МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д.т.н, професор
______Сергій ІГНАТОВИЧ
«__» _________2022 р.

КВАЛІФІКАЦІЙНА РОБОТА

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА
ЗІ СПЕЦІАЛЬНОСТІ
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Аналіз доцільності створення гібридної силової установки для регіонального пасажирського літака»

Виконавець: _________ **Єлизавета САМОЙЛЕНКО**

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Київ 2022

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

DEPARTMENT OF AIRCRAFT DESIGN

PERMISSION TO DEFEND
The head of the Department
Dr. of .Sc., professor
______Serhiy IGNATOVICH
«___» ___________2022 .

MASTER DEGREE THESIS

ON SPECIALITY

”AVIATION AND SPACE ROCKET TECHNOLOGY”

Topic: «Analysis of the hybrid power plant practicability for a regional passenger aircraft»

Fulfilled by: _______________ **Yelyzaveta SAMOILENKO**

Supervisor:

Ph.D., associate professor _____________ **Sviatoslav YUTSKEVYCH**

Labor protection advisor:

Ph.D., associate professor _____________ **Katerina KAZHAN**

Environmental protection adviser:

Ph.D. professor _______________ **Lesya PAVLYUKH**

Standards Inspector:

Ph.D. associate professor ______________ **Volodymyr KRASNOPOLSKYI**

Kyiv 2022

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аерокосмічний
Кафедра конструкції літальних апаратів

Освітній ступінь «Магістр»
Спеціальність 134 «Авіаційна та ракетно-космічна техніка»

Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
Завідувач кафедри
д.т.н., професор

__________С.Р. Ігнатович
«___» ___________202_ р.

ЗАВДАННЯ

на виконання дипломної роботи студентки

Єлизавети Самойленко

1. Тема роботи **«**Аналіз доцільності створення гібридної силової установки для регіонального пасажирського літака**»**, затверджена наказом ректора від 5 жовтня 2022 року №1861/ст.

2. Термін виконання проекту: з 06 жовтня 2022р. по 30 листопада 2022 р.

3. Вихідні дані до проекту: Параметри прототипу літака і розрахунки центра ваги, результат розрахунків по формулі дальності польоту (формула Бреге)

4. Зміст пояснювальної записки: Дослідження доцільності застосування гібридної-електричної силової установки для сучасного авіаційного ринку, порівняння розрахунків центра ваги для стандартної та оновленої конфігурації, аналіз ступеня гібридизації по співвідношенню маси батареї та палива по формулі дальності польоту (формула Бреге).

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: презентація Power Point, розрахунки у Excel, схеми.

6. Календарний план-графік

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1	Дослідницька література про екологічну ситуацію у світі та тенденція розвитку потужних авіаційних батарей.	06.10.2022–18.10.2022	
2	Аналіз стандартної та гібридної конфігурації та їх центри ваги.	19.10.2022-29.10.2022	
3	Аналіз доцільного ступеня гібридизації для прототипу.	30.10.2022-07.11.2022	
4	Аналіз авіаційного ринку та розрахунки пріоритетних цілей за допомогою методу розгортання функції якості (QFD).	06.10.2022-31.10.2022	
5	Виконання розділів, присвячених охороні навколишнього середовища та праці.	01.11.2022-04.11.2022	
6	Оформлення дипломної роботи	05.11.2022-10.11.2022	

7. Консультанти з окремих розділів

Розділ	Консультанти	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці			
Охорона навколишнього середовища			

8. Дата видачі завдання: 5 жовтня 2022 р.

Керівник дипломної роботи: Святослав ЮЦКЕВИЧ

Завдання прийняв(ла) до виконання: Єлизавета САМОЙЛЕНКО

NATIONAL AVIATION UNIVERSITY

Aerospace faculty

Department of aircraft design

Educational Degree «Master»

Specialty 134 «Aviation and space rocket technology»

Educational professional program «Aircraft equipment»

APPROVED BY

Head of department

Dr. of Sc., professor

______Serhiy IGNATOVICH

«___» ____________2022 р.

TASK

For the master degree thesis

Yelyzaveta Samoilenko

1. Topic: **«**Analysis of the hybrid power plant practicability for a regional passenger aircraft**»**, approved by the Rector's order № 1861 «05» October 2022 year.
2. Period of work execution: from 05 October 2022 year to 30 November 2022 year.
3. Initial data: Parameters of the prototype aircraft and calculations of the center of gravity, the result of calculations according to the flight range formula (Breguet formula).
4. Content: Study of the practicability of using a hybrid-electric propulsion system for the modern aviation market, comparison of center of gravity calculations for standard and hybrid configurations, analysis of the degree of hybridization by the ratio of battery weight to fuel according to the flight range formula (Breguet formula).
5. Required material: Power Point presentation, Excel calculations, diagrams.

6. Thesis schedule:

№	Task	Time limits	Done
1	Research literature on the environmental situation in the world and the trend of development of high-density aircraft batteries.	06.10.2022–18.10.2022	
2	Analysis of standard and hybrid configuration and their centers of gravity.	19.10.2022-29.10.2022	
3	Analysis of the appropriate degree of hybridization for the prototype.	30.10.2022-07.11.2022	
4	Analysis of the aviation market and calculation of priority goals using Quality Function Deployment (QFD).	06.10.2022-31.10.2022	
5	Implementation of the sections on environmental and labor protection.	01.11.2022-04.11.2022	
6	Edit and correct the draft, modify the format.	05.11.2022-10.11.2022	

7. Special chapter advisers

Chapter	Consultants	Date, signature	
		Task Issued	Task Received
Labor protection			
Environmental protection			

8. Date: 8 September 2022 year.

Supervisor: Sviatoslav YUTSKEVYCH

Student: Yelyzaveta SAMOILENKO

РЕФЕРАТ

Пояснювальна записка дипломної роботи магістра "Аналіз доцільності створення гібридної силової установки для регіонального пасажирського літака"

78 с.,14 рис.,10 табл., 41 джерело

Ця дипломна робота присвячена процесу впровадження гібридної силової установки для регіонального літака.

Предметом дослідження є доцільність та перешкоди на шляху впровадження гібридно-електричної силової установки.

Метою магістерської роботи є аналіз доцільності гібридних технологій та розгляд аспектів їх реалізації.

Методи дослідження та розробки полягають у порівнянні характеристик палива і батареї для формули дальності польоту Бреге за допомогою Mathcad, методу розгортання функції якості (QFD), виконаного в Excel, та порівняння з гібридними моделями, що використовуються на сьогоднішній день.

Робота містить аналіз характеристик гібридної силової установки, QFD, для дослідження її доцільності та розробки, спрямовані на доведення корисності технології.

Новизна отриманих результатів полягає в тому, що вперше показано точку, в якій фактор гібридизації буде вигідним і не призведе до переобтяження системи, а також показано, наскільки система є необхідною з точки зору детального інженерного аналізу ринку.

Практичне значення полягає у впровадженні використання гібридних технологій в цивільній авіації.

Результати роботи можуть бути реалізовані як в проектуванні, так і в навчальному процесі, пов'язаних з проектуванням літальних апаратів, авіаційної техніки тощо.

Літак, гібридна силова установка, прототип, гібридизація, економічна перспектива, літій-повітряні батареї, рівняння дальності, ступінь гібридизації, розгортання функції якості.

ABSTRACT

Master degree thesis “Analysis of the hybrid power plant practicability for a regional passenger aircraft”

78 pages, 14 figures, 10 tables, 41 references

This thesis is devoted to the process of implementation of the hybrid power plant for a regional aircraft.

The subject of study is practicability and obstacles prior to the hybrid power plant implementation.

The aim of the master’s degree thesis is to analyze the practicability of hybrid technologies and consider aspects of their implementation.

Research and development methods are the comparisons of fuel/battery characteristics for the Breguet range equation using Mathcad, Quality Function Deployment (QFD) method performed in Excel, and comparison with the hybrid models being in use nowadays.

The thesis comprises analysis of the hybrid power plant characteristics, QFD to show its expediency, research and development directed for proving the technology’s utility.

The novelty of the results is the first time to show the point, where the hybridization factor will be beneficial and doesn’t lead to overweight of the system, and show how required the system is in terms of detailed engineering market analysis.

The practical value is to incentive the use of hybrid technologies in civil aviation.

The results of the work can be implemented both in the design and in the educational process related to the design of aircraft, aviation equipment, etc.

Aircraft, hybrid power plant, prototype, hybridization, economical perspective, lithium-air batteries, range equation, degree of hybridization, quality function deployment.

CONTENT

ABBREVIATIONS

ICAO – International Civil Aviation Organization;

EASA – European Union Aviation Safety Agency;

FAA – Federal Aviation Administration;

FAR – Federal Aviation Regulations;

QFD – Quality Function Deployment

CG – Center of gravity;

MAC – Mean aerodynamic chord;

CM – Center of mass.

HEPS – Hybrid electric propulsion system

EM – Electric motor

ICE – Internal Combustion Engines

INTRODUCTION

The air transportation business has experienced the fastest rate of growth in the transportation sector—doubling in size every 20 years—since the invention of jet engines, and it is anticipated that it will maintain this growth rate going forward. However, the public's attention is being drawn to its environmental impact in terms of noise and pollution emissions [1].

Additionally, because of the perceived financial benefits of greater energy efficiency, the transportation sector is urged to invest in alternative energy sources. In order to improve vehicle economy and lessen the impact on the environment, a concept that combines internal combustion engines (ICEs) and electric motors (EMs) in the propulsion system is being researched. This is because a significant portion of greenhouse gas emissions are produced by the aviation industry. This strategy has been referred to as a hybrid electric power plant (HEPS) by certain publications.

The worldwide civil aviation industry has grown significantly in recent years and will continue to do so. By 2050, it is predicted that 1300 additional international airports will be needed, and the fleet of commercial aircraft will have doubled [1].

To fulfill the increasing demand and environmental regulations, as well as to reduce airport-area takeoff and landing noise, energy use, and emissions while maintaining commercial viability, new airplane concepts are needed.

It is a challenging undertaking to complete, but the research of HEPS necessitates a multidisciplinary combined approach embracing all associated subjects. This study reflects the current level of HEPS development, identifies the most difficult needs, demonstrates the state where the hybridization factor will be beneficial without overburdening the system, and demonstrates how essential the system is in terms of aviation market analysis [1].

PART 1. LITERATURE EVALUATION

1.1. Overview of the aviation sector

Hybrid-electric propulsion is a captivating alternative for the light aviation market because it maintains the flight performance, especially range, typical of conventional propulsion, which is based on hydrocarbon fuel while offering the benefits of electric propulsion in terms of lower noise and pollutive emissions in terminal maneuvers. Due to the difficulties in negotiating specifications and making design decisions, the adoption of this novel technology in light aviation may have been hampered in part by the lack of established processes for developing hybrid-electric aircraft. In comparison to conventionally powered aircraft, the number of design variables required to characterize the hybrid-electric power train, which includes both its thermal and electric elements, has increased significantly. Designers and manufacturers of ultra-light (UL) and light general aviation (GA) aircraft have recently focused on electric propulsion for aircraft as a potential means of reducing noise and chemical pollution. The engine is frequently cited as the main cause of the overall noise footprint on the ground and as a major factor in the lack of cabin comfort when it comes to internal combustion engines (ICE), by far the most popular propulsion system in this category. Additionally, because they must use combustion as a method of energy conversion, internal combustion engines (ICEs) are inherently less energy-efficient than electric motors (EM), and as a result of the conversion process, they invariably emit chemicals into the atmosphere, as opposed to electric motors, which perform an emission-free conversion [2].

Some people find the amount of aviation traffic shocking. Over 400 departures per hour are being made by aircraft, and that number only includes scheduled commercial activity (Figure 1.1.).

Air travel carries both passengers and freight throughout the globe, and as bees pollinate the global economy, air travel can have a significant impact on a region's social and economic development as well as its sustainability. To ensure the success and sustainability of the developing mobility industry, sharing and exploiting technology and best practices from aviation and all forms of transportation is essential. The ICAO was designated as the custodian organization for the global indicator for Passenger and Freight Volumes, by Mode of Transport, within the 2030 Agenda framework. The ICAO keeps track of and offers data on the development of resilient infrastructure by states, as well as on inclusive and sustainable industrialization and innovation.

The future of aviation is bright, and the air transport sector is growing.

Around 4.1 billion passengers flew on airplanes around the world in 2017. 37 million commercial flights carried 56 million tons in freight. Over 10 million people and about 18 billion dollars' worth of cargo are transported daily by airplanes. This demonstrates the huge economic influence that aviation has had on the world economy, which is further supported by the fact that aviation accounts for 3.5% of the global GDP (2.7 trillion US dollars) and has generated 65 million employments worldwide.

The sole fast global transportation network is provided by aviation, which boosts the economy, creates jobs, and facilitates global trade and tourism.

Global business is now made possible by aviation, which is also now acknowledged by the international community as a crucial facilitator for reaching the UN Sustainable Development Goals.

The aviation industry is expanding quickly and will do so in the future. According to the most recent projections, over the next 20 years, demand for air travel will rise by an average of 4.3% per year.

Demand for pilots, engineers, air traffic controllers, and other aviation-related employment is anticipated to increase significantly as the industry intends to sustain a nearly doubling of passenger and cargo numbers by 2036. Another certainty is that new technologies and methods will be required to maintain this growth [3].

1.2. Environmental aspects

The aviation industry is expanding quickly and will do so in the future. Recent years have seen a growth in air travel, which is a trend that will continue in the upcoming decades. The increased demand for energy by the general people has led to an increase in the number of aircraft. The aviation industry currently relies on propulsion systems that are driven by fossil fuels; gas turbine and internal combustion engine-powered systems are the most common in the sector. When operating, these engines release hazardous chemicals that have a negative effect on both the environment and human health. Demands for air travel, the cost of fossil fuels, and environmental concerns all continue to climb. Greater focus is required to protect the environment in light of issues like global warming, air pollution, and the depletion of fossil fuels. Many businesses, including the National Aeronautics and Space Administration (NASA), have started researching fossil fuel alternatives to address and alleviate these environmental challenges. Electric propulsion and hybrid-electric propulsion are the two main substitutes for fossil fuels. Electrical aircraft have extremely low levels of emissions and are very efficient. Although switching to electrical propulsion from fuel-based systems is favorable, the move is made more difficult by the existing battery energy densities. As a result, the chapter offers hybrid-electric propulsion as an option. A hybrid propulsion system combines battery- and fuel-powered propulsion. Reduced fuel consumption, fewer emissions, more power, and reduced airplane noise are benefits of hybrid electric propulsion. Small regional aircraft (with a capacity of up to 40 passengers) can encourage airlines to resume service at smaller airports, open up new markets, and improve connection and mobility for passengers. Hybrid-electric propulsion systems are the best technology to fulfill these needs [4].

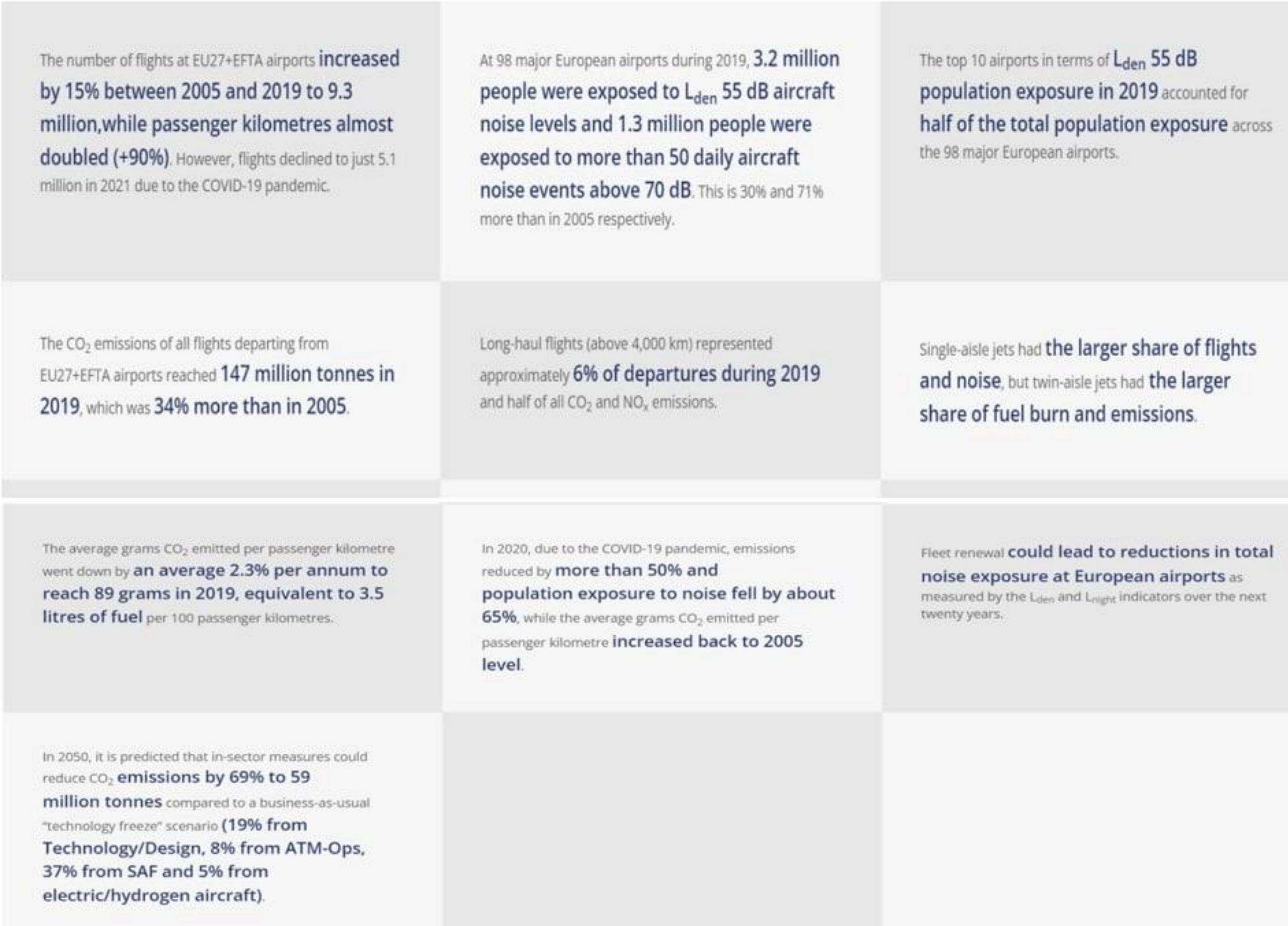

Fig. 1.1. Overview of the Aviation Sector [5]

These benefits make the employment of EMs particularly appealing where public approval is low, as is the case with tiny private and sports aircraft, which frequently operate from smaller airports in densely populated areas and frequently cause noise and chemical pollution problems. The current technological limitations of today's batteries, as well as the lack of customer confidence in this radically new technological application, limit the potential for electric motors to be used as the primary power source for novel light aircraft designs. The latter have low and unfavorable specific energy and power statistics, which translate into an extremely large weight and volume burden on the aircraft and frequently affect the range and endurance of solely electric designs. In this case, the hybrid-electric alternative appears to combine the benefits of ICEs and EMs, enabling efficiency gains and pollution reductions without sacrificing good flight performance. Due to the higher number of components, hybrid-electric propulsion enables operational flexibility. When compared to conventional sources, fuel and battery sources offer more options for controlling the propulsion system during different mission phases and use less energy. However, it suggests a rise in the amount of work that must be done at the design stage and a more complex operation. To meet environmental regulations and cut fuel consumption, proper management of electrical components and combustion is essential. But developing such a complicated system presents a significant challenge: how can it be tested safely in the high-altitude environments where it would need to function?

That same solution is provided by a NASA facility in Ohio, which is safely on the ground.

NASA's Electric Aircraft Testbed (NEAT) is situated at the organization's Neil A. Armstrong Test Facility in Sandusky, Ohio. It enables American technology developers from business, academia, and government to carry experimental aircraft power systems through their design, development, assembling, and testing phases.

“There are many technical challenges associated with building and testing hybrid-electric propulsion systems,” according to Bob Pearce, associate administrator for NASA’s Aeronautics Research Mission Directorate [6].

GE started its test campaign in 2019 and scaled it up by incorporating converters, generators, and motors in the megawatt class. The altitude integration testing, the last obstacle, started in 2021. Test technicians used two complete hybrid electric system sets to simulate the right and left engines of an aircraft in NEAT's huge altitude chamber at altitudes up to 45,000 feet.

“Together, we reached a historic testing milestone of a high power, high voltage hybrid electric integrated system operating at altitude conditions in NASA’s NEAT facility,” said Ali. “The successful completion of this testing has positioned us well for continued development of a megawatt-class hybrid-electric propulsion system” [6].

As part of the agency's Electrified Powertrain Flight Demonstration project, which aims to introduce electrified aircraft propulsion technologies to the U.S. commercial short-range and regional aviation markets over the next ten years, NASA and GE will now move on to flight testing after completing the ground testing phase.

The successful high-power, high-voltage test with GE is only a small part of NASA's larger efforts to develop a range of technologies in support of measures to combat climate change, and eventually, true electric propulsion flight testing.

To hasten the development of electrified aviation, EASA and CAA Norway signed an Innovation Partnership Agreement in June 2019. Norway is seen as an ideal proving ground for investments in electric aviation due to its extensive regional air transport network. EASA is also keeping a close eye on technological advancements related to the use of hydrogen in aviation. EASA is evaluating the potential for these implementations as well as any technical issues and safety hazards along with the industry [7].

The Electric and Hybrid Propulsion System (HEPS) pushes the limits of what is acceptable for an engine type certificate.

The engine architectures could be quite varied and the modular adaptability is very great.

HEPS systems may be so thoroughly integrated into the aircraft that it may even be impossible to define realistic product boundaries.

EASA's strategy in this situation is to provide the greatest amount of freedom possible to accommodate these novel ideas while yet adhering to the prevailing EU legislative framework.

1.3. Li-based batteries overview

As it is mentioned in the EASA EHPS.370 Electrical power generation, distribution, and wirings: «The electrical power generation, distribution, and wirings of the EHPS for any sub-system, as applicable, must be designed and installed to supply the power required for the operation of connected loads during all intended operating conditions» [8].

Power generation is first and foremost dependent on a battery as its source. The invention of the lithium (Li)-ion battery in the present allowed the personal electronics revolution to begin in 1991 and the first commercial electric vehicles to be produced in 2010. Li-ion batteries have most recently been included in the electrical grid to stabilize intermittent renewable generation, boosting the efficiency and efficacy of transmission and distribution. Decarbonization of heavy-duty vehicles, rail, maritime shipping, and aviation as well as the expansion of renewable electricity and grid storage are only a few of the significant applications that are still being developed. This viewpoint contrasts the objectives and demands for energy storage in 2010 with those that exist today and those that will emerge in the ensuing decades. The cost of lithium (Li)-ion battery packs in 2010 was approximately $1,100/kWh, which was too expensive to be competitive with internal combustion engines for vehicles or diesel generators and gas turbines for the grid. These batteries represent the state-of-the-art in electrochemical energy storage. Instead, the development of Li-ion batteries was prioritized to enable the expansion of personal devices, which only need relatively tiny storage capacity in lightweight shapes. The US Department of Energy (US DOE) launched Energy Innovation Hubs about this time to apply cutting-edge science and technology to the most urgent energy concerns facing the world. Since Li-ion batteries' commercialization in 1991, their energy density has increased by a factor of 3 at the cell level and their cost has fallen by a factor of 2 at the pack level, according to the Joint Center for Energy Storage Research (JCESR), which was established in 2012 [9].

Since approximately 20 years ago, Li-ion batteries have been available for purchase. Based on the existing battery chemistry, the technology is regarded as being relatively developed. Li-ion batteries are increasingly being utilized in electric cars in addition to being the primary power source for mobile electronic devices like laptop computers and cell phones. In order to store sustainable energy produced from renewable sources, lithium-ion batteries will also be taken into consideration in sustainable energy systems. Further development of current Li-ion batteries and the creation of next-generation Li-ion batteries, in particular, are required to meet the rising demand for energy storage while lowering the price of Li-ion batteries. The development of new battery chemistry to replace the current Li-ion battery technology is still incredibly difficult (Table 1.1.).

Table 1.1.

Theoretical development of batteries in the future

System	Theoretical Specific Energy	Expected in 2025
Li-Ion (2012)	390 Wh/kg	250 Wh/kg
Zn-air	1090 Wh/kg	400-500 Wh/kg
Li-S	2570 Wh/kg	500-1250 Wh/kg
Li-O2	3500 Wh/kg	800-1750 Wh/kg

It is desirable to find electrode combinations with high specific capacities and high operating cell voltages to boost the energy density of Li-ion batteries. In particular, with extremely desirable Si- and Sn-based anodes, there are numerous anode options that might significantly boost the specific capacities, as was previously discussed. Si nanoparticles preparation on a big scale and at a reasonable cost is still difficult. Due to pulverization, Sn-based anodes have a problem with low cycling performance. As a result, composites made of Si-Sn material may be one of the potential future anodes. Contrary to anode candidates, the low capacity of cathode candidates is what primarily restricts cell capacity. LiCoO2's current cathode material is pricy and extremely poisonous. The capacity of the widely used LiFePO4 is low. The Argonne National Laboratory's easily made Ni-Co-Mn-based cathodes are very appealing, especially from an industrial standpoint. The specific capability is still regarded as moderate because Co and Ni are both pricy and hazardous. From an environmental standpoint, future cathode materials should attempt to avoid using Co, Ni, or other harmful metals. The ideal cathode should also be able to insert/extract numerous electrons per 3D metal in a reversible manner. Future low-cost cathode materials might be based on Mn and/or Fe. It is important to find innovative solutions to the problem of intrinsically low conductivity, most likely using nanotechnology and nanocomposites. With the currently being explored recognized cathode options, there isn't much room to raise functioning cell voltages. The potential of composite cathodes made of two or three 3D metals and polyanions is enormous. Within the next ten years, new cathode chemistry might be created. It's possible that the new cathode chemistry will also call for new electrolytes.

Another issue that requires due attention is one safety. The significance of battery safety has been brought home by recent reports of Li-ion battery fires involving Tesla Model S vehicles and Boeing 787 passenger aircraft. Automakers need to make major investments in battery management systems to improve the safety of the large battery packs in vehicles if they want to assure the widespread adoption of electric vehicles and develop the market for Li-ion battery-powered vehicles. As an alternative, nonflammable Li-ion batteries should be created, including those with an all-solid-state electrolyte or an aqueous electrolyte. The most likely scenario is that high voltage (5 V) cathodes and large capacity anodes will be used in next-generation Li-ion batteries (such as Si- or Sn-based). Therefore, further study is needed to better understand the stability and interactions of certain electrode materials with the electrolyte. Instead of relentlessly pursuing high energy density, more focus should be placed on battery safety. The use of standardized battery safety testing methods should be encouraged [10].

However, major corporations like Airbus have already included Li-ion batteries in their future plans.

The EcoPulse demonstrator aircraft will be powered by a revolutionary high-voltage lithium-ion battery technology, which Airbus has begun testing [11].

The battery, which has been in development for some years, can produce 350 kilowatts and 800 volts DC, which is sufficient to power the six electric motors on the EcoPulse, whose airframe is being put together by Daher. Compared to the power output of batteries now used on aircraft, this constitutes a quantum leap.

According to Julien Laurent, the battery project manager at Airbus, the new battery, which weighs 770 pounds (350 kilograms), has a number of special features. He pointed out that the unit, which was created in-house, has thousands of lithium-ion batteries with safety features that prevent thermal runaway. "Another innovative part is the active cooling system, which ensures the optimum temperature for normal operations," he said, adding that the battery includes a management system. "This helps to minimize maintenance thanks to its built-in test features and ability to highlight the charge status or whether the cells need to be rebalanced" [12].

1.4. Future perspectives

The proposed aircraft can be constructed based on future battery technology since hybrid aircraft are still in the research stage on the market. Ten years from now, E with 1500 Wh/kg is a reasonable expectation based on the preceding data. The various propulsion system efficiencies are shown in the diagram below. The efficiency of a battery-powered propulsion system is higher than that of a traditional turboprop, turbofan, or fuel cell (Figure 1.2.). It is plausible to assume that the total will be 90% ten years from now assuming battery efficiency rises from 73% to 90%.

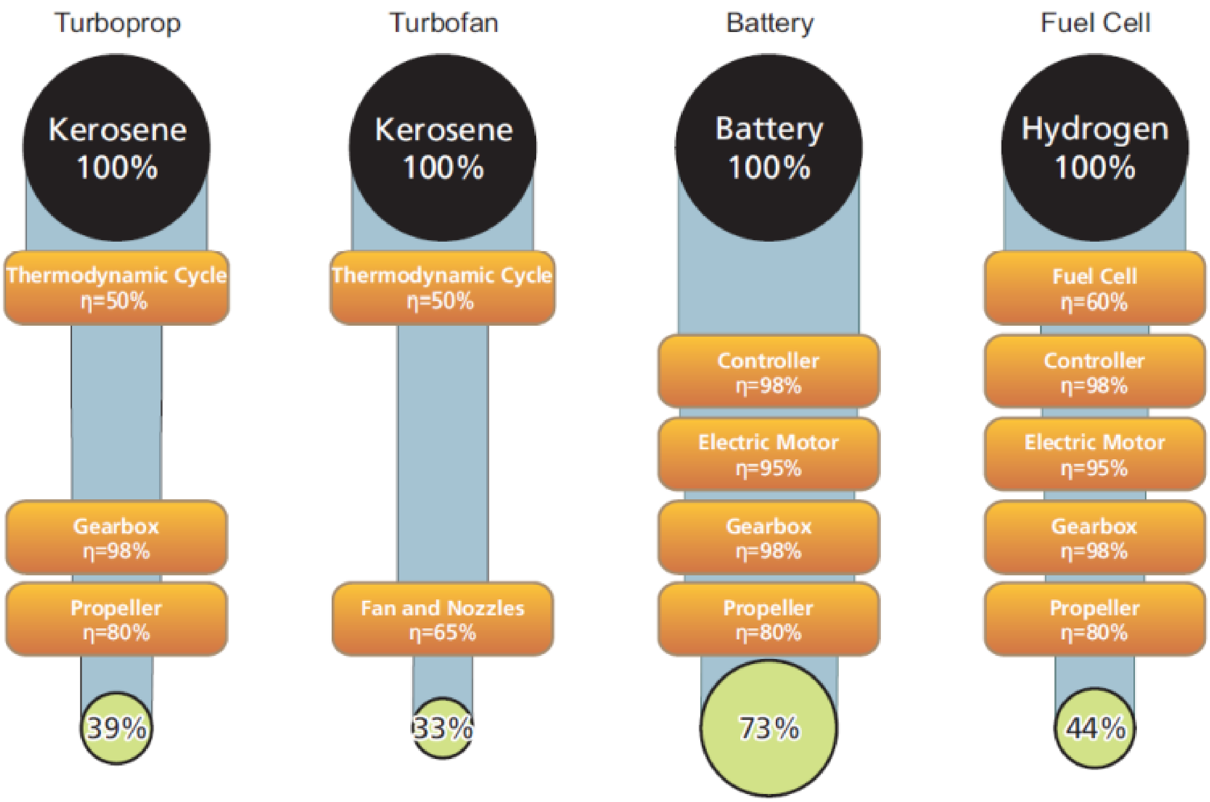

Fig. 1.2. Different propulsion system efficiencies [13]

The cost-effectiveness of this new technology will determine how widely it is used. The cost of new components such as batteries, power plants, chargers, and electricity will affect the switch to hybrid-electric aircraft. The airplane owner makes money if the lower fuel usage covers its cost. This would allow for the proliferation of such an aircraft along with a lessened impact on the environment. The examination of production costs for a fleet of hybrid-electric aircraft is the focus of this thesis. This estimates the prospective demand for the desired aircraft based on a thorough market analysis. Adaptability in configuration and operation is one of the main advantages of hybrid electric aircraft [14]. For instance, electric propulsion can be utilized constantly during flight or just during certain parts of the flight plan where a higher power requirement exists. In order to fully optimize system performance, it is also possible to incorporate suitable energy storage devices in addition to gas turbine-driven generators. Therefore, hybrid-electric propulsion systems have the ability to cut fuel consumption in the aviation industry in opposition to the always-rising energy demand and fuel price. Utilizing the available electric energy during the cruise, which is often the longest flight phase, is projected to result in the highest reduction in fuel consumption. With a greater design range, block fuel reduction potential decreases. During takeoff, just a small percentage of the block fuel is burnt. Therefore, using the electric motor during takeoff should have a minimal influence on fuel consumption. However, using an electric motor would significantly improve the performance of a gas turbine and lengthen the lifespan of the combustion engine. Electric propulsion is also appealing because of electric taxiing and its potential advantages.

Higher energy, energy density, and power will be possible with new battery chemistries and technological advancements, but they may also introduce new failure characteristics that will need to be understood when used in future designs.

Similar to how kerosene-based safety measures are typically utilized in modern aircraft, other energy sources such as alternative fuels (hydrogen, methane, or other hydrocarbons) have differing storage and flammability characteristics.

The Fire Safety Team of the Airport and Aircraft Research and Development Division conducted tests at the William J. Hughes Technical Center to investigate the potential fire safety risks that cylindrical lithium-ion and lithium-ion polymer batteries may present aboard aircraft. Individual battery cells provided by the manufacturer were tested to see how they would respond in a fire. The efficiency of a conventional hand-held extinguisher on a fire involving the battery cells was also tested, as were the possible fire hazards that the battery cells themselves may present. All of the battery cells that were examined were readily available, commercial goods that manufacturers are considering for use in connection with airplane power. Lithium batteries are being used more frequently these days in airplane applications. The studies' findings demonstrated that battery cells of both the cylindrical and polymer types can react aggressively when exposed to an outside fire. The electrolyte would spray out strongly from the cylindrical cells' vents and ignite, which would cause a surge in temperature and pressure. The polymer battery cells lacked venting points. As an alternative, they had a seam along the cell's edge that might open, exposing the flammable electrolyte. The existing fire was substantially exacerbated by the failure of the polymer-type battery cells since the whole amount of electrolyte was instantly exposed to the fire source. The lithium polymer battery cells, which undergo a distinct chemical reaction and have a substantially higher energy density and power capacity than cylindrical cell types, produced noticeably higher temperatures and pressure increases in both single-cell and multi-cell testing. All three types of battery fires could be put out by using a hand-held Halon 1211 fire extinguisher, according to tests. However, the halon extinguishing agent was unable to stop the polymer battery cells from re-igniting despite numerous tries. Lithium battery cell experiments shed a lot of light on the possible risks that these new battery technologies can present. Using the findings, it will be possible to decide what specifications and safety measures should be put in place for the battery packaging system that holds these cells. Suitable vent location and sizing, overcharge and thermal protection circuits, and barriers between cells to stop thermal propagation from one cell to the next cells are a few examples of these safety measures. The next phase will be to put prototype airplane lithium batteries through testing [15].

It can be challenging to locate and fix the damage in an aircraft’s electrical wiring interconnection system (EWIS). The EWIS on much older aircraft that are still in service was frequently built on the "fit and forget" tenet, however aging itself as well as unintentional collateral damage from unrelated maintenance or routine inspections result in airworthiness issues. The difficult-to-detect condition of wiring within the bundles of wires routed together as in "looms" is frequently linked to both degradation and damage. The condition of the outside wires can only be thoroughly examined on these looms and aviation wiring in general since they are frequently in hard-to-reach places. Therefore, much work has gone into creating more practical techniques for verifying wiring circuit integrity generally as well as more efficient inspection processes for wiring loom integrity in particular. Additionally, wiring looms, which in the past were frequently susceptible to damage that went unnoticed and unintentionally occurred during base maintenance, have received attention regarding effective maintenance practices.

The hope of longer-term advancement lies in new technology, notwithstanding the progressive mandates for improved inspection and diagnostic processes for EWIS in aged airplanes. It is now feasible to test an aircraft's EWIS live while it is in flight, which can find intermittent issues that are difficult to find during ground maintenance. Technology for arc fault circuit interrupters is being developed to offer extra safety precautions in the event of a malfunction. Future "smart" wire networks will incorporate nanoscale sensors to instantly identify and fix errors. Fiber optics and wireless technology will eventually lessen the requirement for large wiring looms. Fleets are forced to make careful use of the variety of diagnostic technologies that are already on the market while these and other methods are being developed and tested [16].

Conclusion to part 1

In order to better integrate the system with the aircraft, there must be considerable changes made to staff training, operation, and maintenance as a result of the introduction of new technologies such as electrification, particularly when combined with more autonomy and digitalization.

This chapter explains the aviation industry and the demand for hybrid aircraft. Since it is difficult to totally replace fossil fuels with electricity, hybrid design aids in employing a mix of both gasoline and electricity. This suggested layout is mostly for hybrid regional transit. The use of various battery kinds was demonstrated, along with its advantages and disadvantages.

In particular, the propulsion system's complexity is rising and is expected to be the subject of more research in the near future because of how it interacts with the aircraft.

Hybrid-electric aircraft is not an exception, as such technologies open a new chapter in modern aviation, which has undergone a protracted process of research and certification.

PART 2. PRELIMINARY DESIGN OF HYBRID-ELECTRIC PROPULSION SYSTEM

2.1. Initial data

A two-spar high caisson wing with a large span and secured by contoured struts distinguishes the prototype from earlier research on the subject. The wing consists of two trapezoidal consoles and a rectangular center section. Fuel tanks are the caissons and consoles in the center portion. Ailerons, slats, spoilers, and flaps are all automated and controllable on the wing. The flaps have main links and deflectors and are double-slotted. Two parts are attached to the central section, while two more are mounted on consoles. The leading edge of the consoles has slats inserted. The wing console's upper surface is where the spoilers are placed. The left aileron has a trim tab, and ailerons are mounted on the wing consoles. During takeoff and landing modes, ailerons are automatically deflected at an angle corresponding to the angle of the flaps. With this wing configuration, the aircraft can cruise steadily at low speeds and high angles of attack in addition to steep takeoff and landing trajectories.

The mean aerodynamic chord is determined using a geometrical method (Figure 2.1.). Mean aerodynamic chord:

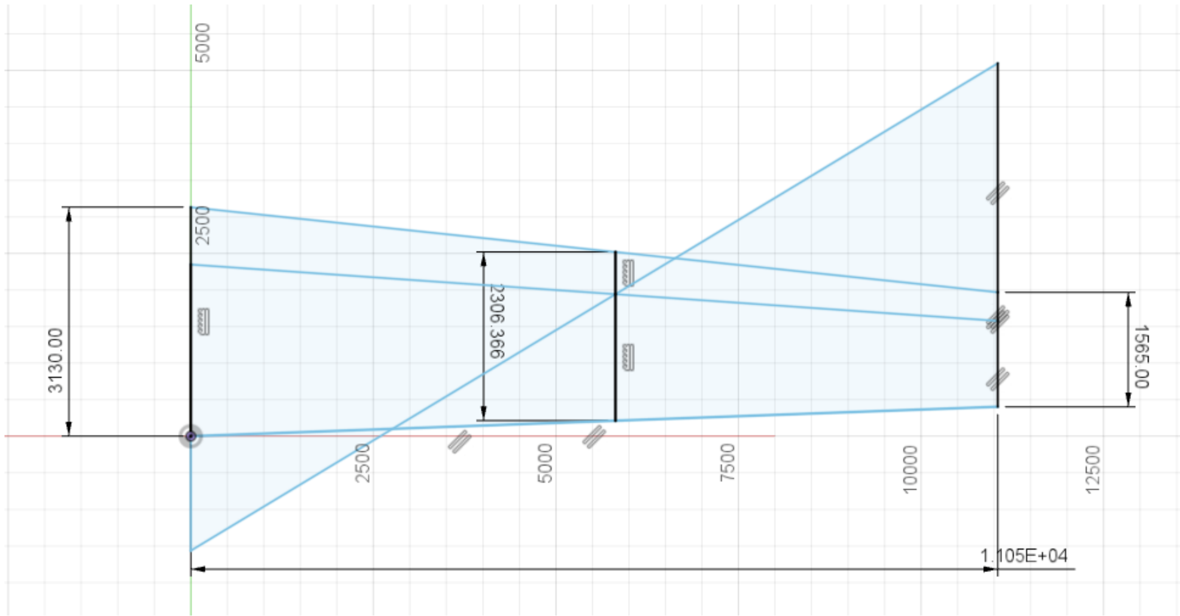

Fig. 2.1. Determination of mean aerodynamic chord

The construction of the equipped wing, the mass of the installed equipment, and the mass of the fuel all contribute to its mass. The main landing gear and the front gear are included in the mass register of the equipped wing, regardless of where they are mounted (on the wing or to the fuselage). The names of the items, their actual masses, and their center of gravity locations are all included in the mass register. The projection of the nose point of the mean aerodynamic chord (MAC) for the surface XOY determines the origin of the supplied coordinates for the mass centers. The terminal portion of the airplane accepts the positive interpretations of the mass center coordinates.

While Table 2.1. shows the centers of gravity for the equipped wing, Table 2.2 shows the centers of gravity for the equipped fuselage. The following formula (2.1) provides the coordinates of the center of power for the equipped wing:

$$X_w^{/} = \frac{\Sigma m_i^{/} x_i^{/}}{\Sigma m_i^{/}} \tag{2.1}$$

Table 2.1.

Trim sheet of equipped wing

N	Name	Mass		C.G. coordinates x_i (m)	Moment $m_i x_i$ (kgm)
		Units	total mass m_i (kg)		
1	Wing (structure)	0,19368	2281,9	1	2262,7
2	Fuel system, 40%	0,0027	31,8	1	31,5
3	Control system, 30%	0,0045	53,0	1,4	73,4
4	Electrical equip. 10%	0,00299	35,2	0,2	8,1
5	Anti-icing system 50%	0,0122	143,7	0,2	33,1
6	Hydraulic system, 70%	0,02401	282,9	1,4	391,4
7	Power units	0,08758	1031,9	0,7	696,5
8	Equipped wing without fuel and LG	0,32766	3860,5	0,7	2800,3
9	Fuel	0,09445	1112,8	1	1103,4
	Equipped wing	0,42211	4973,3	0,8	3903,7

The projection of the fuselage's nose on the horizontal axis is chosen as the coordinate system's origin. The fuselage's construction is provided for axis X.

Table 2.2.

Trim sheet of equipped fuselage

№	Objects	Mass		Coordinates of C.G.	Moment (kgm)
		Units	Total (kg)		
1	Fuselage	0,10526	1240,2	7,8	9710,6
2	Horizontal TU	0,0278	327,5	14,2	4683,8
3	Vertical tail unit	0,02624	309,2	14,2	4420,9
Equipment					
4	Anti-icing system, 50%	0,0122	143,7	5,8	833,7
5	Control syst 70%	0,0105	123,7	7,8	2482,5
6	Hydraulic sys30%	0,01029	121,2	11	1328,9
7	Electrical eq, 90%	0,02691	317,1	7,8	968,7
8	Radar	0,0048	56,6	0,6	33,9
9	Air-navig. system	0,0072	84,8	0,7	67,9
10	Radio equipment	0,0036	42,4	1	46,7
11	Instrument panel	0,0084	99,0	1,2	120,7
Passenger aircraft					
Passenger eq+ Non typical eq+ Additional equipment+ Service equipment					
12	Seats of pass. economical class	0,016	188,5	4,5	843,6
13	Seats of crew	0,00047	5,5	1,7	9,3
14	Seats of flight attendance	0,00037	4,4	10,6	46,3
Furnishing (Lavatory, Galley/buffet)					
15	Lavatory	0,00185	21,8	10,6	229,9
16	Galley	0,00185	21,8	2,5	54,5
	Equipped fuselage without payload	0,34549	4070,6	7,7	31245,6
Payload					
17	Mail/*Cargo*	0,0294	346,4	12	4156,7
18	*Crew*	0,020371	240,0	2,1	504,1
19	Baggage	0,0514825	606,6	11,8	7157,5
20	Meals	0,00377	44,4	2,5	111,1
21	Passengers	0,1273765	1500,7	6,8	10205,1
	Total	0,57789	6808,7	7,8	53379,9

The list of mass objects used in the center of gravity calculation builds on the foundation of the two prior tables (Table 2.3. and Table 2.4.) [17].

Table 2.3.

Calculation of C.G. positioning variants

Name	Mass, kg	Coordinates	Moment
Object	m_i	C.G. m	Kgm
Equiped wing without fuel and L.G.	3860,5	0,7	2800,3
Nose landing gear	132,3	0,8	103,6
Main landing gear	396,9	7,1	2818,2
Fuel	1112,8	1	1103,4
Equiped fuselage	4070,6	7,7	31245,6

Table 2.4.

Airplanes C.G. position variants

№	Variants of the loading	Mass, kg	Moment of the mass, кg*m	Centre of the mass, m	Centering, %
1	Take-off mass	11782,0	99193,9	8,4	38,6
2	Landing variant	11630,4	93869,6	8,1	23,5
3	Transportation variant (without payload)	9283,9	74741,3	8,1	22,7
4	Parking variant (without fuel and payload)	8460,3	67320,9	8	18,6

2.2. Center of gravity for the updated configuration

After the evaluation of the hybrid prototype's centers of gravity for the fuselage and wing, the results are shown in Table 2.5 – Table 2.8.

Table 2.5.

Determination of the prototypes CG for wing

N	Name	Mass		C.G. coordinates x_i (m)	Moment $m_i x_i$ (kgm)
		Units	total mass m_i (kg)		
1	Wing (structure)	0,19368	2281,9	1	2262,7
2	Fuel system, 40%	0,0027	31,8	1	31,5
3	Control system, 30%	0,0045	53,0	1,4	73,4
4	Electrical equip. 10%	0,00299	35,2	0,2	8,1
5	Anti-icing system 50%	0,0122	143,7	0,2	33,1
6	Hydraulic system, 70%	0,02401	282,9	1,4	391,4
7	Engines (-fuel system) +Including HEPS	0,115	1354,9	0,6	812,9
8	Equipped wing without fuel and LG	0,35508	4183,6	0,8	3613,3
9	Fuel	0,0669	788,2	1	781,6
	Equipped wing	0,42198	4971,8	0,9	4394,8

Table 2.6.

Determination of the prototypes CG for fuselage

№	Objects	Mass		Coordinates of C.G.	Moment (kgm)
		Units	Total (kg)		
1	Fuselage	0,10526	1240,2	7,8	9685,8
2	Horizontal TU	0,0278	327,5	14,2	4651,1
3	Vertical tail unit	0,02624	309,2	14,2	4390,1
Equipment					
4	Anti-icing system, 50%	0,0122	143,7	5,7	819,3
5	Control syst 70%	0,0105	123,7	7,8	966,2
6	Hydraulic sys30%	0,01029	121,2	11	1328,9
7	Electrical eq, 90%	0,02691	317,1	7,8	2476,2
8	Radar	0,0048	56,6	0,6	32,8
9	Air-navig. system	0,0072	84,8	0,7	59,4
10	Radio equipment	0,0036	42,4	1	42,4
11	Instrument panel	0,0084	99,0	1,2	118,8
Passenger aircraft					
Passenger eq+ Non typical eq+ Additional equipment+ Service equipment					
12	Seats of pass. economical class	0,016	188,5	4,4	829,3
13	Seats of crew	0,00047	5,5	1,7	9,3
14	Seats of flight attendance	0,00037	4,4	10,6	46,2
Furnishing (Lavatory, Galley/buffet)					
15	Lavatory	0,00185	21,8	10,5	228,9
16	Galley	0,00185	21,8	2,5	52,3
	Equipped fuselage without payload	0,408382	4811,6	7,3	35118,5
Payload					
17	*Crew*	0,020371	240,0	2,1	499,2
18	Baggage	0,0181205	213,5	11,7	2497,9
19	Meals	0,00377	44,4	2,5	111,0
20	Passengers	0,1273765	1500,7	6,8	10175,1
	Total	0,57802	6810,2	7,1	48401,8

Table 2.7.

Prototype calculation of C.G. positioning variants

Name	Mass, kg	Coordinates	Moment
Object	m_i	C.G. m	Kgm
Equiped wing without fuel and L.G.	4183,5	0,8	3613,3
Nose landing gear	132,3	0,8	103,6
Main landing gear	396,9	7,1	2818.2
Fuel	788,2	0,8	781,6
Equiped fuselage	4811,6	7,3	35118,5

Table 2.8.

Airplanes C.G. position variants

№	Variants of the loading	Mass, kg	Moment of the mass, кg*m	Centre of the mass, m	Centering, %
1	Take-off mass	11782,0	91398,4	7,7	28,1
2	Landing variant	11954,9	89467,8	7,5	16,3
3	Transportation variant (without payload)	10023,3	75803,9	7,6	19,7
4	Parking variant (without fuel and payload)	9524,4	71770,3	7,5	18,6

The wing CG with HEPS values is displayed, and the fuel consumption is 324 kg lower than in the conventional configuration. The HEPS mass is split between the wing and the fuselage, and it is combined with the engine in the wing case. In the case of the fuselage CG, the mass of the HEPS system was taken into account as an additional category and all the additional equipment from the prototype's first CG calculation was used for the HEPS system. To maintain the same MTOW as before, the prototype was also devoid of all mail and cargo weight (11782kg). Although it would appear like a disadvantage, the weight of the passengers' luggage stayed the same in this configuration.

The CG positioning on the prototype is shown in Figure 2.4. and Figure 2.5.

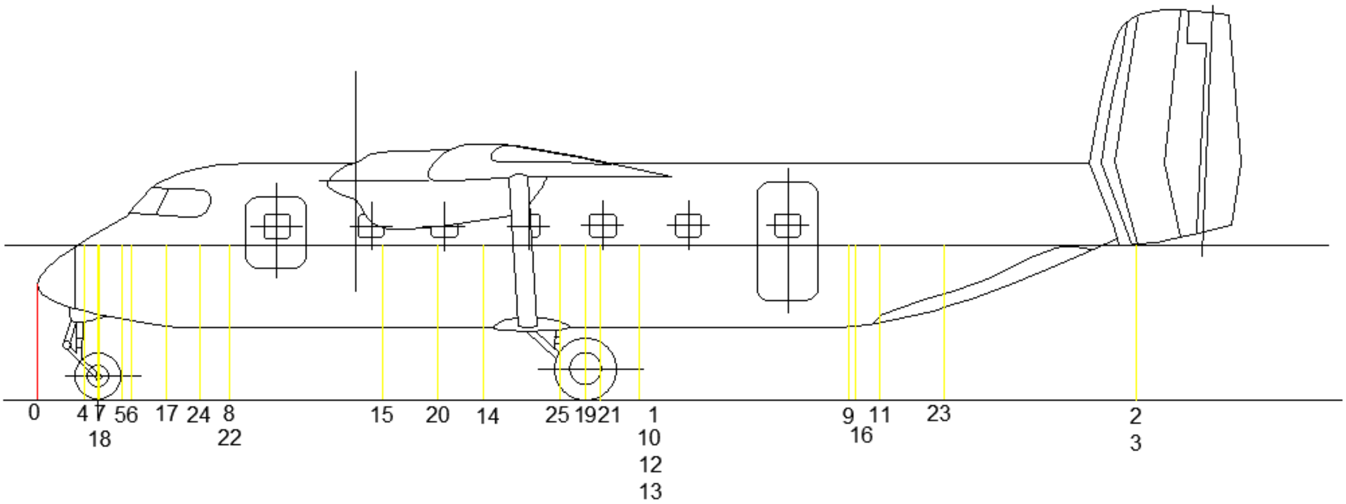

Fig. 2.4. Fuselage CG positioning

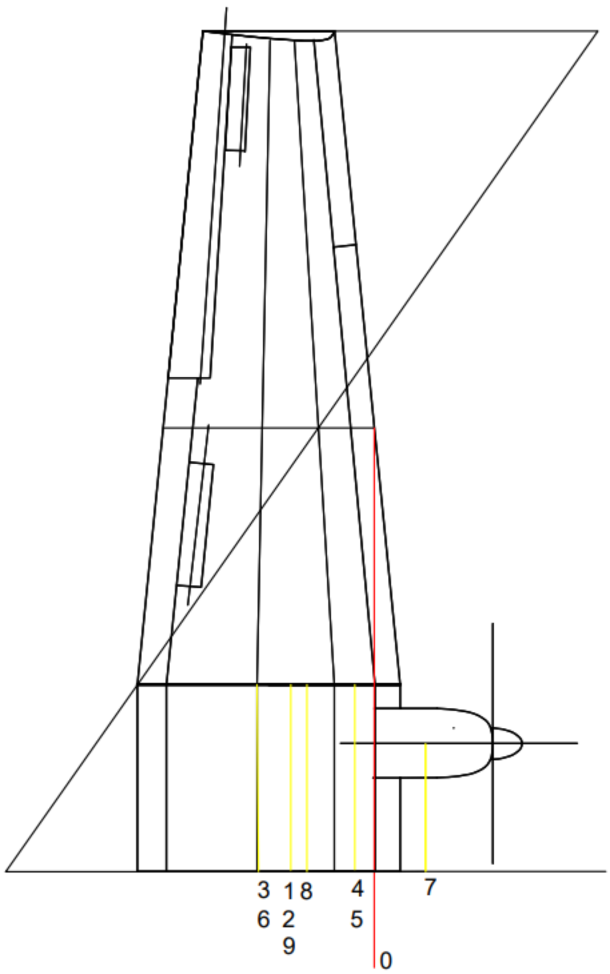

Fig. 2.5. Wing CG positioning

Conclusion to part 2

The original data for the prototype was included, along with the mean chord scheme and a description of the aircraft.

The standard prototype arrangement and the HEPS configuration's centers of gravity (CG) were compared.

By substituting various goods like mail and freight with HEPS mass spread between the wing and fuselage, the amount of fuel was lowered by 324 kg. The prototype itself was developed as a regional passenger aircraft, therefore the passenger items, such as personal baggage, were preserved. Nevertheless, this feature may turn out to be a disadvantage of such a system.

PART 3. AIRCRAFT DESIGN AS AN OBJECT FOR RESEARCH RESULTS IMPLEMENTATION

3.1. Breguet range equation analysis

The Breguet range equation was presented and calculated (3.1), as it was discussed in the initial attempt to applying the HEPS to the prototype [17], and the following result was obtained:

$$R_{hybrid} = \frac{\eta_{prop}}{g \cdot \left(C_P \cdot \frac{H_{fuel}}{g} \cdot (1-S) + \frac{S}{\eta_{elec}}\right)} \frac{C_L}{C_D} \frac{H_{bat} \cdot H_{fuel}}{(\psi \cdot H_{fuel} + (1-\psi) \cdot H_{bat})} \cdot \\ \cdot \ln\left(\frac{\frac{(\psi \cdot H_{fuel} + (1-\psi) \cdot H_{bat})}{H_{bat} \cdot H_{fuel}} \cdot g \cdot E_{start} + W_{empty} + W_{payload}}{W_{empty} + W_{payload}}\right) = 910.4\ (km). \quad (3.1)$$

Depending on the qualities of the gasoline and batteries, the range value may vary. The relationship between the mass of the battery and the mass of the fuel is one of these parameters that alters the formula's result (Appendix A). Specifically, Figure 3.1. depicted the proportion of the system's mass that is accounted for by conventional fuel and/or batteries and how that affects range.

mbat, kg	mfuel, kg	range, km	mbat/mfuel, %	mfuel/mbat, %
2152	0	78	100	0
1500	650	764.585	69.70260223	30.20446097
1450	700	817.415	67.37918216	32.52788104
1400	752	872.359	65.05576208	34.94423792
1364	788	910.394	63.38289963	36.61710037
1300	852	978.01	60.40892193	39.59107807
1250	902	1030.836	58.08550186	41.91449814
1150	1002	1172.895	53.43866171	46.56133829
0	1113	1270	0	100

Fig. 3.1. Initial data of the fuel and battery mass and their percentage (fraction) in the system.

For convenience, the graph was created to show the straight relationship between the battery fraction and the possible range of the prototype (Figure 3.2.):

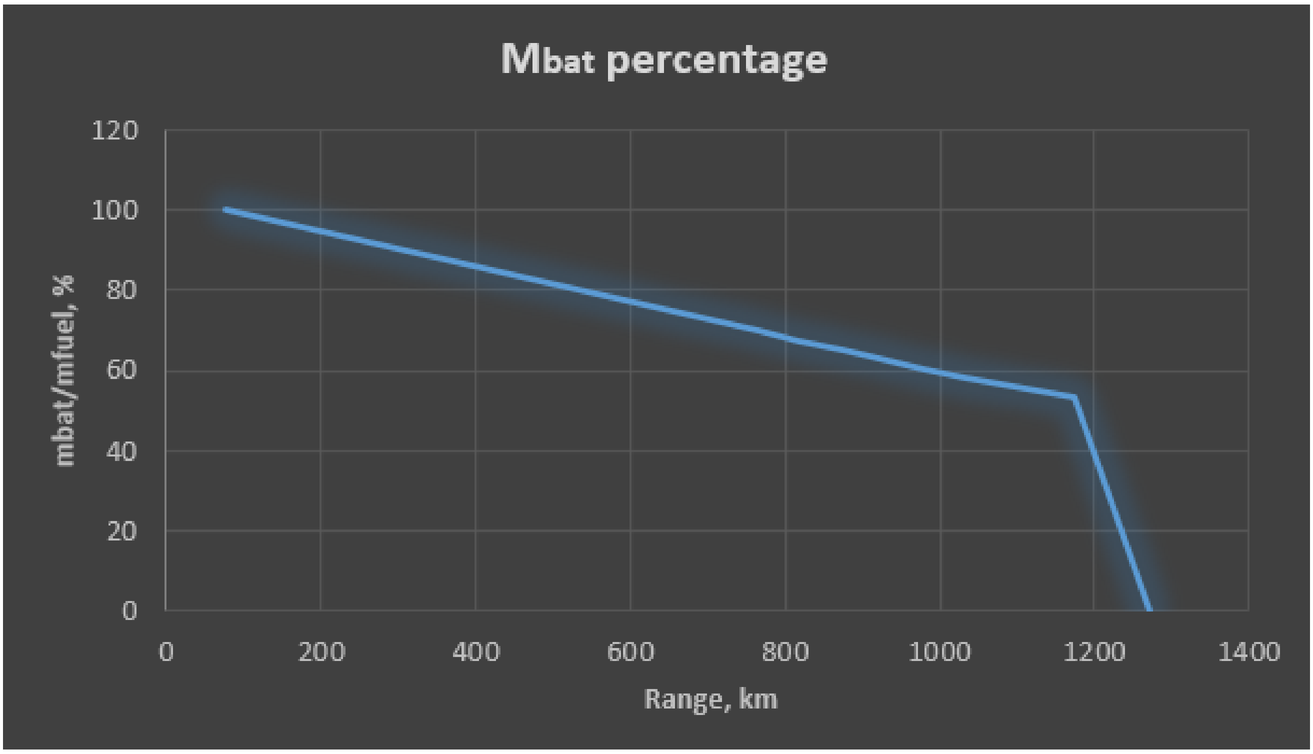

Fig. 3.2. Relationship between the battery fraction and range.

Accordingly, the relation between the fuel fraction and range will be the inversely proportional (Figure 3.3).

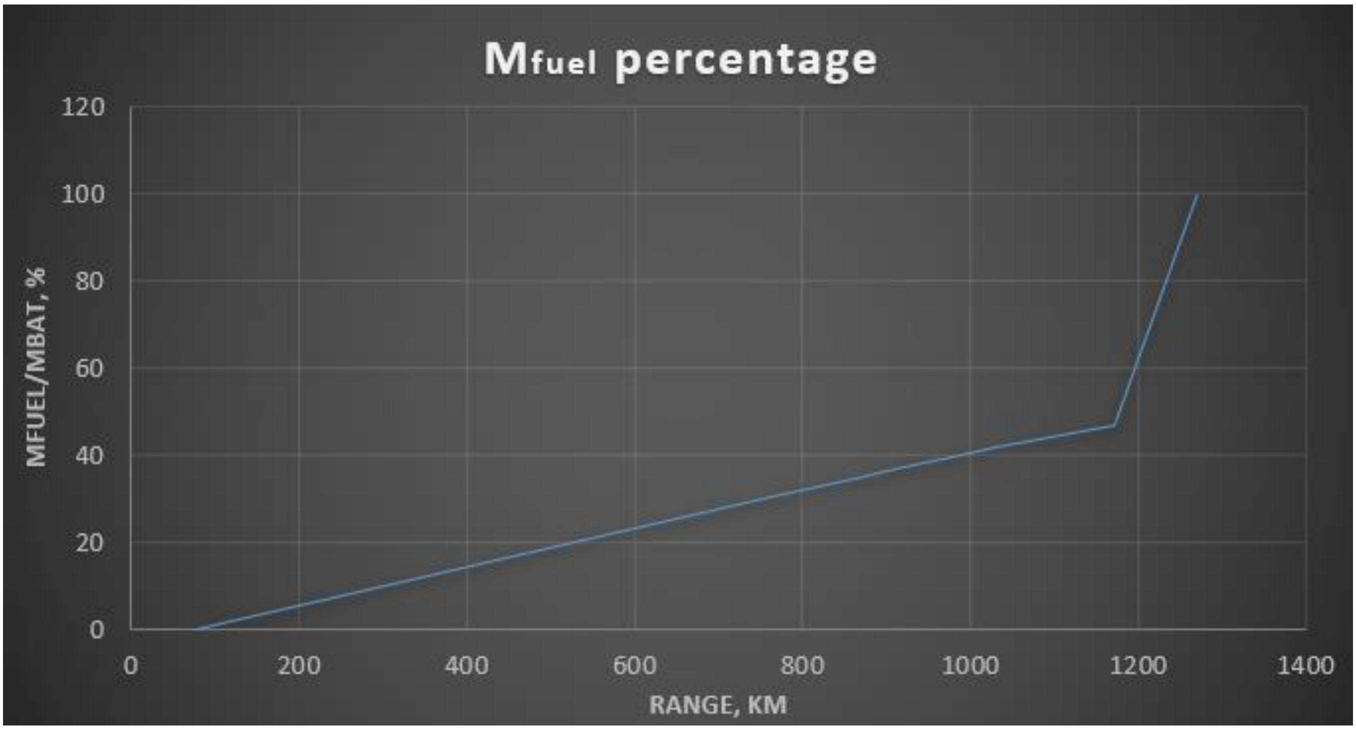

Fig. 3.3. Relationship between the fuel fraction and range.

The range is shown to increase with the amount of fuel present in the system, which explains considering the power of burned fuel. However, the goal of this effort is to integrate HEPS into the prototype and identify the mass value that won't overload the aircraft and will be sufficient to produce the required amount of thrust. According to the study discussed above, battery implementation should continue in the middle ranges (58–67%) until high-power batteries become accessible. In this approach, the environmental benefits of this implementation will result from the fuel consumption being decreased by 33-41%, or roughly 324kg based on the value selected for the prototype.

3.2. Quality Function Deployment (QFD) and the House of Quality (HOQ)

One of the matrices of an iterative process known as Quality Function Deployment is the House of Quality (HOQ) (QFD). It serves as the engine that powers the entire QFD procedure. The most well-known and extensively utilized tool for new product design is the House of Quality Matrix [18].

A procedure and collection of tools called Quality Function Deployment (QFD) are used to precisely define customer needs and translate them into engineering specifications and production schedules for the goods that meet those requirements. In order to drive design targets from the assembly level down through the sub-assembly, component, and production process levels, QFD is utilized to translate customer needs (or VOC) into quantifiable design targets. A defined set of matrices is provided by QFD approach and is used to aid this process.

While working for Mitsubishi's shipyard in the late 1960s, Yoji Akao created QFD for the first time in Japan. Later, other businesses embraced it, including Toyota and its supply chain. The major three automakers and a few electronics manufacturers were primarily responsible for the introduction of QFD in the United States in the beginning of the 1980s. The US was initially very reluctant to accept and increase the usage of QFD, but it has subsequently gained popularity and is now being utilized in manufacturing, healthcare, and service companies [19].

3.2.1. Design flow for House of Quality:

1) Customer attributes portion of matrix (Horizontal),
2) Engineering Characteristics matrix (Vertical),
3) Customer Competitive Evaluation
4) Relationship matrix Between (Central portion),
5) Co-relationship matrix (Triangular shaped Roof)
6) Competitive Technical Analysis
7) Absolute importance, Relative Importance &Target.

3.2.2. Customer Attributes

The client is the foundation of the house of quality, and their needs are referred to as customer attributes (CAs). Through each stage of the product development and production process, or the product realization cycle, customers utilize to characterize products and product qualities. CAs are frequently categorized into collections of characteristics that constitute a broad customer concern. Typically, CAs are rewritten using the clients' own terminology. These criteria are a compilation of all client needs, including happy customers, delighted customers, and unhappy customers. The needs of retailers ("easy to display"), regulators ("safe in a side collision"), vendors ("satisfy assembly and service organizations"), and so on are examples of CAs.

3.2.3. Customer Importance Ratings

The relationship matrix will later use this number. The House of Quality gauges each CA's proportional relevance to the consumer. Weightings are determined by surveys, statistical methods, revealed preference approaches, or direct experience with clients. In the home, weightings are visible next to each CA. The list is then prioritized by giving each demand a degree of relevance score, which is a numerical value. The expected level value is divided by the existing level rating to get the improvement ratio. The next stage is to assess the weight of the customer's needs. It is determined by multiplying the improvement ratio value by the degree of importance value.

3.2.4. Engineering Characteristics

The engineering characteristics are characteristics of the good or service that can be assessed and compared to the alternatives. It sometimes goes by the name "Technical" qualities. Engineering features specify how to alter the product. The engineering characteristics (ECs) that are likely to have an impact on one or more of the customer qualities are listed by the design team along the top of the house of quality. A common engineering characteristic may be redundant to the EC list on the house or the team may have overlooked a customer attribute if it has no effect on the CA. On the other hand, a CA that is unaffected by any EC offers chances to increase a product's physical qualities. The direction of movement for each of the engineering features must be determined when they are defined. EC should quantify the product and have a noticeable impact on consumer views.

3.2.5. Customer Competitive Evaluation

The most crucial component of the House of Quality diagram, which examines the competitive analysis of a specific organization and its rivals, is the planning matrix. This analysis displays customer opinions and satisfaction for a specific customer attribute for various rivals. The planning matrix analyzes how each organization is rated using a scale of 0 to 5. The poorest rating in this situation is 0, and the greatest rating is 5. Businesses that want to compete with or outperform their rivals must first understand how they stack up against them. So, the customer reviews of rival products that are comparable to "our own" are listed on the right side of the house, across from the CAs. It points up the areas that need work. It will be recognizable as a "perceptual map" to marketing experts. To determine the strategic positioning of a product or product line, perceptual maps based on bundles of CAs are frequently utilized. The strategic goal of a firm and the product concept are naturally connected by this area of the house of quality.

3.2.6. Relationship Matrix

The relationship between engineering characteristics (ECs) and customer attributes (CAs) is established in the relationship matrix. Relationships have a numerical value and can be categorized as weak, moderate, or strong. There ought to be some connection between a specific EC and each CA.

Those connections are represented by symbols like;

Θ – Strong relationship

O - Moderate relationship

Δ – Weak relationship.

The outcome of the numeric values for Δ is 1, O is 3 and Θ is 9. Further calculations will make use of the numerical value. The inter-functional team now completes the "Relationship Matrix," which serves as the structure of the building. The evaluations are based on expert technical expertise, consumer feedback, and data from statistical analyses or carefully supervised trials.

3.2.7. Correlation Matrix

Engineers are assisted in specifying the different engineering characteristics that need to be upgraded indirectly by the distinctive roof matrix of the house of quality. Engineering ingenuity is facilitated by roof matrices. The design engineers will benefit greatly from this matrix at the next stage of a project. It must be determined whether enhancing one engineering characteristic will result in the improvement or deterioration of another engineering characteristic.

Symbols such as the following are used to illustrate these relationships:

+ – Positive relationship,

- – Negative relationship.

++ - Strong Positive,

▼ - Strong negative

3.2.8. Competitive Technical Analysis

The engineering traits of each rival are compared in order to gain a better understanding of the competition. Reverse engineering is involved in this procedure. The graphical representation utilizing the color codes assigned to each competitor shows it more clearly. It shows the company's leading or behind position and provides guidance on how to improve engineering traits.

3.2.9. Absolute Importance, Relative Importance & Target Values

Target values are now starting to be established for each engineering characteristic, serving as a baseline for comparison. It adds additional objective measurements below the applicable ECs at the bottom of the house. Specifically, the best new measurements for each EC in a rebuilt product. The easiest strategy to improve is to first identify the EC and then run tests to measure benchmark value. The absolute importance (absolute weights and relative weights) of each engineering attribute is then determined. The cell value and the customer importance rating were combined to get this numerical calculation. It is important to remember that while creating goals, customer satisfaction values should take precedence over tolerances. Therefore, it makes clear which engineering feature of the specified product is most important to potential customers.

3.3. Analysis for House of Quality

3.3.1. Analysis for Customer Competitive Evaluation

It is first necessary to determine the relative weight for each client attribute using the following formula: Relative weight is equal to (weight of importance of a certain CA/total weight of importance) multiplied by 100. Following that, client attributes are prioritized according to relative weights. The CA with the highest score is ranked first and will be put in the top spot, while the CA with the lowest score will be in the bottom spot. The weight of importance for the company must now be established for the planning matrix while taking into account all of the competitors. Next, relative weights for each company are determined by using the following formula: calculated relative weights for each competitor's customer attribute. The findings of the customer competitive evaluation are shown in a graph using the appropriate scale. As an example, the pink color line indicates "Company in consideration," the green color line indicates "competitor A," the light blue color line indicates "competitor B," and so forth. Evaluation reveals the rivals' leading and lagging positions for a specific CA. Results reflect the actual needs and demands that customers have of the business. The business takes into account all measured needs to ensure that the product it launches will outperform its rivals and satisfy customers.

3.3.2. Analysis for Competitive Technical Analysis

For each Engineering Characteristic (EC), "Absolute weights" must first be determined by adding the weights of importance and relationship values for the entire column. It provides the specific EC's absolute weight. The absolute weights for each engineering characteristic under the appropriate columns are now calculated and recorded. The "Relative weights" for each engineering characteristic were then determined. Graphs with the results of competitive technical analysis are shown on an appropriate scale. As previously indicated, the colors utilized for the competitors are pink for "Company in consideration," green for "competitor A," light blue for "competitor B," and so on. Evaluation reveals if a company is ahead of or behind its rivals in terms of engineering and technical efforts. An upward arrow indicates the direction in which each rival's technological efforts are improving. Results indicate that the technological efforts being made by the company under review are either adequate or need to be increased. To attain complete customer satisfaction, corrective measures should be improved in the appropriate amount to suit consumer criteria. These techniques help the corporation develop a successful product, defeat rivals, and experience impressive corporate growth.

3.3.3. Symbols used in House of Quality

The legend correspondence is shown in Figure 3.4.:

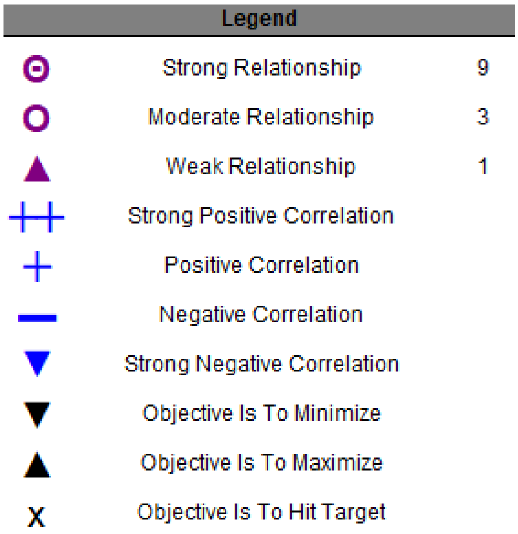

Fig. 3.4. Legends in House of Quality

3.3.4. For Customer Competitive Evaluation:

Customer Competitive Evaluation, which involves evaluating customer qualities for all competitors, should be used to produce the graph for absolute weights and relative weights. For competitive technical analysis, engineering characteristics are similar.

Formula 3.3.5 (Anticipated level value / Current level rating) is the formula for the improvement ratio. (Value of degree of importance * Value of improvement ratio) = Weight of Importance of Customer Need. Absolute weights equal the total of (Weight of importance * Relationship Value of the Corresponding Cell). Relative weight equals (Weight of Importance of Particular CA/ Total Sum of Weight of Importance) * 100.

3.3.6. Linked House of Quality

The House of Quality process begins with gathering information about the customer, continues through design requirements, manufacture planning, and production planning. The Linked House of Quality project's subsequent phases involve repeating the process of establishing the House of Quality. The production source receives the qualities of the client through linked quality houses, and the process continues to the second, third, and fourth phases. In Phase 2, the procedure transforms into a conversion of the engineering characteristics into the language of the part design requirements. The part design parameters are then converted into the language of manufacturing planning in step 3. The voice of manufacturing is finally transformed into the voice of production planning in phase 4 [20].

3.4. Results

The House of Quality is developed in Appendix B to symbolize the viability and potential of hybrid-electric aircraft in the contemporary aviation business. The poll was built in Google Forms to summarize the average assessment of diverse perspectives, and the results were used to determine the initial values for the attributes of customers (Figure 3.5.). The questions were designed to be straightforward in order to meet the needs of the average consumer. Following are the rankings of the significance of client requirements:

Timestamp	Does the new airplane have to be safe?	Does the new airplane have to be economical?	Does the new airplane have to be easy to maintain?	Does the new airplane have to be cheap?	Does the new airplane have to be long range?	Does the new airplane need to have big payload?	Does the new airplane have to be environmental friendly?	Does the new airplane have to be durable (serves long)?	Does the new airplane have to be fast?	Does the new airplane have to be modern (in a way of the appearance, design features)?
10/7/2022 15:12:13	5	5	5	3	3	4	5	5	4	5
10/7/2022 15:25:39	5	4	3	3	3	4	5	4	4	4
10/7/2022 15:27:32	5	5	5	4	3	3	4	4	3	3
10/7/2022 15:30:19	5	4	4	4	4	4	4	4	4	4
10/7/2022 15:31:15	5	4	4	3	1	3	4	4	2	3
10/7/2022 15:32:58	5	3	3	2	3	3	3	5	3	4
10/7/2022 15:44:45	5	2	2	1	2	3	4	5	3	5
10/7/2022 15:47:53	5	4	5	4	4	4	5	4	3	3
10/7/2022 16:20:16	5	5	3	2	2	4	5	4	4	3
10/7/2022 17:16:19	5	4	4	2	2	3	4	5	4	5
AVERAGE	5	4	3.8	2.8	2.7	3.5	4.3	4.4	3.4	3.9

Fig. 3.5. Poll results

The quality attributes were then selected from an engineering perspective, and linkages between them were looked into. Many factors must work together to provide high battery power, reduce weight, and accomplish a particular level of hybridization, which aims to partially replace the power of the conventional engine with battery power.

The competitive analysis has demonstrated that, in comparison to other aircrafts on the aviation market [21-26], the hybrid-electric aircraft prototype selected for this work takes the lead in terms of the characteristic requirements. It demonstrates its viability in terms of contemporary technologies and the applicability of the prototype concept. It should be highlighted that the engine's distinguishing feature is how simple it is to maintain because it retains several features of traditional engines, which have been tried and true for decades.

Strong, moderate, or weak links between Customer requirements and Design requirements were developed, and they resulted in each item's weight and relevance being represented by its numerical number (Figure 3.6.).

Target or Limit Value	Follow the prototype's weight as an initial value	Keep the same engine and connect it in parallel architecture	Calculate the estimated cost of production	Analyze the expected life with the new system	Keep the dimensions of the prototype	Estimate the range of the flight with new system	Reduce the mass of fuel by 30%	Analyze the features of the new materials by various tests	Find the economically beneficial degree of hybridization	Use the market-available components	Follow the developed characteristics of the prototype	~5000kg	Reduce the noise level by 30% and air pollution by 55%	Develop backup systems for any malfunction	750Wh/kg
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	0	1	5	5	0	4	6	5	3	3	4	5	7	8	10
Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Weight / Importance	223.8	535.4	524.3	357.9	347.9	450.5	460.1	348.7	511.1	301.6	346.3	303.7	545.0	249.2	597.4
Relative Weight	3.7	8.8	8.6	5.9	5.7	7.4	7.5	5.7	8.4	4.9	5.7	5.0	8.9	4.1	9.8

Fig. 3.6. The weigh/importance of all targets

The aim of achieving high-density batteries with 750 Wh/kg specific energy is clearly the most significant, yet also the most challenging to attain, according to the results. One of the main objectives of all future aviation technology is to reduce noise levels by 30% and air pollution by 55%. Then, in accordance with the plans for fulfilling the prototype, HEPS is implemented into the conventional engine while the expected cost of production is calculated. The planning of the aircraft production will begin with the given targets.

Conclusion to part 3

Different fuel and battery mass fractions were examined in relation to the Breguet range equation. The comparison of several configurations was displayed, and the fuel fraction emerged as the winner, demonstrating its direct correlation to flying range. It still depends, though, on the development of new, highly efficient batteries that can take the place of outdated ones. The best course of action, for the time being, will be to keep battery application between 58 and 67%. It can offer the benefits of 33–42% fuel savings without overloading the aircraft.

The ideas of the Quality Function Deployment (QFD) and House of Quality (HOQ) were introduced together with a description and explanation of each function's qualities. The findings of the QFD for the new hybrid-electric aircraft were presented. The calculations yielded the largest targets and ambitions.

PART 4. ENVIRONMENTAL MANAGEMENT SYSTEM

4.1. General information

An organization can manage its environmental responsibilities by using an Environmental Management System (EMS), which is a collection of procedures and practices. It can assist businesses in minimizing their negative environmental effects and enhancing resource efficiency.

To ensure that an EMS remains effective, it should be customized to the organization's unique needs and updated and reviewed on a regular basis.

The following components of a successful EMS are suggested by the Environmental Protection Agency (EPA):

• Rules and regulations
• Measurable goals and objectives
• Impacts and elements of the environment
• Law and other prerequisites
• Responsibilities and roles
• Instruction, dialogue, and documentation
• Controls for operations
• Emergency response and preparation
• Measurement and observation
• Reporting and keeping records
• Remedial and preventative measures

The ISO 14000 standard, which governs environmental management, is used to certify an EMS. An organization's commitment to ecological sustainability and the fact that its EMS is current and in compliance with the most recent international requirements are both demonstrated by certification to ISO 14000 [27].

The International Organization for Standardization (ISO) has created and published the ISO 14000 series of environmental management standards for enterprises. The ISO 14000 standards offer corporations a framework or set of guidelines for systematizing and enhancing their environmental management initiatives. The environmental practices of organizations are neither governed by the ISO 14000 standards nor are they intended to help with the enforcement of environmental regulations. The adoption of these standards is optional.

The most significant standard in the ISO 14000 series is ISO 14001. For small to big enterprises, ISO 14001 sets the specifications for an environmental management system (EMS). An EMS is a systematic method for dealing with environmental challenges within a company. Based on the Plan-Check-Do-Review-Improve cycle, the ISO 14001 standard was developed [28].

4.2. ISO 14001: 2015 Standard

The recommended practices for EMS implementation are established by this international standard. Different organizational models can implement such an EMS. The ISO 14000 "series of standards," which includes ISO 14001:2015, is dedicated to managing an organization's environmental responsibility, regardless of the nature of its operations. While other standards in the family place more of an emphasis on specific solutions like audits, communications, labeling, and life cycle analysis as well as environmental challenges like climate change, ISO 14001:2015 is specifically based on implementing environmental systems to achieve its objectives. According to ISO 14001:2015, an EMS may efficiently help top management achieve long-term success and at the same time contribute to sustainable growth.

- preserving the environment by minimizing or avoiding negative environmental effects;
- reducing the possible harm that environmental conditions could do to the organization;
- supporting the organization in meeting its obligations regarding compliance;
- improving the performance of the environment;
- managing or affecting the company's product life cycle;
- attaining financial and practical advantages; and

• conveying environmental knowledge [29].

«An Environmental Management System (EMS) provides a methodology and framework to systemically identify and cost-effectively manage significant environmental aspects of aviation organizations' operations and have proven effective across a wide range of organizations, including airports, air carriers, manufacturers and government agencies» [30].

An EMS's primary goal is to use systematic management practices to significantly reduce the environmental effects of an organization's operations. For instance, a corporation must plan ahead, develop a corporate environmental policy, and carry out several sets of measures in order to offset its environmental consequences. The EMS seeks to aid in the full procedure. (Figure 4.2.).

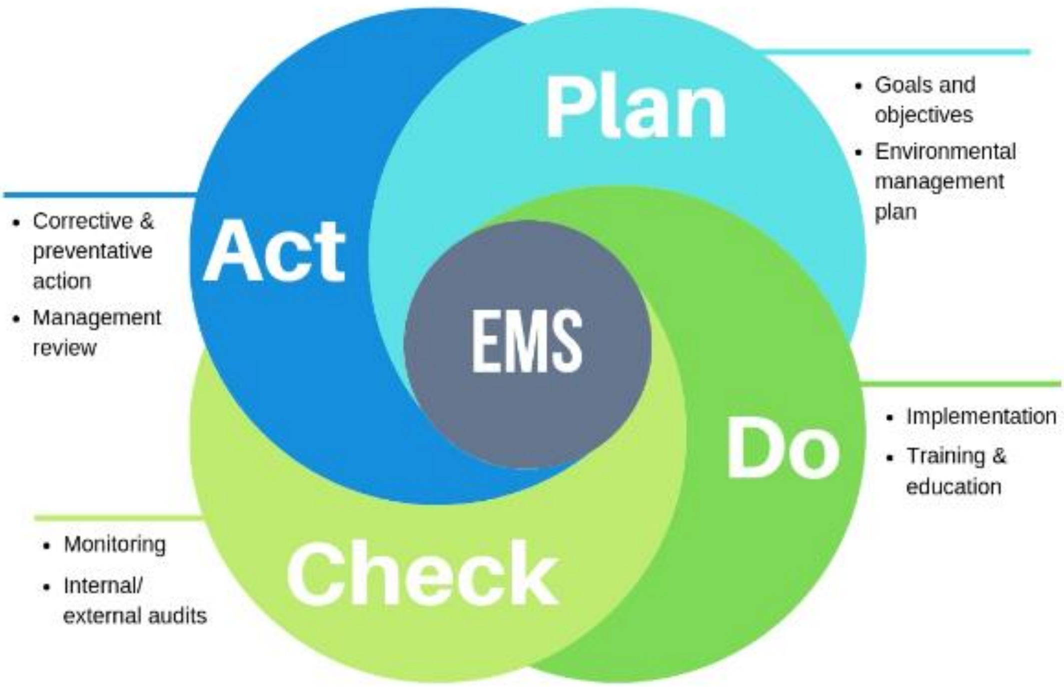

Fig. 4.2. Environmental Management System schematic [31].

4.3. EMAS European Standard

The EMS standard created by the European Commission to assess, report on and improve an organization's environmental performance is called the European Union Eco-Management and Audit Scheme (EMAS). EMAS, like other international standards, is suitable for a wide range of organizational forms, whether they are large or small, public or private. Performance metrics, staff engagement, and stakeholder interaction are a few additional standards found in EMAS in addition to those found in ISO 1400. EMAS also offers legal security through compliance with environmental legislation, which is ensured by government oversight and is thought to be stricter than ISO 14001.

When comparing the criteria, the greatest distinction is that EMAS has a stricter understanding of how environmental activities should be organized and controlled. In contrast to EMAS, which mandates a preliminary thorough environmental analysis of your processes, ISO 14001:2015 asks companies to identify their environmental elements and impacts [32]. EMAS mandates external reporting through a regularly published environmental statement, but ISO 14001 requires companies to define their external legal reporting based on the demands of external parties (such as legal agencies) (Fig. 4.3.).

Topic	ISO 14001	EMAS
Nature	Private standard	Public Regulation
Validity	Valid at international level since its first issuing in 1996	Valid in Europe until 2009 and at international level since 2010
External communication	It is not a mandatory	It foresees to make available for the public an Environmental Statement
Scope	Organisations of all sectors	Organisations of all sectors and experimentally applied in industrial clusters

Figure 4.3. EMAS and ISO 14001 [33]

4.4. EMS policy statement: top management commitment

The top management of an organization must commit to and demonstrate its leadership in relation to an EMS by (at a minimum) creating, enforcing, and maintaining an environmental policy that offers a commitment to environmental protection and a framework for defining environmental goals in line with the organization's activities. The ISO 14001:2015 expects additional leadership commitments, including:

• Creating the elements for the environmental policy's implementation, such as securing the resources, support, and internal coordination needed;

• Taking responsibility for the EMS's beneficial effects.

4.4.1. Planning

An organization that makes use of an EMS should determine the procedures and methods needed to cope with regulatory requirements, environmental considerations, and prospects for growth. Understanding the business and its context, the needs and expectations of interested parties, as well as determining the scope of the EMS, through a thorough planning process, is crucial for addressing risks and opportunities.

4.4.2. Implementation and Operation

It is necessary to plan appropriate controls and create the criteria for necessary operational processes. The organization has the ability to influence and control outsourced processes as well as the implementation of planned changes or upgrades into the operational processes. This method can also take into account issues including life cycle perspectives, disaster planning, and reaction.

4.4.3. Checking

Through analysis and monitoring, the organization must constantly assess how effective it is in protecting the environment. This calls for the employment of a particular approach, adequate criteria, and relevant indicators that must be predefined. The established verification processes can also include internal auditing and management reviews.

4.4.4. Management Review

The organization's top management is in charge of conducting periodic reviews of the EMS to ensure that it remains appropriate, adequate, and effective. These reviews ought to cover the state of the activities from the prior reviews, the changes that need to be taken into account, the environmental goals that have been met, the performance of the environment generally, the sufficiency of resources, and the potential for further progress.

4.4.5. Continual Improvement

The organization is capable of identifying opportunities for progress and the accomplishment of the specified environmental goals through monitoring and evaluation. To ensure continuous improvement, this prospect should include the recognition of errors and the choice to take corrective action.

4.4.6. Plan, Do, Check, Act (PDCA)

The PDCA principle is a continual method used to improve both an EMS's overall performance and each of its component parts. In this way, it can be thought of as a synthesis of the several stated principles.

- Plan: The systematic formulation of environmental goals, together with the procedures and methods required to carry them out in line with the organization's environmental policy.

- Do: The carrying out of the specified Plan's stated set of procedures and activities.

- Check: Continual evaluation of procedures and actions in view of the established environmental policy. Reporting the evaluation's findings is required.

- Act: Take action to develop continuously.

4.5. Benefits of the EMS for the airport

An EMS gives an airport a structured and methodical way to manage environmental activities, which can have a number of additional advantages. An effective EMS enables the airport to manage operations with the potential for environmental impact better and to track and report regulatory obligations more effectively. By offering a structured framework that increases the effectiveness of environmental management, lowers costs, and enables ongoing improvements in environmental performance, the EMS method can simplify complicated environmental concerns.

An EMS enhances internal airport management procedures and raises staff awareness of environmental concerns and duties. The incidence and severity of environmental events have decreased at airports with EMSs, and regulatory compliance has improved. The EMS procedure also makes it easier to report violations and establish compliance, which shows how seriously the airport is taking environmental issues. Finding any holes in an airport's environment management program and evaluation procedures is one of the key advantages of an EMS. The EMS is able to evaluate the general thoroughness of the airport's environment program by offering a comprehensive systematic method to managing an environmental portfolio. Additionally, this can enhance both the public's and employees' health and safety. These advantages add up to a decrease in environmental risk, which is an EMS's main advantage.

An effective EMS process will look for synergies with other management systems, such as airport sustainability planning, Airport sustainability planning, Airport Carbon Accreditation, Energy Management Systems (ISO 50001), or particular storm-water or air emissions programs. The objectives and procedures of these diverse processes can be implemented more successfully and economically when they are included in an EMS. Overall, a well-created and implemented EMS will result in internal consistency by the airport when performing tasks that have an impact on the environment. Although an EMS can cut down on the costs and duration of environmental evaluations, it does not absolve the airport of its environmental obligations. Public relations may be improved as a result of higher efficiency and improved environmental performance. An accredited EMS is a powerful marketing asset for the airport, particularly if it intends to expand.

4.6. Airports with operating EMS

The Environmental Management system is already implemented in the given airports:

1. Two international airports in the Dominican Republic's Aerodom, a division of VINCI Airports, now have ISO 14001:2015 accreditation for their environmental management systems [34].

At the international airports of Las Americas (SDQ) and La Isabela (JBQ), the implementation of an efficient environmental management system is ensured by the ISO 14001:2015 accreditation.

The system must involve all partners and employees in a common aim, take into account the expectations of the stakeholders, and reduce the environmental impact of the airport's operations consistently and sustainably to achieve the certification.

2. By incorporating environmental ideals into all airport operations, the Westchester County Airport is dedicated to attaining excellence in environmental protection. This is done through the AEMS, an ISO 14001-certified Airport Environmental Management System, which also provides environmental training to staff members and allows for continuous improvement of environmental management practices throughout the airport. In order to prevent or lessen negative effects, airport environmental features and impacts are assessed, and goals and targets are set annually [35].

3. One of the top priorities of the sustainable growth strategy of the "Polish Airports" State Enterprise is environmental preservation, which includes reducing the influence of airports on their surroundings, particularly with regard to the Warsaw Chopin Airport [36].

The Enterprise has maintained an Environmental Management System based on ISO 14001 standards for more than ten years. The following actions can be coordinated and facilitated with the use of a systemic approach to environmental management:

- reduction of noise;
- protection of the air;
- management of water and sewage;
- preservation of the land and water environment;
- management of waste.

4.7. Benefits of ECS in case of hybrid-electric propulsion system

The potential benefits of EMS for the airport operating the aircraft with hybrid-electric propulsion system are given in Table 4.1.:

Table 4.1.

Advantages in using the EMS for the airport

• Environmental performance improvements
• Decreased noncompliance with regulatory standards as well as a decrease in the number and severity of environmental events.
• Immediate response to the incidents
• Support in fulfilling the demands and/or expectations of stakeholders.
• Better organization of the aircraft maintenance stuff thus reducing human hours for required work
• Decreased risk to the environment.
• Synergies when applying ISO 50001's Energy Management System or Airport Carbon Accreditation.
• Greater internal consistency while conducting actions that have an impact on the environment.

The initial analysis can show to what degree the airports already have environmental management systems in place and where there are gaps that need to be filled. The promises to prevent environmental damage, pollution, and waste, to comply with legal and regulatory requirements, and to ongoing environmental improvements should all be included in the policy statement. The objective and vision of the airports will frequently be outlined in the policy statement, which should be customized for the airports' unique environment and operating requirements. Senior airport officials must endorse the policy statement, and it must be signed by either the chairman of the airport's governing board, a senior executive, or a senior airport manager. The airports must also make sure that every employee is aware of the policy and comprehends its details.

Airports must conduct internal audits of the EMS at predetermined periods to establish whether the company is in compliance with both internal standards and any applicable international standards. The effectiveness of the EMS's implementation and upkeep must also be evaluated by the audit, which is also used to monitor legal compliance and address issues. The airport must create an internal auditing program with a structure outlining frequency, methodologies, responsibilities, planning needs, and reporting in order to carry out this internal auditing. An internal auditing program must specify the following components: the precise standards to be applied and the audit's scope; the right choice of auditors to ensure objectivity and impartiality; and the assurance that the audit's findings are communicated to the appropriate management. Changes impacting the airport, the process's value to the environment and the findings of earlier audits should all be taken into account.

Conclusion to part 4

The environmental performance of any organization depends first of all on its awareness. To keep track of everything, whether it’s an airport or a factory, there has to be a system that will eventually summarize all the activities throughout the processes being done. The Environmental Management System (ECS) is an effective tool to manage, assess, report on, and improve an organization's environmental aspects.

The international ISO 14001 and European EMAS were compared and discussed.

The EMS processes and policy statements were reviewed.

Particular examples of the implemented EMS in airports, such as Las Americas (SDQ) and La Isabela (JBQ), Westchester County Airport, and Warsaw Chopin Airport were stated.

The advantages of the airport conducting the aircraft with a hybrid-electric propulsion system showed, that the EMS will embrace the aim of pollution reduction.

PART 5. LABOR PROTECTION

5.1 Introduction

For hybrid-electric power plant exploitation, particular cautions and safety measures must be taken into account in order to ensure that no life-threatening conditions will occur. While dealing with any kind of accumulators (e.g., lithium-ion or lithium-air), potential hazards to the environment and humans can appear due to indiscretion. The subject of this work is the mechanic who works on the repair of accumulators. In this chapter will be explained the rules and working conditions during the repairing processes in the workshop.

5.2 Analysis of working conditions

A mechanic's wellness and efficiency during the labor process are influenced by a variety of elements related to both the labor process and the working environment (Fig. 5.2.). Certain harmful production variables of the working environment can become dangerous depending on the kind of activity and its duration. To realize the traits and accepted norms of the threats and stressors people encounter is the best approach to dealing with upcoming problems.

Figure 5.2. Example of the modern lithium-battery workshop

The following physical threats and hazardous aspects should be paid attention to when working with aircraft accumulators:

- shock wave in case of combustible gases explosion;
- increased level of harmful substances in the air of the working area (acid vapors, lead aerosol);
- burns with acid, alkali, electrolyte, and molten lead [37].

5.3 Organizational and assistive technological steps to minimize the influence of damaging repairing elements

5.3.1. Methods of protection against the shock wave in case of combustible gases explosion

The government is responsible for ensuring the protection of the population, territories, environment, and property from emergencies by preventing them, eradicating their effects, and offering aid to victims during peacetime and during a designated period.

There are specifications for the region where all explosive production facilities, storage facilities, bases, warehouses, etc. are located (mainly in unpopulated areas). Construction should be done safely away from towns, other industrial facilities, public highways, waterways, and railroads if this stipulation cannot be reached. It should also have its own access roads.

Most industrial facilities utilize automatic protection systems, which serve the following purposes:

- Alert and notice of urgent circumstances that arise during production; notification in the event of a regulatory parameter violation (temperature, pressure, substance composition, process speed)

- Detection of gas contamination of production facilities and automatic activation of devices that warn of the formation of a mixture of gases and vapors with the air of explosive concentrations; problem-free shutdown of individual units or the entire production in the event of a sudden interruption of heat and electricity supply, inert gas, or compressed air.

- A high degree of professional training for business staff members as well as specialized emergency teams that carry out repairs, supervision, and accident elimination are essential requirements for the trouble-free functioning of any production.

Typically, tiny hits and local explosions within the apparatus and equipment precede explosions of enormous volumes of dust-air mixes.

Weak shock waves in this situation raise substantial amounts of dust that have accumulated on the surface of the floor, walls, and machinery into the air.

In order to avoid considerable dust accumulations in facilities, explosions of dust-air mixes must be avoided. To do this, technology must be improved, along with the equipment's sealing, calculation, and installation of ventilation vacuum cleaners.

Every piece of equipment with a higher pressure should have explosion protection systems that provide for utilizing explosion-proof machinery, fire extinguishers, inert or steam curtains, and emergency pressure release systems to prevent the destruction of equipment during an explosion (safety membranes and valves, quick-acting valves, check valves, etc.)

Organization of training and instruction of personnel; control and supervision over compliance with the norms of the technological regime; rules and regulations for conducting technological processes; industrial sanitation and fire safety; and other organizational and technical measures are also used to protect pressurized systems from the explosion [38].

Battery workers engaged in repairing and charging batteries and preparation of electrolyte, shall be provided with personal protective equipment with the following wearing periods: cotton suit with acid-resistant impregnation - 12 months, rubber boots - 12 months, rubber gloves - regular, rubberized apron - regular, goggles - until worn out and other personal protective equipment in accordance with the collective agreement.

Temperature, humidity and air velocity in the working premises of the site must comply with permissible standard DSN 3.3.6.042-99: in the cold period of the year - respectively 15-21 degrees C, 75%, not more than 0.4 m/s, and in the warm season - 16-27 degrees C, 75%, respectively, 0.2-0.5 m/s.

5.3.2. Methods of protection against the increased level of harmful substances in the air of the working area (acid vapors, lead aerosol);

Industrial sanitation is defined as a system of organizational, hygienic, and sanitary measures and means of preventing the impact of harmful production factors on workers.

Collective preventative actions:

The following are the primary collective actions for the prevention of occupational diseases and injuries:

-Regulatory actions (GOSTs, State Standards, etc.).

-Planning and architectural measures. The locations where work is done using dangerous dusting substances are subject to special standards. For instance, the ceiling, walls, and floor should be smooth and simple to clean.

-Technology-based solutions include replacing chemicals with less dangerous ones and enclosing the technological process.

By keeping the essential microclimate parameters in the production room and bringing the concentration of dangerous compounds to acceptable levels (without exceeding the MPC values for this substance), the air environment can be improved.

By utilizing technical equipment and procedures where hazardous compounds are either not generated or do not enter the air of the working area, it is feasible to lower the content of hazardous substances in the air of the working area. For instance, switching to cleaner gaseous fuel or, even better, using electric heating instead of various thermal systems and furnaces that burn liquid fuel and release a substantial amount of toxic compounds.

Reliable technological process sealing is crucial because it prevents various harmful substances from entering the working area's air and significantly lowers their concentration there (sealing equipment, sealing joints, hatches, and openings, and improving the technological process).

Hygiene and sanitary precautions:

- uniformity of hygiene;

- monitoring of actual flammable substance concentrations (sampling and measurement of actual concentrations, assessment of working conditions class, etc.)

Through ventilation, aspiration, or purification of the air, and the normalization of the air with the aid of air conditioners, engineering, and technological measures can be taken to remove dangerous compounds that enter the air of the working environment. Mechanical ventilation is most frequently employed to lower the concentration of dangerous compounds in the air of the working area, while natural and mechanical ventilation can occasionally be used in combination.

Various ventilation systems, whether general or local, are employed to maintain an acceptable concentration of hazardous compounds in the air. It is advised to automate production or move to remote control of technological operations if the stated approaches do not yield the desired outcomes.

Specific methods and measurements

The following are the primary personal precautions one should take to avoid occupational illnesses and injuries:

-personal protection tools.

-the observance of safety regulations.

-medical precautions (pathogenetic prophylaxis - vitamins, preventive diets No. 1 - 5, medical examinations, sanatorium treatment) [39].

The content of harmful substances in the air of the working area should be checked in due time and should not exceed established maximum permissible concentrations: lead and its inorganic compounds - 0.01/0.005 mg/cubic meter, sulfuric acid - 1 mg/cubic meter, caustic alkalis (solutions in terms of NaOH) - 0.5 mg/cubic meter, arsenic hydrogen - 0.1 mg/cubic meter.

5.3.3. Model occupational safety instruction for burns with acid, alkali, electrolyte, and molten lead

To protect the body from possible burns when working with molten lead, when performing soldering work, when preparing filling mastic, and working with it, the battery operator must wear the provided personal protective equipment. During the preparation, pouring, and topping up of acid electrolyte in the battery must be sure to use protective goggles and rubber gloves.

Before preparing alkaline electrolytes and during work with it, it is necessary to wear protective goggles and rubber gloves. Take dry alkali with tongs or tweezers. Crushing of dry caustic lye should be carried out using a special scoop and burlap. Only cold water should be used to dissolve the lye.

When charging the batteries, the person cannot lean close to the batteries to avoid burns from acid splashes that fly out of its openings.

During battery work is not allowed:

- smoking, entering the charging room with an open flame (lit match, cigarette, etc.);

- use electric heating devices in the charging room;

- store bottles with sulfuric acid in the battery room

acid and bottles of caustic potash more than the daily requirement, as well as an empty vessel, must be stored in a special room;

- jointly store and charge acid and alkaline

batteries in the same room;

- the presence of people in the room for charging batteries, except for service personnel;

- to carry out any unauthorized work in the charging room batteries; to carry out any unauthorized work in the battery charging room.

In the battery compartment, there shall be a sink, soap, cotton wool in a package or a single set, a towel, and closed vessels with a 5-10% neutralizing solution of baking soda (for body skin) and 2-3% solution of baking soda (for eyes) - during maintenance and repair of acid batteries.

During maintenance and repair of alkaline batteries, 5-10% boric acid solution (for body skin) and 2-3% boric acid solution (for eyes) shall be used as a neutralizing solution.

To prevent poisoning by lead or sulfuric acid vapors, the battery operator should monitor the serviceability of ventilation, clean workplaces, and racks daily, at least once a week to wipe the walls, ceiling, cabinets, and windows with a damp cloth.

Safety requirements in emergency situations:

- The battery operator must (if possible, by himself or through other employees) report an accident to his immediate supervisor or other officials and seek help at the medical center or doctor.

- In case of contact with acid, alkali, or electrolyte on exposed parts of the body, immediately rinse this part of the body with running water and then 5-10% neutralizing solution.

- In case of contact with acid, alkali, or electrolyte in the eyes rinse them with running water, then 2-3% neutralizing solution, and immediately consult a doctor.

- Electrolyte spilled on the rack, workbench, etc. must be wiped with a cloth dampened in 5-10% neutralizing solution, and spilled on the floor - first sprinkle with sawdust, collect it, and then moisten this place with a neutralizing solution and wipe dry.

- In case of lead poisoning or electrolyte vapors, sulfuric acid, immediately consult a doctor.

-In case of malfunction of electrical equipment, failure of local or general supply and exhaust ventilation, immediately stop work, disconnect the equipment from the power supply and report the malfunction to the immediate supervisor or contact the appropriate service in the prescribed manner.

- In case of fire, it is necessary to de-energize equipment, report this to the immediate supervisor (foreman, foreman, column chief) or other supervisor and proceed to eliminate the fire.

- If it is impossible to eliminate the fire or eliminate malfunction on their own, it is necessary to inform the immediate supervisor or contact in the prescribed manner the appropriate service of the enterprise.

- Stop work in case of malfunction or disconnection of ventilation [40].

5.4. Fire safety rules at the workspace

When performing operations with gas, measures and means should be provided to prevent exposure of workers to hazardous and harmful factors:

- location of workplaces in hazardous areas, enclosed volumes, at a considerable height relative to the ground or significantly below ground level;
- the probability of fires and explosions;
- increased voltage in the electrical circuit, the closure of which can occur through the human body;
- increased dustiness (gassiness) of the air in the working area.

In the design and technological documentation, in addition to measures of protection against dangerous and harmful factors, the ensuring proper condition of welding equipment, electric cable, gas hoses, their laying, and connection should be provided;

The places of electric welding and gas-flame works on this and on the tiers below (if there is no protective refractory flooring or flooring protected by refractory material) should be free from combustible materials within a radius of at least 5 m, and from explosive materials and equipment (gas generators, gas cylinders, etc.) - at least 1 m.

Welders' workplaces indoors during open arc welding shall be fenced off from adjacent workplaces and aisles by non-combustible and light-transmitting screens (screens, shields) at least 1.8 m high. During welding in the open air, fences must be installed in case of simultaneous work of several welders close to each other and in areas of intensive traffic. When performing electric welding and gas flame works inside closed containers, cavities of structures, underground structures, and workplaces should be equipped with exhaust ventilation. The air velocity inside the container (cavity) should be within 0.3 m/s-1.5 m/s, the temperature of the supplied air should not be lower than plus 20 ° C, and measurements should be performed by a special service [41].

Conclusion to part 5

This part explains the rules and working conditions during the repairing processes in the workshop for the mechanic who works with accumulators. In the workshop various hazardous factors exist, and the precautions and certain safety measures must be taken.

The following common conditions were listed along with the safety precautions that should be taken: shock wave in the event of an explosion of combustible gases; increased levels of hazardous substances in the air of the working area (acid vapors, lead aerosol); burns from acid, alkali, electrolyte, and molten lead.

While operating in a gas or electric workplace, fire safety regulations were indicated.

Any job with the topic of battery maintenance and repairs must be done with safety compliance in consideration.

GENERAL CONCLUSION

Hybrid-electric propulsion is a captivating solution for the light aviation sector since it retains the typical range and flight performance of conventional, conventional propulsion while providing the advantages of electric propulsion in terms of reduced noise and air pollution during terminal maneuvers. The adoption of this unique technology in light aviation may have been delayed in part by the lack of established methods for creating hybrid-electric aircraft due to the challenges in negotiating parameters and making design decisions. The number of design variables needed to define the hybrid-electric power train, which comprises both its thermal and electric components, has greatly grown as compared to conventionally powered aircraft.

Due to the introduction of new technologies like electrification, especially when combined with more autonomy and digitalization, significant modifications to personnel training, operation, and maintenance are required in order to better integrate the system with the aircraft.

Due to its interaction with the aircraft, the propulsion system in particular is becoming more complex and is planned to be the focus of additional research in the coming years. In any case, it takes time to produce any form of the invention; even the regular airplanes we use today had a long development process.

The centers of gravity (CG) of the HEPS configuration and the conventional prototype layout were compared.

The amount of fuel was reduced by 324 kg by replacing various items like mail and freight with HEPS mass split across the wing and fuselage. The passenger goods, such as carry-on luggage, were kept because the prototype was designed as a regional passenger aircraft. However, this trait can end up being a drawback of such a system.

The Breguet range equation was investigated in relation to various fuel and battery mass percentages. The fuel fraction prevailed the comparison of many configurations, indicating that it has a direct relationship with a flying range. However, it still hinges on the creation of brand-new, incredibly effective batteries that can replace inefficient ones.

Keeping battery application between 58 and 67% will be the best line of action for the time being. It can save 33–42% on fuel without adding extra weight to the airplane.

Along with an outline of each function's attributes, the concepts of the Quality Function Deployment (QFD) and House of Quality (HOQ) were introduced. The QFD results for the brand-new hybrid-electric aircraft were displayed. According to the data, the most important but also most difficult goal is to develop high-density batteries with 750 Wh/kg specific energy. The reduction of noise levels by 30% and air pollution by 55% is one of the primary goals of all future aviation technologies. Then, HEPS is included into the conventional engine in accordance with the plans for realizing the prototype while the predicted cost of production is estimated thoroughly. With the provided targets as a starting point, manufacturing planning for aircraft will begin.

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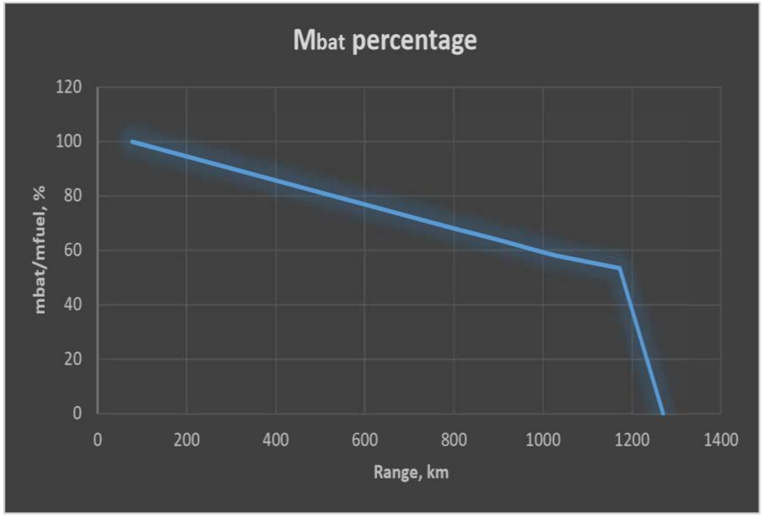
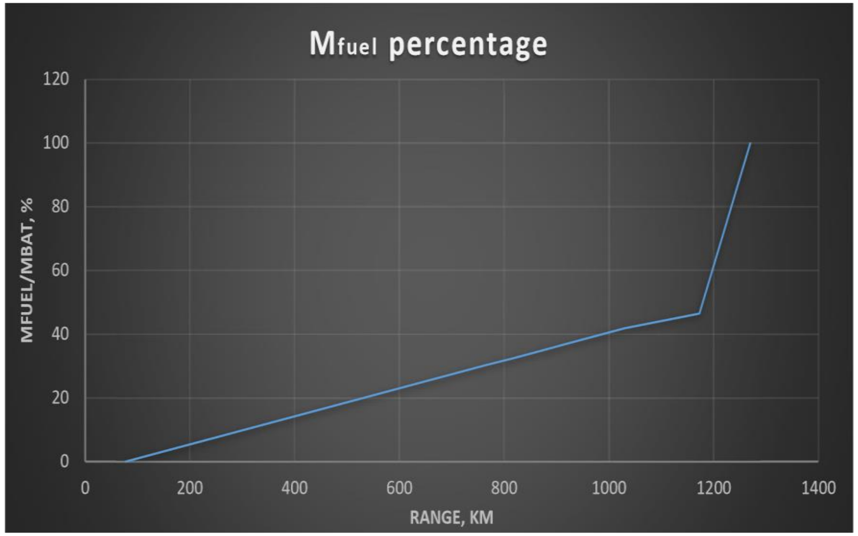
Degree of hybridization analysis

m_{bat}, kg	m_{fuel}, kg	range, km	mbat/mfuel, %	mfuel/mbat, %
2152	0	78	100	0
1500	650	764.585	69.70260223	30.20446097
1450	700	817.415	67.37918216	32.52788104
1400	752	872.359	65.05576208	34.94423792
1364	788	910.394	63.38289963	36.61710037
1300	852	978.01	60.40892193	39.59107807
1250	902	1030.836	58.08550186	41.91449814
1150	1002	1172.895	53.43866171	46.56133829
0	1113	1270	0	100

HEPS, kg	Fuel in prototype, kg
2152	1113





Conclusions: There is straight relationship between the range and fuel contribution in the propulsion system. Till the time when the high power batteries will be available, the degree of hybridization should remain in medium ranges (58-67%) to take the benefits as from fuel, and as from batteries, not overloading the aircraft with battery mass and reducing the noise and fuel emmisions accordingly.

Appendix B

Quality Function Deployment (QFD) and House of Quality (HOQ)

Title: Prototype of the new hybrid-electric regional aircaft

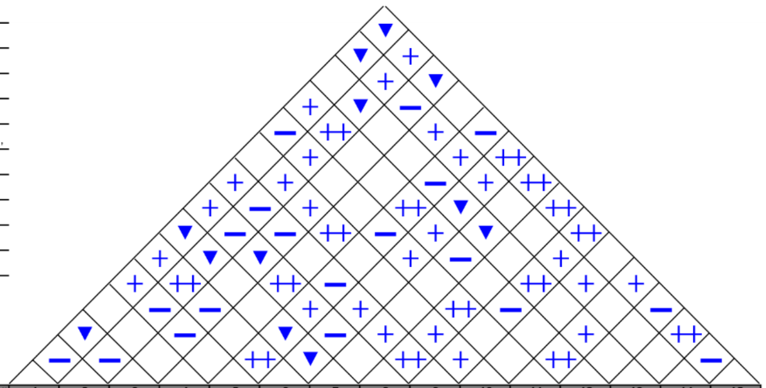
Author: Yelyzaveta Samoilenko

Date: 19/10/2022

Notes: Given House of Quality (QFD) shows the practicability of the hybrid-electric aircraft in aviation market with the comparison of the modern customer requirements, competitors and tendencies, taking into account the main difficulties in its development and further implementation.

Legend

Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▼	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼	▲	▲

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Weight	Engine power	Cost of production	Expected life	Dimensions	Range	Fuel consumption	Materials testing	Degree of hybridization	Interchangeability of the components	Aerodynamic characteristics	Payload	Noise and emissions pollution	Backup systems	Battery power
1	9	13.2	5.0	Safe	▲		O	Θ	O			Θ		O	O		▲	Θ	
2	9	10.6	4.0	Economical	O	Θ	O	▲	O	Θ	Θ	▲	Θ	O	Θ	Θ	Θ	▲	Θ
3	9	10.1	3.8	Easy to maintain			▲	O	O			O	O	Θ		▲		▲	
4	9	7.4	2.8	Cheap	O	Θ	Θ	Θ	Θ	Θ	O	Θ	O	Θ	▲	Θ	O	O	Θ
5	9	7.1	2.7	Long range	Θ	Θ	O	▲	Θ	Θ	Θ	▲	Θ	▲	Θ	O	Θ	O	Θ
6	9	9.3	3.5	Big payload	Θ	Θ	O	▲	Θ	Θ	Θ		Θ		O	Θ	Θ		Θ
7	9	11.4	4.3	Environmental friendly		Θ	Θ		▲	Θ	Θ		Θ				Θ		Θ
8	9	11.6	4.4	Durable (Serves for long time)		▲	Θ	Θ	▲	▲	▲	Θ	▲	O				O	▲
9	9	9.0	3.4	Fast	▲	Θ	O		▲	O	Θ		▲		Θ	O	O		Θ
10	9	10.3	3.9	Modern ((in a way of the appearance, design features)		O	Θ	▲				▲	Θ	O	O		Θ	O	Θ
				Target or Limit Value	Follow the prototype's weight as an initial value	Keep the same engine and connect it in parallel architecture	Calculate the estimated cost of production	Analyze the expected life with the new system	Keep the dimensions of the prototype	Estimate the range of the flight with new system	Reduce the mass of fuel by 30%	Analyze the features of the new materials by various tests	Find the economically beneficial degree of hybridization	Use the market-available components	Follow the developed characteristics of the prototype	~5000kg	Reduce the noise level by 30% and air pollution by 55%	Develop backup systems for any malfunction	750Wh/kg
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	0	1	5	5	0	4	6	5	3	3	4	5	7	8	10
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
				Weight / Importance	223.8	535.4	524.3	357.9	347.9	450.5	460.1	348.7	511.1	301.6	346.3	303.7	545.0	249.2	597.4
				Relative Weight	3.7	8.8	8.6	5.9	5.7	7.4	7.5	5.7	8.4	4.9	5.7	5.0	8.9	4.1	9.8

Competitive Analysis (0=Worst, 5=Best)

Row #	Our prototype of hybrid-electric airplane	E-Fan X	ES-30	Faradair BEHA M1H	Zunum Aero Hybrid Electric Aircraft	Ampaire's Hybrid-Electric aicraft
1	4	4	4	3	3	4
2	4	3	4	2	4	4
3	5	3	2	1	3	4
4	3	1	2	4	3	3
5	4	3	3	4	4	5
6	3	4	3	2	2	1
7	4	4	5	5	4	4
8	4	3	3	3	4	4
9	3	3	3	2	3	4
10	3	3	4	5	4	3