioned issues can be reduced, and eventually mitigated. In this paper, the past developments in this field of electric aviation, present electric aircraft flying in the sky, and the future projects that are intended and/or projected to change the aviation industry are discussed. Also, the different designs associated with electric aircraft are discussed along with their advantages and disadvantages. This paper demonstrates the promising movements of the aviation industry toward the more reliable and efficient solar electric aircraft and reducing emissionss.

1. Introduction

This is a well-known fact that the emission of carbon, metal oxides and other byproducts from the combustion of fuel in the aviation field constitutes to the climate change (e.g., ozone layer depletion, reduced air quality) more than any other modes of transportation [1]. Additionally, it is estimated that 0.7% of local air pollution and around 2.7% of greenhouse emission in the United States are due to aviation emissions which are expected to grow with the increasing use of aircraft as a preferred mode of transportation in coming days [2]. Due to these reasons, along with the fact of running out of the fossil fuels, the engineering society has been working on preparing an electric alternative to these giant fossil fuel consumers.

The aviation technologies, especially in the field of all-electric aircraft, have experienced major changes and it is expected to have more developments over the next several decades. Due to the emissions of carbon, many rules and regulations are being applied to the demand for electric and hybrid electric aircraft. Many organizations like NASA (The National Aeronautics and Space Administration) and Airbus are conducting research works and engineering design for green aircraft propulsion technologies which can lead to cleaner aviation. Although these developments are restricted by the technology of the batteries and storage system, still there are many positive signs of progress in this field. As of today, the gas-powered aircraft is one of the main sources of carbon emissions in the world. The amount of pollution produced by a cargo plane is 25 times more N_2O and approximately 5 times more particular matter than a cargo ship. The contribution of airplanes in CO_2 emission is reported as 700 million metric tons in 2013. The international agreements among the countries to reduce and/or cut the commercial airplane carbon emissions lead to enforce the manufacturers to design and manufacture more efficient aircraft. The movements toward the electric and hybrid vehicles have made a similar trend in the aircraft industry. Many research works have been conducted to reduce the dependency of aircraft propulsion system on gas turbines. Utilizing batteries and hybrid propulsion system as well as solar panels, as a source of energy to charge the batteries, are two examples of these highlighted technologies. In addition to, reducing the weight of aircraft, and increasing efficiency are other investigations that have been performed in this field.

An electric aircraft is a plane which is primarily powered by electric motors, unlike most of the aircraft flying in the sky today, which are powered by fuel combustion engines. In an electric aircraft, electricity is supplied by a variety of methods, including but not limited to batteries, solar cells, and ultra-capacitors. Electric aircraft are mainly can be sorted out into two categories:

- *Manned Electric Aircraft*
- *Unmanned Electric Aircraft*

The manned electric aircraft have electric power generated enough to carry people in it. They require more power to carry the load. The unmanned electric aircraft are not designed and made to carry people on board. This paper will mainly focus on the manned electric aircraft. In this paper, a research has been done in the past, present and the future of electric aircraft. This research work presents the describes the structure of an electric aircraft and compare the different design characteristics of existing and future aircraft. This leads to having a clear overview of the advancement in the field of the aviation industry.

This paper is organized as follows: Section 2 describes the history of manned electric aircraft. The characteristics, specifications, and architecture of an electric aircraft are discussed in Section 3, 4 and 5, respectively. Section 6 provides the structural design of an electric aircraft. The electric aircraft propulsion system is indicated in Section 7. Section 8 investigates the forces of flight and flight dynamics. Section 9, 10 and 11 describe the engineering design, existing electric aircraft design and the future design consideration of the electric aircraft, respectively. The advantages and disadvantages of electric aircraft are discussed in Section 12. Lastly, Section 13 indicates the conclusions.

2. History of Manned Electric Aircraft

The *Solar Riser*, 1979, designed and created by Larry Mauro in 1979, made the first manned flight on solar power at an altitude of 12 meters for 0.8 kilometers [3]. The *Gossamer Penguin*, 1979, designed by Paul MacCready, made the flight on solar power for 3.5 kilometers [4]. The *Sun Seeker I* and *II*, 1990-2008, designed by Eric Raymond, are became the first electric aircraft to fly across the United States of America and to cross mountain range [5-6]. The *Antares 20E*, 2003, designed by Lange Aviation, was the first documented electric aircraft and was capable of reaching higher altitudes [7]. The *FCD*, 2008, designed by Boeing, was the first cell hopped-up craft, and could reach an altitude of 3300 feet and could fly for a period of 20 minutes at 62 mph [8]. The *Sky Spark*, 2009, designed by Digi Sky and City Polytechnic Institute, set a world speed record of 155 mph for a manned electrical craft [9]. The *HB-SIA*, 2010, manufactured by Solar Impulse, completed the primary, manned, twenty-four-hour flight totally on alternative energy [10]. The Taurus G4, 2011, designed by PIPISTREL, won the National Aeronautics and Space Administration Inexperienced Flight Challenge ($ 1.35 M) by demonstrating the equivalent of four hundred passenger-miles/gallon potency at over one hundred mph [11]. Moreover, many research works have been conducted to overcome the major challenges in electric aviation. Ref. [12] discussed the NASA programs for all-electric aircraft. The power management and distribution for the electric aircraft are studied in Ref. [13-14]. The past and future of electric aircraft are investigated in Ref. [14-18]. The challenging applications of electric machines and drives in the aircraft generation are studied in Ref. [19-20]. Ref. [16, 21] have tracked the power conversion in more-electric aircraft. Ref. [16, 22] have studied the power electronics and drives for more-electric aircraft, and Ref. [23-24] have conducted investigations into electrical protection and safety of more-electric aircraft. Also, the battery market analyses for different applications in various electric navigations are performed in Ref. [30-32].

3. Characteristics of an Electric Aircraft

An electric aircraft is not only possible with the use of an electrically powered motor(s). These aircraft have more features than that. To be able to operate an aircraft fully on electric power, more attention is given to the architecture, body structure, dynamics and overall design of the aircraft. With the use of an electric motor, an electric aircraft has several advantages as compared to bio-fuel combustion motors. The advantages of electric motors (EM) compared to bio-fuel are briefly described below:

a) *Lightweight*

Electric aircraft are designed to be light-weight, in order to minimize the need for more power just to carry the load. Therefore, electric aircraft are designed and built with light materials, such as aluminum or carbon fiber sheets as main body skin. That is the reason; electric aircraft are more lightweight than conventional aircraft.

b) Higher Power Per Unit Weight

Electric aircraft run on electricity, which is generated by the battery. Hence, in order to be able to prepare a feasible electric aircraft, special care is given to battery design. The battery is designed so as to provide higher power per unit weight, to meet the take-off power requirements. As a result, electric aircraft have higher power per unit weight.

c) C. More Efficient Energy Conversion

Electric aircraft are designed to carry passengers, and in order to make this possible, more efficient energy conversion is achieved during the design and production process. The battery is designed accordingly, and the anodes and cathodes are also chosen wisely in this process. Thus, electric aircraft have more efficient energy conversion than in traditional fuel engine aircraft.

d) D. Improved High Altitude Performance

Electric aircraft are designed to save more energy during flight. To achieve that, they are designed to glide in higher altitude with the help of wide and long wings, which reduce the need for energy while gliding. Basically, an electric aircraft can sail in the wind. Accordingly, electric aircraft have improved high altitude performance.

e) E. Noise Reduction

One of the important advantages of an electric aircraft is the reduction in noise pollution as it tends to produce less operational noise than the traditional aircraft that run on fuel engine and produce high decibels of noise.

f) F. High Reliability and Safety

Other importance of electric aircraft is its reliability and safety as compared to traditional aircraft. Electric aircraft are less subjected to accidents, and even in the occurrence of an accident, due to no combustible fuel, passengers are less likely to get injured or have burn-related injuries.

g) G. Lower Operating Cost

Electric aircraft are cheaper to produce and also have low operating cost as the batteries are recharged for every flight. Also, there is no need to refuel the aircraft with highly expensive fuels.

h) H. Easier Maintenance

Electric aircraft are easier to maintain as compared to traditional aircraft due to less mechanical parts and structures.

i) I. Lower Pollution

Another advantage is the lower pollution, as they require no or less fuel which produces greenhouse gases and low noise level.

4. Specifications of an Electric Aircraft

Along with the features and characteristics, an electric airplane is designed with more cautions to prevent any mishaps. During the design process, an overall specification is developed, around which the design and manufacturing of an electric aircraft are done. Table 1 shows the general specifications of a light-sport electric aircraft.

TABLE 1. THE GENERAL SPECIFICATIONS OF A LIGHT-SPORT ELECTRIC AIRCRAFT

Specification	Descriptions
Gross Weight	< 1320 lbs.
Stall Speed	< 51 mph
Maximum Speed	< 138 mph
Seating Capacity	1-4 seater
Maximum L/D Ratio	24-40
Construction	Aluminum/Composite
Empty Weight (without batteries)	550lbs
Energy Storage Weight	400 lbs.
Useful Load	370 lbs.
Cruise Speed	100-120 mph
Range	200-300 miles
Endurance	2-3 hours
Rate of Climb	1000

5. Architecture of an Electric Aircraft

The architecture of an aircraft depends upon the purpose of the specific aircraft that is being designed for. Different aircraft serve different purposes. Some aircraft may be used for normal recreational purposes, while may be used for commercial transportation. This is the reason; the architecture may vary from one to another. However, there are basically two pure architectures that can be used to design and operate an electric aircraft. The combination of these two architectures is also used in some cases.

A. Series Hybrid Electric Architecture

As a general definition, a specific architecture is defined as the series when only one mechanical source of power driving the propeller can be identified [26-27]. In series hybrid architecture, both the electric module and the fuel module are connected in series with the electric motor. Figure 1 shows the series hybrid electric architecture.

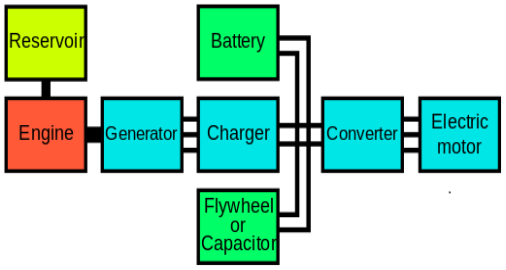

Fig. 1: The series hybrid electric architecture

B. Parallel Hybrid Electric Architecture

An architecture is defined as a parallel when multiple sources of mechanical power are present in the system [26-27]. In parallel hybrid architecture, the reservoir and battery are connected in parallel, which means, with the need both energy sources can act individually or in combination to power the motors. Figure 2 shows the parallel hybrid electric architecture.

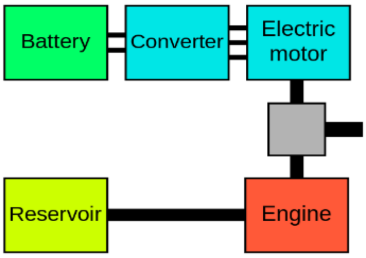

Fig. 2: The parallel hybrid electric architecture

C. Series-Parallel Hybrid Electric Architecture

An architecture is defined to be a series-parallel hybrid electric architecture if the system can choose to operate in series or parallel mode with the requirement of the situation [26-27]. In this architecture, the design is made to optimize both sources, as they can be used in various combinations as needed by the operational needs of the aircraft. Figure 3 shows the series-parallel hybrid electric architecture.

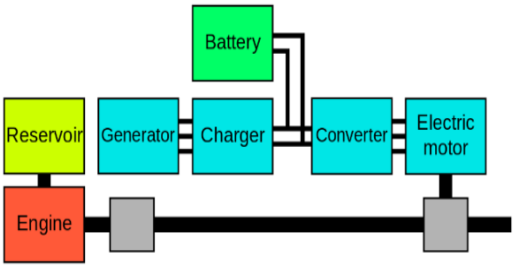

Fig. 3: The series-parallel hybrid electric architecture

6. Structural Design of an ElectricAircraft

Designing an aircraft can be a very complex procedure. While designing an aircraft, different approaches can be made for different types of purposes, an aircraft is being designed. However, for every aircraft, the main body remains the same, even though the elements used in making them may vary. The components of an aircraft have been briefly discussed below [28-29].

A. Airframe

The structural foundation of an aircraft is known as its airframe. The elements used in its production generally varies with the purpose of the aircraft. Airframes of earlier types of aircraft were typically made from wood with the surface of them made with cloth. Then, metal surfaces were used. Most of the electric aircraft's airframe is made from light metals like aluminum or from fiberglass composite sheets, which reduce their weight and maintain the strength. The typical airframe of an aircraft includes:

1) Wings

One or more pairs of large horizontal wings, often with an airfoil cross-section shape. The wing deflects air downward as the aircraft moves forward, generating lifting force to support it on the wings. The wing additionally provides stability in a roll to prevent the aircraft from rolling to the left or right in steady flight.

2) Fuselage

Fuselage may be defined as the main body of an aircraft. This is generally made hollow to reduce the weight of an aircraft. The shape of a fuselage is designed considering the purpose of the aircraft. It is the section of the aircraft which holds everything together.

3) Landing Gear

Landing gears are undercarriage, a group of wheels, skids, or floats that support the plane while it is on the surface. On some aircraft, the undercarriage retracts throughout the flight to reduce back drag.

B. The Empennage and Fore Plane

To comprehend trim, stability, and management, most fixed-wing aircraft have a tail assembly with a fin and a rudder that act horizontally, and a surface and elevator that act vertically. Typically, there also are two or additional fins, spaced out on the surface. Some varieties have a horizontal "canard" fore plane previous the most wing, rather than behind it. This plan could contribute to the carry, the trim, or management of the craft, or too many of those.

1) Vertical Stabilizer

A vertical stabilizer or fin is a vertical wing-like surface mounted at the rear of the plane and usually extending on top of it. The fin stabilizes the plane's yaw (turn left or right) and mounts the rudder that controls its rotation on that axis.

2) Horizontal Stabilizer

A surface or horizontal stabilizer is normally mounted at the tail close to the vertical stabilizer. The surface is used to stabilize the plane's pitch (tilt up or down) and mounts the elevators which offer pitch management.

C. Flight Control System

Flight control system is located at the cockpit of an aircraft. A conventional fixed-wing craft control system consists of control surfaces, several cockpit controls, connecting linkages, and therefore the necessary operative mechanisms to manage associate degree aircraft's direction on the wing, engine controls are often taken as flight controls as they modify speed.

7. Electric Aircraft Propulsion System

All electric aircraft need to have a propulsion system. A propulsion system is defined as the system, in which a power is generated to drive either thrust generating propellers or lift generating rotors. A propulsion system in an aircraft is also designed to do either of the job mentioned above. This system is made of a battery, which gives the power to drive the motors attached to the propellers. These propellers generate thrust with which an aircraft will make a flight. It also consists of control units, instrumentation units, and switching units which are powered solely on electricity. The different components of an electric aircraft propulsion system and their specifications are mentioned below [30].

A. Motor

The motor type in an electric aircraft propulsion system is a Direct drive brushless DC (BLDC) motor with 60 hp peak power and 45 hp average power. The efficiency of this motor is around 90%. This stator type of this motor is the permanent magnet, and the nominal weight of this motor is 1 lb./ hp.

B. Motor Controller

In order to control the speed of an electric aircraft motor, the Pulse Width Modulation (PWM) technique can be used to regulate the voltage across the motor terminal. The peak power of this controller is 60 kW, with 45 kW average power at 95% efficiency. The nominal weight of this controller is approximately 0.06 kg/kW.

C. Energy Storage System

To store the absorbed/generated energy, the storage unit consists of the Lithium-ion battery or the Lithium-Polymer battery can be used. The average power of the Lithium-ion battery unit for an electric aircraft is 25-40 kWhr.

D. Propellers

The propellers in an electric aircraft are full-feathered and their mechanism is the adjustable pitch.

8. Forces of Flight and Flight Dynamics

A. Forces of Flight

An aircraft flight is generally dependent on four types of forces. All these forces are applied on an aircraft to have a safe flight of the aircraft. All these forces are equally important in terms of an electric aircraft as well. These forces are described briefly in this section [30].

1) Lift

Lift is an artificial force employed by the pilot. It is generated through the wings and acts perpendicular to the relative wind and length. The theoretical belief that summarizes the direction and force of carrying is at the center of mass. Lift opposes weight and is equal to weight during the level cruise. Lift is greater than weight during flight and is lesser than weight during descending.

2) Weight

Weight is an uncontrollable force generated by gravity that acts perpendicular to the earth’s surface. In theory, weight is exerted through the center of gravity and opposes lift.

3) Thrust

Thrust is an automatic force employed by the pilot and generated through propulsion system that acts horizontally, parallel to the flight path. Thrust opposes drag. When velocity is constant, thrust is equal to drag. When velocity is higher, thrust is greater than drag, and when velocity is low, or the aircraft is slowing down, thrust is lesser than drag.

4) Drag

Drag is that the natural resistance of an aircraft when it is moving through the air. It is partially controlled by the pilot. Drag may be a horizontal force acting parallel to the flight path and is opposite to thrust.

B. Flight Dynamics

Flight dynamics is the science of an aircraft’s orientation and management in three dimensions. Three essential flight dynamics parameters measure the angles of rotation in three dimensions concerning the vehicle's centre of mass, referred to as roll, pitch and yaw. Aircraft engineers develop management systems for an aircraft's orientation (attitude) concerning its centre of mass. The management systems embody actuators, that exert forces in varied directions, and generate motility forces or moments concerning the middle of gravity of the craft, and so rotate the craft in pitch, roll, or yaw [30].

9. Engineering Design of an Aircraft

This section describes the engineering design of a light-sport electric aircraft (LSEA).

A. Specifications

TABLE 2. The Specifications Of A Light-Sport Electric Aircraft

Feature	Measurement
L/D Ratio	30
Wing Area	130 ft^2
Stall Speed	42 mph
Gross Weight	1320 lbs.
Rate of Climb	600 ft/min
Drag (at best L/D)	44
Motor Efficiency	0.9
Motor Controller Efficiency	0.95
Prop Efficiency (climb speed)	0.6
Prop Efficiency (cruise speed)	0.85
Flight Time (at 75% power)	0.8 hr
Empty Weight (without battery)	579 lbs.
Battery Weight	384 lbs.
Useful Load (Passengers)	357 lbs.
Minimum Horsepower (at best L/D)	13.35
Excess Horsepower (at best L/D)	40
Total Horsepower (at best L/D)	53.35
Motor	62 hp
Maximum Continuous Power	46.55 kW
Total Energy Storage	27.93 kWhr
Maximum Speed	127.44 mph
Cruise Speed (at 75% power)	115.80 mph
Best Glide Speed	67.2 mph
Flight Time (best L/D)	2.41 hr
Range (at cruise speed)	92.64 miles
Maximum Range (at best glide)	188.45 miles
Maximum Endurance	2.80 hr
Energy to Climb to Desired Altitude	3.88 kWhr

B. Body Design

1) Fuselage Layout

The fuselage is sized to provide adequate room for four passengers. A body could be a long, thin body, typically with pointed or rounded ends to form its form aerodynamically smart. The body could contain the flight crew, passengers, freight or payload and batteries. The pilots operate the aircraft from a cockpit situated at the front of the body and are equipped with controls, windows, and instruments.

2) Engine Selection and Disposition

To produce a clean flow over the wings, a fuselage-mounted single engine is chosen. An electrical motor with an output power of 160 kW and a 3-blade propeller with a diameter of 5.2 ft are selected.

3) Wing Design

A cantilever, the low wing is chosen for the wing design, due to its favorable lift throughout takeoff and the shorter landing gear that helps in reducing the structural weight. Also, the wings are used as a step to enter the aircraft.

4) Landing Gear

A normal wheeled undercarriage is chosen to reduce drag and to provide the best streamline flow over the wing during flight. The landing gear specifications and placement are determined by the ground clearance and tip over criteria. To provide adequate clearance for the mechanical device, the length of the nose landing gear and the main landing gear are chosen at 4 and 3 ft, respectively.

5) Empennage

A T-tail is chosen for the design as it is hoped to provide the most effective location for staying out of the wing wake. It will increase the efficiency of the aircraft, as it requires a smaller area.

6) High Raise Devices

A plain flap is the most straightforward high raise device that provides a maximum increment of 0.9 whereas adding less structural weight. Hence a plain flap is chosen.

C. Energy Storage Design

The aircraft uses the Lithium-ion Polymer batteries as the storage unit based on table 3.

TABLE 3. The Specifications Of The Battery Unit For The Light-Sport Electric Aircraft

Feature	Measurement
Specific Energy	160-200 Whr/kg
Energy Density	330 Whr/L
Specific Power	3.2 kW/kg
Charge-Discharge Cycles	600-1000

It should be noted that the specific energy is based on the system weight and not individual cell weight. Also, the charge-discharge cycles depend on the charge rate and temperature.

D. Cost of Energy Storage Unit

The value of the Lithium-ion Polymer battery and the total energy storage are $650/kWhr and 27.93 kWhr, respectively. As a result, the total cost of the battery would be $18,154 [31-33].

E. Bill of Materials for the Light-Sport Electric Aircraft

Table 4 shows the bill of materials of a light-sport electric aircraft.

TABLE 4. Bill Of Materials

Component	Cost
Airframe	$76000
Motor	$2000
Controller	$2000
Battery and Charging System	$18154
Instrumentation and Avionics	$8000
Parachute	$5000
Interior	$1000
Miscellaneous	$2000
Total	$114,154

10. Existing Electric Aircraft Design

This section of the paper briefly discusses some of the existing electric aircraft, which might have been designed in the past, but are still flying and serving their purposes.

A. PC-Elektra One

PC-Elektra One is an electric aircraft designed and built by PC-Aero in Germany. It is a single seat aircraft with electrically powered motors. Elektra One is equipped with solar cells on the wing surface and onboard Lithium batteries to power the motor. This electric aircraft flew its first test flight in March 2011. It was built with carbon-glass composite to ensure low weight with the advanced aerodynamic design. It also has efficient propellers and motor driver [34]. Table 5 shows the PC-Elektra One electric aircraft specifications [35].

B. Yuneec E430

The Yuneec E430 is an electric aircraft designed and built by Yuneec International in China. It is a two-seat aircraft with electrically powered motors. Yuneec E430 is equipped with Yuneec Power Drive 40, powered by Yuneec OEM Lithium polymer batteries onboard to power motor which drives two-bladed fixed pitch turbine. It took its first test flight in June 2009 [36]. Table 6 shows the Yuneec E430 electric aircraft specifications [37].

TABLE 5. The Specifications of PC-Elektra One

Specification	Descriptions
Maximum Takeoff Weight	300 kg
Empty Weight	100 kg
Battery Weight	100 kg
Payload	100 kg
Wingspan	8,6 m
Wing Surface	6.4 m^2
Maximum Engine Power	16 kW
Maximum Range	> 400 km
Maximum Endurance	> 3 hr
Cruise Speed	160 km/hr
Aspect Ratio	11.65
Best Glide Ratio	25
Certification	Ultralight-class-Germany

TABLE 6. The Specifications of Yuneec E430

Specification	Descriptions
Length	6.98 m
Wingspan	13.8 m
Wing Area	11.37 m^2
Empty Weight (with batteries)	250 kg
Gross Weight	470 kg
Propellers	2-bladed fixed pitch
Maximum speed	150 km/hr
Cruise Speed	90 km/hr
Stall Speed	70 km/hr
Range	227 km
Maximum Glide Ratio	25:1
Endurance	2 hr

C. PIPISTREL Taurus Electro G2

Taurus Electro G2 is an electric aircraft designed and built by PIPISTREL in Slovenia. It is a two-seater variant developed to be more sophisticated from PIPISTREL Electro. It is the first self-launching sailplane. Taurus Electro G2 is powered by 40 kW Lithium batteries on-board to drive the electric motor. It was launched in February 2011 [38]. Table 7 shows the Taurus Electro G2 electric aircraft specifications [39].

D. Schempp-Hirth Discus-2

Schempp-Hirth Discus-2 is an electric aircraft

TABLE 7. The Specifications of Taurus Electro G2	
Specification	Descriptions
Length	7.27 m
Wingspan	14.97 m
Wing Area	12.33 m^2
Empty Weight (with batteries)	306 kg
Maximum Takeoff Weight	450 kg
Power Plant	Lithium Batteries
Propellers	2-blade/1.65 m diameter
Maximum Speed	225 km/hr
Cruise Speed	163 km/hr
Stall speed	71 km/hr
Range	200 km
Maximum Glide Ratio	33:1
Endurance	2 hr

designed by Klaus Holighaus and built by Schempp-Hirth in Germany. It is a one-seater variant developed to be a standard class glider. It was the first production sailplane to have a distinctive swept-back leading edge. It is the first self-launching sailplane. It is powered by 22 kW Lithium Polymer batteries on-board to drive the electric motor. It was launched in 2015. Table 8 shows the Schempp-Hirth Discus-2 electric aircraft specifications [40].

TABLE 8. The Specifications of Schempp-Hirth Discus-2	
Specification	Descriptions
Wingspan	15 m
Wing Area	10.16 m²
Aspect Ratio	22.2
Fuselage Length	6.78 m
Empty Mass (Approx.)	335 kg
Max. All-Up Mass	525 kg
Wing Loading (Approx.)	36.9 - 51.7 kg/m²
Max. Permitted Speed	280 /h

11. The Future Design Consideration of Electric Aircraft

This section mainly focuses on the designs that are under development and hoped to be flying in the sky very soon. While talking about the future, with the advancement in battery design and production, the possibility of an electric aircraft as a mean of transportation is increasing day by day. This section covers some of the revolutionary designs and projects in the field of electric aircraft.

The Airbus model, E-Fan craft, has been attributed to be placed into production in 2017. The E-fan is a flash machine plane steam-powered by 2 electrical motors, with a relative speed and carrying capability way less than those needed by industrial carriers. However, within a few decades, this technology might touch short-range commuter and business craft - particularly targeting routes that also use standard aircraft with fuel-based propulsion. Airlines have medium-term plans for such an aircraft, with a target capability of about sixty passengers - creating it an acceptable platform for short-haul commuter flights. Safety and dependability should be addressed before electrical aircraft are adopted by airlines, very much like the electrical automobile still must bring home the bacon a crucial level of public confidence, perceived dependability can have a big impact on consumer's trust in the new craft. If prototypes like the E-Fan will build public confidence, this might mark a "tipping point" in overcoming the technical challenges inherent in any new sort of transportation, particularly in aviation that includes a data of speedy innovation. Advances - notably in new materials, storage, and power physical science technology -might supply the prospect of strictly electrical industrial craft inside successive 20 years. The Future of Aviation depends upon several factors related to battery systems, the material selection and the overall aircraft design principles which might have to change, in order for the people to be able to fly in an electric aircraft. Some of the factors that an electric aviation depends upon are described briefly in the following section [41-42].

A. *Boosted batteries*

In order to produce fully electric planes, the first step that developers will take is producing a battery that weighs the least possible, takes up the least amount of space, and holds an exceptional amount of power. It will make an aircraft design more flexible in terms of the weight bearing capacity of the passengers.

B. *Ultra-Light Materials*

Since the more energy is used, the heavier an airplane is, companies will produce lightweight parts from fiberglass and other such materials in order to cut down on the energy needed.

C. *Electric Mid-Sized Crafts*

Once better batteries and materials are produced, companies will be able to develop larger all-electric planes. At the moment, a two-seater is the largest all-electric aircraft made. However, as better parts are created, larger planes will be produced, as well.

D. Electric Commercial Aircraft

The hope for all-electric airplanes is to not only have them available for private use but for commercial use, as well. Since the U.S. alone uses over 18 billion gallons of jet fuel each year, expanding the use of electric planes to the commercial field will significantly reduce the U.S. carbon output.

E. A Complete Turn from Petroleum

The end result of creating electric planes will be a complete end of the use of petroleum for fuel. Once this happens, not only will save the environment, but also will save the money and time, as well [42]. Here are some of the future aircraft that are being developed to serve as a passenger aircraft.

1) NASA X-57 Maxwell

NASA X-57 Maxwell is an experimental aircraft being designed by NASA. It is a hybrid electric research plane equipped with 14 electric propeller-turning motors located along the wing leading edges. This plane will be passed through a number of tests over the next couple of years in an effort to demonstrate that electric propulsion can make planes quieter, more efficient, and environmentally friendly [42].

2) E-Thrust

E-Thrust is a joint project from Rolls-Royce and Airbus Group Innovations. They are working on the technology to have their product launched by 2050. E-Thrust is concentrated on delivering lower fuel consumption, fewer emissions and noise for future aircraft through a hybrid/electrical distributed system. Building on E-Fan’s all-electric grid, the E-Thrust conception options electrically-driven fans distributed in clusters on the wingspan and a complicated gas engine to produce power for the fans and for recharging the energy storage system (potentially high-density batteries) counting on the section of flight [43].

3) Ce-Liner

Ce-Liner was publicly presented for the first-time during ILA Berlin Air Show in September 2012. When realized, it may be a totally electrical business rider plane that can carry nearly two hundred travelers between continents and over oceans. The distinctive "*C-wing*" in this improves mechanics potency and makes the goal of powering transatlantic flights with electricity a lot feasible. The analysis establishment predicts that battery technology can advance enough by 2030 to permit a flight varies of nearly 700 miles. that may jump to 1000 miles by 2035, and to 1600 miles by 2040 [44]. Additionally, emissions-free flight (provided the electricity is made from renewable resources), the Ce-Liner will have a half an hour airfield work time, simply reversible motors for higher speed management, and seat style that provides passengers a lot of areas once the plane is not full. More significantly, the electrical flight might rework aviation. Airlines, now not captive to rising oil costs, would be free of the requirement to pack flights and scale back service to provide profits. Electricity would truly build traveling pleasant, particularly since there is no any engine noise.

4) E-Genius

Recently, in the French Alps during summer, a plane set seven new world records. The two-seater aircraft climbed in under two minutes more than 20,000 feet and reached speeds of 142 miles per hour. It flew non-stop up to 300 miles. Still, these figures do not sound very remarkable. However, it should be considered that consider that the aircraft burned no fuel and emanated zero emissions. As an alternative, the plane used an all-electric motor powered by a single battery. This is known as the E-Genius and designed by the engineers at the University of Stuttgart. The most outstanding fact about this all-electric airplane is the cost of flying it. During a 62-mile stretch of its historic flight, the plane used about 25 kW of electricity for an overall energy cost of just over $3. In all, E-Genius used up just a fifth of the energy of a typical, fuel-powered two-seater airplane. In the modern era, the advancement in technology leads to electric-powered flight these days won't solely create the act of flying cheaper for the people. Crucially, they additionally promise to revolutionize, however, the natural philosophy trade impacts the world setting. Airplanes unharness around five hundred million plenty of greenhouse gas into the atmosphere annually, representing a major contribution to heating. Electrical flight replaces organic compound consumption with cleaner, powered electricity [45-47].

12. Advantages and Disadvantages of Electric Aircraft

A. Advantages

Due to the absence of a combustion engine, electric aircraft seem to be quieter. Also, they solely work on electric power from batteries, which makes the aircraft eco-friendlier. Moreover, there will be less vibration due to the absence of mechanical parts. Electric aircraft are lighter, and more efficient which reduces the dangers of hazardous accidents.

B. Disadvantages

Charging time will be higher for electric aircraft due to huge batteries that they use. Furthermore, long-haul travels are still not feasible due to the maximum throughput of batteries. Besides that, most of the aircraft’s weight is due to batteries of large sizes.

13. Conclusions

Even though plenty of research and development are going in the field of an electric aircraft still, several breakthrough developments have to be done in the field of battery technology to make the electric long-haul aircraft possible and feasible. If proper development is done in this technology, fights will be with less pollution and emission-free. Proper care has to be given in the aerodynamics and material selection for the manufacturing. It is also found that weight at takeoff makes a huge difference in the overall endurance of the aircraft. This, of course, is as a result of the L/D magnitude relation, which reduces the energy required throughout the flight, and as a consequence, the specified battery weight. If all aspects are taken care of the future of electric, aircraft are bright and glorious. Having proper battery design in the hybrid systems and manufacturing batteries with higher capacity to satisfy the large power requirements of the electric aircraft engines are some restrictions that can have the direct impact on the speed of development in the aviation industry. As a result of the developments discussed throughout this paper, research works will proceed to investigate methods to deal with today's technological limitations and achieve the objectives to improve the aircraft efficiency even further.

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