Concept and Preliminary Design of a Light-Weight Electric-Powered Aircraft with Two Seats Capacity

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Abstract. Green transportation is transportation based on the use of new and renewable energy sources. Currently, the application of green transportation is highly important. Aside from reducing the use of non-renewable energy, it also aims to maintain the level of pollution, the greenhouse effect, and the stability of the earth's temperature, thus preventing global climate change. This research presents the concept and preliminary design of a green transportation that is a light aircraft with a capacity of two seats that is powered by an electric motor, or, as we know, an electric-powered light aircraft. The results of this electric motor-powered light aircraft are still experimental, but it is hoped that it can be mass produced and used as a private, trainer, surveyor, or sport aircraft in the future. The results of the research and design will determine the basics of aircraft configuration, dimension, and flight performance, such as maximum take-off weight, maximum landing weight, maximum cruising speed, rate of climb, rate of descent, maximum range, maximum endurance, ceiling point, electric motor and propeller model selection, power required, landing gear arrangement, and others.

Keywords: Concept & Preliminary Design, Electric-Power Aircraft, Two Seats.

1 Introduction

1.1 Global Warming, Green House Effect and Air Pollution

Global warming and the greenhouse effect are two terms that have been familiar since the beginning of the 21st century. The definition of global warming is a process of increasing the average temperature of the air climate (atmosphere) in various land and

AVINER 2023, November 08-09, Jakarta, Indonesia

DOI 10.4108/eai.8-11-2023.2345841

sea surface areas, while the greenhouse effect is a process that occurs when gases in the Earth's atmosphere trap the heat of the sun's rays and block the reflection of these heat rays out of the atmosphere or into space. Based on data analysis conducted by the United States national space agency, or the National Aeronautics and Space Administration (NASA), it informs the condition of climate change or temperature increase in the last 50 years (compared to the climate from 1951 to 1980). There is a variation in temperature increase in various regions of the Earth's atmosphere by 0.2 degrees to 6.5 degrees Celsius (see Fig. 1) [1].

There are several factors that are known to contribute to the occurrence of global warming and the greenhouse effect, including the main factor caused by exhaust gas pollution from combustion (both transportation and industrial engines); this condition is known as the greenhouse effect or greenhouse gases; other additional factors are due to agricultural production activities by deforesting without a good reforestation system or natural forest fires.

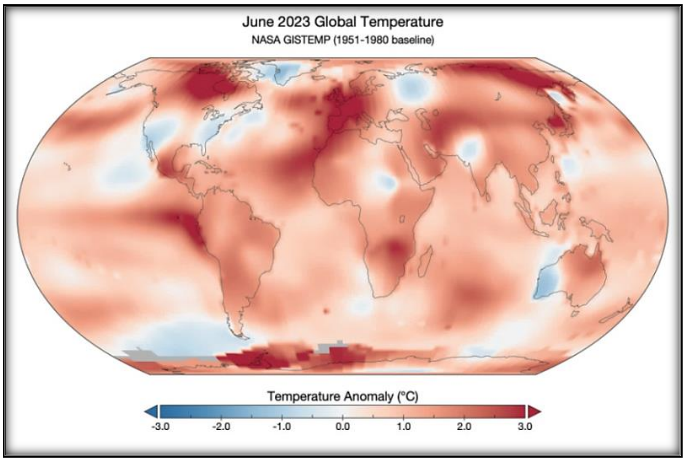
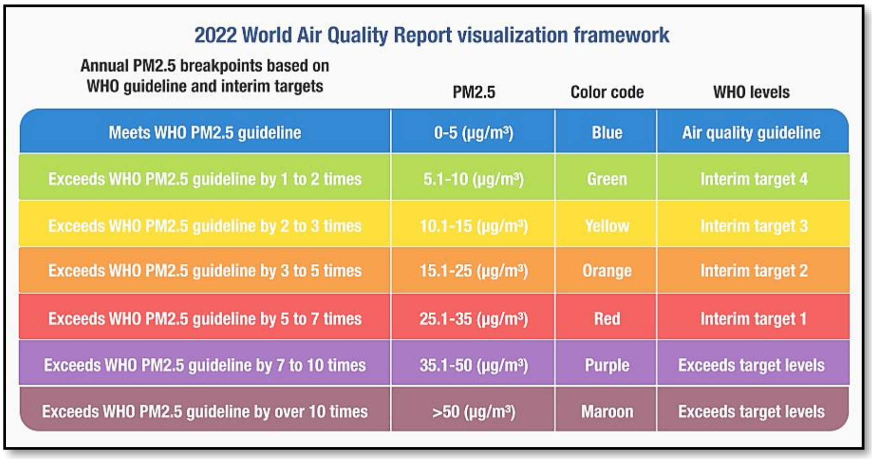


Fig. 1. Climate change phenomena of the last 50 years

The World Health Organization (WHO) states that in the last decade, the problem of air pollution affecting environmental health has had a high and urgent risk level, contributing to at least 7 million premature deaths each year, and about 98% of children under five have breathed toxic air. Air pollution is also the leading cause of death for children under the age of 15 and kills 600,000 people every year [2].

The Air Quality Index (hereafter abbreviated as AQI) is used to report air quality conditions in an area. This index provides information on the value of air pollution, which will have an effect on health. AQI focuses on the health effects that may be experienced within hours or days of breathing polluted air. As the air pollution level of an area increases, the AQI value will increase, along with associated public health risks in the area. Humans and/or animals will experience respiratory or cardiovascular problems, which are generally the first groups affected by poor air quality. Levels of air quality index values (see Table 1) [2].

Table 1. Air quality index.



2022 World Air Quality Report visualization framework

Annual PM2.5 breakpoints based on WHO guideline and interim targets	PM2.5	Color code	WHO levels
Meets WHO PM2.5 guideline	0-5 (μg/m³)	Blue	Air quality guideline
Exceeds WHO PM2.5 guideline by 1 to 2 times	5.1-10 (μg/m³)	Green	Interim target 4
Exceeds WHO PM2.5 guideline by 2 to 3 times	10.1-15 (μg/m³)	Yellow	Interim target 3
Exceeds WHO PM2.5 guideline by 3 to 5 times	15.1-25 (μg/m³)	Orange	Interim target 2
Exceeds WHO PM2.5 guideline by 5 to 7 times	25.1-35 (μg/m³)	Red	Interim target 1
Exceeds WHO PM2.5 guideline by 7 to 10 times	35.1-50 (μg/m³)	Purple	Exceeds target levels
Exceeds WHO PM2.5 guideline by over 10 times	>50 (μg/m³)	Maroon	Exceeds target levels

Based on information from the European international agency that handles environmental issues, the European Environment Agency has categorized the level of pollution contribution that occurs from various types of vehicles or modes of transportation as 74.5%. The level of pollution is then followed by several other types of vehicles, such as road (passenger) at 45.1%, road (freight) at 29.4%, aviation at 11.6%, shipping at 10.6%, rail at 2.2%, and other 1% [4]. CO2 emission pollution continues to increase due to the results of fuel combustion exhaust gases from various types of motorized vehicles, including exhaust gases from aircraft propulsion systems that have a large enough combustion system, as well as an increase in aviation traffic (see Fig. 2) [3].

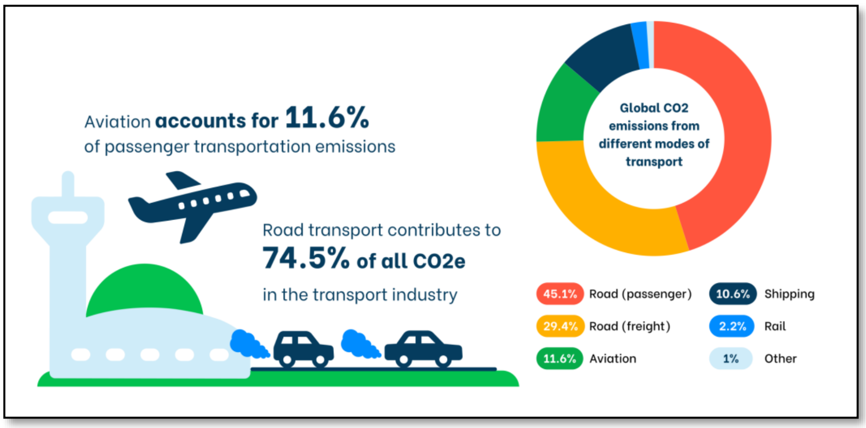
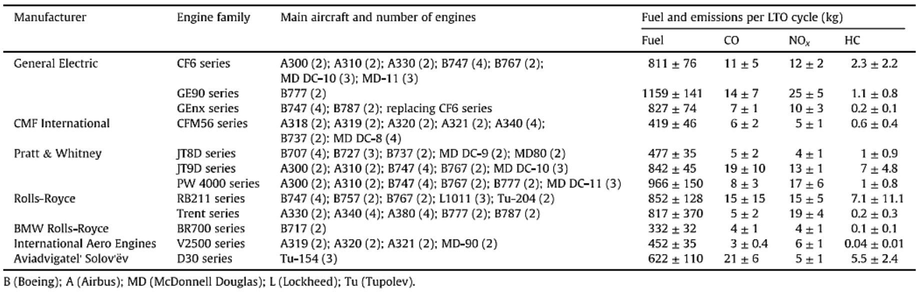


Fig. 2. Pollution by various types of transportation vehicles

1.2 Exhaust Gas Emission and Noise

Aircraft emission standards have actually been around for about 30 years and basically apply to all commercial aircraft. The United States Environmental Protection Agency (EPA, for short) has cooperated with the FAA and ICAO in the development of international aircraft emission standards. In 2016, the UN's International Civil Aviation Organization (ICAO) set CO2 emission standards for new aircraft in two tiers. One standard applies to new aircraft already certified and in production. More stringent emissions efficiency standards have been imposed for engine designs certified after January 1, 2020, for commercial jet engines and January 1, 2023, for business jets, with each category of aircraft entering service approximately four years after certification. Efficiency requirements will apply to all new aircraft deliveries from January 1, 2028. The standards are based on the weight classification of the aircraft, requiring an average four percent reduction in fuel consumption compared to new aircraft delivered in 2015 [4].

Table 2. Emissions from some aircraft engine models [4].



Manufacturer	Engine family	Main aircraft and number of engines	Fuel and emissions per LTO cycle (kg)			
			Fuel	CO	NO_x	HC
General Electric	CF6 series	A300 (2); A310 (2); A330 (2); B747 (4); B767 (2); MD DC-10 (3); MD-11 (3)	811 ± 76	11 ± 5	12 ± 2	2.3 ± 2.2
	GE90 series	B777 (2)	1159 ± 141	14 ± 7	25 ± 5	1.1 ± 0.8
	GEnx series	B747 (4); B787 (2); replacing CF6 series	827 ± 74	7 ± 1	10 ± 3	0.2 ± 0.1
CMF International	CFM56 series	A318 (2); A319 (2); A320 (2); A321 (2); A340 (4); B737 (2); MD DC-8 (4)	419 ± 46	6 ± 2	5 ± 1	0.6 ± 0.4
Pratt & Whitney	JT8D series	B707 (4); B727 (3); B737 (2); MD DC-9 (2); MD80 (2)	477 ± 35	5 ± 2	4 ± 1	1 ± 0.9
	JT9D series	A300 (2); A310 (2); B747 (4); B767 (2); MD DC-10 (3)	842 ± 45	19 ± 10	13 ± 1	7 ± 4.8
	PW 4000 series	A300 (2); A310 (2); B747 (4); B767 (2); B777 (2); MD DC-11 (3)	966 ± 150	8 ± 3	17 ± 6	1 ± 0.8
Rolls-Royce	RB211 series	B747 (4); B757 (2); B767 (2); L1011 (3); Tu-204 (2)	852 ± 128	15 ± 15	15 ± 5	7.1 ± 11.1
	Trent series	A330 (2); A340 (4); A380 (4); B777 (2); B787 (2)	817 ± 370	5 ± 2	19 ± 4	0.2 ± 0.3
BMW Rolls-Royce	BR700 series	B717 (2)	332 ± 32	4 ± 1	4 ± 1	0.1 ± 0.1
International Aero Engines	V2500 series	A319 (2); A320 (2); A321 (2); MD-90 (2)	452 ± 35	3 ± 0.4	6 ± 1	0.04 ± 0.01
Aviadvigatel' Solov'ëv	D30 series	Tu-154 (3)	622 ± 110	21 ± 6	5 ± 1	5.5 ± 2.4

B (Boeing); A (Airbus); MD (McDonnell Douglas); L (Lockheed); Tu (Tupolev).

Noise from aircraft operations is one of the most significant causes of adverse public reactions to operations near airports. This is expected to remain the case in most regions of the world for the foreseeable future. One of ICAO's top priorities is to limit or mitigate the impact of aircraft operational noise, particularly for those affected in the vicinity of airports. In order to establish noise standards, an understanding of current research and technology development is essential. Technological advances continue to drive the aviation community to realize ICAO's objectives and continuously monitor research and development in noise abatement technologies, which complements the process of setting standards. In ICAO Global Environmental Trends, a series of scenarios were developed for the assessment of future noise trends. The noise indicators used were the total contour area and population within the contour of the annual average day and night level (DNL) of 55 dB at 315 airports worldwide, representing about 80% of global traffic (see Fig. 3) [5].

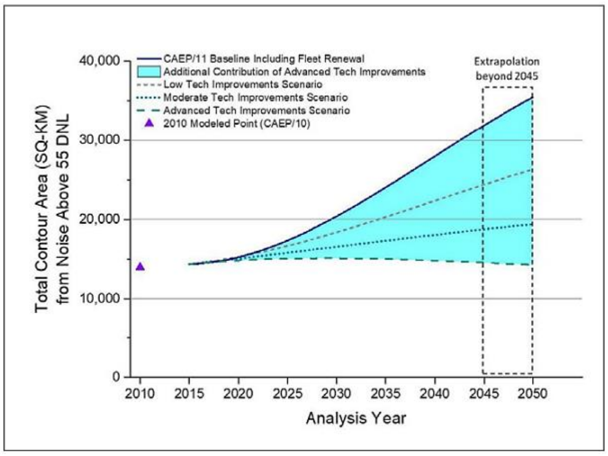


Fig. 3. Noise emission trends above 55 dB DNL at 315 airports [5].

Tables below (3 and 4) show a comparison of the noise reduction values recorded between internal combustion engine aircraft and electric-powered aircraft.

Table 3. Noise reduction Extra 330LT & Extra 330LE Aircraft[6].

LASmax [dB(A)]	Extra 330LT with combustion engine	Extra 330LE with electrical motor	**Noise reduction**
Low altitude (50 feet)	101.2	94.5	**6.7 dB**
High altitude (1000 feet)	83.7	69.2	**14.5 dB**

Table 4. Noise Fusion 212 & eFusion Aircraft [6]

LASmax	Magnus Fusion 212 with combustion engine	Magnus eFusion with electrical motor	**Noise reduction**
60 knots – low altitude (50 feet)	80.1	78.2	**1.9 dB**
90 knots – low altitude (50 feet)	84.4	80.8	**3.6 dB**
60 knots – high altitude (1000 feet)	57.6	56.5	**1.1 dB**
90 knots – high altitude (1000 feet)	61.7	51.4	**10.3 dB**

1.3 Green Transportation Program

The problem of increasing emissions has led to the development of science and technology in various fields with an environmentally friendly orientation. In this case, various industrialized countries always strive to master and find new technologies by increasing research and development activities, both in the field of manufacturing and product technology that is environmentally friendly. This is in line with the Presidential Regulation (Number 55 of 2019) on "Accelerating the Battery Electric Vehicle Program for Road Transportation." The Presidential Regulation also states that "industrial companies, universities, and/or research and development institutions can conduct research, development, and technological innovation in the battery-based KBL industry" [7].

Starting with land transportation modes, experts first designed, made, and developed electric motor vehicles (electric vehicles or automobiles). Furthermore, it quietly spread to the aviation industry with the existence of electric motor-powered airplanes, which, of course, is expected to have more and more designs of electric-powered airplanes in the future. As with electric automotive vehicles, this electrically powered air transportation fleet is not only environmentally friendly but also has low operating costs, which is beneficial for users or passengers because plane tickets will be cheaper. Realizing that in the development of technology, an aircraft in the future will have an environmentally friendly design concept. In this case, it means that all aircraft experts are competing to design and make aircraft that have new and renewable fuel propulsion systems [8].

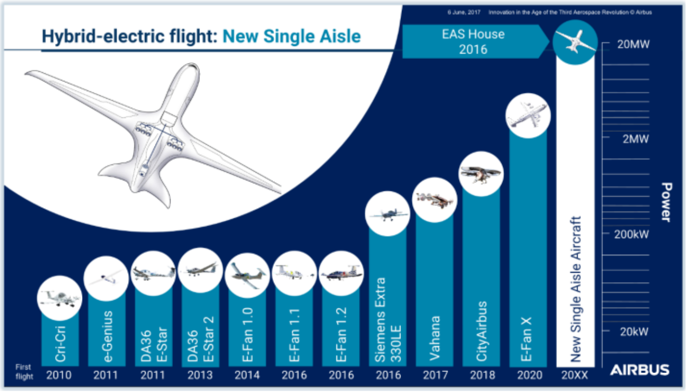


Fig. 3. Development of electric motorized aircraft [8]

By 2050, the European Union wants to reduce CO2 emissions by 75%, NOx emissions by 90%, and noise emissions by 65% in the aviation industry. A new carbon offsetting and reduction scheme for international aviation has been agreed upon by 70 countries and will come into effect in 2020. As early as 2010, Airbus, the largest aircraft manufacturer in continental Europe, embarked on a journey of aviation electrification design concepts, developing the first four-engine aerobatic aircraft powered entirely by electricity, named CriCri. Since then, Airbus has designed several other aircraft with significant advances in aviation electrification and driven the commercialization of emission-free urban air mobility vehicles and eventually large commercial aircraft (see Fig. 3) [8].

2 Electric Aircraft Development

The development of the electric-powered airplane has been called the "Third Revolution in Aviation." As already known, the "First Revolution" was the first flight of the Wright brothers, whose first successful airplane flight was made. The "Second Revolution" occurred at the time of the invention of the jet engine, which made it possible for aircraft to fly faster and farther. The growth of the aviation world was followed by the problem of substantial carbon emissions, giving rise to electric-powered aircraft technology and marking a dramatic transformation towards zero carbon emissions for aviation, and this is the "Third Revolution" [9].

Aircraft electric propulsion (AEP) is an aircraft whose propulsion system is powered by electrical energy derived from fuel cells, solar cells, ultracapacitors, and batteries. Electric and hybrid-electric propulsion technologies are rapidly evolving in various industries, from automotive to marine, and the aviation industry is no exception. With the increasing mastery of new energy-efficient and environmentally friendly technologies, including aircraft propulsion systems, several concepts of zero-emission-oriented propulsion systems have emerged.

Airbus is committed to developing, building, and testing future electric and hybrid-electric technologies that will enable the aviation industry to significantly reduce CO2 emissions. In 2010, Airbus began its electrification journey, developing the first fully electric four-engine aerobatic aircraft, the CriCri. Since then, Airbus has made significant progress in aviation electrification to drive the commercialization of emission-free urban air mobility vehicles and eventually large commercial aircraft [10].

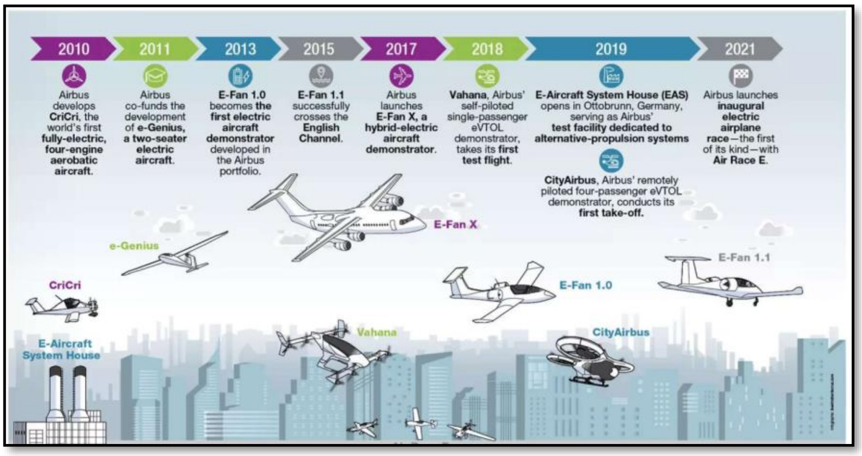
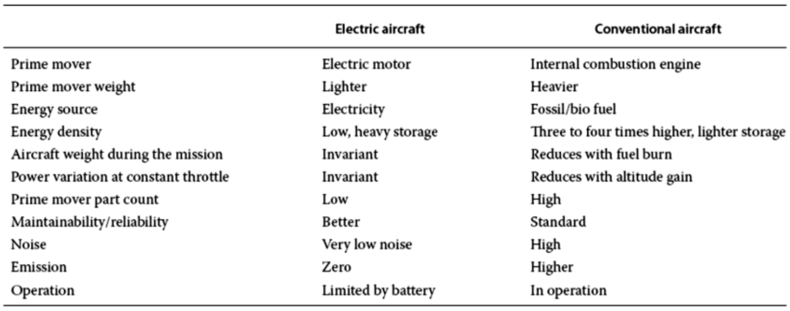


Fig. 4. Electric aircraft models by Airbus [10]

On paper, the use of electric aircraft is very profitable and has many advantages. With their power, electric airplanes are also able to keep up with speeds equivalent to those of oil-fueled airplanes. Nevertheless, electric-powered aircraft cannot be ascertained until they are realized for the needs of the commercial fleet. The reason is that aviation engineers are still figuring out the amount of power-to-weight ratio that is feasible in accordance with flight standards. The following describes the operational comparison between electrical aircraft and conventional aircraft [11].

Table 5. Electrical and conventional aircraft comparison [11]



	Electric aircraft	**Conventional aircraft**
Prime mover	Electric motor	Internal combustion engine
Prime mover weight	Lighter	Heavier
Energy source	Electricity	Fossil/bio fuel
Energy density	Low, heavy storage	Three to four times higher, lighter storage
Aircraft weight during the mission	Invariant	Reduces with fuel burn
Power variation at constant throttle	Invariant	Reduces with altitude gain
Prime mover part count	Low	High
Maintainability/reliability	Better	Standard
Noise	Very low noise	High
Emission	Zero	Higher
Operation	Limited by battery	In operation

3 Aircraft Design Phases and Requirements

Aircraft design is one of the disciplines that is different from the analytical sciences such as aerodynamics, structure, control, and propulsion. Several stages or processes in the design must be carried out carefully, disciplined, and accurately. An aircraft designer must have a general knowledge of the analytical sciences in each of these design processes. There are at least three stages to designing and manufacturing an aircraft: conceptual design, preliminary design, detailed design, and then production [12].

Conceptual design is the first stage in aircraft design. As a basis for carrying out the next steps in designing an aircraft, concept design is required, which is the first activity in realizing the configuration to be used. At this early stage, the designer takes a sketch in the form of an aircraft configuration into consideration in order to meet the required specifications, such as aerodynamics, propulsion, performance, structure, and control. The fundamental aspects of fuselage shape, wing configuration, and engine dimensions are considered at this stage. Design issues, as they are known, are taken into account at this early stage. The final product of conceptual design is a sketch of the conceptual layout of the aircraft configuration [12].

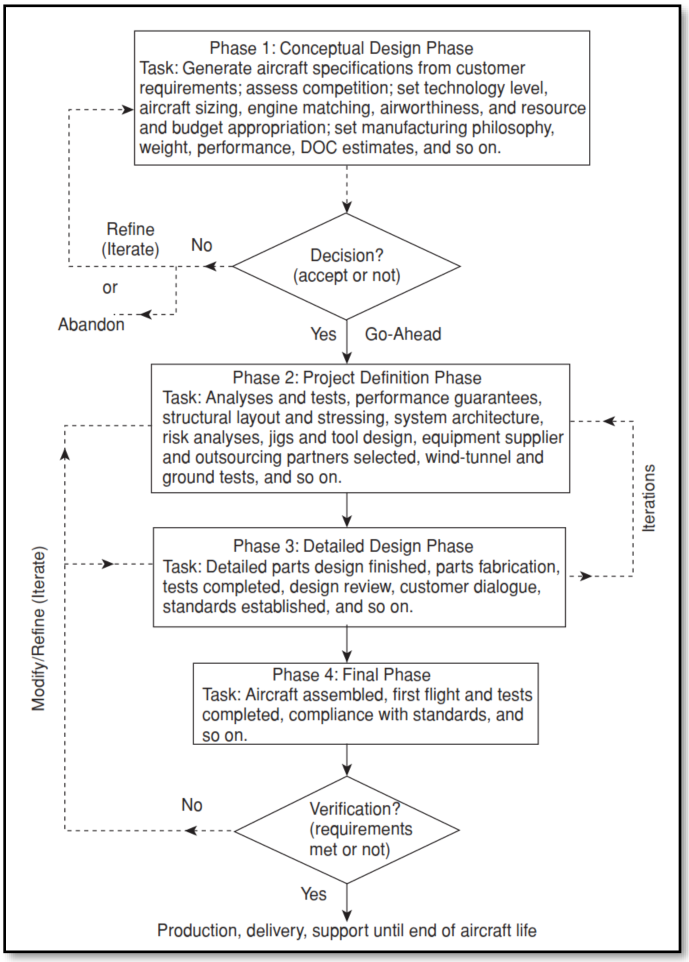


Fig. 5. Aircraft design phases and requirements [12].

The results of the concept design that has been determined will continue to be explored and developed in the next stage, namely the preliminary design stage. At this stage, several rounds of the design process need to be repeated in order to select the shape, material, size, structural strength, and functions of the design. At this stage, computerized calculations and/or simulations need to be carried out, and small-scale physical models of the design are made and tested. At a later stage, the design will be revised and modeled in terms of parameters. At this stage, aerodynamic testing of the model will be carried out, either using a wind tunnel or computational fluid dynamics. A major structural and control analysis is also conducted at this stage. The final product of the preliminary design is an improved sketch with aircraft geometry dimensions and parameters. In this stage, a market survey will be conducted to see whether the design with the obtained functions and performance meets the market needs or not. Input from the market survey will be used as additional data to improve the next round of design. This is done until the final design obtained is deemed to have reached an optimum and the initial design process is continued or frozen [12].

In the detailed design stage, all that is needed to prepare for the manufacture of the desired product. The design will be described in detail, down to the smallest parts, such as materials, production equipment, and production methods and techniques. A set of blueprint drawings, a list of materials, and details of the estimated costs involved should be prepared. Then one or more prototype aircraft are built and tested, either static load structural tests or dynamic load tests (metal fatigue), and flight tests will be conducted [12].

At this stage, the design must be ready to enter the manufacturing stage, for example, in concept and preliminary designs. Designers only design the wing in the form of its general geometry. Therefore, at this design stage, the designer will detail the wing design into several parts of the wing structure, such as ribs, spars, and skins, each of which must be designed and analyzed separately [12].

4 Electric Aircraft Concept Design

Conceptual design is the initial stage in designing an aircraft. The output of this stage is an initial guess or an approximate sketch of the aircraft configuration. The conceptual design phase involves developing the aircraft configuration, size, weight, and some performance parameters. The conceptual design phase can be a very iterative process. It can be observed that, at all stages of the conceptual design phase, the designer must always check back to ensure that the aircraft design has met all the requirements (see Fig. 6) [13].

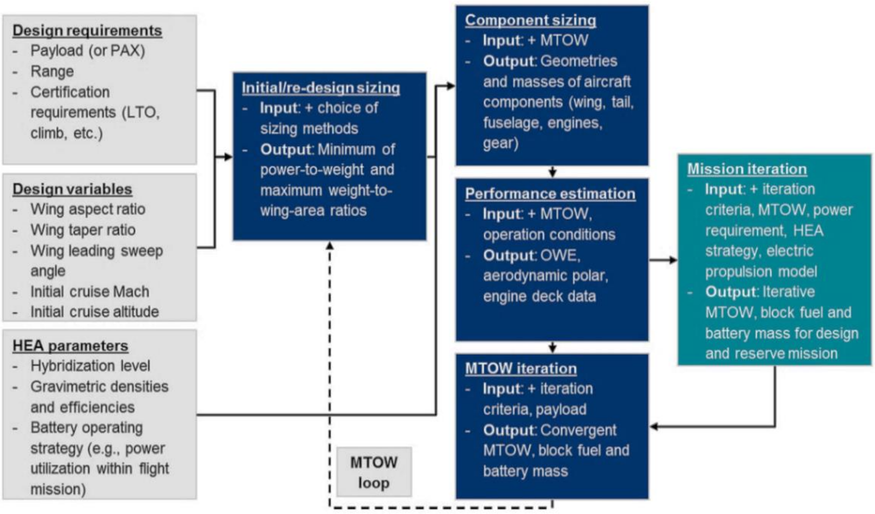


Fig. 6. Aircraft conceptual design phases requirements [13].

Determining the parameter requirements of the conceptual design is done by applying empirical data regression calculations from class aircraft (2 and 4 seats), both powered by internal combustion engines (piston engines) and electric propulsion. The classes of aircraft in question are as follows:

a. Electric Aircraft: Diamond eDA40, E-Flyer 2 Aircraft, Extra 330LE LuFo Siemens, Magnus eFusion Aircraft, Pipitrel Velis Electro, Pipistrel Alpha Electro, Pipistrel Taurus, U15E-Nix, and Yuneec e430.
b. Piston Engine Aircraft: Bristell B23, Jabiru J-230D, Pipistrel Virus SW, SkyLeader 200, SkyLeader 400, SkyLeader 600, Storm RG Fury, TL-2000 Sting S4, Waiex-B, and Zenith CH-650XL.

This light electric aircraft is named the Elementya Reaserch Club-eXperiment 01 (URC-X01), which has the following basic configuration:

a. Single tractor propulsion by electric motor
b. Maximum 2-seat capacity
c. Low-wing, tappered, and dihedral types
d. Conventional fixed landing gear type
e. T-Tail plane and V-Tail plane (optional)

This light aircraft with a capacity of 2 is very suitable for use (mission) as a trainer aircraft, sport aircraft, experiment aircraft, surveillance aircraft, and others. The results of regression calculations on a number of empirical data carried out to obtain the values of the aircraft dimensions, sizing, weights, and basic flight performance parameters can be seen in Table 6.

5 Conceptual and Preliminary Design Results

The following presents the dimensional parameters and performance fundamentals from the calculations performed (see Table 6).

Table 6. dimensional parameters and performance of aircraft design`

Initial Dimensions	Value
Aircraft Height (m)	2.1
Aircraft Length (m)	6.7
Wing Span (m)	10.1
Wing Area (m²)	12.2
Wing Chord (m)	1.2
Wing Aspect Ratio	8.34
Cabin Width (m)	1.18
Cabin Height (m)	1.1
Horizontal Stab.Span (m)	3
Horizontal Stab. Area (m²)	5.45
Vertical Stab. Height (m)	1.27
Horizontal Stab. Aspect Ratio	5.45

Root/Tip Chord Hor. Stab. (m)	0.7 / 0.4
Up/Down Chord Ver. Stab. (m)	0.7 / 1
2-Blades Propeller Dia. (m)	1.6
Initial Performances	
MTOW (kg)	612
Payload (kg)	228
OEM (kg)	365
Takeoff distance (m)	209
Landing distance (m)	347
Max. Range (km)	700
Max. Endurance (hrs)	3.5
Cruise Ceiling (m)	3000
Max. Cruise Speed (m/s)	53.5
Max. Rate of Climb (m/s)	1.97
Power to Weight Ratio	6.2
Wing Loading	56.92
Battery Capacity (kWh)	32
Wing Airfoil Type	NACA 2412
Tail Airfoil Type	NACA 0012

Fig. 7. URC-X01 electric aircraft configuration design

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