Title: Maximizing Fixed Wing UAV Flight Time Through Computer Simulation

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Abstract:

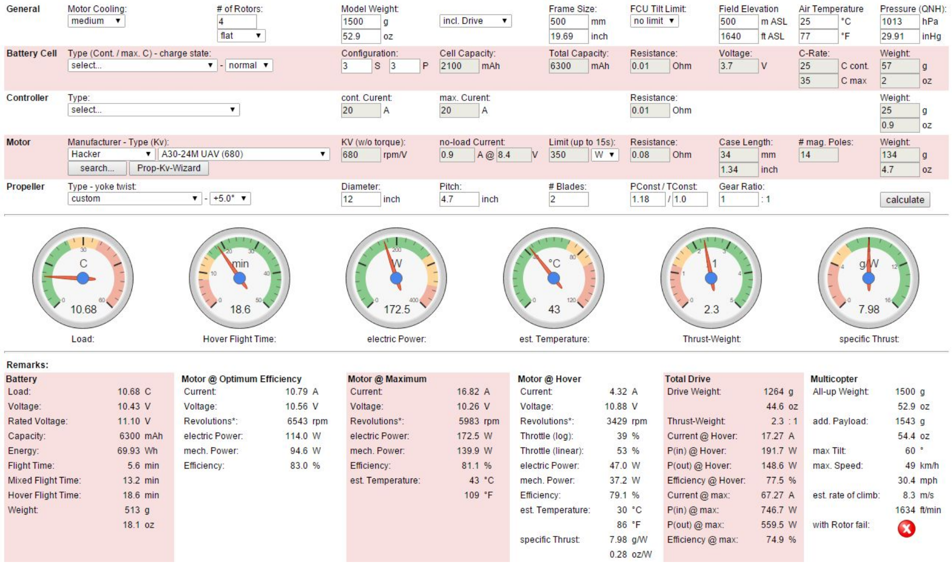
Increasing UAV flight time increases the number of applications for UAVs. This experiment designs and simulates a model that can fly for 65.8 minutes by using the programs ECALC and XFLR5. Through simulation airflow testing in previous studies, a “flying wing,” or delta design, with a high camber airfoil, is selected for a proposed airframe type. NACA value 2411 was used for the high camber foil and simulated in XFLR5. Electronics are determined by the size, weight, torque, and demands of the aircraft and are simulated through use of the program ECALC. The results of trials through programs ECALC and XFLR5 indicate that the aircraft can fly for over an hour.

Introduction:

Remote Control (RC) or Unmanned Aerial Vehicle (UAV) technology has increased rapidly in the past 10 years, creating a large market for use and research. Currently, there are many applications for use of UAVs in multiple fields. According to Boccardo et al, some examples would be “disaster mapping and information gathering, community capacity building, logistics, and even transportation of goods” (Boccardo, P., et al, 2015). Additionally, the police force uses multiple different types of UAVs for easy, transportable, short range surveillance and tracking. These UAVs can be used as “high-altitude moving camera[s] to cover a much wider area” than other forms of surveillance (Yalong, M., et al, 2016) (Kai-Wei, et al, 2015). However, the range and or applicability is directly affected by flight endurance. To obtain decent usable flight time, a combination of weight, motor type, aerodynamic factors, and battery capacity as well as voltage and power rating has to be balanced to an optimal point (Gabriel, et al, 2011). As per the universal laws of aerodynamics, the main forces that act upon an aircraft in flight are:

"thrust, lift, drag, and obviously the gravitational force that acts downward" (Zaharia, S. M., 2015). One of the direct and most essential aspects of any aircraft is the type of airfoil (wing shape) used. There are many types of airfoils, and "the loss of lift of flow around the [airfoil] body directly depends on the body's shape" (Kostić, Č., et al, 2016). A high lift or high camber wing (for maximum efficiency) will be chosen for the UAV. For most applications (police, military, general), the aircraft must be able to fit in the back of a car. For the aircraft's electronics and systems, a brushless motor and propellor, electronic speed controller (ESC), and lithium polymer (LiPo) battery will be required at minimum and will be integrated into the simulation.

To ensure maximum efficiency and therefore flight time, an online database and program called ECALC are used in order to calculate flight electronics. The site contains a vast brushless motor database as well as other electronics to calculate variables such as flight time, amp draw, temperature of electronics, propellor size, and thrust generated (see Fig 1).



General
Motor Cooling: medium
\# of Rotors: 4 flat
Model Weight: 1500 g / 52.9 oz incl. Drive
Frame Size: 500 mm / 19.69 inch
FCU Tilt Limit: no limit
Field Elevation: 500 m ASL / 1640 ft ASL
Air Temperature: 25 °C / 77 °F
Pressure (QNH): 1013 hPa / 29.91 inHg

Battery Cell
Type (Cont. / max. C) - charge state: select... - normal
Configuration: 3 S 3 P
Cell Capacity: 2100 mAh
Total Capacity: 6300 mAh
Resistance: 0.01 Ohm
Voltage: 3.7 V
C-Rate: 25 C cont. / 35 C max
Weight: 57 g / 2 oz

Controller
Type: select...
cont. Curent: 20 A
max. Curent: 20 A
Resistance: 0.01 Ohm
Weight: 25 g / 0.9 oz

Motor
Manufacturer - Type (Kv): Hacker - A30-24M UAV (680)
KV (w/o torque): 680 rpm/V
no-load Current: 0.9 A @ 8.4 V
Limit (up to 15s): 350 W
Resistance: 0.08 Ohm
Case Length: 34 mm / 1.34 inch
\# mag. Poles: 14
Weight: 134 g / 4.7 oz

Propeller
Type - yoke twist: custom - +5.0°
Diameter: 12 inch
Pitch: 4.7 inch
\# Blades: 2
PConst / TConst: 1.18 / 1.0
Gear Ratio: 1 : 1

Remarks:

Battery		
Load:	10.68	C
Voltage:	10.43	V
Rated Voltage:	11.10	V
Capacity:	6300	mAh
Energy:	69.93	Wh
Flight Time:	5.6	min
Mixed Flight Time:	13.2	min
Hover Flight Time:	18.6	min
Weight:	513	g
	18.1	oz

Motor @ Optimum Efficiency		
Current:	10.79	A
Voltage:	10.56	V
Revolutions*:	6543	rpm
electric Power:	114.0	W
mech. Power:	94.6	W
Efficiency:	83.0	%

Motor @ Maximum		
Current:	16.82	A
Voltage:	10.26	V
Revolutions*:	5983	rpm
electric Power:	172.5	W
mech. Power:	139.9	W
Efficiency:	81.1	%
est. Temperature:	43	°C
	109	°F

Motor @ Hover		
Current:	4.32	A
Voltage:	10.88	V
Revolutions*:	3429	rpm
Throttle (log):	39	%
Throttle (linear):	53	%
electric Power:	47.0	W
mech. Power:	37.2	W
Efficiency:	79.1	%
est. Temperature:	30	°C
	86	°F
specific Thrust:	7.98	g/W
	0.28	oz/W

Total Drive		
Drive Weight:	1264	g
	44.6	oz
Thrust-Weight:	2.3	: 1
Current @ Hover:	17.27	A
P(in) @ Hover:	191.7	W
P(out) @ Hover:	148.6	W
Efficiency @ Hover:	77.5	%
Current @ max:	67.27	A
P(in) @ max:	746.7	W
P(out) @ max:	559.5	W
Efficiency @ max:	74.9	%

Multicopter		
All-up Weight:	1500	g
	52.9	oz
add. Payload:	1543	g
	54.4	oz
max Tilt:	60	°
max. Speed:	49	km/h
	30.4	mph
est. rate of climb:	8.3	m/s
	1634	ft/min
with Rotor fail:	☒	

Fig 1: ECALC Website

The lithium polymer battery will be simulated during trials due to its high energy density, light weight, scalability, and compatibility with brushless motors and ESCs and is measured in milliamp hours (mah). The lithium polymer or “Lipo” for short has a higher energy density and is lighter than other batteries of this scale, making it the ideal choice due to weight constraints and power needs. The higher the capacity, (greater the mah) the longer the battery can power the electronic systems, and the longer the flight time can be. However, a higher capacity means a heavier battery, which would add excess weight to the airframe, resulting in negative aerodynamic effects. Currently, the brushless motor is the industry standard and provides adequate thrust for its light weight (Shen, S., & Zhou, P., 2016). The reason brushless motors are selected over brushed motors is due to several factors: brushed motors have a much lower power output; don’t last as long; and are overall lower quality. Brushless motors have less friction due to the geometry of the magnets and coils. Instead of having tight coils centered around the outside of a shaft, they contain permanent magnets on the outside and electromagnet coils on the inside, with a small space in between. Overall, they are more efficient and more applicable for use on UAVs. A speed controller (ESC) wired to the motor is also needed in order to control power output and distribution to all extra aircraft systems. Besides managing power output, speed controllers adjust the RPM of the motor depending on signal from operator, meaning if the throttle stick is pushed forward on the transmitter, the RPM and power will increase.

For ECALC analysis, the thrust to weight ratio should be at minimum 1:1 to ensure the aircraft is able to stay airborne -- therefore setups that return values under a 1:1 thrust to weight ratio will be marked as not applicable (Shen, S., & Zhou, P., 2016). For this experiment, flight time and thrust to weight ratio will be the important tested factors, and other variables will be held in applicable zones.

For the aircraft design, the XFLR5 program simulates entire aircraft in the form of a 3D model. Aircraft wings are in the geometric shape of an airfoil, which enables the aircraft to generate lift (Kostić, Č., et al, 2016). By having higher camber on the top of the wing and less on the bottom, the airflow has to travel faster over the top of the wing in order to meet up with the slower particles flowing on the bottom. This creates an area of high pressure under the wing and low pressure above the wing (Kostić, Č., et al, 2016). The pressure differences on both sides of the airfoil produce lift. In order to categorize airfoils, NACA (National Advisory Committee for Aeronautics) classification is used. Airfoil shapes are stored in 4-6 digit alphanumerical values, and can be used in various simulations and design applications. XFOIL is a good example of a program that utilizes these values -- it is used for simulating airflow over different 2D airfoil types. XFLR5 uses assets from XFOIL to generate 4-5 digit NACA airfoils and runs them fixed to a wing shape, designed by user, using different variables set constant (i.e. fixed lift, fixed airspeed). As stated above, the aircraft should have a higher lift wing, therefore the NACA value should correspond with a shape that contains a high camber, meaning high lift (in order to fit the surveillance application purposes) (Triputra, F. R., et al, 2015).

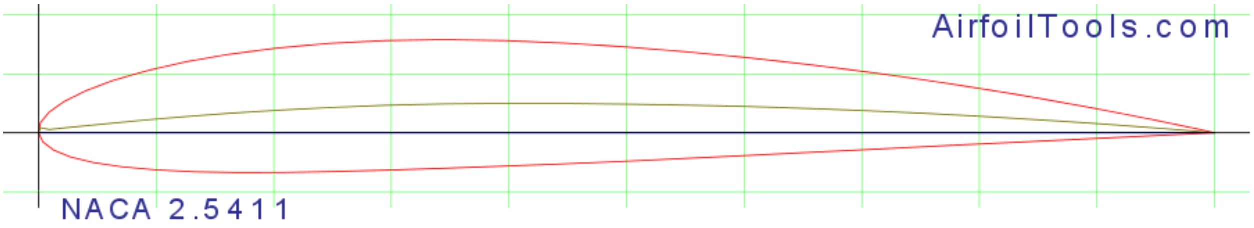


Fig 2: NACA airfoil value 2411 (high camber = high lift + low speed)

However, because this is a delta wing design, the airfoil must be self-stable (Basic, 2013). Because XFLR5 cannot directly modify the 2411 airfoil, future work will have to be done in order to modify it so that it is self stable. Self stable airfoils have a reflexed camber line, meaning that the tail of the airfoil points up as opposed to pointing downward. Figure 2 is an example of an airfoil with a tail pointing down. Overall, the aerodynamic efficiency of the aircraft is “determined by the lift to drag ratio of the wing” (Mueller, T. J., & DeLaurier, J. D., 2003). Through the use of the programs ECALC, and XFLR5, a UAV that meets the previously stated standards will be designed and simulated.

Objectives/Purpose:

Design a system for uses in 3D mapping, surveillance, fire fighting, reconnaissance, etc. Have a simulated flight time of 30-60+ minutes and a thrust to weight ratio of at minimum 1:1. Simulate the craft design in order for it to fit in the back of the trunk of a police cruiser or small car. Options for expansion (in complete design, not simulated): OSD (on screen display or automated flight controller), solar cells on wings, multiple sizes for different uses.

Hypothesis/Predicted Results:

Once the right combination of electronics, battery size, and aerodynamic airfoil type are factored into the simulations, the UAV will be simulated to fly for 30-60+ minutes. Additionally, the wing design simulated in XFLR5 will be aerodynamically sound in preliminary analysis with NACA airfoil value of 2411 (high camber).

Materials:

- Computer
- ECALC Program

- XFLR5 Program
- http://fwcg.3dzone.dk/ website (for CG calculation)

Safety Issues:

- Computer/hard drive failure
- Data corruption

Methods:

The project was done entirely through computer simulation and theoretical analysis.

Part 1 (Electronics simulation and flight time):

Controls: Model weight, wing area, battery size (initial), battery cells, ESC, Motor, prop brand

Independent Variables: Prop size, prop pitch, battery size (end)

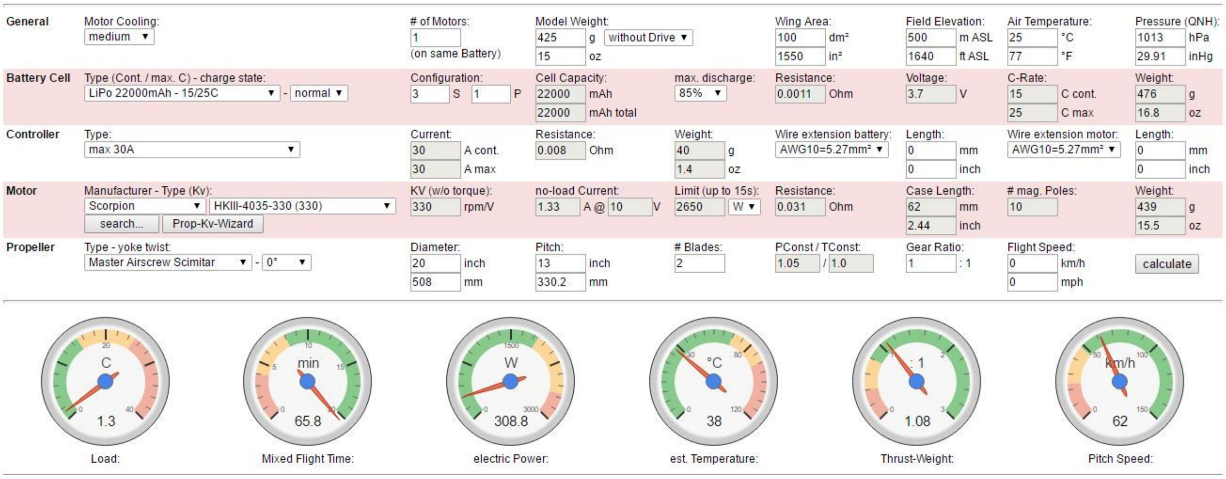
Dependant Variables: Flight Time, Thrust to weight ratio

In this step, the most optimal and efficient electronics were selected to achieve a simulated runtime of 30-60+ minutes. A brushless motor was selected for simulation that had a relatively low RPM for low amp draw. During this process, ECALC (program used for calculating efficiency and power-to-weight ratios of RC aircraft using an extensive motor database) was used not only to find the correct motor but also to find the correct propellor size. Scorpion brand motors were selected for use due to high strength wire wind rated for up to 180 degrees C, custom CNC cut material for best fit, and high efficiency (Scorpion, 2015). Each calculated value for thrust to weight ratio of the aircraft had to be at or above 1:1, and the temperatures and amp draw were held constant at a manageable value (within rating and no simulated overheating). The speedometer graphs indicated a green zone, where the range of each controlled value or independent variable was applicable. In order to more efficiently determine optimal values, a system of data tables was created. The appropriate motor that best fit the project goals was found in preliminary testing, and the data collection was based off of this motor (HKIII-4035-330). To record data, the prop brand, battery size, ESC size, and weight without drive (all other variables) were held constant and unchanged throughout sections of isolated testing. In each section the number of prop blades was held constant. In order to evaluate the motor, the number of battery cells was held constant throughout at 3 cells (more cells = greater electric current). The prop size was then adjusted within the available limits of the motor. Within each prop size, the prop pitch was adjusted until stall occurred at the blade tip and thrust was no longer possible (blue error message). The process was continued for different numbers of propellor blades. The end result of each trial returned the flight time and thrust to weight values. Using this list, thrust ratios between 1:1 and 1:1.1 were separated from those greater that 1:1.1. Using the ratios greater than 1:1.1, battery size was increased in order to increase flight time (greater thrust means more allocated weight for a larger battery). After completion of electronics evaluation, the wing area was set to allocate for appropriate wing loading (15 oz/sq ft max) and the values for overall weight were put into XFLR5 to continue airfoil and design analysis (Gabriel, D. L., et al, 2011).

Part 2 (designing aircraft): XFLR5 was used to simulate aircraft design. The aircraft shape was set to that of a swept wing (no fuselage/body) to maximize drag and ensure maximum efficiency through eliminating the fuselage. Wingspan was set to 2 meters with a 30 degree sweep (angle of wings in relation to each other) as to fit the project goals, then the wing area was adjusted accordingly to fit the wing loading calculated in ECALC (1 meter squared). The wing NACA airfoil value was set to that of a high lift, high camber type (2411). Vertical stabilizers were included in appropriate wingtip locations at 1 meter distance on one side, then mirrored to account for the other side. The stabilizers were placed to ensure correct tracking would occur and lift and drag is calculated as accurately as possible. NACA values for the stabilizers were set to that of a symmetrical airfoil so the airflow flowed evenly on both right and left sides (0008) (having an asymmetrical airfoil would disrupt the airflow and create tracking issues). The weight of each component (calculated through ECALC) was put into fixed point weight values and placed in respective positions. Motor weight (439 g) was placed at rear center of wing at position (500, 0, 0) (to provide rear-facing thrust). Battery and ESC weight were adjusted and corrected for appropriate positions within the body of the aircraft. The battery is placed far forward at (-90, 0, 0) in order to help balance out the center of gravity at 115 mm from leading edge, which should be approx. ⅓ of the wingspan from the leading edge and ahead of the neutral point, but calculated with online delta calculator: http://fwcg.3dzone.dk/. The ESC was placed at (50, 0, 0). Analysis parameters were calculated for each 2D airfoil, and then run for viscous fluid for the aircraft with flight speed (35 mph, calculated in ECALC) set constant using analysis method T1-35.0 mph-VLM2-proj_area. Data points were set for -5 degrees to 15 degrees of angle of attack, and delta (change in value) was set to .5 degree intervals. Analysis returned lift concentration points and airflow over each surface of the wing at each angle of attack (color spectrum in 3D model), and graphs indicating coefficient of lift, coefficient of drag, pitching moment coefficient, and alpha (angle of attack).

Results:

A Scorpion HKIII-4035-330 was used in the final analysis, and spun a 20 x 13 inch 2 blade prop which was simulated in ECALC to provide over 1:1 thrust to weight ratio.



General	Motor Cooling: medium ▼	# of Motors: 1 (on same Battery)	Model Weight: 425 g without Drive ▼ 15 oz		Wing Area: 100 dm² 1550 in²	Field Elevation: 500 m ASL 1640 ft ASL	Air Temperature: 25 °C 77 °F	Pressure (QNH): 1013 hPa 29.91 inHg
Battery Cell	Type (Cont. / max. C) - charge state: LiPo 22000mAh - 15/25C ▼ - normal ▼	Configuration: 3 S 1 P	Cell Capacity: 22000 mAh 22000 mAh total	max. discharge: 85% ▼	Resistance: 0.0011 Ohm	Voltage: 3.7 V	C-Rate: 15 C cont. 25 C max	Weight: 476 g 16.8 oz
Controller	Type: max 30A ▼	Current: 30 A cont. 30 A max	Resistance: 0.008 Ohm	Weight: 40 g 1.4 oz	Wire extension battery: AWG10=5.27mm² ▼	Length: 0 mm 0 inch	Wire extension motor: AWG10=5.27mm² ▼	Length: 0 mm 0 inch
Motor	Manufacturer - Type (Kv): Scorpion ▼ HKIII-4035-330 (330) ▼ search... Prop-Kv-Wizard	KV (w/o torque): 330 rpm/V	no-load Current: 1.33 A @ 10 V	Limit (up to 15s): 2650 W ▼	Resistance: 0.031 Ohm	Case Length: 62 mm 2.44 inch	# mag. Poles: 10	Weight: 439 g 15.5 oz
Propeller	Type - yoke twist: Master Airscrew Scimitar ▼ - 0° ▼	Diameter: 20 inch 508 mm	Pitch: 13 inch 330.2 mm	# Blades: 2	PConst / TConst: 1.05 / 1.0	Gear Ratio: 1 : 1	Flight Speed: 0 km/h 0 mph	calculate

Load:	Mixed Flight Time:	electric Power:	est. Temperature:	Thrust-Weight:	Pitch Speed:
1.3 C	65.8 min	308.8 W	38 °C	1.08 : 1	62 km/h

Fig 3: Raw ECALC data

The speedometer graphs indicate each returned value being tested in the simulation, including all variables used and results. Load, electric power, temperature, and pitch speed were all set to a value within the green zone -- the range for acceptable specifications. The portion of the diagram above the speedometer graphs is the input area -- where user parameters are entered for each run. In the “General” category, the control variables changed from default were model weight and wing area. In the “Battery” category, the type/C rating drop down menu was changed to the 22,000 size, and the “Configuration” was set to 3S 1P, meaning a 3 cell battery in a 1 cell series (linear, one cell per unit). In the “Controller” category, the “Type” was set to 30A, allocating for the amp draw from the motor. The “Motor” category had the Scorpion HKIII-4035-330, and the “Propellor” category had a Master Airscrew Scimitar 20x13 inch prop.

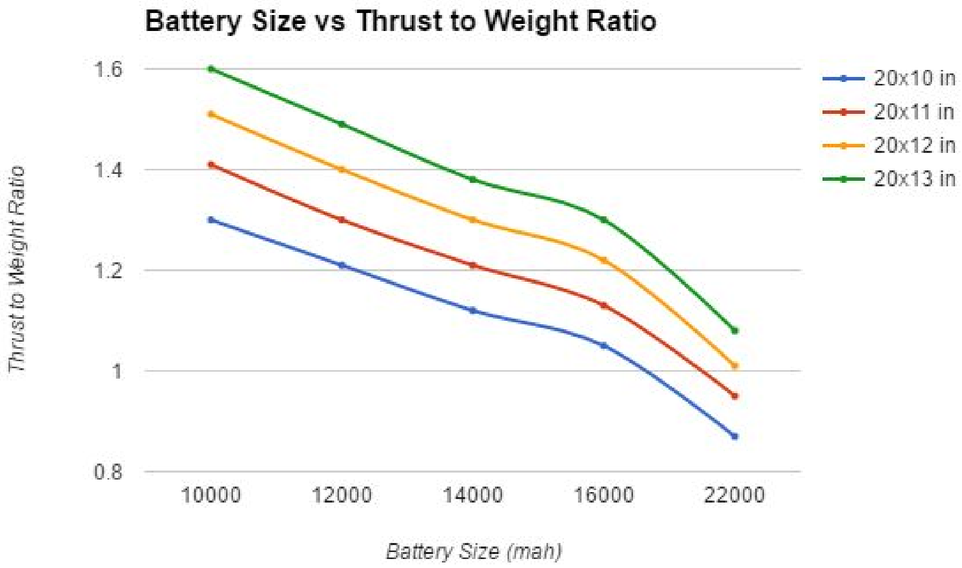


Fig 4: Battery Size vs Thrust/Weight Ratio ECALC Data

For each propellor size, the thrust to weight values decreased at constant rates and at similar intervals of separation. The pattern and nearly identical curve of each plot shows the consistency of the ECALC simulation and methods. Flight time was simulated to be 65.8 minutes running the electronics setup above. The battery size was a 22,000 mah (max for simulation) 3 cell, and rated for 15/25C.

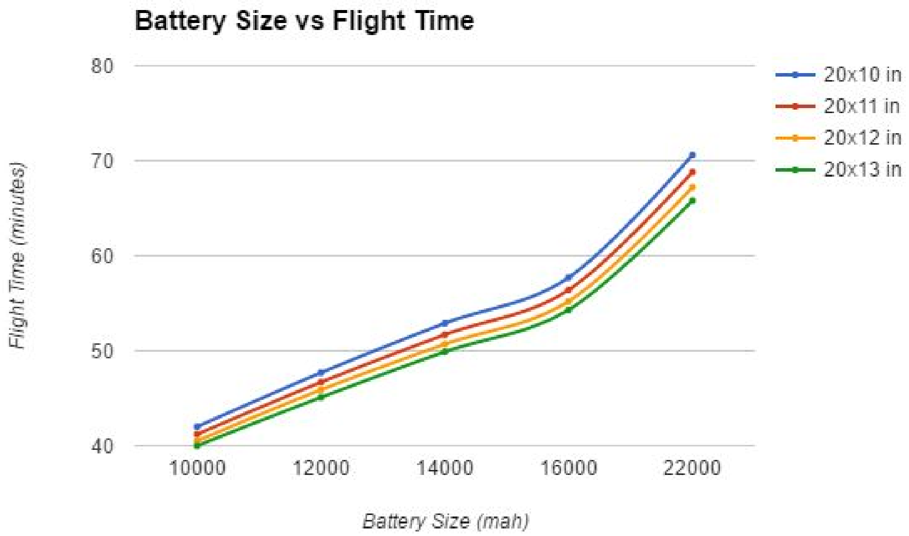
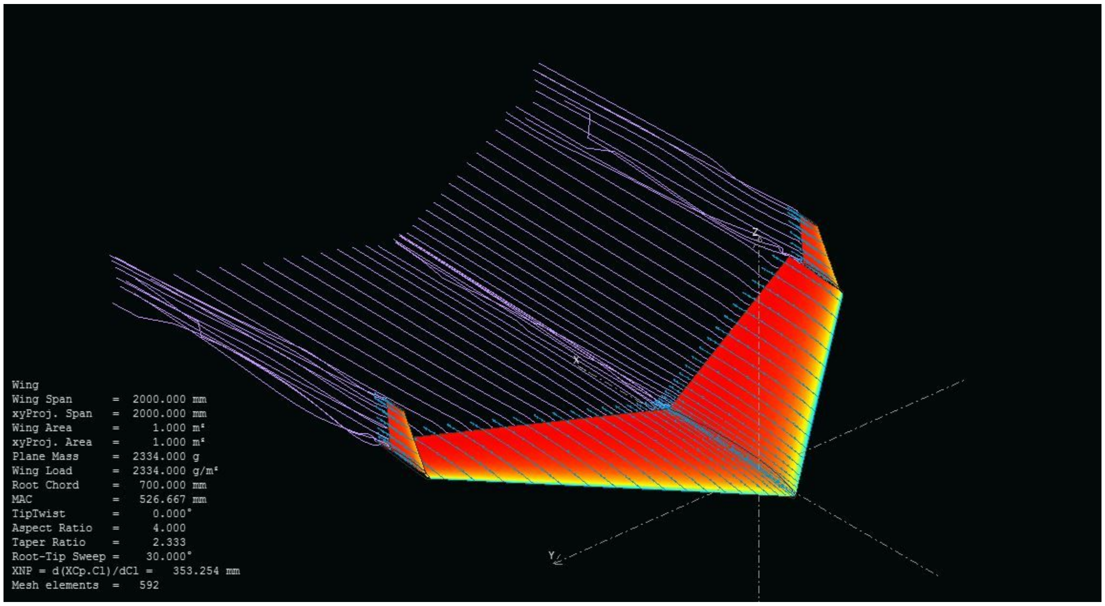


Fig 5: Battery Size vs Flight Time ECALC Data

Similar to the data from Fig 4, each data plot has almost identical curves and equal separation. As battery size increased, flight time increased as expected, showing how the battery size used for final results, the 22,000 mah size, provided the longest flight time for the thrust to weight ratio.

A wingspan of 2 meters that has a NACA airfoil value of 2411 (and fins with 0008) was put into XFLR5 and simulated to generate a suitable amount of lift at the predicted flight speed returned by ECALC, and how much per each angle of attack plotted by coefficient of lift, drag, and angle of attack (alpha). The coefficient of pressure (darker color = higher value) is higher at lower angles of attack.



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Wing
Wing Span      =  2000.000 mm
xyProj. Span   =  2000.000 mm
Wing Area      =     1.000 m²
xyProj. Area   =     1.000 m²
Plane Mass     =  2334.000 g
Wing Load      =  2334.000 g/m²
Root Chord     =   700.000 mm
MAC            =   526.667 mm
TipTwist       =     0.000°
Aspect Ratio   =     4.000
Taper Ratio    =     2.333
Root-Tip Sweep =    30.000°
XNP = d(XCp.Cl)/dCl =   353.254 mm
Mesh elements  =   592
```

Fig 6: Aircraft Analysis

The color of the airframe shows strength and concentration of the Cp (coefficient of pressure) and the airflow over the wing and vertical stabilizers. The white text in the left corner indicates parameters of simulation that match those returned by ECALC such as total weight and wing area.

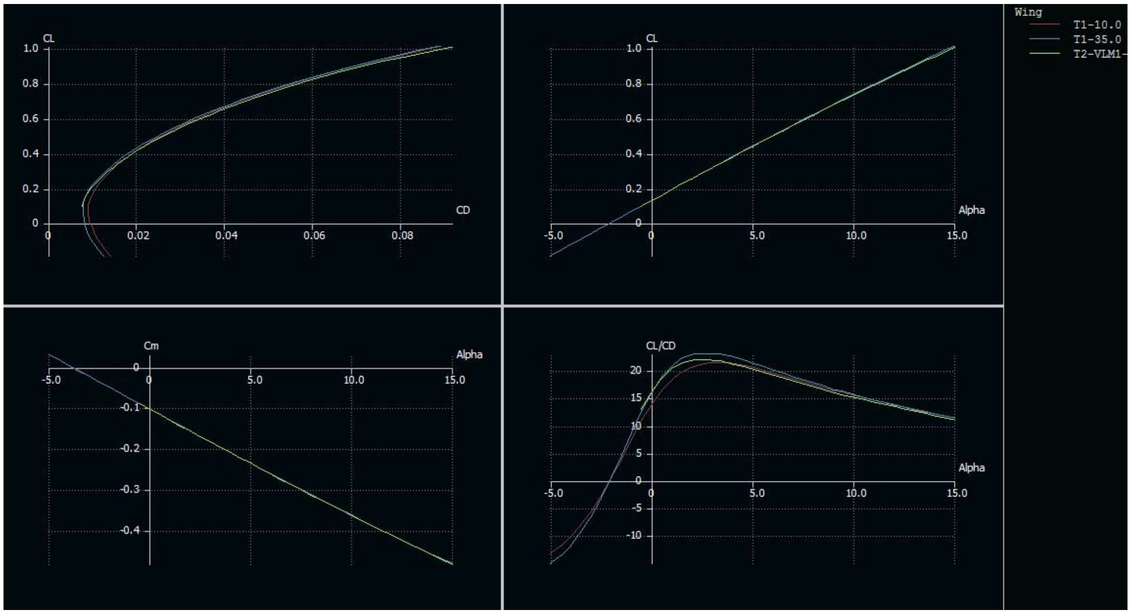

Fig 7: Analysis Graphs - CL vs CD, CL vs Alpha, Cm vs Alpha, CL/CD vs Alpha

The graphs show expected curves, and the Cm vs Alpha curve indicates a stable airplane, but not a stable airfoil (for a delta wing). A self stable airfoil will be required for total stability and further stability analysis. By simulating and adjusting these certain variables relating to motor type, size, and aircraft design, the hypothesis was proven correct. The electronics setup was simulated to run at adequate power for 65.8 minutes, and upon initial analysis the airframe from XFLR5 was shown to be stable.

Discussion:

This experiment was conducted in order to calculate and design an efficient, practical, fixed wing UAV for the stated applications. Based on data and results from the methods, the goal of achieving over an hour of flight time was fulfilled, and the aircraft could be integrated into some form of application.

The motor selected (HKIII-4035-330) outperformed other motors in preliminary testing because it proved more efficient while producing the same amount of thrust. The value after the last hyphen indicated the Kv, or the RPM/volt of the motor. Lower Kv values indicate more torque when compared to higher Kv values of the same motor series (Shen, S., & Zhou, P., 2016). This motor has a Kv of 330, and overall had a higher efficiency when compared to a motor of Kv 500 when using similar propellor set ups. After selecting the most applicable prop data, the 20 inch by 13 inch (length x pitch) propellor running on the motor returned the flight time of 65.8 minutes, well above the initial goal. However, the thrust to weight ratio was 1.08:1 -- low, but still applicable. In order to increase this in the final design, assuming this setup is used, the battery size could be dropped to +- 20,000 mah (3 cell), thus reducing weight, increasing thrust to weight ratio, and most likely keeping the flight time over 60 minutes. The reason this battery size could not be tested is because the simulation database did not include it as an option--the choices jumped from 16,000 mah to 22,000 mah. If needed, the battery size could be adjusted differently for different applications, such as shorter missions that require more intense flying vs long missions with premade flight plans and steady flight time. Custom or modified electronics could also be used in order to either provide more thrust or increase efficiency and flight time.

Using the delta wing design, the viscous type analysis returned the airflow over the wing in the 3D model portion of the simulation. The color spectrum indicated on the airframe shows the coefficient of pressure in the specified areas, with a darker color indicating a higher value. At lower angles of attack, the aircraft has a significantly higher coefficient of pressure (red color) than at high angles of attack. The areas of high Cp are on the top of the airframe, which is where they should optimally be positioned. At higher angles of attack, the airframe shows a blue color, indicating lower pressure. For the graphed data, the most important graph is the Cm (pitching moment coefficient) vs Alpha. Having a negative slope indicated stability and a correctly designed airframe, meaning the delta design, upon initial analysis, is a flyable aircraft (XFLR5, 2013). Other delta or even conventional designs could be applied to the same electronics to get different results in flight performance and stability if this certain delta shape with the 30 degree sweep does not work for the applied function. Because the electronics are small and portable, they are able to be removed and attached easily for different applications.

Conclusion:

Building such an aircraft could provide a low-cost, efficient, portable UAV for use in many applications. Because UAVs have become such a fast advancing technology, there will be room for additional, improved electronics in the future. The implementation of a ducted fan system may also be an option to increase thrust and efficiency. In 2002, Anita Abrego and Robert Bulaga performed a study on ducted fans and found that putting the motor in a tube-like shaft concentrated the flow of air coming from the motor and therefore provided more direct thrust in the direction the motor is facing (Abrego, A. I., & Bulaga, R. W., 2013). Another thought for future flight time improvement is the addition of solar cells to the top of the wing or embedded inside. The airframe designed in this experiment, or other frames using similar electronics, could allow for these future accommodations due to customizability and engineering applications. Also, as electronics improve and batteries become more efficient and lower weight, custom electronics could be included in the final design of such a UAV. The implementation of this design could pave a new path for small UAV efficiency and production in the future, which would improve the applicability even more than it already has.

Further Work:

For the future, and to improve design and obtain more accurate results, a stability analysis could be run for the airframe. Because of the delta wing design, the aircraft may have an uncontrollability factor not able to be simulated by the initial analysis (Basic, 2013). What the stability analysis does is put the aircraft through various x, y, and z movements in order to obtain extra data at different types of aerodynamic angles. As stated in the introduction, for a delta wing, the airfoil must be self stable, meaning it will have a reflexed camber line at the tail. (see fig 7).

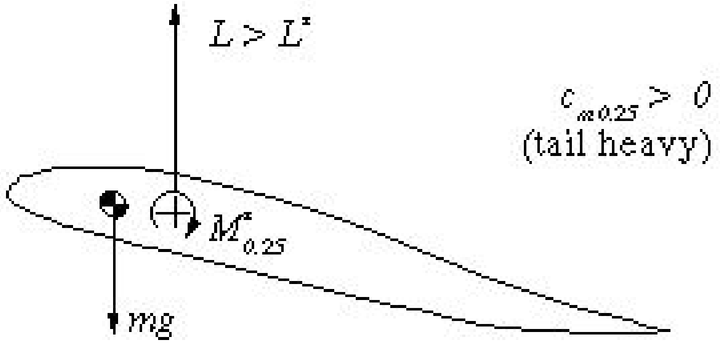

Fig 8: Self stable airfoil shape (Basic, 2013)

Self stability means that at higher angles of attack, there will be an additional air force acting behind the CG, resulting in an “additional nose heavy moment… [making] the wing pitch down, reducing the angle of attack, until the equilibrium state is reached again” (Basic, 2013) When the airfoil does not have the rear reflexed camber line, a tail wing is needed to stabilize the aircraft. Because XFLR5 doesn’t support the modification of set NACA airfoils, it is not possible to modify the NACA 2411 in order to make it self stable. Therefore, further work would have to be done in order to run a stability analysis on a custom self stable airfoil using the simulated airframe delta wing design.

The most accurate and applicable way to test how this design would work is to physically build and test a real world small test model and/or full size UAV. For testing the airframe design and airfoil type, a smaller model could be built and put through wind tunnel or viscous chamber analysis to see how it would react in real world, and more accurate, conditions. The conditions and controls for the analysis would be set to those similar or identical to the analysis run in XFLR5 (35 mph fixed speed, etc.). This could also be performed for a full size airframe depending on the size of the wind tunnel and quality of the lab. For electronics testing, the actual components simulated in ECALC could be ordered and implemented into a full size airframe and then flight tested. Although it is impossible to flight test any aircraft in a perfect controlled environment due to weather changes, the testing would be more accurate in the sense of real world applications. However, to help eliminate any variables that could be harmful to data collection, a systematic flight pattern could be executed. For example, if wind is coming from a consistent direction, a flight pattern could involve an ovular shape -- half of the circuit flying into the wing and half flying away from it. Selecting days with similar weather conditions and temperatures would also help prove data repeatable and keep results reliable.

Designing other airframes with one or multiple wings/stabilizers in XFLR5 would also be another option for expansion. Taking the weight of the electronics system from this experiment and putting it on different designs could show a better or more efficient aerodynamic design. If a main wing and a horizontal stabilizer are implemented, entirely different results would occur, as the aircraft geometry would be drastically different. Different delta designs could be tested with different sweeps, wingspans, and centers of gravity. This experiment included a delta having a 30 degree sweep, and deltas with different sweeps but same wing area could be compared to one another. Different NACA airfoils on each frame could also be evaluated and compared for efficiency, stability, and applicability. Analyzing different foils could provide different insight into UAV development and applications. For example, if one design of a wing has a highly swept wing but a thick camber, the aircraft most likely wouldn't fly because a swept wing is more efficient at high speeds while a thick camber is more efficient at low speeds. However, if the airfoil NACA value is changed to that of a thinner camber, the aircraft would be ideal for high speeds, and most likely be stable at speeds greater than an aircraft with a low sweep and high camber would be.

As conducted by Aerovironment in their UAV designs, autonomous systems could be integrated into the final physical aircraft. Not only would these systems make the aircraft more stable, safer, and easier to operate (if done correctly), but they would improve flight time by using less electrical power. All human operated UAVs have radio receivers, which receive radio waves from a transmitter/remote used by an operator and interpret them into actions such as throttle change or control surface movement (Gabriel, D. L., et al, 2011). These receivers use a large portion of the electrical output from the battery, reducing flight time and usable stored power that could be used by other systems. Overall, autonomous software and hardware would be beneficial for integration in UAVs for surveillance and other government related purposes.

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