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DESIGN, BUILD AND FLY THE UITM'S VERTICAL TAKE-OFF AND LANDING (VTOL) AIRCRAFT

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ABSTRACT

The aircraft with a vertical take-off and landing (VTOL) technology has been widely studied all around the world as it is one of the most advanced systems that could be used by modern aircraft. It was invented for any types of simple multirotor aircraft to a more complex transitioning vehicle. In this project, the vertical take-off and landing (VTOL) radio-controlled (RC) aircraft were designed, build, and test. The USB-based microcontroller, Teensy 4.0 board will be incorporated into this aircraft to control the varying multirotor thrust vector to lift the aircraft. The design of the aircraft was inspired by the Fighter Jet Sukhoi SU-30. It was designed through CAD drawing using the CATIA software. From the CAD drawing, the aircraft then was fabricated and installed with the electronic devices. Through the electronic devices, the tilt angles of the rotors need to be changed smoothly and steadily using the coding inside the Arduino software before they can be inserted into the Teensy 4.0 programming to ensure the stability of the aircraft during take-off and landing. The RC aircraft then went through a few flights test to get the performance data of the aircraft such as the maximum speed, the rate of climbing and landing, and the hovering stability. The size of the VTOL RC is 0.84 meters in length,0.58 meters in the width, and a height of 0.32 meters. The VTOL RC aircraft were successfully designed and fabricated.

Keywords*: Aircraft, Radio Control, Sukhoi SU-30, Teensy 4.0, VTOL.*

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1. Introduction

VTOL is the vehicle that has the capability to take off, hover, and land vertically without any runaway needed for them to perform such activities. There are currently two types of VTOL technology which are the rotary-wing and powered-lift aircraft. The rotary-wing aircraft is an aircraft that creates the lift force by using the rotor blades that spin around the central mast while the powered-lift aircraft is an aircraft that can take off and land vertically but behave differently than rotorcrafts while in flight and often have a fixed-wing design (TechTarget Contributor, 2019).

The development of VTOL technology has emerged and raised in numbers in recent years. Many studies and research show their own interest and different result in studying the

VTOL mechanism and behavior. Most of the study and research focus on the Aerial Unmanned Vehicles (UAV). Unmanned Aerial Vehicles (UAVs) are aircrafts that can fly autonomously or controlled remotely by a human pilot. These vehicles can be used in several applications, like remote sensing, precision agriculture and atmospheric data monitoring (Silva, Marconato & Branco, 2015). Not just that, the UAV also have the demand commercially due to their advantages and not risking the pilot on demanding missions (Orbea *et al.*, 2017). However, the study of the VTOL application towards the conventional aircraft is not popular and lower in publications. There are a lot of things that need to be considered when it comes to the application of VTOL inside conventional aircraft because of the risk and past research on it. However, there are a lot of advantages if the VTOL technology would be implemented in conventional aircraft. On the other hand, fixed-wing aircraft have an extended range, as the entire thrust force is along the direction of motion and are inherently more stable but are limited by their takeoff and landing strip requirements (Panigrahi, Krishna & Thondiyath, 2021). Therefore, the VTOL technology must be studied first and need to build a prototype before it can be implemented into real aircraft. In this study, the VTOL technology will be implemented into the Radio-controlled (RC) aircraft to study the behavior of the aircraft.

Research and information concerning this Vertical Take-Off and Landing (VTOL) technology were very limited. There is a lack of knowledge application on the conventional aircraft types since most of the studies are focusing on the VTOL application towards a simple rotor aircraft such as the helicopter and Unmanned Aerial Vehicles (UAV) drones. Therefore, there is a lack of experience in handling the VTOL technology in conventional aircraft application. The most popular vehicles that is using the vertical take-off and landing process is helicopter, but there is one fighter jet that can do such process is the F-35 fighter jet from American (Plummer, 2017). It can take-off and land from a standing start off the back of the aircraft carrier without required a runway for them to have enough force to fly the aircraft. The rotorcraft and power-lifted vehicles are two different types of vertical take-off and landing motions. Helicopters, quadcopters, and gyrocopters are examples of rotorcraft, which produce lift by rotating rotor blades around a central mast. Powered-lift vehicles, on the other hand, conduct vertical takeoff and landing differently since they have a traditional fixed-wing plane design. They use fixed wing lift in normal flight but still can take-off and landing vertically such as the Bell Boeing V-22 Osprey and F-35 fighter jet (Plummer, 2017).

The objectives of this study are to design and build the Vertical Takeoff and Landing (VTOL) vehicles as well as to fly the VTOL aircraft while observing the characteristics of the aircraft by undergoing the flight test. The scope of this study will focus on building the VTOL RC aircraft inspired by Sukhoi SU30 RCs. The vertical take-off and landing features will be added. This study starts with finding the proper airfoil, statistical analysis, and detailed design of the VTOL RC aircraft. The characteristics and the behavior of the VTOL RC are obtained by flying the aircraft and getting a certain parameter to determine its stability.

No wind tunnel testing will be done. The maximum capacity of the battery is just 1100mAh which would last for about 20 minutes. The rudder of the VTOL RC aircraft is fixed and non-adjustable. Due to that, the operator of the aircraft was not able to control the aircraft when it is in the air and surely can't give the best flight experience to the operator of that respective aircraft. Lastly, the position of the vertical motor and blade is close enough to the ground and this is the reason why the VTOL RC aircraft need to have a higher landing gear so that the blade will not collide with the ground.

2. Methodology

The flow chart was illustrated in Figure 1 to give a simple visualization of the procedures of the study upon achieving the objectives:

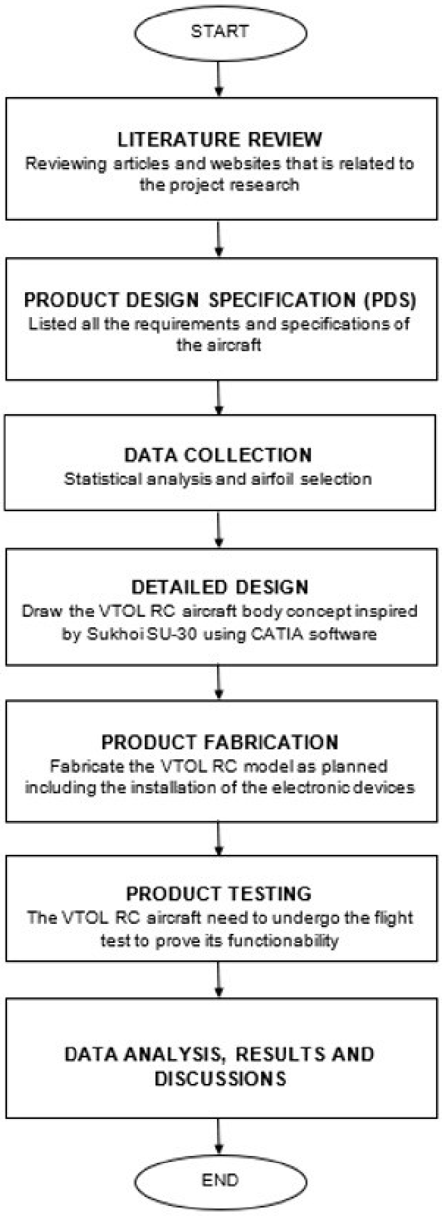

Figure 1. Methodology Flowchart.

The product design specifications (PDS) are the specification or requirement that was listed and need to be fulfilled to make sure that the VTOL, RC aircraft can be operated in the desired condition. All the specifications are just a limit that has been put to reduce the probability of the VTOL, RC aircraft from any problems such as, it cannot fly because of the overload from any parts. The product design specifications have been summarized in Table 1 below.

Table 1. Product Design Specifications of the VTOL RC.

Parameter	Value / Choice
Propulsion system	Electric Motor with propeller
Weight	Maximum 8kg
Maximum payload weight	Maximum 750 grams
Endurance	15 minutes
Range	500 meters
Material	Lightweight
Aesthetic	Bright body colour

The statistical analysis is an analysis that was collected from literatures of the RC aircraft. The data collected then will be plotted into the graph and by using the curve fitting graph to determine the best line (Hamada, Sultan & Abdelrahman, 2016). These fitted curves then will be used to get the first estimation of the weight and the speed of the design and will be compared to the actual behavior of the VTOL RC. The graph plotted for span vs weight were shown in Figure 2 and the graph for speed vs span were shown in Figure 3.

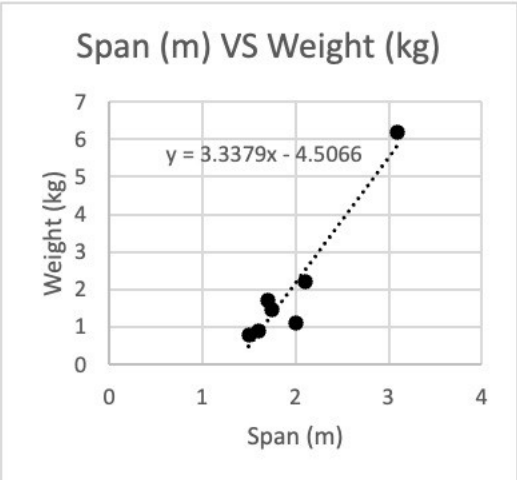

Figure 2. Span VS Weight Graph.

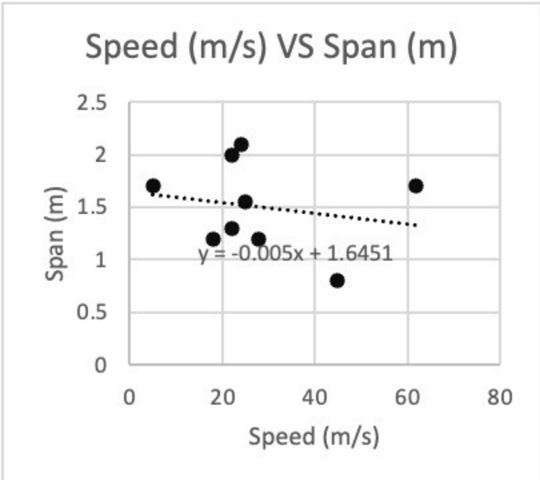

Figure 3. Speed VS Span Graph.

The airfoil selection is based on the purpose of the usage of the aircraft. For VTOL, RC aircraft, the Clark-Y airfoil type was chosen as it is used for a sports plane which is excellent in producing the lift-drag ratio (Willwoodsb, 2013). The Clark-Y is a flat-bottomed airfoil shape with a thickness of 11.7% of the chord. Figure 4 below shows the dimension and percentage of chord for the Clark-Y airfoil (Anonymous, n.d.).

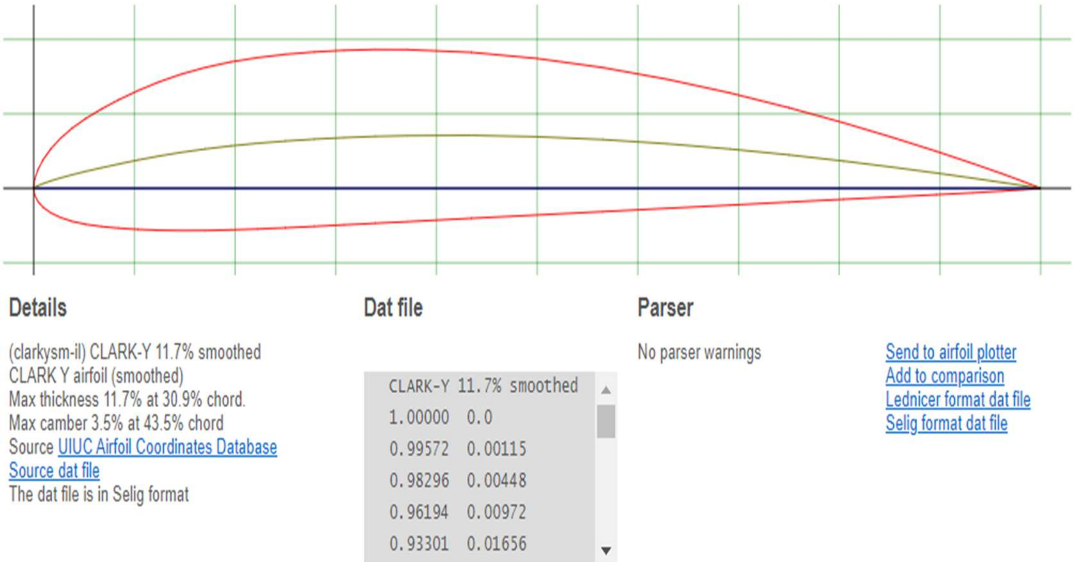

Figure 4. Clark-Y Airfoil Configuration.

Detailed design is the phase where the design is refined and plans, specifications, and estimations are created. Detailed design will include outputs such as 3D models. Table 2 shows the electronic parts that will be used for the VTOL RC aircraft.

Table 2. Electronic Parts Used in the VTOL RC Aircraft.

Component	**Specification**	**Amount**
Teensy board	4.0 Version	1
Distribution board	Matek V3	1
Accelerometer and Gyrometer	IMU MPU6050	1
Electronic Brushless Motor	kV: 2550 Weight: 35 g	3
Electronic Speed Controller	Current: 30 A Protocol support: OneShot 125 protocol	3
Battery	Capacity: 1100 mAh Battery type: Lithium Polymer (LiPo) Cell number: 4 cells	1
Propeller	Blade: 3 Diameter: 5 Inch Hole Diameter: 5 mm	3
Micro Servo	Weight: 9g Gear material: Metal	5
Receiver	Channel number: 6 Frequency: 2.4 GHz Receiver type: PPM receiver	1

The design for this VTOL RC was done by using the CATIA V5 software. Creating a design on CATIA aids in creating a more accurate design as well as having a better visualization of the final product. The detailed drawing was made using the CATIA V5 software before it can be built by using the proper material to fly the aircraft were shown in Figure 5.

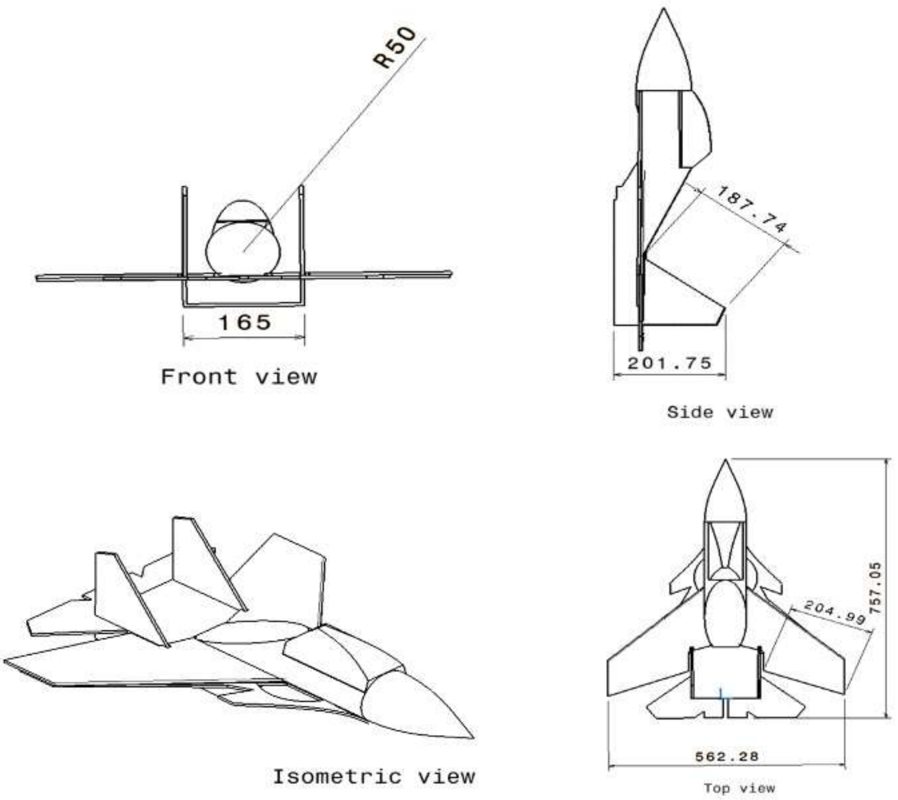

Figure 5. CAD Drawing of the VTOL RC.

The product fabrication process for this VTOL RC aircraft takes 14 days or 2 weeks in total to finish all the processes together. It may consist of a few processes including laser cutting of the foamboard, body and electronic part assembly, and coding input.

i. Laser Cutting

The plasma laser cutting machine usually uses the small plasma cutter as it allows heat to transfer into the foam and cut the foam into the shape of the desired design. Before the plasma laser cutter starts the operation, the computer needs to be connected to the machine and the data from Computer-Aided Design (CAD) will be transferred to the machine and starts to cut the foam based on the design. The plasma cutter was very efficient in terms of power consumption and low probability of doing any error during the cutting process.

ii. Body and Electronic Part Assembly

The body assembly consisted of a cutting, folding, and gluing process. The foamboard that has been cut using the plasma laser cutting machine then will be refined before it can be folded and glued together to form the aircraft shape. Figure 7 shows the body part assembly process. For the electronic part assembly, it consists of wiring, soldering, and gluing process. All the configurations of the electronic parts were figured from the dRehmflight VTOL documentation (Rehm, 2020). Figure 8 shows the soldering process.

iii. Coding Input

The last process for fabrication would be the coding input. The coding will be inserted into the Teensy 4.0 board by using the Arduino software and it is connected by the serial USB wire type. The coding is retrieved from the dRehm hackaday profile website (Rehm, n.d.).

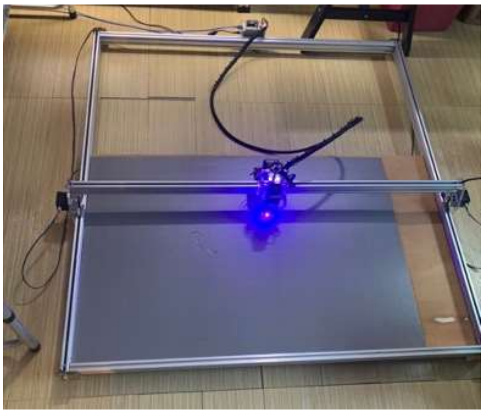

Figure 6. Plasma Laser Cutting Machine during Operation.

Figure 7. Body Part Assembly Process.

Figure 8. Soldering Process.

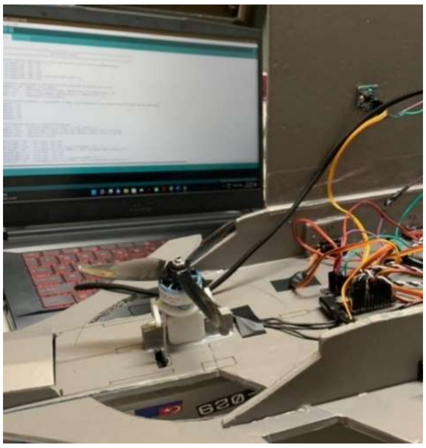

Figure 9. Coding Input Process.

3. Result and Conclusion

3.1 Prototype

All the body parts and electronic parts were successfully assembled into one product. All details of work have been done to ensure that the final product follow the CAD drawing design. All the requirement for product design specifications were followed to make sure that the aircraft can be operated successfully. Figure 10 shows the finished prototypes of the VTOL RC model.

Figure 10. Prototypes of the VTOL RC Model.

3.2 Flight Test

During the configuration of the coding inside the Teensy 4.0, there is a problem countered when the aileron did not go to the desired state or direction. This will give a worst flight experience if the aileron did not go as command. Every unit and value have been examined and still not giving any positive impact on the desired state of the aileron of the aircraft. Other than that, the position of the propeller and the body were close enough. During the pre-flight test, the propeller collides with the body parts of the aircraft and damage the aileron. This have affected the aileron performance as the so-called propeller hit the aileron. As a precaution, the flight test cannot be run because it might cause more damage to the aircraft if the problem cannot be solved.

3.3 Conclusion

Only the first objective of this study has been achieved which is to design and built the Vertical Takeoff and Landing (VTOL) vehicles. The behavior of the VTOL RC in term of performance data such as maximum speed, rate of climbing and landing, and hovering stability cannot be observed since the VTOL RC aircraft did not undergo flight test that need to be done on it. Even though the aircraft cannot fly, the aircraft have been built successfully from the desired material and every electronic specification that have been planned at the first place.

There are a few suggestions that can be made for future studies on this project and one of it is to design and put the propeller in a safe position from any parts of the aircraft. This is to ensure the safety of the body part and prevent the propeller from hitting the aircraft since the force of the propeller from the motor is high enough to break the foamboard. Other than that, the position of the vertical propeller needs to be far enough from the ground as it will give an advantage for the aircraft as it will not require any landing gear to takeoff and landing vertically.

Not just that, when there is no landing gear, the weight of the aircraft can be reduce. Lastly, the electronic parts especially the Teensy 4.0 board, gyro meter and the distribution board need to be covered with anything that could prevent it from any disturbance to get into it such as water and bugs. The lower part of the aircraft where the electronic parts were placed need to be design with a cover in front of it so that the electronic parts will be protected from any disturbance from getting inside that compartment during the flight and prevent from electronic short or short circuit. To add the point, decision making of the engineering system of this project is an essential process of obtaining a desired result based on a set of criteria under consideration from a set of alternatives (Ahmad, Mohamad & Azman, 2020). There are many techniques and approaches that have been introduced to provide a systematic way in finding the solutions. A multi criteria decision making method (MCDM) is one of the techniques that can be employed when conflicting benefits and cost criteria are included and can be considered.

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Author Contribution

Author 2 performed the experiments and analysed the data and wrote the manuscript. Author 1 help analysed the data, contributed to the final version of the manuscript, supervised the project, and in charge of overall direction and planning. Author 3 helped supervise the project.

Conflict of Interest

Not applicable.

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