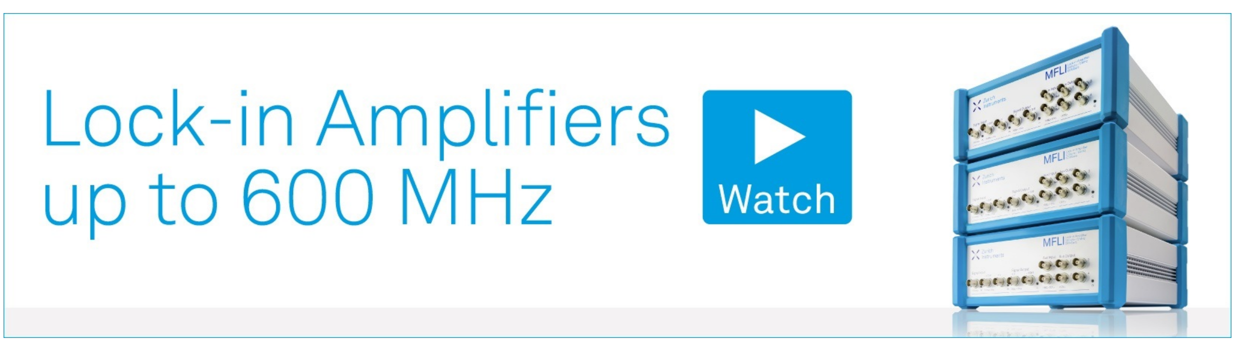
Improving aerodynamic efficiency of a Skywalker drone

Cite as: AIP Conference Proceedings **2233**, 020011 (2020); https://doi.org/10.1063/5.0001918
Published Online: 05 May 2020

Jayavarman, Abdulkareem Sh. Mahdi Al-Obaidi, Swee King Phang, and Yong Guan How



Improving Aerodynamic Efficiency of a Skywalker Drone

Jayavarman [1], Abdulkareem Sh. Mahdi Al-Obaidi [1,a)],
Swee King Phang [1] and Yong Guan How [2]

[1]*School of Engineering, Taylor's University, Malaysia*
[2]*Poladrone Solutions Sdn Bhd, Malaysia*

[a)]*Corresponding author: abdulkareem.mahdi@taylors.edu.my*

Abstract: Nowadays, fixed wing drones are being adapted widely into many industries. However, fixed wing drones are relatively more costly than quadcopter drones and have a lot of improvement to be made. For example, in terms of aerodynamic efficiency. This paper aims to improve the flight time of a Skywalker drone by using a different airfoil for the wing. By implementing an E420 Airfoil to replace its original NACA4412 airfoil, this study proves that the cruising speed of the aircraft is reduced by 45%. On top of that, the change of the airfoil also reduced the drag generated by 67.5%. This is all done by just changing the airfoil of the wing, while still keeping all its geometric design and properties. This study ignores the effects of lift and drag produced by the fuselage and tail of the aircraft and focuses solely on its wing. This study uses analytical and numerical approaches with pending real flight test data to be included to confirm the improvement achieved.

INTRODUCTION

In today's day and age, manned vehicles such as helicopters and planes are rapidly being replaced in some industries by unmanned vehicles. They are beginning to take over industries such as agriculture, architecture, emergency services, engineering and environmental monitoring [1]. In 2010, the market of drones is estimated at $4.9 billion [2]. Based on forecasts, the drone industry is valued to grow to around $127 billion [3]. This proves that the demand for better and more sustainable drones is also growing.

In the mapping industry, drones are equipped with many sensors and data-logging capabilities, which performed better than traditional surveying methods, especially in the agricultural industry [4, 5]. Quadcopters quickly became the most available option for most people as companies began to make them easier to operate and safer without compromising data quality. However, the downfalls of a quadcopter is that it can only be operated for a short time. On average, a quadcopter can operate for around 30 minutes [6]. This is a crucial downfall, as the mapping industry requires these drones to cover vast land at high altitudes. Estates and farms that cover tens of thousands of hectares will hugely benefit from the efficiency of fixed wings has to offer.

Due to this, fixed wing drones become better alternative as they are very efficient with flight times of more than 50 minutes on average. This is because their body is aerodynamically made to generate lift by moving forward. Hence, fixed wing drones only require power to move forward unlike a quadcopter that require power to keep them air bound and to move forward. Due to their efficiency, fixed wing drones are slowly becoming favourable in the mapping and surveying industry. However, fixed wing drones comes at a higher cost compared to quadcopter drones. A common mapping fixed wing drone is the senseFly eBee Classic, which costs $25,000, and it covers a land area of 200 Ha in a single flight of 50 minutes at an altitude of 120 m [7]. Based on the conducted research and study, the most common mapping drones available today ranges with a range from 140 ha - 680 ha. The models are illustrated in Table 1 against its flight time and its cost for each model.

13th International Engineering Research Conference (13th EURECA 2019)
AIP Conf. Proc. 2233, 020011-1–020011-13; https://doi.org/10.1063/5.0001918
Published by AIP Publishing. 978-0-7354-1992-6/$30.00

TABLE 1. Specifications of flying wing models in the market.

Model Name	Flight Time (mins)	Cost (USD)
eBee SQ [8]	55	10,800
Aeromapper EV2 [9]	60	10,500
TuffWing UAV [10]	40	8,000
Xeno FX [11]	40	6,500
E384 [12]	110	3,500

Referring to Table 1, it can be seen that the range of these common models are from 40 minutes to 110 minutes. As for price, it ranges from $3,500 (RM14,500) to $10,800 (RM45,000). An increase in flight efficiency can contribute to the increased use of fixed wings compared to the mainstream usage of quadcopters today. As a result, bigger business opportunities in more diversified sectors other than agriculture, aerial survey and photography can be explored. Since the work focuses on improving the efficiency, a fixed wing body kit, specifically the Skywalker 1800, will be attained to ease the manufacturing process of the fixed wing drone. With this in mind, the goal of the current paper is to improve the flight efficiency of the Skywalker by at least 25%. The Skywalker kit is studied and analysed to see what airfoil it has in its wing and what can be done to improve its aerodynamic performance. The Skywalker 1800 kit is shown in Figure 1.

FIGURE 1. Skywalker 1800 Kit [13]

LITERATURE REVIEW

As stated above, the growing industry of drones' demands for more efficient drones to be made to take on bigger tasks and missions. There are a few fixed wing drones in the industry that are the popular choice for companies that require them for mapping and aerial surveying purposes. These are the senseFly eBee SQ, Aeromapper EV2, TuffWing UAV, Xeno FX and the E384 Drone. On average, these fixed wing drones fly for around 50 minutes, and can cover around 200 ha on average at 120 m altitude.

A crucial design parameter when designing an aircraft is the configuration of its body shape. A study done found that the conventional plane shape is the most stable shape compared to a flying wing configuration. As for the wing platform, the optimum wing platform is a straight wing as long as it is flying in low subsonic speeds [14]. A common material for the manufacturing the body of a fixed wing drone is foam, balsa wood, resin and carbon fiber as they are both light and fairly cheap.

Since these airfoils will be on a drone, which will not travel as fast as a commercial jet, interest was shown towards research for airfoils for unmanned aircraft at low speeds. Typically, remote controlled UAVs operate at a Reynolds number of around $3X10^4$ to $3X10^5$ [15]. A study was carried out to compare the best airfoils used in UAVs which is the EPPLER423, EPPLER420, WORTMANN FX74-CL5-140 and the Selig1223 airfoil. The data acquired from the research is plotted in Figure 2.

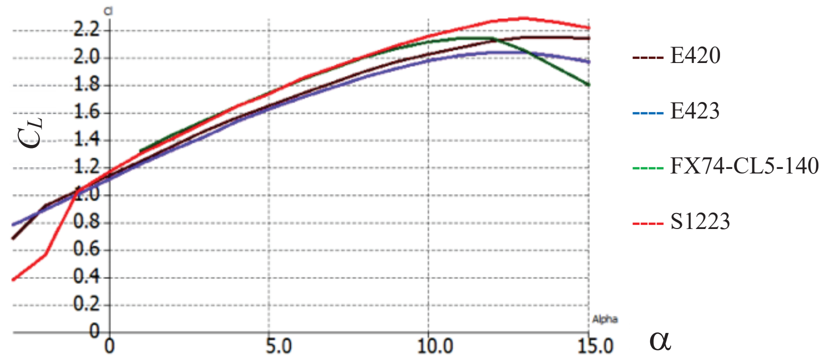


FIGURE 2. Plot of C_L with AoA of -3^0 to 15^0 [16]

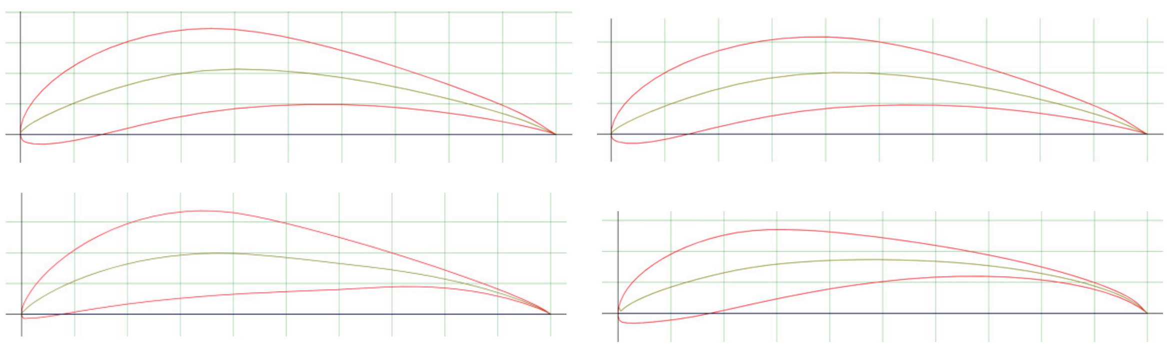


FIGURE 3. E420 Airfoil (Top Left), FX74-CL5-140 Airfoil (Top Right), E423 Airfoil (Bottom Left), S1223 Airfoil (Bottom Right)

The wing section of the Skywalker aircraft was traced on its cross section and found to have an airfoil identical to the NACA4412. From this, the aerodynamic properties of the NACA4412 airfoil will be studied and compared to the airfoils above to see how much better the airfoil performs compared to the original airfoil and choose the perfect airfoil to replace the NACA4412 airfoil to improve its flight efficiency.

A comparison between a flying wing and a conventional plane showed that from efficiency point of view, flying wings are better in terms of efficiency but they are unstable and difficult to control [17]. Flying wings are designed for high-speed applications and not appropriate for short take-offs. As for conventional planes, high-wing planes are said to be perfect for maximizing lifting capacity. It is also found that by tapering the wings of the aircraft closer to an elliptical wing, it would increase the efficiency of the aircraft [18].

The second major component of flight is drag. Drag in the most basic terms, is the "friction" that resists any sort of motion through any given fluid [19]. An example of drag, would be when you put your hand out of the window of a moving car, and feel it push back [20]. Drag is known to be the culprit to reduce efficiency of flight. The higher the drag of an airplane, the lower its efficiency of flight.

Kumar T. R. S. et al. [21] investigated the aerodynamic performance of a two-element camber morphing airfoil at low Reynolds number using the transient SST model in ANSYS FLUENT 14.0 and e^N method in XFLR5. The two-element camber morphing concept was employed to morph the baseline airfoil into another airfoil by altering the orientation of mean-line at 35% of the chord to achieve better aerodynamic efficiency. NACA 0012 was selected as baseline airfoil. NACA 23012 was chosen as the test case as it has the camber-line similar to that of the morphed airfoil and as it has the same thickness as that of the baseline airfoil. The simulations were carried out at chord based Reynolds numbers of 2.5×10^5 and 3.9×10^5. The aerodynamic force coefficients, aerodynamic efficiency and the location of the transition point of laminar separation bubble over these airfoils were studied for various angles of attack. It was found that the aerodynamic efficiency of the morphed airfoil was 12% higher than that of the target airfoil at 4° angle of attack for Reynolds number of 3.9×10^5 and 54% rise in aerodynamic performance was noted as Reynolds number was varied from 2.5×10^5 to 3.9×10^5. The morphed airfoil exhibited the nature of low Reynolds number airfoil.

As a summary, it is seen that there are many perspectives and conclusions, on which airfoil generates the most optimum lift and has a low drag bucket for a UAV fixed wing. This allows a study to choose and implement the best airfoil and body configuration into a real working prototype and carry out a real flight test to further verify the study done.

METHODOLOGY

Analytical Approach

Theoretically, the E420 airfoil has a higher chamber compared to the NACA4412 airfoil, which would result in higher lift. The fundamental equations of lift and drag are used to analyze and compare the effects of the change of airfoil in the airplane to the overall lift and drag of the aircraft. The equations used in this analysis of lift and drag are:

$$L = C_l \frac{1}{2}\rho v^2 S_w \tag{1}$$

$$D = C_d \frac{1}{2}\rho v^2 S_w \tag{2}$$

where C_l and C_d represent the lift and drag coefficient of the wing airfoil respectively, ρ, the density of air at 120 m altitude, v represents the velocity of airfoil, and S_W is the planform wing area.

Prior to the use of the lift and drag equations, the wing of the Skywalker aircraft is analyzed. The chord of the wing at five points along the span is measured and a graph is plotted to figure out the equation of the wing profile to be used for further calculations.

After plotting the points, the line of best fit is generated and its equation, *c(x)*, is integrated to determine the planform wing area using Eq. (3),

$$S_w = 2\int_0^{b/2} c(x)\,dx \tag{3}$$

Once the area of the wing is calculated, the mean aerodynamic chord is calculated using Eq. (4):

$$C_{MAC} = \frac{2}{S_w}\int_0^{b/2} c^2(x)\,dx \tag{4}$$

Finally, the spanwise location of the mean aerodynamic chord is determined by using Eq. (5):

$$y_{MAC} = \frac{2}{S_w}\int_0^{935} c(x)x\,dx \tag{5}$$

The location of the mean aerodynamic chord is used during the simulation stage to obtain the lift and drag values at that exact point.

Numerical Approach

The next step is to model the wing section of the Skywalker in 3D and have a model with the E420 airfoil used in the wing section. This is so the lift and drag values are more credible as they are simulated to the actual wing profile of the aircraft. The simulation process will be aided with the use of the *ANSYS Fluent* software. The wing profiles are first modelled in 3D. The fuselage and tail will be neglected in the simulation as they are not meant to be modified and is to be kept constant during the modification process. The models are first meshed using the Hex Dominant Method with a mesh sizing control applied to it to keep the element sizes at 30 mm. This produced an average

Skewness and Orthogonal Quality of 0.12204 and 0.91781 respectively for the wing with the E420 airfoil. For the wing with NACA4412 airfoil, it produced a Skewness of 0.15782 and an Orthogonal Quality of 0.87179. Referring to Tables 2 and 3, it can be seen that both have a mesh of excellent skewness and very good orthogonal quality.

TABLE 2. Skewness metrics of a mesh.

Excellent	Very Good	Good	Acceptable	Bad	Unacceptable
0 – 0.25	0.25 – 0.50	0.50 – 0.80	0.80 – 0.94	0.95 – 0.97	0.98 – 1.00

TABLE 3. Orthogonal quality metrics of a mesh.

Excellent	Very Good	Good	Acceptable	Bad	Unacceptable
0.95 - 1	0.70 – 0.95	0.20 – 0.69	0.15 – 0.20	0.001 – 0.14	0 – 0.0001

The turbulent model used in this simulation would be the k-∈ model, as it is a common turbulence model and does not require heavy computational power, which in return can save the overall time to run these simulations. The fluid of the study is set to be air and all its physical properties are double checked to be correct. After that, the inlet velocity of the simulation is set to be 11.11 m/s as this is the cruising speed of the aircraft. A velocity monitor will be placed on the mean aerodynamic chord of both wings to study the velocity of air surrounding the wing during cruising flight. These velocity data will be plugged into the standard lift and drag equations to get the lift and drag values of both wings at the stated cruising speed.

Prototype Manufacturing

To further verify the results gathering through calculations and simulations, a real Skywalker kit is built alongside the new E420 airfoil wing, so that real flight tests can be carried out. The Skywalker kit consists of ready-made parts that just needs to be glued and assembled together. As for the E420 wing, it is manufactured using the rib and spar method. The airfoils are made using 3D Printing technology as it is cheaper and provides precise dimensional accuracy, which is important in this study. Carbon fibre tubes are then used as the spar of the wing, due to its lightweight and strong physical properties. After that, the rib and spar is then wrapped with EPO foam to complete the wing build. Figure 4 presents the rib and spar of the E420 wing before being wrapped.

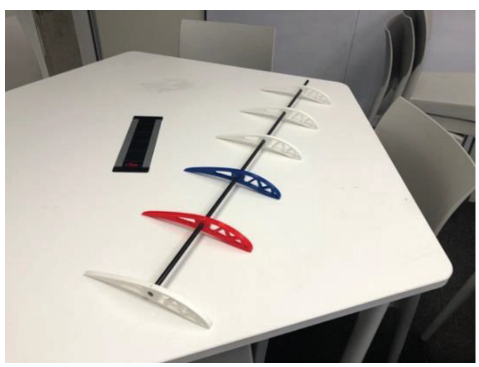


FIGURE 4. Rib and Spar of E420 Wing

Once the wing is built, the control surfaces such as the ailerons are then made. Then, the wiring phase of the wing begins, where the control surfaces are hooked up to a standard servo and wired to the on-board controllers. The aircraft is then equipped with flight controllers and sensors to collect and measure data in real time. A ground control software will be used to measure the flight speed, altitude and location of the aircraft from the ground. Figure 5 shows the completed prototype of the Skywalker kit with the E420 wing.

FIGURE 5. Completed prototype

RESULTS & DISCUSSIONS

Calculations and Simulations

The equation of the wing is first determined by plotting five points along the wing of the kit and measuring its chord length. Then, the curve of best fit is generated and its equation is used for further calculations. It is shown in Figure 6.

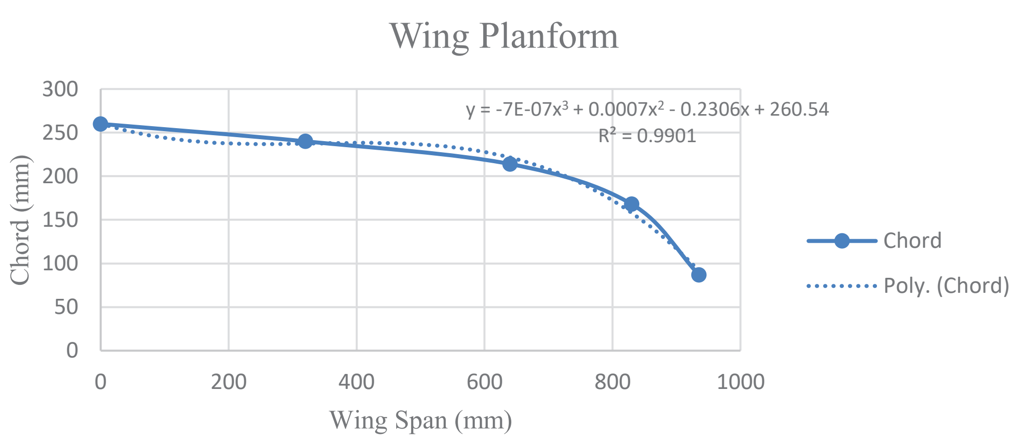


FIGURE 6. Wing planform plot

Integrating the equation would yield the area of the wing, S_W, as in Eq. (3):

$$S_w = 2\int_0^{935} [(-7\times 10^{-7})x^3 + 0.0007x^2 - 0.2306x + 260.54\,]\ dx$$

$$S_w = 399{,}572\ mm^2 = 0.399572\ m^2$$

Next, the mean aerodynamic chord, c_{MAC}, is determined from Eq. (4):

$$c_{MAC} = \frac{2}{399{,}572\ mm^2}\int_0^{935} [(-7\times 10^{-7})x^3 + 0.0007x^2 - 0.2306x + 260.54\,]^2\ dx$$

$$c_{MAC} = 221.29\ mm$$

To determine its spanwise location, y_{MAC} , the values are plugged into Eq. (5):

$$y_{MAC} = \frac{2}{399{,}572\ mm^2} \int_0^{935} [(-7 \times 10^{-7})x^3 + 0.0007x^2 - 0.2306x + 260.54\ ]\ x\ dx$$

$$y_{MAC} = 424.25\ mm$$

Next step, a 2D simulation was ran using XFLR5 with the AG35, E420, E423, FX74_CL5_140 and the Selig1223 airfoils to determine the lift coefficient, C_l against its Angle of Attack (AoA) and compare them with NACA4412 airfoil, which is the default airfoil in the Skywalker 1800 Kit. The results are shown in Figure 7.

From Figure 4, the best airfoil is seen to be the E420 airfoil as it possesses one of the highest lift and lowest drag. Hence, it will be the chosen airfoil to be used in this study to replace the NACA4412 airfoil. Next, a 3D Model of a wing with NACA4412 airfoil and E420 airfoil is made to be simulated in 3D. In this simulation, the inlet velocity will be set a 11.11 m/s as it is the cruising speed. The area of interest is highlighted to be the C_{MAC}, which is 424.25 mm from the center of the wing. The results are seen in Figures 8 and 9.

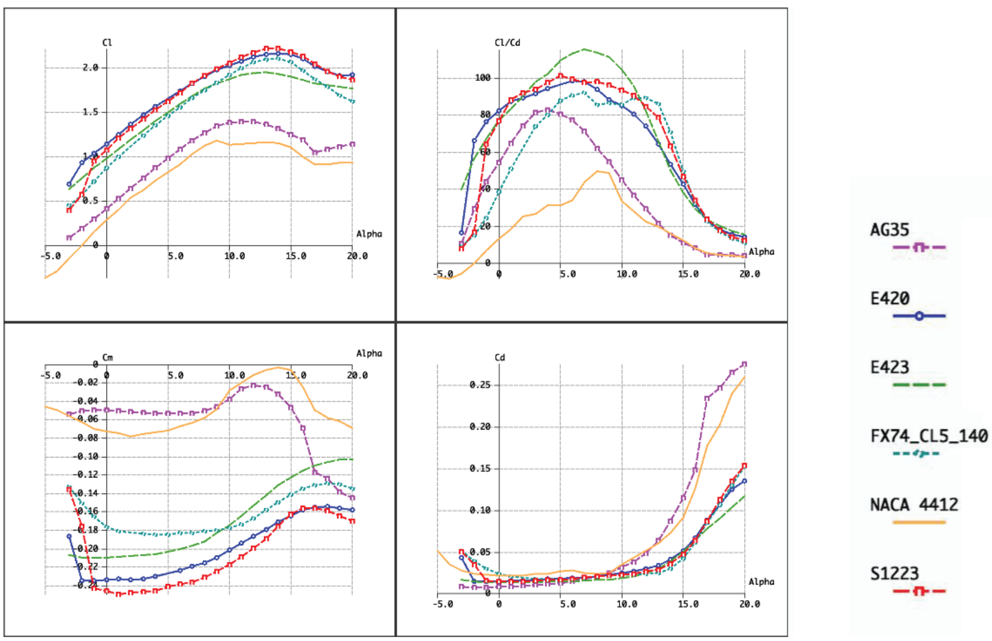


FIGURE 7. Aerodynamic properties of various airfoils

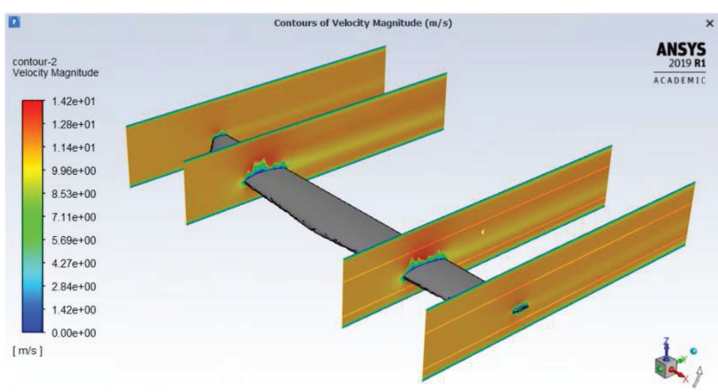


FIGURE 8. Simulation results of NACA4412 airfoil

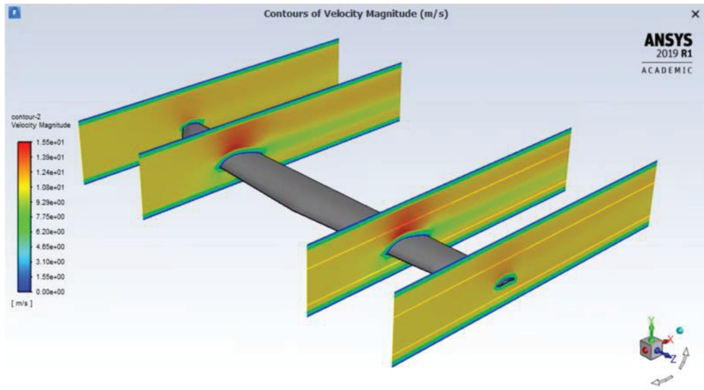


FIGURE 9. Simulation results of E420 airfoil

From there, the velocity data at the c_{MAC} is exported and plugged into Eq. (1) and (2) to obtain the lift and drag plot of both the wings. These data are presented in Figure 10 and 11.

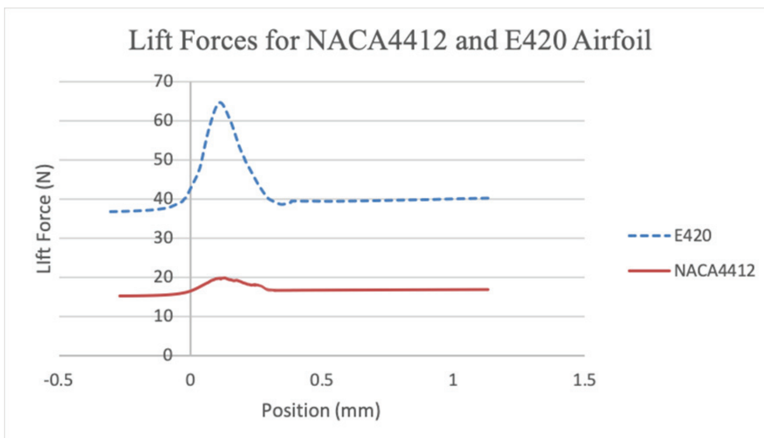


FIGURE 10. Lift forces for E420 and NACA4412 airfoil

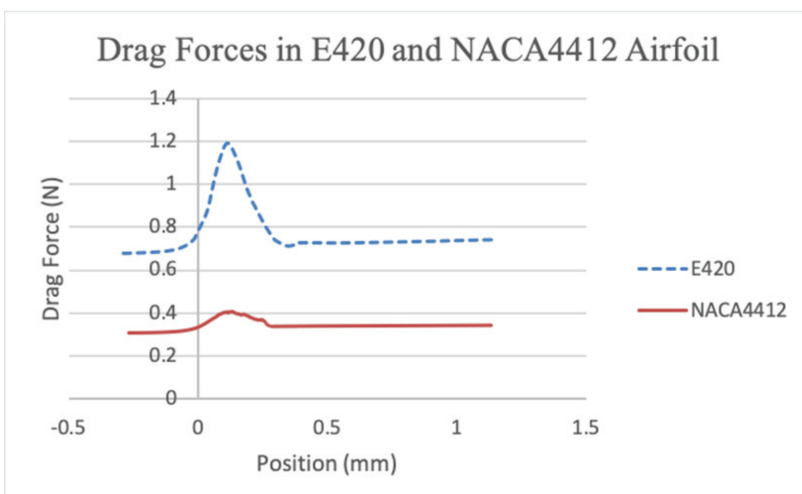


FIGURE 11. Drag forces of E420 and NACA4412 airfoil

It is clear from Figures 10 and 11 that at the same cruising speed of 11.11 m/s, NACA4412 airfoil produces a maximum lift of 19.97 N and a drag of 0.4 N whereas the E420 airfoil produces a lift of around 64.61 N and a drag of 1.19 N. From this, calculations must be done to determine the required speed for the E420 airfoil to produce the same amount of lift as the NACA4412 airfoil at 11.11 m/s, which is 19.97 N. So, simulations are ran again, but this time with inlet velocities of 5.5 m/s , 6 m/s , 6.5 m/s and 7 m/s, to produce a graph whose equation can then be used to calculate the required speed to achieve the required lift. This equation is presented below, where '*y*' represents the lift generated and '*x*' represents the inlet velocity.

$$y = 0.0327x^3 - 0.2455x^2 + 5.7349x - 13.707 \quad (6)$$

Making 'y' to be 19.97 N, the equation will give us three roots, where two of them are imaginary and the only one real root, being 6.16345 m/s. To double check, a simulation is ran with the inlet velocity bring 6.163 m/s and the data shows a maximum lift of 19.90 N and a drag of 0.13 N. These values are tabulated in Table 4 for easier comparison purposes.

TABLE 4. Properties of wing.

	NACA4412 Wing	**E420 Wing**
Inlet Velocity (m/s)	11.11 m/s	6.163 m/s
Lift Generated (N)	19.97 N	19.90 N
Drag Generated (N)	0.4 N	0.13 N

The percentage reduction in speed is calculated as

$$\%\,reduction = \frac{11.11 - 6.123}{11.11} \times 100\,\%$$

$$= 44.9\,\% \approx 45\,\%$$

Since there is also a reduction in drag, the percentage reduction of drag is also calculated as

$$\%\,reduction = \frac{0.4 - 0.13}{0.4} \times 100\,\%$$

$$= 67.5\,\%$$

Assuming an inversely proportional relationship with speed and flight time, as the slower the plane flies, the lesser battery power it has to use to keep the plane airborne, a 45% reduction in speed, would mean a 45% increase in flight time. As the original flight time of the Skywalker is at 60 minutes, the implementation of the E420 aircraft would yield an estimated flight time of 87 minutes. Another crucial parameter when it comes to fixed wings, are the takeoff distance required for the plane. Reducing the takeoff distance of a fixed wing drone can lead to many benefits as it can be used in more places that does not have the luxury of space. Hypothetically, an airfoil with high lift coefficient like the E420 airfoil will require lesser distance to takeoff compared to an airfoil with lesser lift. To analyze the takeoff distance of the Skywalker fixed wing, calculations are done. First, the minimum velocity required for both the wings are calculated using Eq. (7)

$$v_{min} = \sqrt{\frac{2mg}{\rho s C_{L,max}}} \quad (7)$$

where the mass, m, and the gravitational acceleration, g is divided by the density, wing area and maximum lift coefficient of the respective airfoil. For the NACA4412 airfoil

$$v_{min} = \sqrt{\frac{2(3)(9.81)}{(1.211)(0.4127)(1.2)}}$$

$$v_{min} = 9.91 \text{ m/s}$$

For E420 airfoil:

$$v_{min} = \sqrt{\frac{2(3)(9.81)}{(1.211)(0.4311)(2.2)}}$$

$$v_{min} = 7.16 \text{ m/s}$$

From this, the acceleration of the aircraft, a, is assumed to be constant, which means the velocity is halved to obtain the average velocity. For NACA4412, the average velocity will be 4.95 m/s and the E420 is 3.58 m/s. From here, the time taken to reach the average velocity, t, is calculated by multiplying the inverse of the acceleration to the minimum takeoff velocity as seen in Eq. (8). The acceleration of the aircraft is assumed to be 2 m/s^2. So, for the NACA 4412

$$v_{avg} \times \frac{1}{a} = t \tag{8}$$

$$4.95 \times \frac{1}{2} = 2.475 \text{ s}$$

For the E420 airfoil:

$$v_{avg} \times \frac{1}{a} = t$$

$$3.58 \times \frac{1}{2} = 1.79 \text{ s}$$

From this Eq. (9) shows how to determine the required takeoff distance:

$$v_{min} \times t = d \tag{9}$$

where the minimum velocity is multiplied by the time taken to reach the minimum velocity, to find out the distance required to takeoff. So, the values are plugged into Equation 9. For the NACA4412 airfoil:

$$d = 2.475\ (9.91) = 24.53 \text{ m}$$

For the E420 airfoil:

$$d = 1.79\ (7.16) = 12.82 \text{ m}$$

Once the distance required is calculated, the real flight tests are carried out and the minimum distance for takeoff is also measured and compared.

Real Flight Tests

Real flight tests were carried to proof as validation to the data gathered. However, due to time constraints and limited resources, the only parameter that can be measured is the takeoff distance required for the aircraft with both wings. Both tests are launched with constant parameters such as throttle, aileron angle and elevator angle. Hypothetically, the wing with the E420 airfoil would be shorter than the NACA4412 airfoil. Table 5 shows the takeoff distance of both wings along with the parameters of the plane as it takes off. Figure 12 shows the takeoff angle for the aircraft with E420 wing and NACA4412 wing.

TABLE 5. Operating parameters for takeoff.

Wing	Elevon Angle	Takeoff Distance
NACA 4412	15^0	25.5 m
E420	15^0	14.4 m

(a) (b)

FIGURE 12. Takeoff with E420 Wing (a). Takeoff with NACA4412 wing (b)

It can be seen that in Figure 12, that the takeoff angle with the E420 wing has a steeper angle. Due to this, the plane reached stall angle during the flight test right as it took off with an elevon angle of 15^0 while the aircraft with the NACA4412 wing had a proper takeoff. This is due to the different stall characteristics of the airfoils and the fact that the E420 airfoil has greater lift compared to the NACA4412 at the same angle.

The takeoff distance was measured by measuring the tire tracks left on the soft sand on the ground. This served as an easy and accurate way of acquiring the takeoff distance. Based on the data seen in Table 5, the takeoff distance of the aircraft with the E420 wing is around half of the original takeoff distance with the NACA4412 wing. Referring to the calculations made for the takeoff distance in Equation 8, the values are seen to differ quite a little. Table 6 shows the values of the mathematical analysis alongside the real flight tests data.

TABLE 6. Comparison of takeoff distances.

Wing	Calculated Takeoff Distance (m)	Real Takeoff Distance (m)	Percentage Difference (%)
NACA 4412	24.53	25.5 m	3.95
E420	12.82	14.4 m	12.32

The difference for the original wing is small as parameters such as total takeoff weight and the design parameters are accurately made by the manufacturers and all values taken from there are used for the comparison purposes among the two wings. As for the E420 airfoil, since it is manufactured without the ideal resources, can lead to variations in overall shape, lift force and drag compared to the data acquired through the simulations and calculations. Another factor of the difference would be that both tests are done in different runway conditions. The E420 airfoil was done with a rougher ground, which can affect the velocity needed, as rougher grounds require more thrust to overcome the friction. The test with the NACA4412 wing was done on smoother grounds and led to a more accurate data being collected. The reduction in takeoff distance along with the implementation of the new airfoil is calculated by:

$$\%\, reduction = \frac{25.5 - 14.4}{25.5} \times 100\ \%$$

$$= 43.5\ \%$$

This is a 43.5% reduction in takeoff length needed with the new airfoil. Relative to the 45% reduction in cruising speed calculated previously, there is an almost similar reduction in takeoff distance. This proves that the real flight tests are close to the expected values calculated.

CONCLUSION & RECOMMENDATIONS

It can be seen that there are many choices of airfoils to be used in UAVs to obtain the required aerodynamic properties for efficient flight. From the top five airfoils in the UAV sector, which are the AG35, E420, E423, FX74_CL5_140 and the Selig1223 airfoil, it is clear that the E420 airfoil produces one of the highest lift and lowest drag. This is proven above, that when the E420 airfoil replaced the conventional NACA4412 airfoil, the Skywalker UAV can now cruise at much lower speeds without compromising its lift generated. On top of that, the E420 airfoil has reduced the drag generated of the plane at cruising speeds. This is all done without changing any geometric characteristics of the wing, such as its wingspan and shape.

This shows that the implementation of the E420 airfoil has reduced the cruising speed of the Skywalker UAV by 45 % and a reduction in drag by 67.5 % .This would directly translate to lesser power being used by the motors, which means that it can fly longer with the same amount of battery power in a single flight as before. Furthermore, the takeoff distance of the aircraft is reduced by 43.5 %. This is one of the most important result as shorter takeoff distances are one of the most sought after features for fixed wing in the market today. Short takeoff distance allow the fixed wing to be used in locations that do not offer the luxury of space, which contributes to the increase in usage of fixed wing drones in the market.

To further improve this study, the whole body including the fuselage and tail can be included in the simulation process to give a more accurate and comprehensive overview about the changes in aerodynamic properties in the entire plane. Another suggestion would be to run 3D simulations for all the top five airfoils mentioned above and measure the lift and drag generated and compute the cruising speed required for the aircraft to achieve the same lift as its original NACA4412 airfoil. On top of that, wind tunnel tests can be done to scale down prototypes of the Skywalker aircraft, to get a more diverse and accurate set of readings to be compared amongst each other. Finally, more in-depth tests can be carried out which includes data about the flight time, cruising speed, altitude, land coverage in a single flight and many more.

REFERENCES

1. Uzialko, A. (2019). *Cool Business Uses for Commercial Drones*. [online] Business News Daily. Available at: https://www.businessnewsdaily.com/9276-commercial-drones-business-uses.html [Accessed 5 May 2019].
2. tealgroup.com, "Teal group predicts worldwide uav market will total over $80 billion" [online] Available: http://www.tealgroup.com/index.php?option=comcontent&view=article&id=62:uav-studyrelease&catid=3&Itemid =16 [Accessed 5 May 2019].
3. CB Insights Research. (2019). *How Drones Will Impact Society: From Fighting War to Forecasting Weather, UAVs Change Everything*. [online] Available at: https://www.cbinsights.com/research/drone-impact-society-uav/ [Accessed 5 May 2019].
4. Rees, E. (2019). *How Drones Can Optimize Surveying and Mapping Projects*. [online] Available at: https://medium.com/soar-earth/how-drones-can-optimize-surveying-and-mapping-projects-51dc88dbd4d0 [Accessed 5 May 2019].
5. R. C Poornia and S. Gupta, "Highly Dynamic Networks: Current Trends and Research Challenges", *International Journal of Advanced Studies in Computers, Science and Engineering*, vol. 5, no. 6, 2016. [Accessed 5 May 2019].
6. Martinez, K. (2019). *Best Drone With Longest Flight Time [Fall 2019] Longest Flying Drones*. [online] Dronethusiast. Available at: https://www.dronethusiast.com/best-drones-with-longest-flight-times/ [Accessed 14 Oct. 2019].
7. senseFly. (2019). *senseFly - eBee Classic*. [online] Available at: https://www.sensefly.com/drone/ebee-mapping-drone/ [Accessed 5 May 2019].
8. V. Puri, A. Nayyar and L. Raja, "Agriculture drones: A modern breakthrough in precision agriculture", *Journal of Statistics and Management Systems*, vol. 20, no. 4, pp. 507-518, 2017.
9. Sattar, F., Tamatea, L. and Nawaz, M., "Droning the pedagogy: Future prospect of teaching and learning." *International Journal of Educational and Pedagogical Sciences*, *11*(6), pp.1632-1637, 2017.
10. Hill, A.C., "Economical drone mapping for archaeology: Comparisons of efficiency and accuracy." *Journal of Archaeological Science: Reports*, *24*, pp.80-91, 2009

11. CAMERA, M. (2019). *Hitec Xeno FX*. [online] MAPIR CAMERA. Available at: https://www.mapir.camera/products/hitec-xeno [Accessed 14 Oct. 2019].
12. Package, E. (2019). *E384 Complete Package – Event 38 Unmanned Systems*. [online] Event38.com. Available at: https://event38.com/product/e384-complete-package-4/ [Accessed 14 Oct. 2019].
13. GmbH, m. (2019). *New Skywalker 1800 kaufen | FPV24.com*. [online] Fpv24.com. Available at: https://www.fpv24.com/en/skywalker/new-skywalker-1800 [Accessed 14 Oct. 2019].
14. M. Ariyanto, J. Setiawan, T. Prabowo, I. Haryanto and Munadi, "Design of a Low-Cost Fixed Wing UAV", *MATEC Web of Conferences*, vol. 159, p. 02057, 2018. Available: 10.1051/matecconf/201815902057.
15. Merchant, M. and Miller, L.S., Propeller performance measurement for low Reynolds number UAV applications. In *44th AIAA Aerospace Sciences Meeting and Exhibit* (p. 1127), January 2006.
16. "Performance Analysis and Comparison of High Lift Airfoil for Low-Speed Unmanned Aerial Vehicle", in *International Conference on Mechanical, Industrial and Energy Engineering 2016*, Bangladesh, 2016.
17. Bolsunovsky, A., Buzoverya, N., Gurevich, B., Denisov, V., Dunaevsky, A., Shkadov, L., Sonin, O., Udzhuhu, A., and Zhurihin, J., "Flying wing - problems and decisions". Aircraft Design, 4, pp. 193–219, 2001
18. Koma, A.Y., Afshar, S., Maleki, H., Mohammadshahi, D. and Shahi, H., "Design and fabrication of delta wing shape MAV" In *WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering* (No. 10). World Scientific and Engineering Academy and Society, May 2008
19. H. Garden, "How Airplanes Work", *HowStuffWorks*, 2019. [Online]. Available: https://science.howstuffworks.com/transport/flight/modern/airplanes1.htm. [Accessed: 15- Jun- 2019].
20. "NASA - The Four Forces of Flight", *Nasa.gov*, 2019. [Online]. Available: https://www.nasa.gov/audience/foreducators/k-4/features/F_Four_Forces_of_Flight.html. [Accessed: 15- Jun- 2019]
21. Kumar, T. R. S., Sivakumar, V., Ramakrishnananda, B., Arjhun, A.K, Suriyapandiyan, "Numerical investigation of two element camber morphing airfoil in low Reynolds number flows". Journal of Engineering Science and Technology, vol. 12, no. 7, pp. 1939–1955, 2017.