Analysis for the Design & Feasibility of an Electric Powered Light Aircraft

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1. Introduction

The aim of this study is to assess the needs and requirements of an electric-powered light aircraft and analyze its feasibility. Over the years, as technology has advanced, aircraft design has matured significantly. However, the powerplant of the aircraft still remains the same. For a light aircraft, which is powered by a piston-reciprocating engine, aviation gasoline is the typical fuel in use currently. The use of aviation gasoline is harmful to the atmosphere, and the gasoline engine itself is not very efficient. With advances in electric battery and fuel cell technology, there lies a great opportunity in being able to replace gasoline-powered aircraft with electric-powered ones which are safe with respect to the environment and at the same time, more efficient than gasoline engines. In the following sections, the various advantages and disadvantages of the use of electric power and aviation gasoline are discussed, followed by an analysis of stakeholders for the development of an electric-powered light aircraft. Once the stakeholders have been identified, the needs and requirements are assessed, following which a preliminary feasibility study is conducted.

2. Comparison between Avgas and Electric Energy

2.1 Aviation Gasoline

Aviation gasoline is what fuels most aircraft that are equipped with reciprocating engines. The working principle of such an engine is to ignite a mixture of fuel and air to build pressure which is then used to rotate a shaft that is connected to a propeller. Since the 1920's, a chemical known as Tetra-ethyl lead (TEL), later identified as a neurotoxin, was used in aviation fuel (Wood). It started to get phased out, and was apparently gone by 1995. However, in more recent times, a small amount of this toxic lead compound has found its way into 100 low-lead aviation gas, which is the most commonly used aviation fuel. The purpose of TEL in Avgas is to reduce the spontaneous detonation of gasoline under very high temperatures and pressures; as such detonations can cause engine failure.

Although Avgas is a standard fuel in general aviation today, the effects it has on the environment can be quite harmful. Figure 1 indicates the amount of Carbon Dioxide emissions for various transportation fuels. From this chart, one can infer that aviation gasoline may not be the highest contributor to a rise in CO_2 emissions. However, with a rapid growth in the aviation industry over the years and with an increase in piston engine aircraft in the recreational flight sector, the environmental impact of Avgas has certainly become significant.

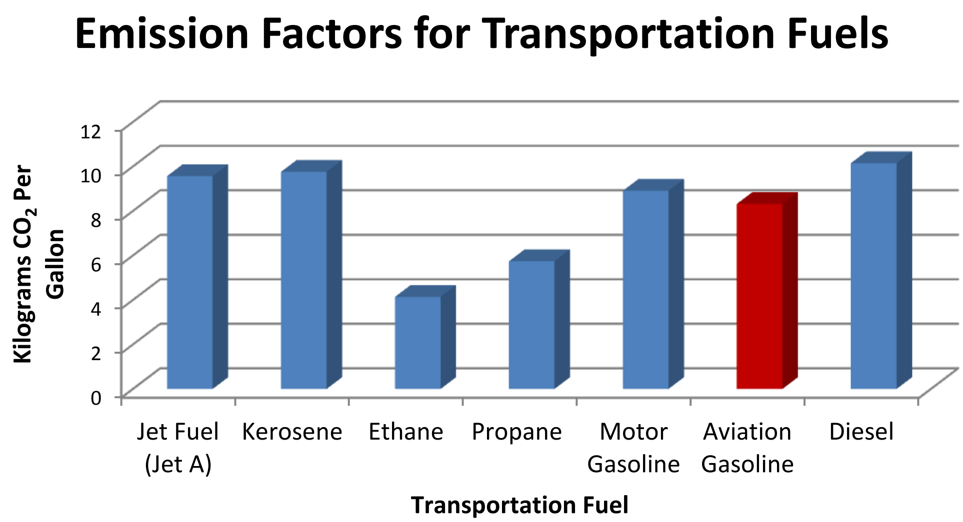


Figure 1: Emission Factors for Transportation Fuels (EIA)

2.2 Electrical Energy & Fuel Cells

Electric-powered cars are already in production and are quite popular in certain parts of the world. With an increase in electric energy density of batteries and fuel cells over the recent years, the power output and endurance of electric motors has increased, making the concept of an electric-powered light aircraft an attractive opportunity for the general aviation market. The way that the electric power system works is shown in Figure 2, for a Lithium-ion battery powered aircraft concept. Figure 3 on the other hand shows a similar power system, using hydrogen fuel cells to power such a concept aircraft. The source of energy, supply method and delivery is also illustrated in Figures 2-3.

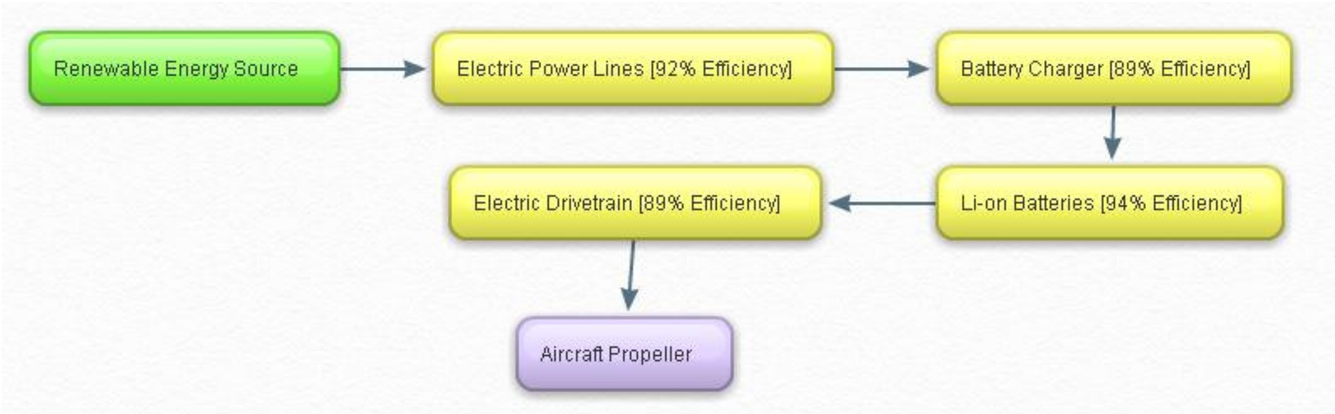


Figure 2: Lithium-ion Electrical Power System [Data: (Eaves)]

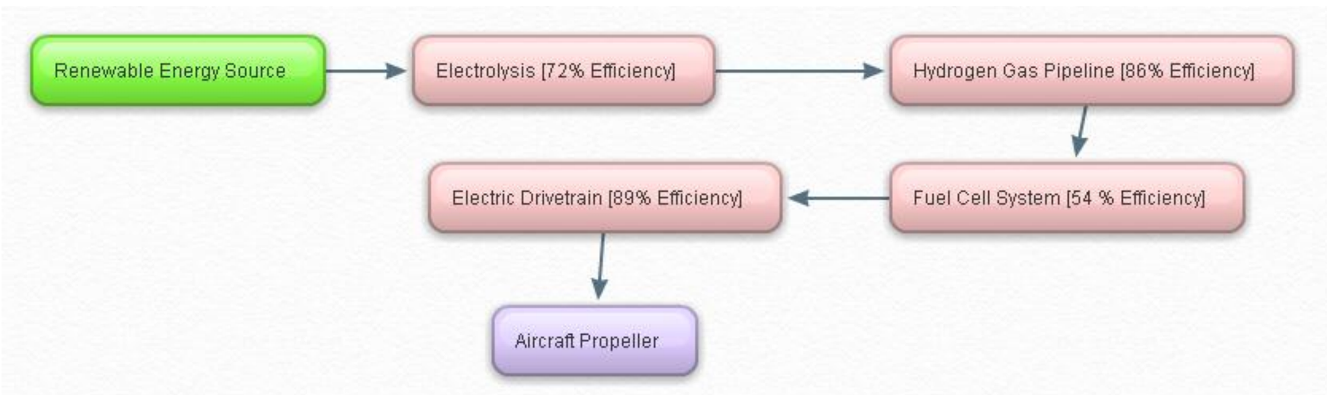


Figure 3: Fuel Cell Power System [Data: (Eaves)]

The efficiency of an electric power system (~90% using Li-ion battery) is certainly higher than that of a typical gasoline powered engine which is about 40-50% at most (E.A.I). This provides great motivation to explore the concept of an electric-powered aircraft. However, in order to do this, one must first understand who the stakeholders are, what the needs and requirements are, and finally, assess the overall feasibility of developing this concept.

3. Stakeholders

To start developing an electric-powered light aircraft, one must first understand the functioning of the aviation industry, the regulating organizations, and all parties that can be identified as stakeholders in the category of light aircraft manufacture and operation. The stakeholders are first listed, and then described in detail. The various stakeholders have been identified as:

- Federal Aviation Administration
- Target Customers
  - Flight enthusiasts, recreational Pilots
  - Flight instruction institutions
  - Small private charter firms
- Pilots
- Manufacturers of aircraft parts and subsystems
- Airport Authorities
- Aircraft Maintenance Personnel
- Suppliers of Renewable Energy

3.1 Federal Aviation Administration

The Federal Aviation Administration (FAA) is responsible for regulating and monitoring civil aviation in the United States. There are several roles that the FAA plays in general aviation, which include but aren't limited to:

- Verifying if an air carrier is capable of operating at the highest degree of safety.
- Prescribing regulations and safety standards for operation.
- Regulating air carrier processes and programs.
- Certification of air carriers and aircraft airworthiness

Any aircraft that is to be designed must meet the FAA's safety and reliability requirements. The FAA will conduct several tests on the aircraft to ensure that their safety and reliability criteria are met. So, the FAA is definitely an important stakeholder in the development, testing and operation of this aircraft.

3.2 Target Customers

The ‘primary aircraft’ subcategory within the broad category of ‘small airplanes’ is defined by the FAA to have the following characteristics:

- Maximum takeoff weight of 2700 lbs (3375 lbs if seaplane)
- Maximum seating capacity of 4
- Unpressurized cabin

This kind of aircraft is typically used for recreational flight. It is also commonly used for flight training and private charter. Therefore, the target customers are:

- Flying enthusiasts, hobbyists who are holders of private/recreational pilot licenses.
- Small companies that offer short range private charter
- Flight instruction institutions

Even within the category of light four seater aircraft, there are a wide range of existing options available that range from low cost aircraft, to high end models. Amongst the customers identified, most would want an aircraft that has a low cost. For example, flight instruction institutions would not be willing to pay for high end aircraft for use in training.

3.3 Pilots

The aircraft is operated by a pilot, who must understand the behavior of the aircraft and be able to control it. Thus, the pilot is an important stakeholder in the development process since the aircraft itself is to be designed around a human operator. There are several factors in the aircraft’s final design that will impact the pilot directly. These include (but are not limited to):

- Ease of aircraft control
- Similarity of aircraft control systems to those of other common aircraft in the light aircraft category
- Aircraft response to operator commands

Typically, pilots have been trained in and have an operational license for a certain kind of aircraft. It will not only be difficult to readjust to a new kind of cockpit, but this readjustment process may take time. For a private charter company that has few pilots, a period of retraining for a new aircraft is not favorable, as it will cause the company significant losses without their pilot being able to fly during that period. The aircraft control system similarity factor must be kept in mind during the design stage of the aircraft, as it will be necessary in order to sell the aircraft.

3.4 Manufacturers

After an aircraft has been developed and tested, it must be put into production. This is where the manufacturers come in. The manufacturers basically comprise of organizations that make various aircraft parts and components. Very rarely is it the case that the company that manufactures the interior parts of the aircraft also manufactures the wings. It is necessary to keep in mind that all the various parts of the aircraft have to be such that they can be manufactured, given today's tools and technology. The following manufacturers would be stakeholders in the development of the aircraft:

- Manufacturers of Electronic and Control Systems – Companies that manufacture aircraft control systems such as navigation and communication systems.
- Manufacturers of Aircraft Engines – Since the engine will be a key factor in determining the success of the electric-powered aircraft, the manufacturers of aircraft engines are important stakeholders.
- Manufacturers of Interior Components – Companies that manufacture aircraft interiors, such as seats and insulation.
- Manufacturers of Landing gear – Companies that manufacture the landing carriage of the aircraft, including the hydraulic systems and wheels.
- Manufacturers of Airframes – Companies that manufacture the structural components that make up an aircraft, such as the fuselage and wings.

3.5 Airport Authorities

Since the aircraft must be compatible with the airport system, the authorities that are responsible for airport operations such as air traffic control (ATC), aircraft refueling services, parking and so on, are stakeholders for the development of the aircraft. In civil aviation, there is a system of airspaces which are basically zones of airspace that are assigned to various types of aircraft that are in the sky. Thus, the aircraft must be compatible with this airspace system as well. This implies being able to navigate within the airspace, communicate and synchronize with other air traffic and follow predetermined aerial routes.

3.6 Aircraft Maintenance Personnel

There are always a team of technicians and engineers for each aircraft, whose job is to ensure that the aircraft is well maintained so that it can keep operating flawlessly. These maintenance personnel are also stakeholders in the development of the aircraft since they will be the ones who continuously monitor the health of the aircraft, and make any necessary fixes or adjustments over the aircraft's lifespan. A maintenance personnel's viewpoint is quite different from the pilot's viewpoint, since the maintenance personnel must not only understand the aircraft well, but must also be able to comprehend various interactions between the parts of the aircraft and understand the implications of their operations on the aircraft.

3.7 Suppliers of Renewable Energy

In order to make the electric-powered aircraft design sustainable, it is necessary to tap into the natural sources of energy. This suggests the use of sources such as wind turbines and solar farms to derive the electric energy from, which is then stored in the battery or used in the electrolysis process for a fuel cell. Figures 2-3 illustrate the process of deriving energy and delivering it to an aircraft's propellers. Suppliers of renewable energy thus seem to be important stakeholders in the development of the electric-powered light aircraft.

Having discussed the stakeholders in the development of the electric-powered light aircraft, the needs and requirements can be assessed keeping the target customer and other stakeholders in mind.

4. Needs & Requirements

The design of the electric-powered light aircraft will have to not only meet customer needs and requirements, but must also meet the requirements of the FAA. The needs and requirements for this particular aircraft must be split up into customer specific needs and FAA requirements. The standards which the FAA has set for the category of "Primary Aircraft" act as constraints on the design of the aircraft. This is because the FAA requirements are sets of predetermined values, which are thresholds for the functional parameters that a newly designed aircraft must have.

The customer in this this case has already been identified in section 3.2 to be private/recreational pilots, flight instruction institutions and private charter firms. Keeping this in mind, one can start to think about the needs and requirements that each of these individual customers would have. First of all, the aircraft is always operated by people who either hold a private/recreational pilot license or those who are receiving instruction from instructors who at least hold a private pilot license. This means that these people have already been trained in and are probably accustomed to conventional piston engine driven light aircraft. The control systems, navigation systems and other flight systems are consistently similar between all aircrafts in the "small airplane" category. So an initial customer need would be that these flight systems be similar to what they are used to.

An aircraft must be safe to fly in, and must also be safe for people on the ground. Safety is a key concern of the customers, and although it cannot be directly parameterized, it can be broken down into safety characteristics that customers look for in an aircraft. One of these is the operational range of the aircraft. Since flights take place over hostile terrain and water bodies, it is essential for the aircraft to be able to fly long distances without being refueled. The range itself is a function of the operating environment and aircraft design parameters. In short, the customers are looking for long range across various operating conditions. A pilot would want that the engine of the aircraft be powerful enough for the pilot to perform safe maneuvers at both sea level, and at the maximum altitude that the aircraft can achieve. This allows greater control over the aircraft, and at the same time, in an emergency situation, it provides the pilot with adequate thrust to perform emergency maneuvers. One of the most important areas in safety is considered to be the takeoff and landing distances of the aircraft. Preferably, it is good to have as small a landing and takeoff distance as possible. This is because the aircraft must be able to takeoff in such a way that it can avoid possible obstacles in its path. The same goes for landing, where the aircraft must be able to fly over obstacles and land, coming to a stop at a safe distance away from the end of the runway. So, if anything goes wrong, the pilot will have enough runway length to make corrective maneuvers.

Another customer need is that the aircraft must be reliable. From a customer standpoint, the aircraft must function consistently well throughout its lifetime. From the standpoint of the maintenance personnel working for the customers, it would be important that the aircraft have a relatively small and easy maintenance routine. This leads to discussion of the lifespan of the aircraft. The customer is probably going to make a high value purchase of an aircraft once in a span of 10-15 years. One must keep in mind however, that customers may be looking for newer aircraft as technology advances. A direct implication of an increase in target lifespan of an aircraft, is a rise in the aircraft cost. This is because in making the aircraft provide longer service life, more expensive materials may be used and perhaps compromises may have to be made in other areas of aircraft performance. This is undesirable for the customer, and hence a particularly high aircraft lifespan is undesirable as a requirement on the design of the aircraft.

Although this aircraft is to be electric-powered, it is meant to compete in the market segment of small aircraft which have piston driven engines. This also implies that the cruise speed of the aircraft has to be comparable, if not greater, than that of existing aircraft in this category. Customers want to get from source to destination in the quickest amount of time possible, and thus the cruise speed can be an important factor in a buying decision for a potential customer. While travelling in or operating aircraft, comfort is also an important aspect of design. A customer would need a comfortable, spacious interior that is suitable for long flights. Thus, cabin volume is also an important parameter that is relevant to the design and development of this aircraft.

When buying an aircraft, a customer may or may not look at the environmental impact or hazards that the aircraft poses. This parameter is often neglected because the aviation industry is more inclined towards providing cost saving through design optimization. However, as discussed before, there are environmental concerns about the use of certain types of Avgas in the industry. Furthermore, with rising fuel costs, it seems fit to have an electric-powered aircraft that can not only decrease environmental impact of aviation, but at the same time decrease the fuel costs. This leads to the conclusion that fuel cost is an important parameter for the customer, and along with this, a reduction of CO_2 emissions into the atmosphere is also important for sustainability in the aircraft industry.

Having discussed and explained customer expectations, needs and requirements, one can begin to parameterize and list all of these needs and requirements along with the set of requirements set forth by the FAA for the design of an aircraft within the light aircraft category. The requirements can be seen as functional characteristics that the final product must match up to or surpass and are discussed in detail in the following section.

4.1 Table of Requirements

Table 1: Table of Requirements

Requirement Reference Number	Requirement Statement
Req-01	Aircraft has a seating capacity of not more than four persons, consisting of 1 pilot and a maximum of 3 passengers.
Req-02	Aircraft has a Maximum Takeoff Weight of less than 2700 lbs.
Req-03	Aircraft's Landing configuration stall speed is 61 knots or less.
Req-04	Aircraft's cabin must be unpressurized. Maximum (allowable) Service Ceiling is 9800 ft.
Req-05	The Aircraft's Engine is able to deliver adequate power for safe flight operation at sea level.
Req-06	The Aircraft's Engine is able to deliver adequate power for safe flight operation at service ceiling altitude.
Req-07	Aircraft's Maximum Range when flying in best economy mode is reasonably long and competitive with respect to other aircrafts in the same category.
Req-08	The aircraft requires minimum maintenance with respect to a relatively large number of hours in flight operations.
Req-09	Aircraft has a lifespan of at least 15 years, assuming maintenance is carried out regularly.
Req-10	Aircraft's maximum cruise speed is comparable, if not higher than that of other aircrafts in the same category.
Req-11	Aircraft's interior offers comfortable space, adequate for one pilot and a maximum of three passengers.
Req-12	Aircraft has a significantly high fuel economy, when compared to other aircraft in the same category. The fuel cost per mile is low.
Req-13	Aircraft is environmentally friendly, and produces minimum emissions. The carbon footprint of the aircraft is as small as possible.
Req-14	Aircraft is able to perform a takeoff from a standard runway within a small distance, under standard day conditions.
Req-15	Aircraft is able to land on a standard runway within a small distance, under standard day conditions.

4.2.1 FAA Regulation & Design Constraints (FAA, 14 CFR Part 21)

Requirement Req-01

Maximum seating capacity of 4

The aircraft must be able to seat not more than 4 persons. This means that other than the pilot, three passengers can be seated at most.

Metric = Maximum Seating Capacity
Value = 4 persons

Requirement Req-02

Maximum takeoff weight of 2700 lbs

The weight of the entire aircraft including payload and fuel must not exceed 2700 kg. This is a constraint on the weight of the structure, payload and fuel capacity.

Metric = Maximum Takeoff Weight
Value = 2700 lbs

Requirement Req-03

Landing configuration stall speed of 61 knots or less

Landing Configuration is defined as flaps extended, spoiler retracted and landing gear down. The stall speed at this configuration must not be greater than 61 knots.

Metric = Landing configuration stall speed
Value = 61 Knots

Requirement Req-04

Unpressurized cabin & Service Ceiling requirement.

This requirement constraints the altitude and the environment in which the aircraft can fly. Since pressurization is essential over 9800 ft, this shall be the maximum altitude that the aircraft can operate on. However, the service ceiling should be as high as possible within the maximum allowable range.

Metric = Maximum Altitude (Service Ceiling)
Value = 9800 ft

4.2.2 Aircraft Specific Needs & Requirements

Once the FAA requirements have been explained, one can begin to justify and parameterize the needs and requirements of the aircraft with respect to the customer, pilots, maintenance technicians and other stakeholders.

Requirement Req-05

Engine Power Required at Sea Level

Although the FAA has not set any such requirement as yet, there is still a need from the pilot's point of view of having enough power available for safe operations in any given condition as discussed in the needs and requirements section. This requirement basically underlines the minimum amount of power available at sea level for operation. This value has been determined using historical data and analysis on aircraft that operate in the primary, piston powered category (Brandt, Stiles and Bertin).

Metric = Power Available at Sea Level
Value = 150 Horsepower

Requirement Req-06

Power Available at 9800 ft

As discussed earlier, the engine must be able to deliver adequate power for safe maneuvering of the aircraft at its maximum altitude or service ceiling. At the absolute service ceiling of the aircraft, the power available should be 80 Horsepower or greater (Brandt, Stiles and Bertin). This is about the average amount of power that a reciprocating engine can deliver at this altitude, which allows the pilot to make necessary corrections in aircraft attitude and perform any emergency maneuvers at that altitude.

Metric = Power Available at 9800 ft (Service Ceiling)
Value = 80 Horsepower

Requirement Req-07

Aircraft Range

As discussed earlier, one of the parameters that are most important for customers is the range of the aircraft. To be competitive in the aircraft industry, range has to be increased without sacrificing fuel efficiency. Also, the operator of the aircraft would not want to make frequent fuel stops. With the concept of the electric-powered aircraft, range is a critical factor for success because the battery must deliver the required power for flight and sustain that power for a long time to keep the aircraft cruising longer. After analyzing competitors in this aircraft market segment, a range of 700 nm must be achieved at a minimum in order to attract potential buyers and be competitive in the market segment of light aircraft (Lewis). One must note that this range will vary based on the engine mode being used and the flight conditions. Best economy mode will deliver maximum range, whereas maximum power mode will deliver sustained maximum power. Thus, this range is with respect to the best economy mode of the engine.

Metric =Maximum Range (Best Economy)

Value = 700 nm

Requirement Req-08

Maintenance Hours

The aircraft has to be kept in a good working condition at all times. However, the design requirement is to ensure that the number of hours that the maintenance personnel have to spend on maintaining the aircraft is minimized. An increase in maintenance hours means a potentially higher chance of human error in adjusting or fixing the aircraft. This decreases the reliability of the aircraft and thus, minimum maintenance is a design requirement for this aircraft. For every hour of maintenance, the operation cost of the aircraft rises. By using various competitors as benchmarks and analyzing FAA guidelines for safety (Flight Standards Service); for every 50 hours of operation, 1 hour of maintenance is an appropriate maintenance schedule.

Metric = Maintenance Hours
Value = 1 hr (for every 50 hrs in operation)

Requirement Req-09

Aircraft Lifespan

As discussed earlier in Section 4, the lifespan of the aircraft is a function of various design parameters and operating environments. However, to have a particularly high life span is not desirable either, since the customer would want to upgrade or advance to the latest technology. Since one does not want an over-engineered aircraft, or an aircraft that has a relatively low lifespan, the target value for the lifespan is being set at 15 years, as per customer expectation.

Metric = Aircraft Lifespan

Value = 15 years

Requirement Req-10

Cruise Speed

Through analysis of various competitors in the market segment of light aircraft, a requirement for the maximum cruise speed of the aircraft seems to be approximately 160 KTAS (Lewis). Thus, the requirement is that the maximum cruise speed of the aircraft is at least 160 KTAS.

Metric = Maximum Cruise Speed

Value = 160 KTAS

Requirement Req-11

Cabin Volume

Although this is to be a small aircraft, the interior must be comfortable enough for four persons. It must be spacious enough to accommodate passengers as well as their carry-on luggage. This sets a requirement on the minimum cabin volume to be 25000 in^3, which is a figure approximated from the information of cabin volumes of typical aircrafts in this segment (Lewis). However, it must be noted that increasing the cabin volume beyond a point can have a negative impact on fuel economy, since drag on the aircraft would be significantly higher for a larger profile area.

Metric = Minimum Cabin Volume
Value = 25000 in^3

Requirement Req-12

Fuel Economy

To calculate fuel cost/mile: using an average fuel economy of approximately 27 miles per gallon and a fuel price of approximately $ 5 per gallon for 100LL Avgas (AirNav), the average fuel economy works out to be approximately $0.2 per mile (Lewis). This can be used to set a minimum target that the aircraft must achieve or surpass, in order to maintain a competitive edge. Thus, the fuel cost per mile must be $0.2/mile or less.

Metric = Fuel Cost per Mile
Value = $0.2/mile

Requirement Req-13

Environmentally friendly operation

The aircraft must not pollute the environment at any given time. The idea of having an electric-powered aircraft is to decrease emissions. Ideally, the aircraft should have zero CO_2 emissions. A target of 0.5 kg/gallon in CO2 emissions seems reasonable, given the other requirements of power and range that the aircraft must fulfill.

Metric= CO_2 Emissions [kg/gallon]
Value = 0.5 [kg/gallon]

Requirement Req-14

Minimum Takeoff Distance

Since the aircraft must operate in and out of airports, it is necessary that the aircraft be able to takeoff and land from standard runways. A typical runway is approximately 1800 meters long. However, there are requirements set forth on the maximum allowable distance that the aircraft can roll, before getting airborne. Typically, aircrafts in the light aircraft category are expected to takeoff within 650 meters (Lewis). Using this as a requirement, the aircraft must takeoff in not more than 650 meters under standard day conditions. Standard day is defined as Density = 1.2 kg/m^3, Pressure = 101.3 kPa, Temperature = 15 C and Viscosity = 17.3 μPa·s (NASA).

Metric = Minimum Takeoff Distance

Value = 650 [m]

Requirement Req-15

Minimum Landing Distance

This requirement is complementary to Requirement Req-14. The aircraft must be able to land in airports that have runways of standard length. Using the value of 500 meters as a standard in the light aircraft category, the requirement is to be able to conduct a landing in not more than 500 meters under standard day conditions. Standard day is defined as Density = 1.2 kg/m^3, Pressure = 101.3 kPa, Temperature = 15 C and Viscosity = 17.3 µPa·s (NASA).

Metric = Minimum Landing Distance

Value = 500 [m]

5. Table of Metrics

Table 2: Table of Metrics

Metric	Value	Unit
Maximum Takeoff Weight	< 2700	[kg]
Maximum Seating Capacity	<= 4	[Persons]
Stall Speed (Landing Configuration)	< 61	[Knots]
Maximum Service Ceiling	9800	[ft]
Engine Power available at Sea Level	>=150	[Horsepower]
Engine Power available at Service Ceiling	>=80	[Horsepower]
Maximum Range	>=700	[nm]
Maintenance Hours	< 1 per 50 hrs of flight	[hr]
Aircraft Lifespan	15	[years]
Cruise Speed	>= 160	[KTAS]
Cabin Volume	>= 25000	[in^3]
Fuel Economy (Cost/Mile)	<=0.2	[$/Mile]
CO_2 Emissions	<= 0.5	[kg/gallon]
Minimum Takeoff Distance	<=650	[m]
Minimum Landing Distance	<=400	[m]

6. Requirements Analysis & Feasibility

6.1 Importance Rankings & Inferences from the House of Quality

From the House of Quality, one can infer that one of the most important requirements is range. After this, one can move on to the stall speed (landing configuration), which is the second most important requirement followed by engine power available at service ceiling. Following these two requirements, comes the need for being environmentally friendly. This emphasizes the point discussed earlier in Section 4, that the performance characteristics, along with safety needs of an aircraft are more important than anything else. This is followed by the need of an electric-powered aircraft to be environmentally friendly. Although the maximum takeoff weight parameter is not shown in the House of Quality (HoQ) to be as important, it certainly has high correlation with all the other parameters as seen in the roof of the HoQ. Thus, it gets a higher importance rank.

Using this knowledge gained from the HoQ, relative weights of needs from the customer's standpoint and FAA regulations, one can rank the requirements in terms of their importance as shown in Table 3.

Table 3: Requirements, ranked in terms of importance.

Requirement Reference Number	Detail	Importance (Rank)
Req-07	Range	1
Req-05	Power Available at Sea Level	2
Req-03	Landing Configuration Stall Speed	3
Req-06	Power Available at Service Ceiling	4
Req-01	Maximum Takeoff Weight	5
Req-13	Environmentally friendly	6
Req-12	Fuel Economy	7
Req-08	Maintenance Hours	8
Req-10	Cruise Speed	9
Req-09	Aircraft Lifespan	10
Req-14	Minimum Takeoff Distance	11
Req-15	Minimum Landing Distance	12

Req-02	Seating Capacity	13
Req-04	Service Ceiling	14
Req-11	Cabin Volume	15

6.2 Feasibility

Based on the needs and requirements analysis conducted, using tools such as the House of Quality, and assessing the importance of these needs and requirements one can come to the conclusion that the emphasis is certainly on achieving emission free operation without sacrificing performance. The key here is the powerplant of the aircraft. To assess the feasibility of using fuel cells to supply electrical energy to the motor of the aircraft, one must understand the current technological status of fuel cells with respect to efficiency, power output and size. According to data gathered by the World Energy Council (W.E.C), a hydrogen fuel cell operating at 25°C has a maximum theoretical efficiency of 83%. This is considered to be quite good; however, the rising cost of materials to manufacture fuel cells has led to the cost per kilowatt produced to be relatively high. For a typical 5.4 kW system, the current cost per kW is approximately $400 (W.E.C).

The power requirement for a light aircraft, as found earlier in the needs and requirements section, varies between 80 and 150 horsepower. It seems that the power requirement is too high for an electrical power system, since the price point may not be competitive with gasoline powered engines. An in depth analysis of the various types of fuel cells currently available is shown in Table 4. There are various advantages and disadvantages of using certain types of fuel cells, as listed by the U.S Department of Energy (U.S.D.E).

Table 4: Comparison of Fuel Cell Technologies. Source: U.S Dept. of Energy (U.S.D.E)

Fuel Cell Type	Common Electrolyte	Operating Temperature	Typical Stack Size	Efficiency	Applications	Advantages	Disadvantages
Polymer Electrolyte Membrane (PEM)	Perfluoro sulfonic acid	50-100°C 122-212°F	< 1kW–100kW	60% transportation 35% stationary	• Backup power • Portable power • Distributed generation • Transporation • Specialty vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up	• Expensive catalysts • Sensitive to fuel impurities
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90-100°C 194-212°F	10–100 kW	60%	• Military • Space	• Cathode reaction faster in alkaline electrolyte, leads to high performance • Low cost components	• Sensitive to CO_2 in fuel and air • Electrolyte management
Phosphoric Acid (PAFC)	Phosphoric acid soaked in a matrix	150-200°C 302-392°F	400 kW 100 kW module	40%	• Distributed generation	• Higher temperature enables CHP • Increased tolerance to fuel impurities	• Pt catalyst • Long start up time • S sensitivity
Molten Carbonate (MCFC)	Solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600-700°C 1112-1292°F	300 kW-3 MW 300 kW module	60%	• Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP	• High temperature corrosion and breakdown of cell components • Long start up time • Low power density
Solid Oxide (SOFC)	Yttria stabilized zirconia	700-1000°C 1202-1832°F	1 kW–2 MW	60%	• Auxiliary power • Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte • Suitable for CHP & CHHP • Hybrid/GT cycle	• High temperature corrosion and breakdown of cell components • HT operation requires long start up time and limits shutdowns

A Lithium Ion battery, delivering approximately 60 kWh of energy weighs approximately 415 kg, while a fuel cell with the same energy output weighs in at around 617 kg (Eaves). Although these figures are typical values for automobiles, scaling the engine to deliver the required energy for an aircraft would mean that both the weight and the cost would go up significantly. The cost of such a power system would be up to three or four times higher than a power system for an automobile. Thus, the total cost of the fuel cell engine would come to approximately $120,000 while a battery engine (Lithium Ion) would be cheaper at about $80,000 (Eaves).

The customer requires safety and reliability. Since this is of prime importance to the customer, those metrics that assess safety and reliability such as engine power available at sea level and landing configuration stall speed have a relatively higher importance rating (Table 3). This raises the point whether an electric-powered aircraft will be able to satisfy these customer needs. It seems at this point that certain trade-offs will have to be made in the design of such an aircraft, making it have a more powerful engine but compromising on range. This is because a more powerful engine will consume more energy, depleting the electric battery's reserve much faster and hence providing less range.

A heavy battery or fuel cell on an aircraft means that the maximum takeoff weight will be much higher. Looking at the roof of the HoQ, one can easily notice the negative impact of a higher takeoff weight on all the other parameters. If the battery were to be scaled down, to produce adequate power while having less weight then the cost would go up significantly. Optimization of the aircraft design and research developing compact, low cost batteries that produce adequate power seems to be crucial in making the electric-powered aircraft a success.

Along these lines, one can take a look at attempts made in the past to develop an electric-powered aircraft and their end results. The most notable attempt so far has been the development of the SkySpark prototype by the Polytechnic University of Turin (S.r.l.). This aircraft has been able to achieve a top speed of 250 km/h. However, the unit cost of the aircraft has not been listed and the aircraft did not go into production, possibly because the design was not feasible enough to be used as a replacement for piston driven engines. Furthermore, the aircraft was also unable to carry a heavy payload. Three years ago, Boeing attempted to display the use of fuel cell technology in an aircraft by delivering the Fuel Cell Demonstrator Prototype. However, even this project did not gain momentum because of the high cost of hydrogen fuel cells and the inability to offer adequate power (Robertson).

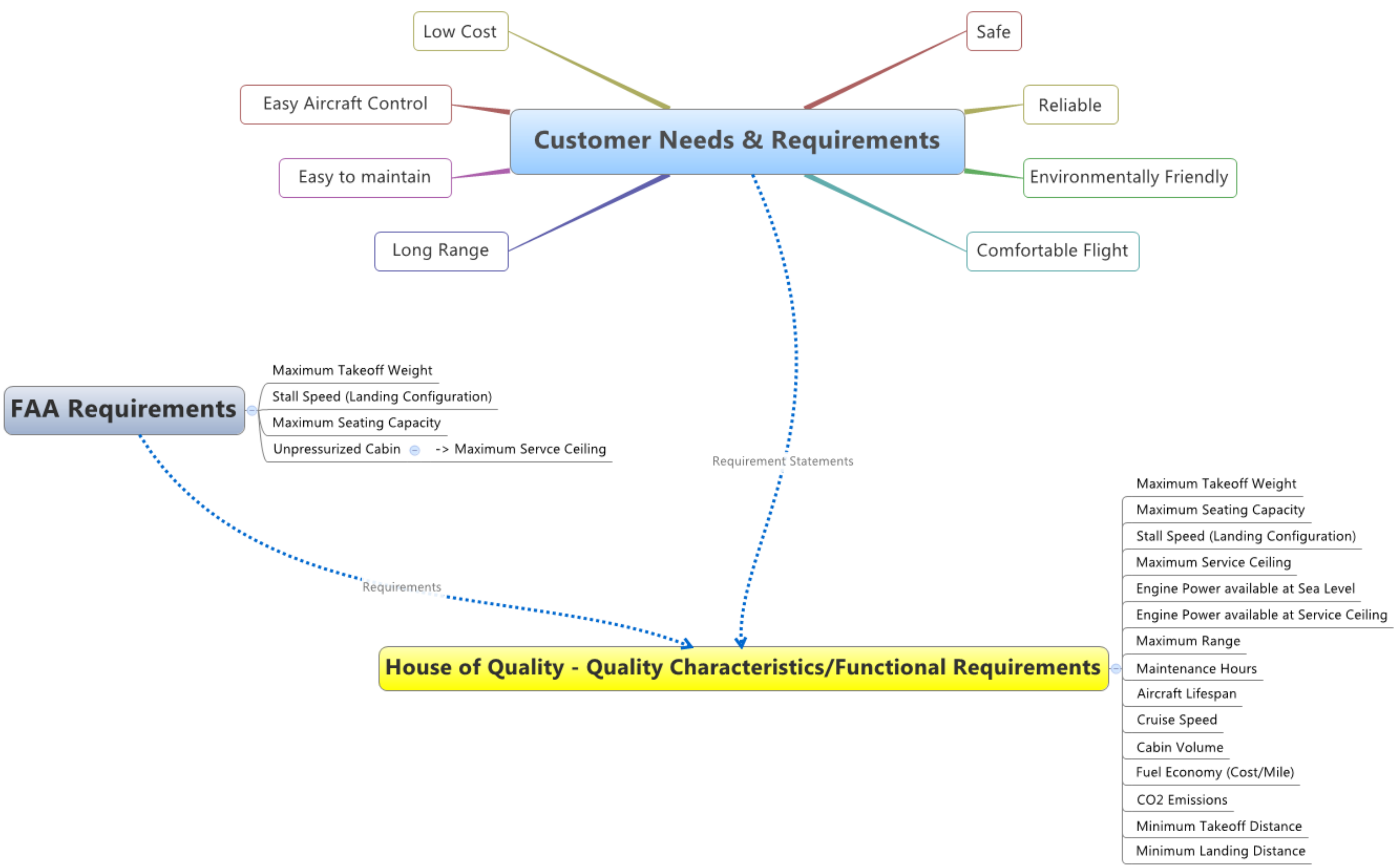
In conclusion, the weight and cost of an electric powerplant for an aircraft are indeed working out to be quite high. Although the calculated figures in the feasibility study are just ballpark estimates for the cost and weight, one can understand the scale of the problem when the power requirements are analyzed. Between the available options, Lithium Ion batteries seem to be the most feasible and practical choice for use in an aircraft. The electric powered aircraft requires radical innovation in the fuel cell and battery area to drastically lower size, weight and cost of fuel cells while being able to supply greater power. The endurance of an aircraft engine and the power output are crucial factors in determining the success of the aircraft in the highly competitive aviation industry. A synthesis of optimized aircraft design, the use of clean energy and efficient motors while maintaining low costs in production will ultimately pave the way for realization of the electric-powered aircraft.

Appendix A – Benchmark Data (Lewis)

Cessna 172	Piper Cherokee	Cirrus SR-22
Maximum Passenger Capacity	*Maximum Passenger Capacity*	*Maximum Passenger Capacity*
4	4	3
Engine	*Engine*	*Engine*
1 X Lycoming O-360 l2a flat 4	1 X Lycoming o 320 D3G	1 X Continental IO-550-N
Power (From Single Engine)	*Power (From Single Engine)*	*Power (From Single Engine)*
160.00 Horsepower	160.00 Horsepower	310.00 Horsepower
Avionics	*Avionics*	*Avionics*
Garmin G1000 glass cockpit	Avidyne Entegra Integrated	Cirrus Perspective Avionics Suite
Maximum Travel Range	*Maximum Travel Range*	*Maximum Travel Range*
687.00 Nautical Miles	513.00 Nautical Miles	1,000.00 Nautical Miles
Service Ceiling	*Service Ceiling*	*Service Ceiling*
13,500.00 feet	11,000.00 feet	25,000.00 feet
Max Cruising Speed	*Max Cruising Speed*	*Max Cruising Speed*
141.00 mph	134.84 mph	252.00 mph
Rate of Climb	*Rate of Climb*	*Rate of Climb*
720.00 fpm	640.00 fpm	1,400.00 fpm
Minimum Take Off Distance	*Minimum Take Off Distance*	*Minimum Take Off Distance*
464.82 meters	493.78 meters	313.33 meters
Minimum Landing Distance	*Minimum Landing Distance*	*Minimum Landing Distance*
381.00 meters	353.57 meters	347.78 meters
Maximum Take Off Weight	*Maximum Take Off Weight*	*Maximum Take Off Weight*
2,450.00 lbs	2,440.00 lbs	3,400.00 lbs
Maximum Payload	*Maximum Payload*	*Maximum Payload*
830.00 lbs	906.00 lbs	1,080.00 lbs
Fuel Tank Capacity	*Fuel Tank Capacity*	*Fuel Tank Capacity*
26.00 gallon	48.00 gallon	92.00 gallon
Fuel Economy	*Fuel Economy*	*Fuel Economy*
26.40 miles per gallon	10.69 miles per gallon	10.87 miles per gallon
Overall Exterior Length	*Overall Exterior Length*	*Overall Exterior Length*
7.67 meters	7.25 meters	7.92 meters
Fuselage Diameter	*Fuselage Diameter*	*Fuselage Diameter*
N/A	1.55 meters	N/A
Wingspan	*Wingspan*	*Wingspan*
10.90 meters	10.67 meters	11.68 meters
Cabin Height	*Cabin Height*	*Cabin Height*
1.22meters	1.24meters	1.27meters
Cabin Width	*Cabin Width*	*Cabin Width*
1.01meters	1.05meters	1.24meters
Cabin Length	*Cabin Length*	*Cabin Length*
3.60meters	3.12meters	3.30meters
Baggage Volume	*Baggage Volume*	*Baggage Volume*
0.00 cubic meter	0.74 cubic meter	0.00 cubic meter
Price	*Price*	*Price*
0.19 Million USD	0.20 Million USD	0.59 Million USD

Appendix B: Overview of HoQ Construction Process

Relative Weight	Customer Need
10.0	Safe
10.0	Reliable
10.0	Environmentally Friendly
8.0	Comfortable Flight
7.0	Long Range
7.0	Easy to maintain
6.0	Easy Aircraft Control
8.0	Low Cost



Appendix C: QFD (House of Quality)

www.ptrivedi.com/projects/electric_aircraft_hoq.pdf

Appendix D: References

Administration, U.S Energy Information. EIA. 31 January 2011. <http://www.eia.doe.gov/oiaf/1605/coefficients.html#tbl2>.

AirNav. 100LL AvGas Price Checker. February 2011. <http://www.airnav.com/fuel/local.html>.

Brandt, Steven A., et al. "Introduction to Aeronautics: A Design Perspective." 2004. 215-217.

Division, Aircraft Maintenance. Flight Standards Service. December 2009. <http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs300/more/>.

E.A.I. Experimental Aircraft Info. 3 3 2011 <http://www.experimentalaircraft.info/articles/aircraft-engine-performance.php>.

Eaves, Stephen. A Cost Comparison of Fuel-Cell and Battery Electric Vehicles. Charlestown, Arizona: Eaves Devices, 2004.

FAA. 14 CFR Part 21. <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&rgn=div5&view=text&node=14:1.0.1.3.9&idno=14#14:1.0.1.3.9.11.11.1>.

—. Federal Aviation Administration. 23 July 2009. <http://www.faa.gov/about/initiatives/atos/air_carrier/roles/>.

Lewis, Venus. Aircraft Compare. February 2011 <http://www.aircraftcompare.com>.

NASA. Standard Day Conditions. 3 3 2011 <http://www.grc.nasa.gov/WWW/K-12/airplane/airprop.html>.

Robertson, David. Times Online. 3 April 2008. 3 3 2011 <http://business.timesonline.co.uk/tol/business/industry_sectors/transport/article3675188.ece>.

S.r.l., DIGISKY. SkySpark. 3 3 2011 <http://www.skyspark.eu/web/eng/index.php>.

U.S.D.E. "Comparison of Fuell Cell Technologies." 2011.

W.E.C. World Energy Council. 3 3 2011 <http://www.worldenergy.org/focus/fuel_cells/380.asp>.

Wood, Janice. General Aviation News. November 2009. <http://www.generalaviationnews.com/2009/11/29/preparing-for-the-end-of-100ll/>.