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Propulsion system for a small unmanned aerial vehicle

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Abstract

For unmanned aerial vehicles there is a wide variety of selection for propulsion systems. Depending on the specific choice of system, the characteristics of the aircraft vary significantly. The choice is also dependent on the size of the UAV itself as well as desired performance and utility. Propulsion systems have made significant advancements over the last decades in the UAV sector. The Skywalker X8 is a popular small UAV and most commonly flown electrically. What propulsion would then be fitting for the originally 2 m wingspan Skywalker X8 if its size in dimensions were doubled. This study presents an early suggestion of a propulsion system for the double sized Skywalker X8. The final propulsion system is a hybrid system consisting of a fuel cell and batteries, giving a time of operational flight of 19 hrs. The results show that the method of choice works as an early design solution of selecting a propulsion system and determining performance. However, it may be an inaccurate representation of the physical model and needs to be followed up by more detailed analysis of the UAV. It is concluded that further experimentation should be done in order to verify the data calculated with this model.

För obemannade flygfordon finns ett stort urval av framdrivningssystem. Beroende på det specifika valet av system varierar flygplanets egenskaper väsentligt. Valet är också beroende av storleken på farkosten själv och önskad prestanda och användbarhet. Framdrivningssystem har gjort betydande framsteg under de senaste decennierna. Skywalker X8 är en populär obemannad luftfarkost och flygs oftast elektriskt. Vilken framdrivning skulle då passa för den ursprungliga Skywalker X8 med 2 m vingspann om dess storlek i dimensioner fördubblats. Denna studie presenterar ett tidigt förslag om ett framdrivningssystem för den dubbelt så stora Skywalker X8. Det slutliga framdrivningssystemet är ett hybridsystem som består av en bränslecell och batterier, vilket ger en drifttid på 19 timmar. Resultaten visar att valmetoden fungerar som en tidig designlösning för att välja ett framdrivningssystem och bestämma dess prestanda. Det kan dock vara en felaktig representation av den fysiska modellen och måste följas upp av en mer detaljerad analys av farkosten. Det dras slutsatsen att ytterligare experiment bör göras för att verifiera de data som beräknats med denna modell.

Contents

Nomenclature

P_r power required, W

T thrust, N

V_∞ free stream velocity, m/s

CG Center of Gravity

CP Center of Pressure

EE Electrical Engine

ICE Internal Combustion Engine

LiPo Lithium Polymer

PEMFC Polymer Electrolyte/Proton Exchange Membrane Fuel Cell

UAV Unmanned Aerial Vehicle

1 Foreword

1.1 Covid-19

This project was started and went on during the Covid-19 outbreak. Due to this occurrence the scope of this report had to be changed. Various resources were no longer available and so the extent of what the study would contain has been altered since what was initially planned for could not be done, such as wind tunnel experiments that would have provided improvement of some of the results. With this mentioned, in any further reading of this article the reader is asked to keep these circumstances in mind.

1.2 Acknowledgements

Special thanks to our supervisor Raffello Mariani for helping us to carry out this project during these exceptional times.

2 Introduction

The UAV industry has grown significantly in the recent years, having a variety of applications in both civilian and military areas such as surveillance, transportation of goods or simply for fun flying. The choice of the propulsion system is crucial for the usability, sustainability and flight endurance of the aircraft. A system which is too difficult to manage could lead to unwanted cost as well as less applicability for civilian usage. Sustainability is important in an environmental sense, the goal is to achieve a net zero carbon footprint and not have any other adverse effect on the environment. The flight endurance dictates the amount of time the UAV can remain in the air. The greater the endurance, the less amount of times the UAV is required to land and refuel during an extended mission. Subsequently reducing the cost in addition to increasing operability.

The propulsion system can be split into four parts: The energy source, the storage media, the mechanical energy converter and finally the lift/thrust converter [1]. When choosing the specific options for the different parts, the main things to consider from a purely performance standpoint are: the specific energy and the amount of stored energy per weight of the energy source. The fuel storage weight percentage is the percentage of weight that is fuel in the energy storage module. The specific power, the power output per unit of weight for the mechanical energy converter. The efficiency per module is the energy losses at each specific point of the propulsion system and what percentage amount of energy is lost for the entire system altogether, from the energy storage to converter.

One common type of UAV on the market is the Skywalker X8. This airplane is characterized by its flying wing design. There are only two main wings attached to the fuselage as seen in figure 1.

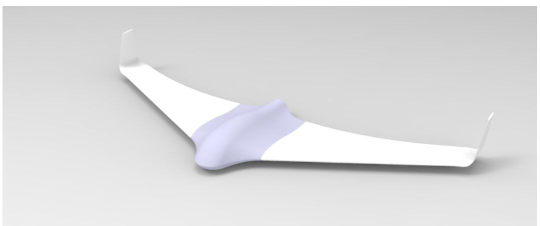

Figure 1: CAD model of the Skywalker X8

The aim of this report is to give insight in the process of choosing a propulsion system for the Skywalker X8 with the properties of a 4 meter wingspan and a body weight of 10 kg (not including the propulsion system), scaled up twice from the original model.

3 Problem

What is a suitable propulsion system for the Skywalker X8 with a wingspan of 4 meters and a body weight of 10 kg that satisfies a moderate ease of use, is sustainable in an environmental sense, as well as having a flight endurance of at least 4 hours in cruise flight. It should also be able to provide enough thrust to fly at an airspeed of 100 km/h.

4 Method

A comparison of the four different modules (energy source, energy storage, mechanical energy converter, thrust converter) of the propulsion system will be made, in respect to specific power/energy, power/energy density, efficiency, operability, sustainability and flight endurance. A suitable propulsion system will then be chosen specifically for the upscaled Skywalker X8.

In order to determine the required properties of the propulsion system, one must assess the operating conditions such as: cruise speed, cruise altitude, the total amount of drag and lift affecting the aircraft and the maximum power output required during the flight (e.g. during takeoff/landing).

In order to determine the lift and drag affecting the aircraft, the tool used will be the software called XFLR5. The optimal angle of attack will be where the lift-to-drag ratio is at its greatest. Cruising at this angle gives the maximum lift for the least amount of power.

Then the approximated model of power required,

$$P_r = TV_\infty$$

where T, being the thrust, and V_∞ the free stream velocity will be used to determine the required specifications of the propulsion system.

Once the comparisons have been made and a propulsion system with its corresponding components have been chosen, the analysis of the aircraft concept is made.

Range and endurance are calculated based on the *Breguet equations*. Only the performance of the fuel cell system is analyzed this way since performance of battery powered aircraft cannot be calculated using the Breguet equations [2].

The propeller efficiency is expected to be around 70%. However, given the flight conditions and the propeller diameter the ideal propeller efficiency can be calculated with the *momentum theorem* [3].

5 Analysis and Results

5.1 Energy Source and Energy Storage

The purpose of the energy source is to provide energy to the relevant systems in the plane. Properties that are relevant to the energy sources are: the specific energy, density and sustainability.

The specific energy is the amount of energy per weight of the energy source, in units *J/kg*: the higher the specific energy the more fuel can be supplied before reaching the maximum take-off weight.

The density of the fuel is the amount of mass per volume of the energy source, in units kg/m^3 and higher density enables the fuel to occupy less space. In small UAVs this property is very relevant since there is often a very limited amount of space on board.

Sustainability is determined by the environmental impact of the fuel. Both the production and the fuel consumption are to be considered during the analysis of the fuels sustainability. Specifically to the fuel, the greatest environmental impact is the release of greenhouse gases such as carbon dioxide or large amounts of non recyclable waste products.

The purpose of the Energy Storage is to have as high percentage fuel weight as possible in order to reduce the overall weight of the propulsion system.

It is also important that the energy source and storage be able to exert the required operational power.

The ultimate goal of the propulsion system is combining high power with high energy and low weight.

5.1.1 Hydrocarbons

Hydrocarbons are chemicals comprised of hydrogen and carbon. The most common hydrocarbons are biofuels, gasoline and jet fuel. Jet fuel has the specific energy of 43 MJ/kg and energy density of 35 MJ/L which allows for good endurance during flights. Biofuels and gasoline have around the same range of specific energy and energy density as jet fuel. The process in which heat is created is through full combustion by the process below:

$$C_xH_y + zO_2 \longrightarrow xCO_2 + \frac{y}{2}H_2O, z = x + y/4$$

The by products are water vapour and carbon dioxide. [4, 5]

5.1.2 Lithium-Polymer Batteries

Lithium-Polymer (LiPo) batteries have a very low specific energy ranging from 0.36-0.72 MJ and a energy density of 0.5-1.5 MJ/l, but tend to have a higher specific power of about 200 W/kg. With these properties, LiPo batteries meet the required operational power very easily for small air crafts, the issues arises with energy capacity. Since the specific energy is at such a low level for a LiPo battery, powering an aircraft for an extended period of time using solely LiPo batteries would lead to a very high aircraft weight. [5]

5.1.3 Ultra-Capacitors

Ultra-Capacitors have the benefits of having a very high specific power, high efficiency, a very fast charging rate in addition to a very long lifetime. In comparison to LiPo batteries, Ultra-capacitors have a 10x higher specific power, slightly higher efficiency, faster recharge rate at the cost of only having one-tenth of the specficic power of batteries. It is therefore more suitable to use an ultra-capacitor where high influxes of power are required for short amounts of time. [5]

5.1.4 Solar Cells

Solar cells are the best energy source in an endurance aspect since it can supply energy for an undetermined amount of time (until component failure) with the sole requirement of the weather being sunny. The energy production from the solar cells is completely clean in an environmental sense as well. There are two major issues with solar cells when implementing it into UAV technology, the first being the weather requirements. It is only possible for solar cells to produce energy when struck by direct sunlight, making the system obsolete during nighttime or cloudy weather. The second issue is the design requirements. Unlike other energy sources volume is not the main issue with solar cells, instead it is the surface area. In order to achieve the surface area required to produce the operational power for the UAV, one must design the fuselage and the airfoil specifically to have high surface area in order for solar cells to be attached. [6]

5.1.5 Hydrogen

Hydrogen has a very high specific energy of 120 MJ/kg, but suffers heavily in regards to energy density [4]. It is converted into energy by using a PEMFC (Proton-exchange / polymer electrolyte membrane fuel cell). PEMFCs function by converting hydrogen and oxygen into water vapour, creating an electric potential as a consequence. PEMFCs have a relatively low specific power output compared to batteries, but make up with higher specific energy with the combination of a hydrogen storage which allows for a higher flight endurance. The efficiency of the fuel cell is about 40-60 % [7] depending on the operating conditions, the losses stem from hydrogen simply not reacting inside the fuel cell. The fuel cell itself requires a constant stream of pure hydrogen from a hydrogen source and oxygen from the nearby air to function, and its only by-product is water which is simply released back into the atmosphere in the form of vapour. The fuel cell also operates at a relatively low temperature of only 50-100 degrees Celsius and does not require any greater amount of cooling compared to an ICE. The electric potential created by the PEMFC is then used in an electrical engine to create torque for the the thrust converter. The PEMFC suffers from a very slow transient response time creating issues when the operational power changes quickly. [8, 9]

5.1.6 Chemical Storage and reforming of hydrogen

Borohydrides are the most common form of chemical storage with sodium borohydride being the most used $NaBH_4(s)$. The sodium borohydride is then soluted in water, with a weight concentration of 25 %. The solution then passively releases pure hydrogen which can be directly supplied to the fuel cell. The release rate of the hydrogen is very slow but can be increased to the wanted level by adding a metal catalyst. Post flight, the by-products can be recycled in its entirety except for the metal catalyst. Sodium borohydride has a slightly higher volumetric density but suffers in regards to usability, the solution has to be prepared right before the flight since the process of releasing hydrogen is always occurring as a solution. [1, 7, 10]

5.1.7 Storage Tank

By far the most efficient storage tank material is that of composite material, they can reach a gravimetric efficiency of 15 %. Steel cylinder tanks in comparison only have a gravimetric efficiancy of 1-3 %. Liquid hydrogen is also an available option, being able to achieve 40 % gravimetric efficiency. An issue with liquid hydrogen is the losses due to evaporation, almost half of the total hydrogen stored on board is evaporated during the flight. With the losses from the fuel cell, this leads to only 25 % of the hydrogen actually being used. At 300 bar the compressed hydrogens energy density reaches 2.25 MJ/l which is low, but reasonable, while liquid hydrogen has an energy density of 8.5 MJ/l. [7]

5.1.8 Hydrogen production

Hydrogen is not found naturally and has to be produced for usage. The current main way to produce hydrogen is through natural gas reforming. The process converts methane into hydrogen and carbon dioxide through a two chain process, first converting the methane + water into carbon monoxide and hydrogen, then the carbon monoxide + water into carbon dioxide and hydrogen [8]. Due to the nature of gasoline powered internal combustion engines and the high specific energy from methane, emissions would be reduced by about 50 % by using hydrogen from natural gas reform instead of gasoline. There are also other ways to produce hydrogen with no carbon emission, this includes electrolysis which converts electricity to hydrogen with an efficiency of around 20-30 %. Other ways are also being researched such as hydrogen extracted from biomass. [11]

5.2 Mechanical Energy Converter

The purpose of the mechanical energy converter is to produce torque for the thrust converter. The most important property is high efficiency, low weight and a rapid transient response. [1]

5.2.1 Internal Combustion Engine

An ICE (Internal Combustion Engine) operates by converting heat into torque by small explosions, the benefit of combustion engines are their high power to weight ratio in addition to having an overall low weight for the entirety of the system. The major issues with the ICEs available for smaller UAVs are their high carbon dioxide emissions, high degree of fuel inefficiency and having a high noise level. [12]

5.2.2 Electrical Engine

Electrical engines have high efficiency, typically around 90 %. They benefit from having a lower thermal and audial noise in comparison to the internal combustion engine, in addition to having a very low maintenance requirement. Electrical engines also have a very fast transient response, being able to quickly change the power output to satisfy the demand required power during acceleration or deceleration. [5]

5.2.3 Hybrid Alternatives

Combining the high specific energy of fuel cells and hydrogen with the high specific power of batteries or ultracapacitors to create a propulsion system with high specific energy, power and low weight in addition to being environmentally friendly. The main idea consists of the fuel cell powering the aircraft during cruise, while the batteries/capacitors function as auxiliary power to the engine during the moments where a higher power consumption is required, such as during take off. The engine of choice for a hybrid propulsion system is the electrical engine. [13]

5.3 Flight conditions

The studied case is of the aircraft in cruise flight, or steady flight, meaning travelling horizontally at a constant altitude. The assumption is made that the angle of attack is small, as well as the angle between flight path and the horizontal line [14]. Hence, the forces acting on the aircraft can be approximated with a free body diagram as in figure 2.

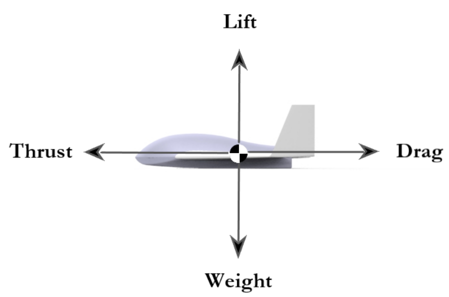

Figure 2: Forces on the aircraft in flight.

The flight conditions are setup for steady cruise flight at a constant altitude of 2000 m. The relationship between the forces are [14]:

$$L = W \tag{1}$$
$$T = D \tag{2}$$

It is emphasized that this is an approximation used best at small angles of attack for the Breguet equations to be valid [14, 15].

5.4 Modelling/Computation Fluid Dynamics

To find the aerodynamics of the airplane an approximate model is designed and analyzed in XFLR5, a platform for 2D and 3D aircraft analysis. Since the wing profile of the X8 is unknown in this case a substitute airfoil, given by the supervisor, is used to represent an estimate for the entire wing as figure 3.

Figure 3: The MH49 airfoil.

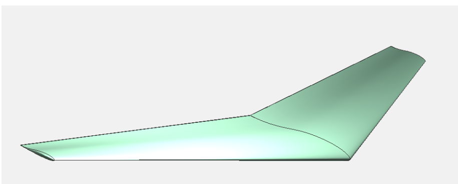

Figure 4: Simplified model of Skywalker X8 in XFLR5.

Wing span	Wing area
4.24 m	3.21 m^2

Table 1: XFLR5 model specifications.

Note that the plane body is modelled without fuselage and winglets partially due to the rough approximative measurements at this stage and method of analysis, software limitations and computational power demands.

The model used for the simulations is shown in figure 4. Specifications are given in table 1.

5.4.1 Angle of Attack

With the results from XFLR5 the drag polar and lift-to-drag ratio is calculated for the case of *constant lift*, meaning the free stream velocity is varied to accommodate for the change in angle of attack such that the the lift is held fixed for the aircraft at all times. For maximum energy efficiency, the UAV is to be flown at and angle of attack of 5.5°, as can be seen in figure 5.

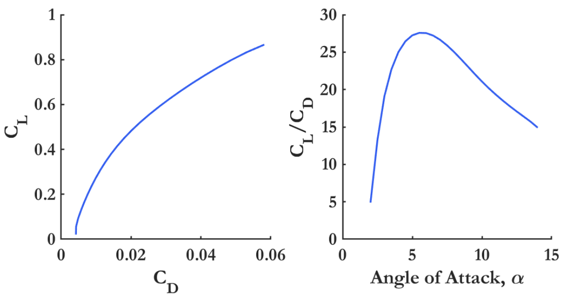

Figure 5: Drag polar and lift-to-drag ratio.

5.4.2 Momentum Theorem

No particular propeller has been chosen since power efficiency is highly dependent on experimental data for the specific design. Instead the momentum theorem has been used to get the ideal efficiency for a propeller given a certain diameter [3]. With the supervisors guidance about propeller size, with the information handed to us that the 12 inch propeller for the originally sized Skywalker X8 was more than enough to power it, the diameter is set to 40 cm or about 16 in. This is merely an educated guess expected to satisfy the thrust requirement. Estimated efficiencies are shown in table 2.

Airspeed	η_p
100 km/h	83 %
50 km/h	80 %

Table 2: Propeller efficiency, η_p.

5.5 Component Choices and Placement

5.5.1 Chosen Components

By going for a hybrid propulsion system there are a few available options on the market. Horizon Energy System provides lightweight fuel cell systems for aerial operations and have proven to satisfy the requirements for this aircraft and have been used in earlier research [13, 9]. Therefore, this is the primary manufacturer's products that have been looked at. After comparing their different products the final components chosen for the propulsion system are:

Part	Product
PEMFC	HES Aerostak A250
Fuel tank	HES F6
Pressure reducer	HES Pressure Reducer
Motor	Turnigy SK3, 5055-280KV

Table 3: Final selected products.

These satisfy the power and energy requirements along with the earlier mentioned benefits of hydrogen powered systems. The mass for all the parts accounted for in the final solution are given in table 4. Mass data is based on manufacturer and retailer specifications, [16, 17]:

Parts	Mass [g]
Fuselage and wings	10000
PEMFC	700
Fuel tank	250
Pressure reducer	280
Fuel, H_2	160
Motor	369
Prop and misc.	500
Total mass	14509

Table 4: Mass of the parts.

5.5.2 Lift and Drag

With lift and drag coefficients, C_L and C_D, lift and drag are easily calculated from the definitions [18],

$$C_L \equiv \frac{Lift}{q_\infty S} \tag{3}$$

$$C_D \equiv \frac{Drag}{q_\infty S} \tag{4}$$

where q_∞ and S are the dynamic pressure and wing planform area respectively, with the data given from XFLR5 results.

5.5.3 Range and Endurance

To calculate range for the PEMFC configuration the Breguet equation for range, and endurance, for propeller engines are used, [14]

$$Range = \left(\frac{\eta}{c}\right)\left(\frac{L}{D}\right)\ln\left(\frac{W_{initial}}{W_{final}}\right),$$

$$Endurance = \left(\frac{\eta}{c}\right)\sqrt{2\rho S}\left(\frac{C_L^{3/2}}{C_D}\right)_{max}(W_{final}^{-1/2} - W_{initial}^{-1/2}),$$

Here η is the motor and propeller efficiency. c represents the fuel consumption rate. $W_{initial}$ and W_{final} are the weights of the aircraft fully fueled and when fuel has been depleted respectively. Since these equations are not feasible for calculating battery performance any recharging capabilities of the PEMFC are omitted [2]. Only energy from the hydrogen will be accounted for.

The engine chosen is the Turnigy Aerodrive SK3 - 5055-280KV which has higher voltage limit as required with regards of the voltage output of the fuel cell [19, 13]. With brushless electric motors known for having an efficiency of around 90% this has been the set value for the calculations.

5.5.4 Velocity

In order for the UAV to stay in air for as long as possible during operation finding the minimum power usage for level flight is of great interest. The speed at which maximum endurance is achieved is given by [14]:

$$V_{max\ C_L^{3/2}/C_D} = \left(\frac{2W}{\rho S}\sqrt{\frac{1}{3\pi ARe C_{D0}}}\right)^{1/2}$$

AR is the wing aspect ratio, e being defined as the wing span efficiency and C_{D0}, the zero-lift drag coefficient.

5.5.5 Power Required

Consequently the power output to generate the minimum thrust to maintain stable flight for maximum endurance is calculated as per definition with [14]

$$P_{required} = TV_{max\ C_L^{3/2}/C_D}$$

where T, the thrust, is for steady flight given by the following equation

$$T = \left(\frac{C_D}{C_L}\right) W,$$

as can be derived from eq.(1-4).

5.6 Performance

The characteristics of this model have a polar and lift-to-drag ratio in accordance with figure 5. The results in table 5 are given from XFLR5 data used in conjunction with the Breguet equations.

Maximum range	1073 km
V_{max} for maximum range	58 km/h
Maximum endurance	19 hrs
V_{max} for maximum endurance	44 km/h
Fuel cell power required at 100 km/h	243 W
Fuel cell power required at 48 km/h	88 W

Table 5: Performance with the fuel cell system.

5.6.1 Stability

Assuming linear scaling and weight distribution of the model, the location of the CG is calculated as twice the distance from the front of the aircraft as stated on the manufacturer's website under specifications [20].

The location of center of gravity is critical for maintaining static stability. The CG should therefore be right on or slightly in front of center of pressure. This way any disturbance causing a change in angle of attack is counteracted by the moment caused by the center of pressure [21]. Preferably the fuel tank should be installed at the CG, thus preventing shifting CG as fuel is depleted over the operational time. In this case however the hydrogen propellant stands for $< 1\%$ of the total weight of the aircraft and such that the change in CG is negligible in this analysis. XFLR5 provides data for CP, but model quality must be taken into account for evaluation of the output accuracy. This is only an estimate until further experimentation has been made.

5.6.2 Placement

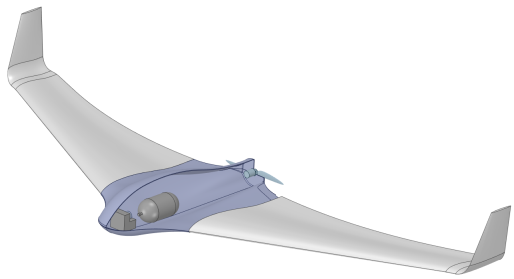

Figure 6: Component placement of the propulsion system.

Most components of the propulsion system are placed in the forepart of the model. This will move the CG as far in front of the aircraft as possible. The PEMFC is placed farthest ahead to maximize performance from easy access of air through inlets around the nose. Following the PEMFC comes the fuel tank. Motor and propeller are installed in a *pusher configuration*, as seen in figure 6.

6 Discussion

The fuel cell manages to stay under 250 W output even at 100 km/h. Its peak power output is 300 W according to the documentation [16]. In short bursts of high power requirements such as during take off and rapid climbing or maneuvering exceeding the rated power output may not be a problem. The Aerostak fuel cell also makes use of its hybrid LiPo battery system to aid the fuel stack where it cannot output the power needed and/or is lacking in dynamic response [16]. So the question then becomes what the effects on the system are if you go over 250 W for a longer period of time. Research has been done trying different battery sources combined with the

Aerostak fuel cell and comparing the differences between them [13].

Another seemingly promising method is to simulate the flight operation with software such as PLA.N.E.S as mentioned in [2]. With this approach they managed to analyze the fuel cell powertrain as well a battery powertrain. Perhaps this could be implemented in a way to account for the battery integrated into the Aerostak 250. Because the Aerostak can recharge its batteries in flight the range and endurance can be expected to be greater than when only accounting for the energy available at takeoff. However this requires a more complex model of the powertrain. And depending on the battery properties the aircraft will have varying performance [13].

The assumption made was that the weight of the aircraft body, that is the fuselage and wings, would weigh 10 kg. This number is motivated by multiplying the size of the original by two, hence a cubic increase in volume and therefore weight as well. This initial preliminary estimation is a "best-guess" value, and does not take into consideration any specific material property or structural design. After discussing with our supervisor, a total of 15 kg was set to be the expected weight of the aircraft (including the propulsion system).

Assembling the propulsion system in the model was done with a few aspects in mind. First being to get CG in the desired location. Results from XFLR5 model and using the data for the Skywalker X8 provided by the manufacturer website, the CG was found to be aft of CP by 196 mm. An attempt was made to move the CG in front of it by putting most of the propulsion system closer to the nose. However, this showed to not be enough. It is difficult to make any conclusion of how close this represent the real life case and should be studied with a more accurate model or through experimental data.

What should be mentioned also is that no payload was accounted for in the calculations. Paylod must be taken into account if this model is to be used in real life applications. Adding payload might change the weight distribution in addition to adding extra weight, this will lead to a decrease in performance. Therefore the endurance of 19 hours should be seen as the performance ceiling as it will have a lesser endurance once payload is added. A couple of kilograms reserve weight assigned for the payload is crucial in order to allow for transportation of miscellaneous items such as cameras for surveillance, or goods in general. Preferably one should place the payload area at the point of desired CG, this is to prevent the CG from changing and as such causing issues with stability.

Unlike most combustion engines, the power generator for the electric motor does not have to be close to the power generator as long as electricity can be transferred. This gives us some freedom in terms of motor and propeller placement. A benefit of this propulsion system regarding the possibility of payload being introduced to the system is that the power generator and fuel storage are relatively free to be positioned wherever they fit best in the fuselage. As an electrical power system it is independent of the motor's location as long as power can be transferred from one to the other.

Moreover the power and fuel systems do not have hard restrictions on the placement in the fuselage, the only restriction with using fuel cell technology is ensuring a stream of air always reaching the fuel cell to supply the required oxygen.

7 Conclusions

This study discusses the choices of a propulsion system for the Skywalker X8 of twice its original size. The suggested system for the requirements initially set is a hybrid system which combines the high specific energy of the hydrogen/fuel cell combination with the high specific power of the LiPo battery. The estimate takeoff weight is 14.5 kg. As follows, the resulting performance shows that in order to achieve the longest possible endurance the UAV should be flown at cruise in 44 km/h. This gives us an endurance of 19 hrs.

It is also concluded that for further work on this system for the UAV this solution method should be used with more accurate data as to give a more accurate representation of the final aircraft characteristics and performance. However this does not change the method used to find the solution.

For a more comprehensive study on the Aerostak hybrid system the battery should be taken into account. The durability and lifespan of this present system is in great interest if it were to be implemented.

In order to account for the entirety of the hybrid propulsion system, a full analysis, including both the power train of the fuel cell and of the battery, should be done.

Installment configurations should be compared with each other. The number of propellers and the placement will affect the performance of the aircraft and depending on mission requirements some configurations might be more suitable than others.

It is also of interest to consider the use of ultra-capacitors in the place of LiPo batteries due to a higher degree of efficiency, a faster recharge rate and a higher specific power.

The choice of propulsion system is highly dependent on mission requirements of the aircraft, expertise and experience of the system of choice and availability of resources.

The fuel cell system brings the benefit of long endurance flight at the expense of energy density. No exhaust gases except for water vapour and the availability of producing hydrogen without CO_2 emissions makes this a possibility of being a green energy source.

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