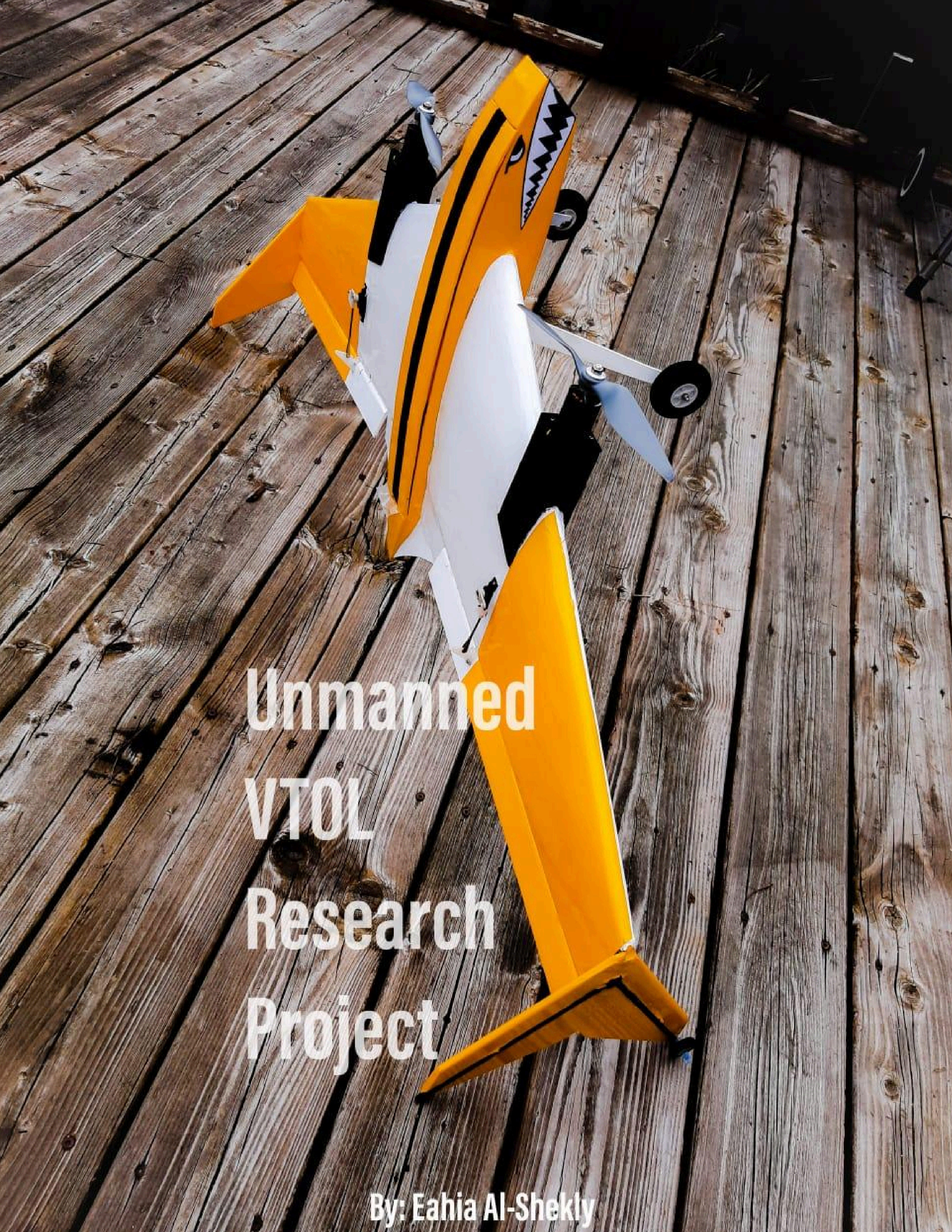
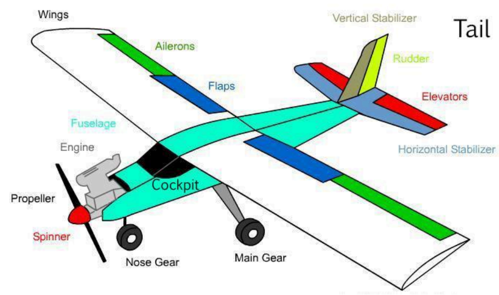


Unmanned VTOL Research Project

By: Eahia Al-Shekly

Background Information:

*(good to know before you read)An aeroplane is a fixed-wing heavier-than-air craft that can fly because of its wings. An aircraft is any object that can fly through the air[3].

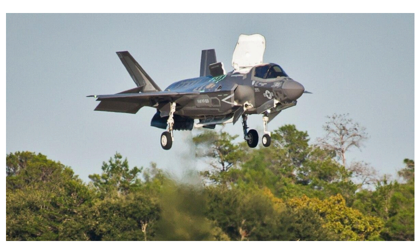


[Image, 1]

Some airplanes are known for their high efficiency and long flight time because their motors don't need to lift the weight of the aircraft, it's the wing that does that, but they are also known to require large runways to tack off and land, where a rotary-wing[2] aircraft i.e helicopter or a multicopter[1] i.e drones can take off and land virtually anywhere but with the sacrifice of flight time and efficiency because the engine or motor have to produce the efficient thrust to lift the weight of the craft.

For example, a Boeing 747 has a thrust to weight ratio of 0.3 and can still fly for 4 hours and 56 minutes and carry passengers and cargo[4]. Where any multi-copter or rotary-wing in the world needs a thrust to weight ratio[5] of more than 1.0 to tack flight and can still carry cargo and passengers but from much less time and cover less distance.

Since a long time scientists and engineers have always had the endeavor to design a vehicle that can take-off like a rotary-wing aircraft and cruise like an airplane, combining the mobility of helicopters and the efficiency and the long-range of an aircraft, this type of aircraft is known as a vertical tack-off and landing vehicle (VTOL)[6] that can combine both flyings aspects of multi-copters and airplane.



[Image, 2]

And as the technological capability advances the idea of having a remotely piloted aircraft or unmanned aerial vehicle (UAV)[7] appealed with many advantages like keeping the pilot away from the dangerous environment, smaller size vehicles, and cheaper prototyping cost which I will be taking full advantage of in this project.

Purpose:

The purpose is to expand the research in VTOL UAVs by designing and constructing a flyable aircraft to demonstrate the technical and practical advantage of such vehicles and also show the challenges of this technology in the endeavor of making this technology more accessible to the science and aviation community.

This project endeavors to expand the research in VTOL UAVs and highlight the potential capabilities of this technology in the following scenarios:

- Cargo delivery in urban areas or areas without runway infrastructure
- Delivering medical supplies to remote or high traffic areas in a short time
- Provide a green electric alternative to typical cargo transport methods
- Data gathering or mapping in areas without runways
- High endurance and mobility

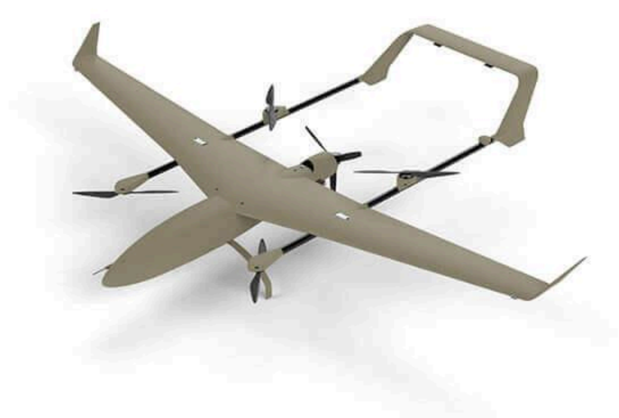
Basically, any scenario where an unmanned vehicle is needed to do a long mission without runaway availability.

- ## Hypothesis/Question

The hypothesis:

An unnamed vertical tack-off and landing vehicle design that uses the same aerodynamic surfaces for both phases of the flight to achieve efficient cruise and ability to operate without a runway.

I said, "*uses the same aerodynamic surfaces for both phases of the flight*" because that would decrease the cost by keeping the aircraft relatively simple, also it's easy to strap 4 motors, in a quadcopter configuration, to an airplane and call it a day [image, 3]. But this means that the hovering aerodynamic surfaces will only cause **drag** in cruise flight which will decrease efficiency and range.



[Image, 3]

Materials List:

Hardware (building materials):

- Balsa wood
- Plywood
- Carbon fiber rods
- Aluminum main fixed landing gear with 2 foam wheels
- 2 secondary foam wheels
- Foam sheets
- Monokote

Hardware (Electronics):

component	Price	Source
Teensy 3.1 features a 32 bit ARM processor.	$19.80	https://www.pjrc.com/store/teensy3.html
Eagle A3 Super 3 V2 Programmable 6-Axis Airplane Gyro	$40.99	https://www.motionrc.com/products/eagle-a3-super-3-standard-edition-airplane-gyro
Power Distribution Board	$8.55	https://rb.gy/u0de9b
Brushless motors *2	$25.33	https://rb.gy/0chueu
Electronic speed controllers *2	$43.82	https://rb.gy/x6bpjf
Battery: 4 and 3 cell lithium polymer	$120	Hobby story

** as an RC hobbyist I have a Futaba T9FG transmitter, receiver and servos that I used for this project

Software:

- Inkscape and adobe illustrator: vector editing software
- Fusion 360: 3d modeling and simulation software
- A3 Super 3 V2 configurator for tuning and programing the gyro
- Arduino IDE
- Google Sketchup

Facilities/ membership/ insurance:

- I'm a member of the Model Aeronautics Association Of Canada
- I have the Model Aeronautics Association Of Canada insurance
- I'm a member in Mississauga Model Flying Club (where the flight tests took place)
- I have assembled/ designed the aircraft in my basement with basic common tools.

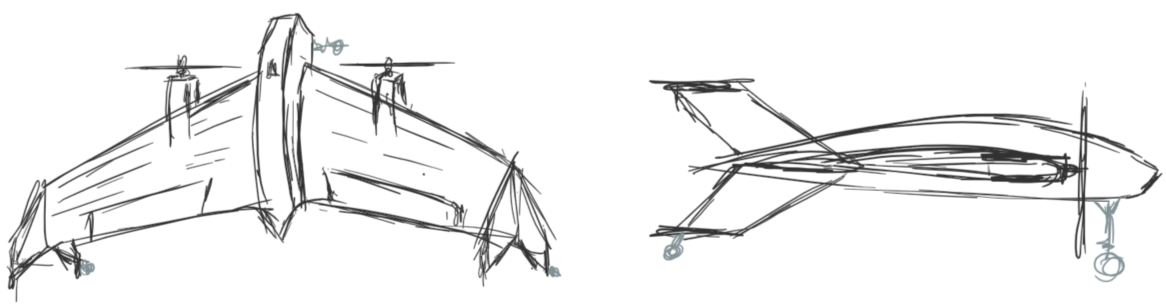
*** THE FACILITIES WERE CLOSED DUE TO COVID-19 WICH LIMITED THE NUMBER OF TEST FLIGHTS.

Methods:

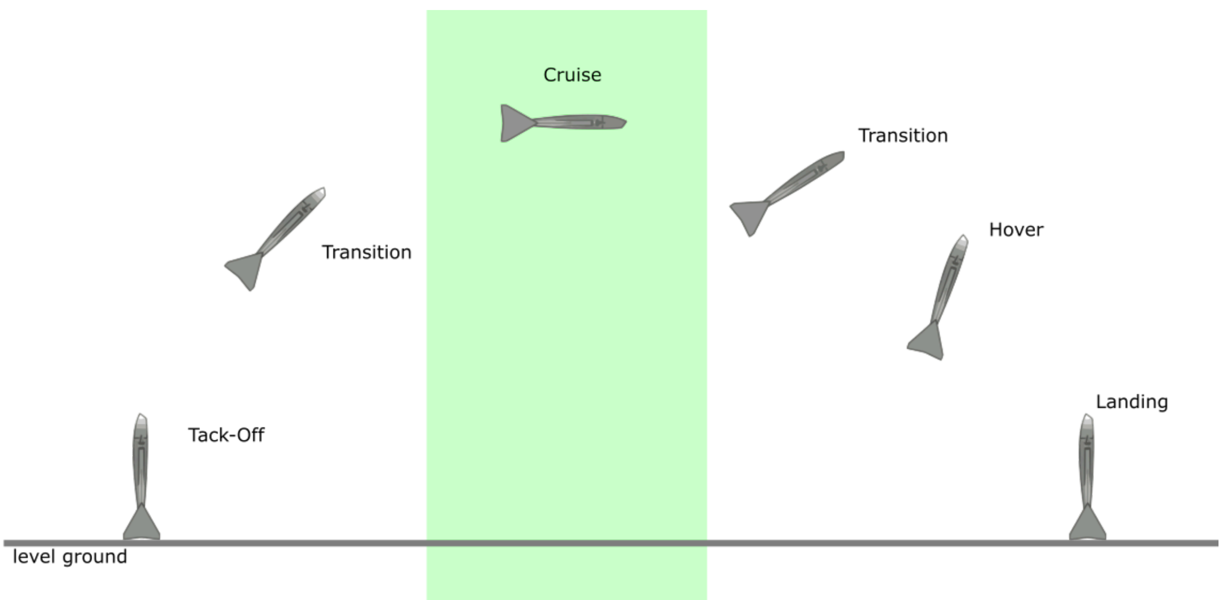
To build this aircraft I used the following methods in chronological order:

- ***Brainstorming and planning***

To achieve the goal I had to brainstorm an efficient aircraft design that can be functional in two phases of flight (hover and cruise), so inspired by the "Convair XFY Pogo" [8] I designed a tailsitter [9] aircraft that flies like a normal aircraft but when it comes to land it increases the angle of attack[10] to 90 degrees pointing the nose to the sky and gradually reduce altitude until it lands on its tail. So I chose a flying-wing design because it eliminated the drag from the tail, and gave me the possibility to land on the rear by the support of the wing fins.



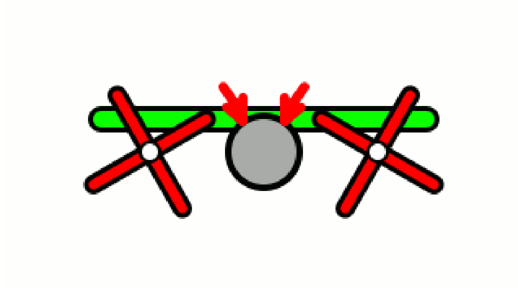
[the first sketch of that demonstrate the overall idea of the aircraft]



[Mission side view, my illustrations]

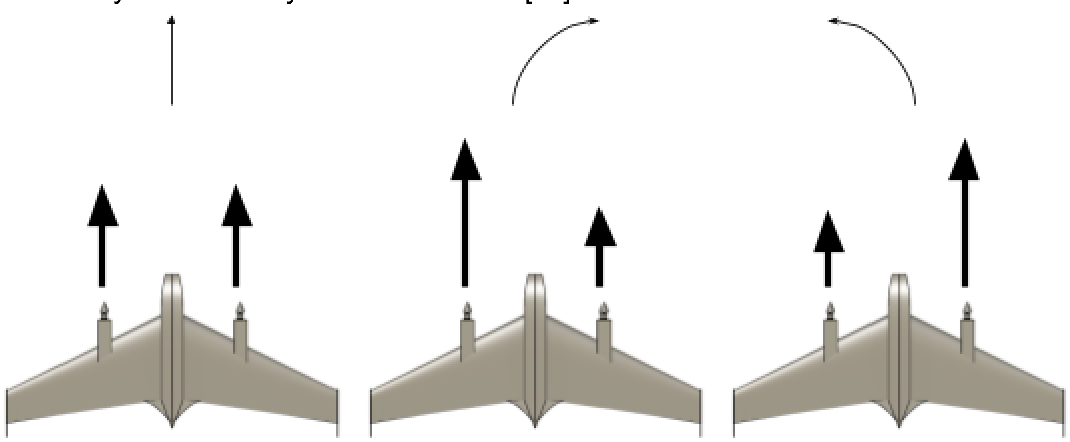
another design factor that has been implemented is the use of two counter-rotating propellers on each wing for a number of reasons like:

- They will cancel each other’s torque



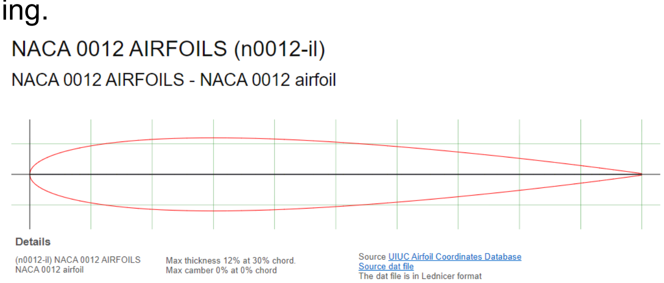
[image, 6]

- sustain linear airflow over the wing even with high angles of attack which the aircraft will experience during the takeoff and landing, which prevents stall.
- Provide yaw control by differential thrust[11]



[yawing using differential thrust, my illustrations]

Also, the aircraft's wing has a symmetrical airfoil that maintains similar handling and characteristics during hovering and cruising which will translate easier predictability in flight-controller[12] tuning.

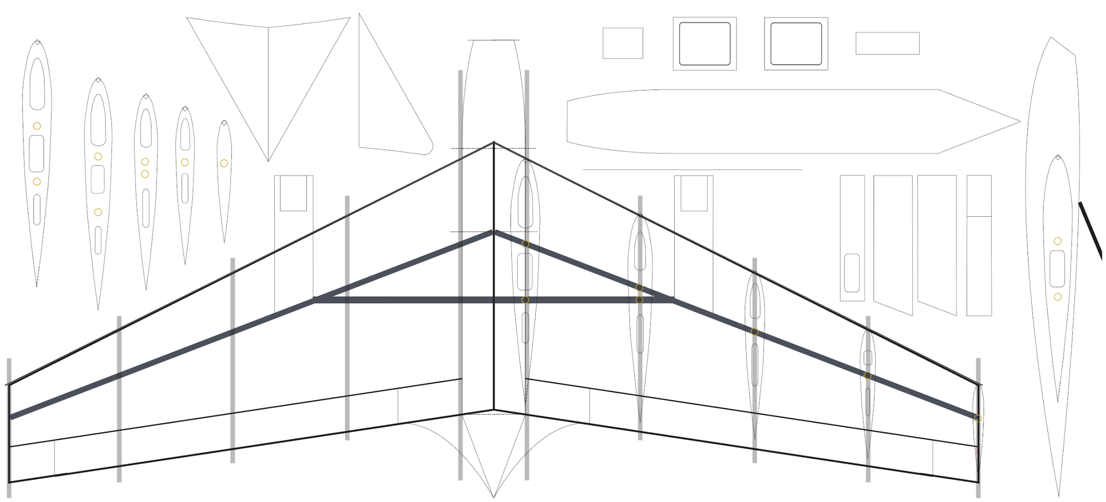


[the airfoil used, image 5]

- ***Computer-aided engineering***

Before executing the design aircraft is virtually built-in CAD software to enable essay editing and refining in the future, also having CAD plans for the parts makes it easy to build accurate models.

[3d cad model of the design]

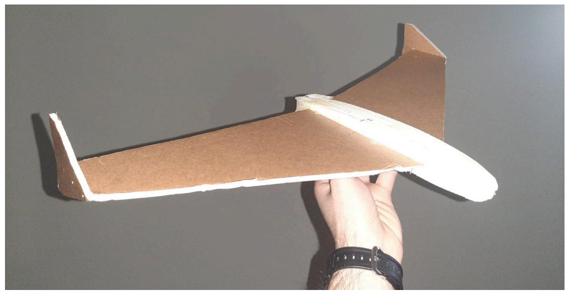


[the CAD 2d plans for the aircraft]

- ***Small scale prototyping (Modeling)***

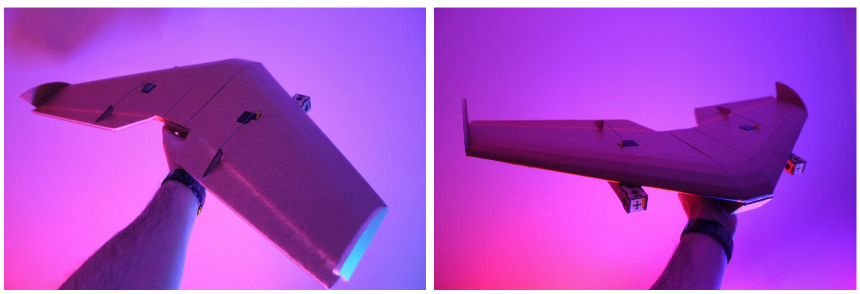
Considering that the initial design is based on theory and educated assumptions, it could perform little differently than intended, So I had to build my way to the full intended scale gradually.

1. Build a chuck model



[camera roll]

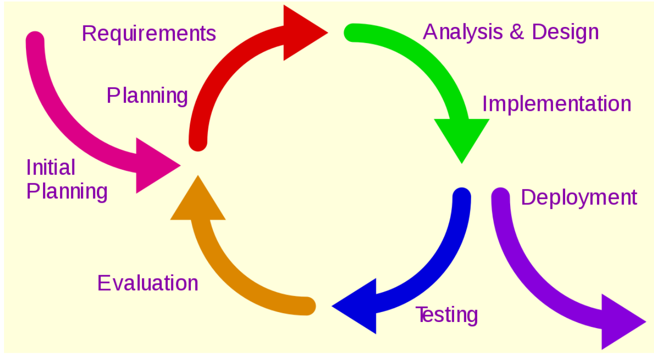
2. Bould 35 cm wingspan radio controlled model



[FT small scale model from my camera roll]

Data and analysis are gathered during this phase and the design is refined based on that.
*data is in the following section

- ***Iteration cycle (iterative and incremental development)***



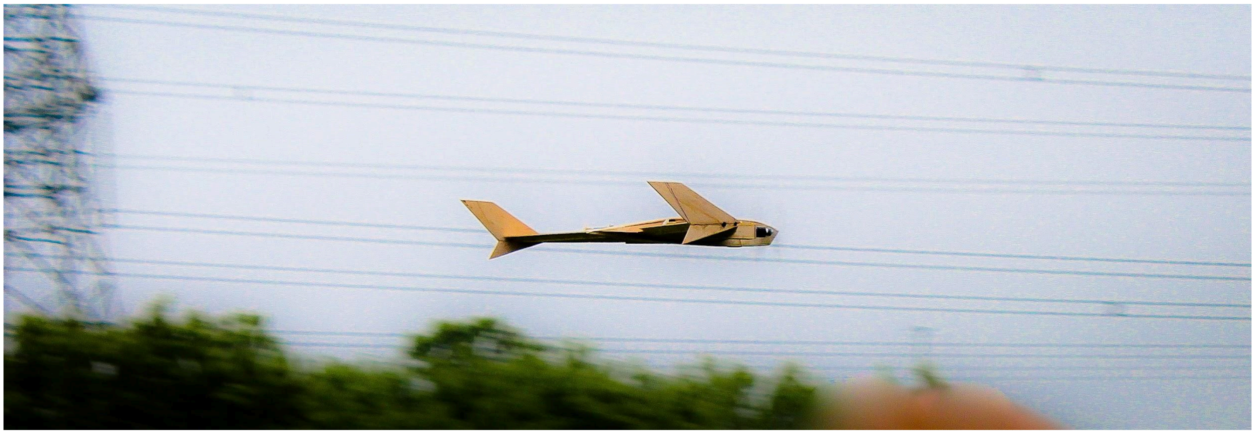
[image, 4]

Collecting feedback and data and refinding the original design to eliminate as much of the error to produce the best possible product.
iteration is used in the aerodynamic portion of the design as explained above, and also is a fundamental method to program the flight controller that stabilizes the aircraft during the hover, the code is discussed in the following section.

After that, the final 1.1-meter wingspan model is constructed after the design is refined

[camera roll]

Then the intended full-scale model is constructed, and flight test began using the same Iteration concept



High-speed low pass

Crause flight

hover / transition

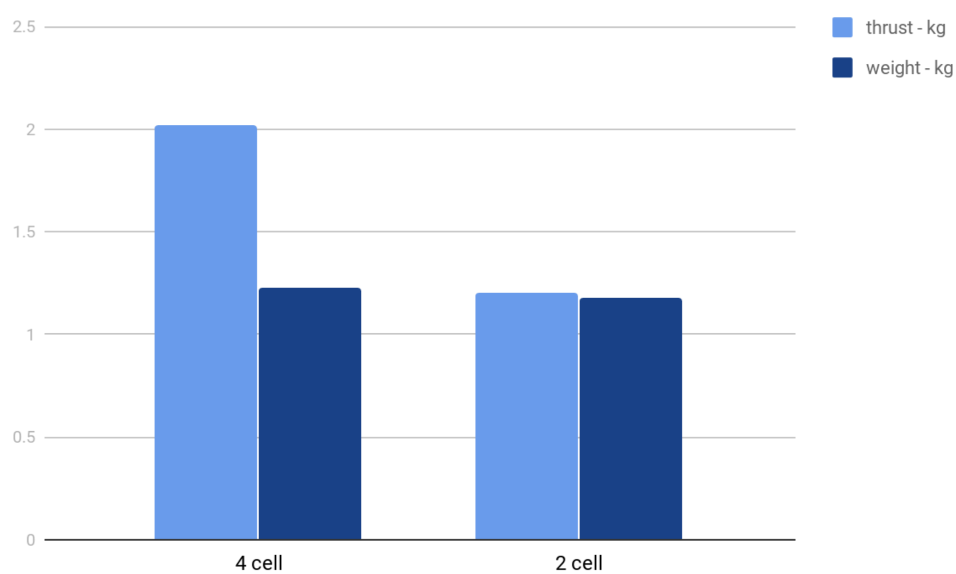
[camera roll of the early flight(note; the aircraft was not “printed” yet)]

Data/Results:

function	***Reslot***	***Other observation***
Horizontal conventional cruise flight	Success	According to observation during the flight, the aircraft was very stable and controllable.
Vertical hover	Success	According to observation during the flight the aircraft did hover.
Vertical landing	*Success	* The aircraft has demonstrated the capabilities of vertical landing in-flight testing, but the execution of it has been delayed due to COVID-19.
Vertical tack-off	Success	The aircraft demonstrated a sufficient thrust to weight ratio to take off vertically
transition	Success	According to observation during the flight, the aircraft did the transition with little to no help from the pilot

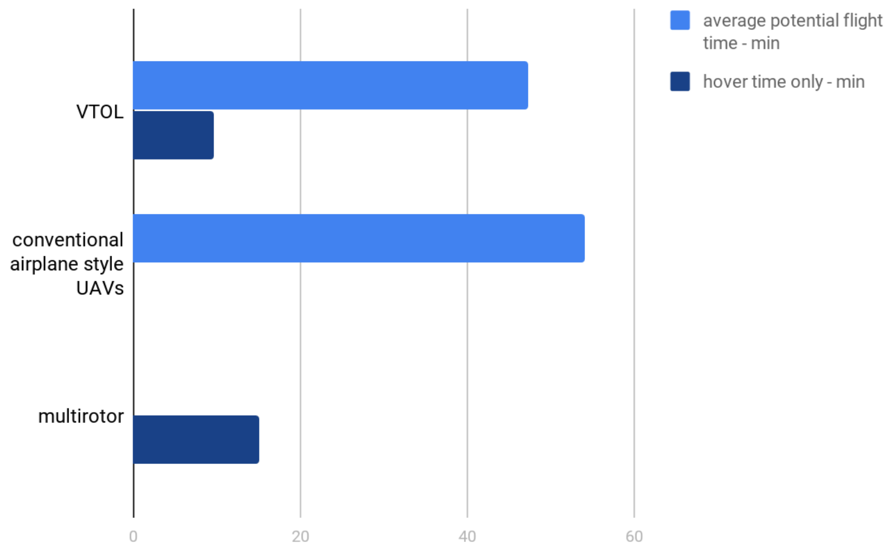
*** The data measured above from my experience flying and observing the aircraft, videos are attached in the log file.

Thrust to weight ratio of 3cell and 4cell battery:

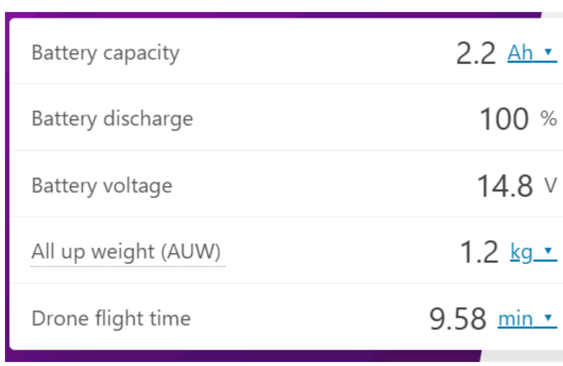


The data was gathered by measuring the weight of the aircraft and the thrust given from each battery (4cell and 3cell lithium polymer), and that proves that the aircraft can support its weight in hover flight especially with the 4cell lithium polymer battery.

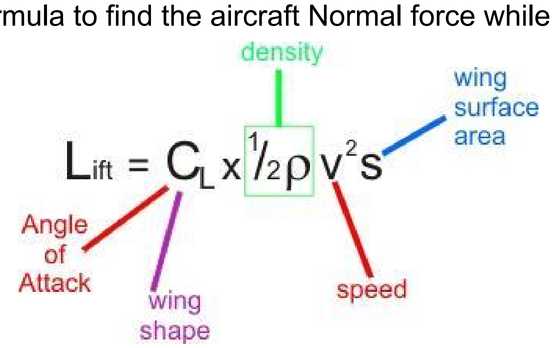
Endurance:



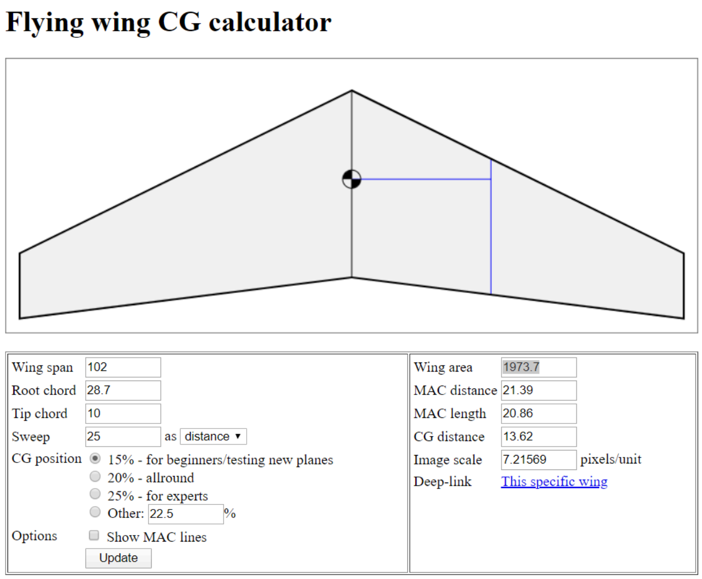
This graph demonstrates the endurance of the VTOL's flight time in cruise and hovers in comparison to multi-copters and airplane UAVs.
The data has been estimated for airplane still UAVs and multirotor based on the average flight time of vehicles offered in the market similar in size and price to the VTOL vehicle discussed in this research.
When it comes to the VTOL hover time I used "omnicalculator.com/other/drone-flight-time" online calculator



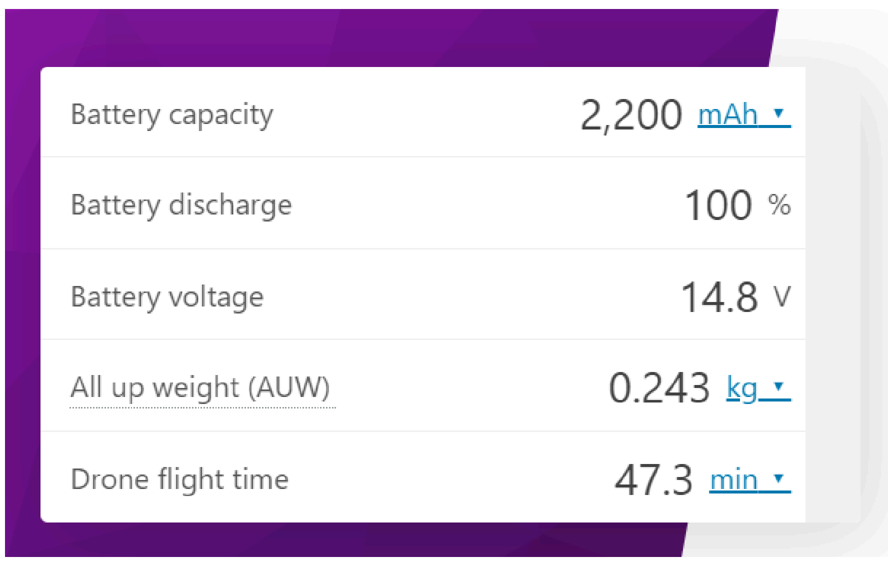
, but I had to use the lift formula to find the aircraft Normal force while in cruise flight:



For finding the wing surface area I use https://fwcg.3dzone.dk/ center of gravity online calculator that also calculates wing area.



With these variables in hand, plugging it to the lift equation will result in the normal force which is 0.957 kg, subtracting the weight of the aircraft 1.2kg = 0.243kg

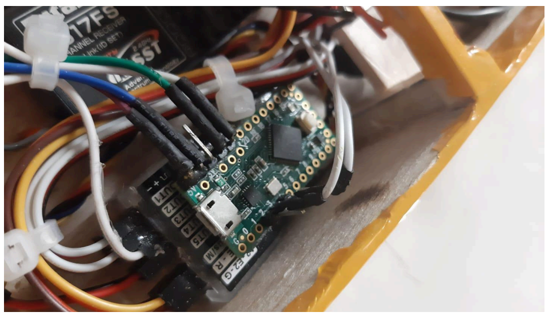


Keep in mind these numbers are ***close*** to real-life uses, from practice, the real number is roughly 25-30% less due to the sweepback[13], and the aspect ratio[14].

Analysis of Results:

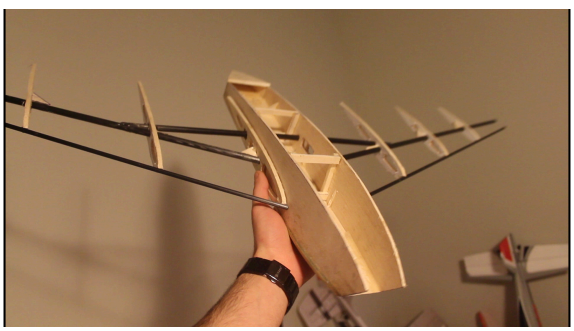
Looking at all the success of the complete mission task the aircraft proves its capability of performing vertical tack off, landing transition, cruise, and optional conventional landing. Also, the estimated flight time of the aircraft endurance proves efficiency, while the average thrust to weight ratio during the entire flight stays under 0.3 while keeping the benefit of VTOL, in comparison of multi-rotors where the average thrust to weight ratio is more than 1 to 1. During the execution of this research, many problems have appeared and solved, the following are some of the major problems:

- Configuring a flight controller to stabilize the aircraft during the hovering: solved by combining a fixed-wing aircraft flight controller with a microcontroller to translate the values to the aircraft unique requirement.



[camera toll]

- The aircraft needs to support itself structurally when landing on its tail: carbon fiber reinforcement has been fixed across the span of the wing to support the tail.



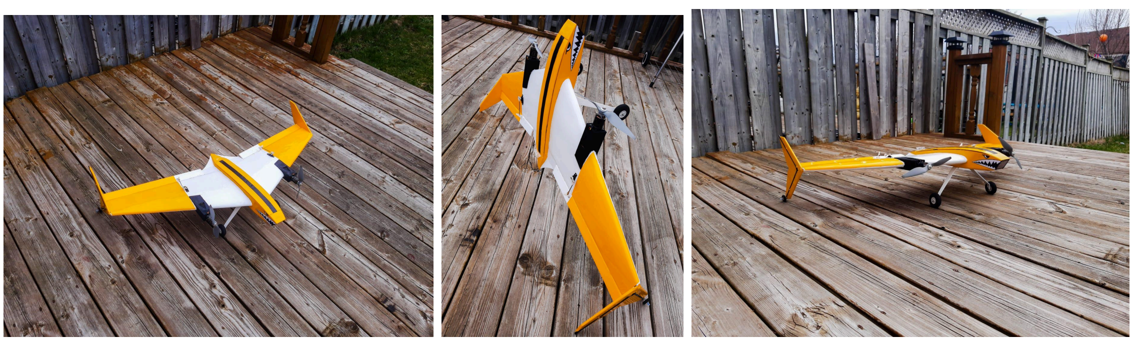
[camera toll]

- The aircraft needed to land conventionally in case of low battery, failure in the flight controller, high wind, or in the tuning/testing stages of the flight controller: solved by fixing conventional landing gear on the aircraft.

[camera toll]

Conclusion:

Creating a VTOL UAV or using a flying wing design in the past was a very challenging task because flight controllers were not fast enough and the research in this field were limited due to the high risk and expense that come with it, but nowadays flight controllers are faster than a human will ever be and expense and risk can be reduced by using modeling engineering methods, and that what has been proven in this project.



[camera toll]

An unnamed vertical tack-off and landing vehicle design that uses the same aerodynamic surfaces for both phases of the flight to achieve efficient cruise and ability to operate without a runway has been accomplished, and along the way of the making, this research challenges have been found and conquered leaving the task of improving the existing design or the process of creating a new design more conscious.

References:

Knowledge referenced in [number]

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Image reference [image + number]

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