FC6P01
Final Year Report

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1. Introduction

This project documents the creation of an all-terrain vehicle. This vehicle will not only have the ability to drive on land and water but also have the capability to fly through the sky. To do this it will be capable of seamlessly transforming between a hovercraft and drone form.

The primary objective of this project is to address the challenge of transporting items from point A to B in locations with limited human accessibility. The robot, named ARTEx (All-terrain Robotic Transportation and Exploration System), is specifically designed for deployment in the medical industry, enabling the swift delivery of medical items to critical areas. Inspired by initiatives like Zipline's operations in Rwanda, ARTEx aims to overcome the limitations of gliding drones, particularly in urban settings such as London with numerous high-rise buildings. Unlike traditional gliding drones, this system avoids dropping medical packages via parachute during flight, minimizing the risk of damage or getting stuck in inaccessible locations such as trees.

1.1 Aims and Objectives

The aims and objectives of the project are as follows:

- To create a working hovercraft.
- To make an embedded solution for the control system, RF Control, and Battery PSU.
- 3D model a drone and hovercraft solution.
- Further develop C programming language skills.
- Further develop CAD skills.
- To create a working drone.
- For the vehicle to be able to hold item(s).
- For the vehicle to be able to switch forms seamlessly.

1.2 Project Deliverables

The deliverables of the project are as follows:

- Research different types of motors for the propellers – pref. Kyrio A2212 Brushless Motor 2200KV.
- Design and research compatible propellers – pref. CESFONJER 10pcs APC Composite Propeller 6x4 E.
- Research and implement different types of Servo Motors for the best result 3D model of different materials for the casing – i.e. the body of the robot.
- Skirt – To allow it to become an airboat.
- Design and implement a PCB solution for the electronics.
- Design and form a concept for item holders.

1.3 Project Plan

The weekly project plan is in the Gantt chart documented in Figure 1. Gantt charts are a vital tool when carrying out projects as it aids in facilitating coordination and meeting deadlines. Gantt charts provide an overview of the necessary tasks that need to be completed along with what should be a relatively accurate estimation of the completion time. Gantt charts help both the client and the organisation when carrying out the project to know if it is possible to complete it within the specified time frame.

In the case of developing ARTEx, the Gantt chart highlights that the project should be completed 2 months before the deadline assuming there are no hiccups throughout the development of the ARTEx. The Gantt Chart specifies that the preparatory phase where research will be conducted should take no longer than a month. While research is being done the building and testing phase will also begin. This was a fair assumption especially considering research would need to be done while the components are in hand. The Gantt chart then ends with the delivery phase, allowing the final product to be tested and cleaned up, removing any kinks. This Gantt chart would also allow time for the further development/expansion of ARTEx.

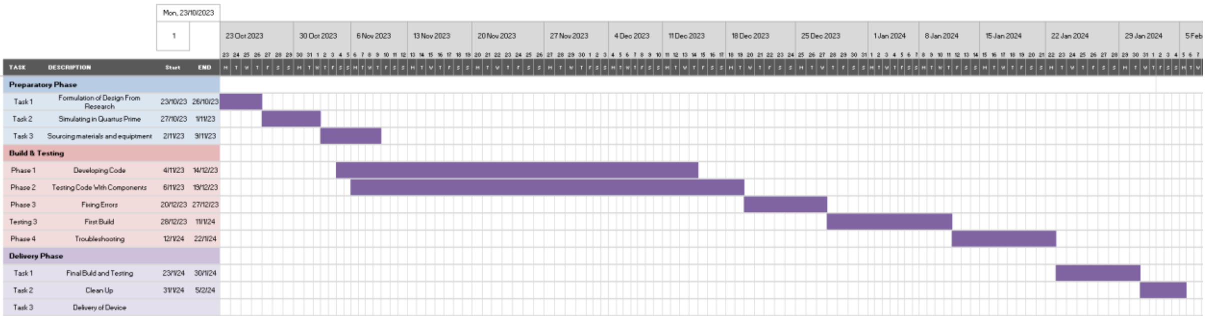


Figure 1 - Project Plan Gant Chart

1.4 Risk Analysis

Considering the time frame that has been allowed to complete this project, the risks that come with developing ARTEx are extremely low. The Gantt chart in Figure 1 clearly shows that there should be more than enough time to develop the ARTEx and make further improvements if needed. The main risks that this project could encounter are budgetary constraints. Drones tend to be quite expensive, and the budget allowed for this project was £50. This limitation in funds makes it quite risky to develop the ARTEx. This risk can be negated with extensive research and diligence when deciding which components to use.

There are also safety concerns that arise. Drones have motors that rotate extremely fast at rates of 45,000 rotations per minute (RPM) and higher. This could be very dangerous to deal with when constructing and testing the ARTEx in public areas.

Vehicles are also very prone to environmental damage, especially ones that fly. The tough terrains on the ground could potentially damage the skirts on the ARTEx and strong winds could send it falling out of the sky. On top of that, heat and rain can easily break many of the components.

1.5 Legal, Social, Ethical and Professional Issues

1.5.1 Legal Issues

There are numerous legal issues regarding piloting drones in the UK. As of 2024, the Civil Aviation Authority of the United Kingdom (CAA), the nation's governing body for aviation matters, has implemented a comprehensive and robust set of drone laws. A long list of the laws can be found on the metropolitan police website which specify altitude limitations, age restrictions and licenses to fly. Figure 2 documents just a few of these laws.

Figure 2 - Drone Laws

There are also major concerns regarding drones/devices and cameras causing some to worry about "who is watching". Liability issues in the case of accidents, property damage, or injuries caused by the drone's operation are also another concern. This alludes to why some laws were put in place about how many people a drone can be piloted over along with the reasoning for height restrictions.

1.5.2 Social Issues

Unlike legal issues, the social issues of piloting a drone and a hovercraft have several crossovers. For example, both types of vehicles can be very loud due to the high-intensity motors and may disturb people, so there is the problem of noise pollution.

1.5.3 Ethical Issues

Regarding this project, there are few ethical issues. Privacy concerns and data security aren't an issue with the ARTEx as it wasn't built to read or collect data on people. This iteration of ARTEx does not use cameras. At most, the integration of a camera on the ARTEx will aid with obstacle avoidance. When piloting the ARTEx it would rarely be at eye level. It will usually be on the ground or in the sky. There are environmental considerations as piloting the ARTEx could cause habitat disturbance or wildlife disruption.

1.5.4 Professional Issues

Drones and Hovercrafts are complex vehicles. Combining them will be no easy suit. There are a lot of minor intricacies that one must work out and tweak in order to get a well-performing vehicle. For example, when creating a drone, how someone connects to and controls the drone is a massive aspect. If there is a lot of delay and buffering between each input, it could lead to crashes when flying low. ARTEx could potentially crash into buildings or trees if sensors and actuators aren't calibrated which could cause safety issues and or affect whether a package is delivered in time or at all.

1.6 Report Structure

This report will cover the research and findings throughout the progression and development of the ARTEx. It will initially cover the scientific and mathematical side of making the ARTEx functional, then touch on the build and development of the ARTEx over time.

2. Literature Review

This project requires extensive research to be able to make everything operate optimally. Considerations need to be made regarding the weight of the drone. The ARTEx needs to be lightweight so it can generate enough lift to fly while also remaining stable and heavy enough to remain evenly weighted and planted on the water. The casing for the ARTEx also needs to be strong enough to avoid breaking or sustaining damage due to the vibration caused by the many motors attached to it. I will break down the research I have done and my current findings below.

2.1 <u>Initial Decisions and Considerations</u>

When it came to deciding what the best approach would be for designing the ARTEx, initial considerations needed to be made regarding the form factor of the vehicle. The ARTEx's main function was the flight system. In order to help it get over and around large obstacles while still maintaining its ability to manoeuvre well around corners it was decided that the best form factor for its flight would be one that imitated a helicopter rather than a plane. This reduces speed but increases precision and control when piloting.

Figure 3 - V-22 Osprey

Speed wasn't the primary focus of the ARTEx. The ARTEx could become faster in the sky by integrating functions from military vehicles such as the V-22 Osprey where the motors would rotate 90 degrees so that the vehicle would no longer act like a helicopter but a place. Figure 3 details an example of a V-22 Osprey seamlessly changing form from that of a helicopter to one that imitates a plane. This could be similarly integrated into the ARTEx via the use of Servos. The issue with this is that servos tend to be big and heavy. On a project where weight matters significantly, especially since the aim is to transport objects, it would be best to avoid using the servos. Speed isn't a primary factor at the moment.

Considering the potential size of the ARTEx as well, it would be best to stray from the conventional design of a helicopter and use that of a drone. Helicopters have 2 motors. One on the top (usually more central) and one towards the back that is horizontal. Both motors are extremely vital in the control of the helicopter. Again, taking into account how small the ARTEx will be, it is fair to assume that the rear motor would be at risk of damage as it may touch the floor or suffer water damage when driving over water.

Regarding the base of the ARTEx that will aid it when travelling along a variety of surfaces, the most suitable option was to integrate the functionality of a hovercraft. Compared to conventional boats, hovercrafts are far superior in performance due to reduced drag and lower horsepower requirements meaning higher speeds and lower fuel consumption. The main reason for integrating the designs of a hovercraft is that hovercrafts excel in speed and perform not just on water but on rough surfaces as well. They fall into the three primary categories being amphibious, non-amphibious, and semi-amphibious. Weight also plays a crucial role in the design, prompting the use of lightweight materials.

Figure 4 - Military Hovercraft

2.2 Physics and Mathematical Analysis

This section will cover the mathematical and physical analysis that was undertaken when considering how to construct the ARTEx. It will also discuss some of the limitations regarding the development of the ARTEx and how that could affect the project's development timeline.

2.2.1 Drone

2.2.1.1 Configuration

As was brought out in section “2.1 Initial Considerations and Decisions”, it would be best to imitate the conventional design of a drone as opposed to a helicopter. Figure 5 shows possible drone configurations that could be implemented for the drone aspect of the ARTEx. This project needs the drone to remain light while still maintaining a high level of control over the ARTEx. The first configuration is what is used by the V-22 Osprey in Figure 3. The V-22 Osprey has very complex mechanical systems at play helping to remain stable such as the rudders located at the back and thick chassis providing exceptional stability while airborne. Simply put the vehicle is very complex to create on a smaller scale. For this reason, it is better to use more motors to counterbalance the ARTEx. Bearing this in mind, any of the quad drone configurations would be suitable for the project.

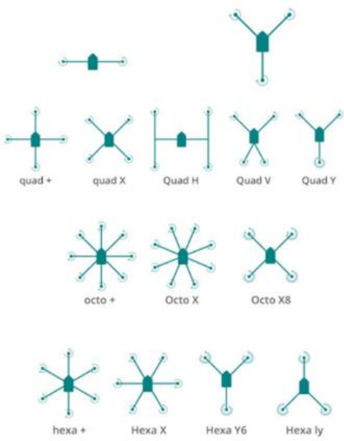


Figure 5 - Possible Drone Configurations

It is good to note that a higher number of motors has benefits. These benefits include increased stability, manoeuvrability, weightlifting capabilities, and what is likely the most beneficial factor being backup motors. Backup motors significantly improve reliability as if one motor breaks, another can take over its place mid-flight and prevent crashes or accidents. While having numerous motors has its benefits it is simply excessive, expensive to fund and time-consuming to work with a large number of motors. A quadcopter configuration provides the ARTEx with enough upthrust to be able to lift the weight of the drone vertically up into the sky while reducing the weight impact that the motor inflating the hovercraft skirt will have to deal with.

2.2.1.2 Physics

Weather conditions are a massive factor to consider when flying a drone. Factors such as wind, rain, fog, dust storms and other weather can easily ground a drone. Due to this, analysis of the physics of the ARTEx would need to be taken into careful consideration to not only assure stability but control when using the ARTEx to travel. The basic studies of momentum, kinetic and potential energy along with Newton's Laws of motion describe how drones work without having to understand aerodynamics to a high level. Hovering, climbing, and travelling are important areas to consider especially concerning how they are affected by conditions in an unclosed system. These include looking into aspects such as the drag of the motors and the turbulence produced by the motors. Furthermore, the efficiency of motors, batteries, and other components need to be taken into consideration.

2.2.1.2.1 Altitude Change

The first area to consider would be altitude change. If the drone segment of the ARTEx can't lift from the ground then it won't be able to fly anywhere and all of the other points of consideration will become redundant. To lift off the ground the ARTEx would need to produce more upthrust than its weight. During the ascent, external factors such as wind conditions, temperature, and air density can heavily impact a drone during take-off.

The air arriving at the rotors has speed denoted as v_r, which is the rotational velocity of the motors. The relationship between these velocities is given by $v_r = (v_s + v)/2$, where v represents the ascending velocity. The change in momentum per second is $\rho n A v_r (v_s - v) = F = mg$, where:

- ρ is the air density,
- n is the number of motors,
- A is the area of the motor blades, and
- $v_s - v$ represents the relative velocity of the air arriving at the motors compared to the climbing speed of the ARTEx.

The energy produced by the drone motors is $P = \frac{1}{2}\rho n A v_r (v_s^2 - v^2) + mgv = \frac{1}{2}mgv_r + mgv = \frac{1}{2}mgv_s + \frac{3}{2}mgv$.

External conditions such as wind can affect the relative velocity () of the air arriving at the motors. If the ARTEx is flying against winds the relative velocity decreases, reducing the effective airflow through the motors and slowing down the climb speed. If the ARTEx on the other hand is flying in the same direction as the wind, then the climb speed will also increase. Crosswinds on the other hand affect the stability and control of the ARTEx during flight. Temperature on the other hand can affect the air density which in turn affects the thrust generated by the motors. Generally lower temperatures result in higher air density leading to more efficient performance and higher temperatures the opposite. Higher temperatures also have the potential to affect the battery as well.

Descending vertically at a few meters per second creates challenges as the drone falls into turbulent and downward-flowing air it generates. The rotors must work harder to support the drone, and a rapid descent can become unsustainable, leading to a crash. Controllers should regulate descent speed, emphasising a slow or angled descent to prevent such issues.

2.2.1.2.2 Hovering

In order for the drone to hover its motors need to be producing an equal amount of upthrust to support the drone’s weight (mg). These values must remain in equilibrium. Any imbalance between these forces can result in either a gradual ascent or descent, depending on the direction of the imbalance, following Newton's third law.

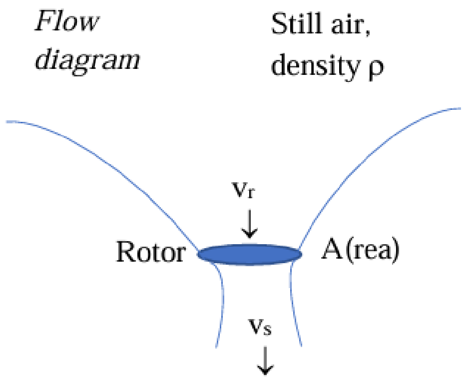


Figure 6 - Motor Airflow

According to Newton's second law, the force exerted to displace air downward is proportional to the rate of change of momentum of the air. The design of the rotor compensates for the increased speed of air in the outer region. As air, initially at rest, accelerates toward the rotor, it undergoes a pressure change, which generates the force necessary to support the drone's weight during hovering, equivalent to mg. Figure 6 depicts a flow diagram illustrating the channelling of air through the rotor.

2.2.1.2.3 Forward Motion

In contrast to a propeller plane, where the airscrew aligns perpendicularly to the direction of motion, drone rotors are steeply angled. When moving horizontally, drones must contend with the frictional drag of displacing air. This drag force is determined by the equation $\frac{1}{2}cd\rho Av^2$, where cd represents the drag coefficient. To maintain a constant speed, drones compensate for air resistance by tilting, thereby reducing the vertical component of rotor thrust. This necessitates an increase in rotor speed to prevent descent.

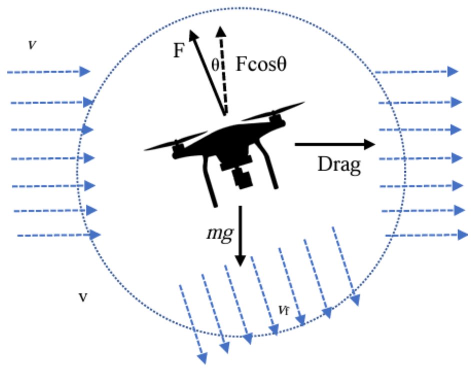


Figure 7 - Drone Motion Physics

The power required to counteract drag and propel the drone forward is calculated as $\frac{1}{2}cd\rho Av^3$. The relationship between tilt angle and horizontal velocity is described by the equation $\frac{1}{2}cd\rho Av^2 = mg\tan\theta$. When considering forces from the drone's perspective in a wind tunnel, the upward thrust generated by the rotors must balance the drone's weight, as expressed by the equation $F\cos\emptyset = mg$.

2.2.2 Hovercraft

The biggest concerns regarding the physics aspect of the ARTEx stem from how it will inflate the skirts for the integrated hovercraft segment of the vehicle. As the weight of the ARTEx increases, so does the required strength of the motor inflating the skirts. Given the compact form factor of the ARTEx, it's likely that only one motor will be used to inflate the skirt. Reversing the polarity of this motor to retract the skirts would aid in the airflow of the drone's motors. Therefore, research into the airflow physics of a hovercraft is necessary to identify and implement the most effective method for trapping air inside the skirts.

After extensive research, the decision was made to configure the skirts in a doughnut shape, as this configuration enhances air trapping. Considering Figure 8, a flexible skirt may be optimal in some cases, but the peripheral jet configuration is deemed most suitable for our project.

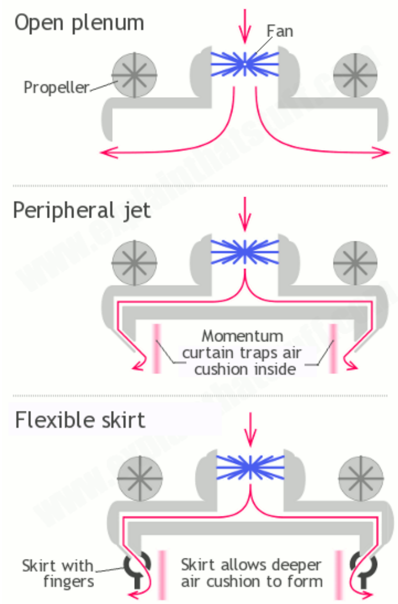


Figure 8 - Hovercraft Skirt Configurations

Hovercrafts glide just above surfaces like snow or water, utilizing a cushion of air to minimize friction. This air cushion, known as the skirt, is maintained by a continuous air supply, facilitating movement with minimal resistance. Typically equipped with one or two engines, the hovercraft generates lift force for the air cushion and thrust for omnidirectional movement. This lift is achieved by directing air towards the ground, creating pressure that inflates the cushion and lifts the craft. Despite some air leakage, methods are employed to minimize it, ensuring efficient skirt inflation. The application of Bernoulli's principle and equation allows for the calculation of the hovercraft fan's volumetric flow rate. Detailed equations and images regarding the physics of hovercraft operation will be provided in Appendix A1 – Hovercraft Equations.

3. Technical Background

When building a functional ARTEx, a strong set of technical skills is required. Drone and hovercraft design and fabrication, electronics and embedded systems, along with CAD experience is vital. One would need to demonstrate these skills as the project requires the implementation of a number of dependencies such as aerodynamics, propulsion systems, and structural design, to name a few. Good performance in these areas (and more) is key otherwise the whole system will fail to work. In projects of this calibre, problem-solving abilities shine. Experience in design and prototyping, adeptness at identifying design flaws, troubleshooting technical issues, and implementing improvements through multiple design iterations are presented.

4. Methodology/Design

4.1 Sourcing of Components

When sourcing the components for the ARTEx, the decision was made to purchase a prebuilt drone from Amazon and use the parts to perform the drone and hovercraft functions. This decision was primarily made due to the budget set and guaranteed that all the parts needed for (at least the main drone segment) would be there making it a convenient and efficient method of sourcing components. However, this proved very difficult and led to challenges later on.

Considering the skirts in the ARTEx need to be inflated and the ARTEx would move in 2 dimensions while on the ground, this would mean that the ARTEx would need to accommodate a minimum of 5 motors. There are no motor controllers that accommodate 5+ motors and the ones that do are very expensive (regarding the budget of the project). It would be significantly cheaper to buy a premade drone and repurpose it. The problem also remains regarding how to control the skirts.

The initial drone purchased was the 4DRC mini drone which has a 720P FPV camera. Having this camera would mean that the ARTEx could then integrate it allowing for more possibilities of expansion and improvement down the line using techniques from computer vision etc. The 4DRC drone (like most) falls in line with the drone configuration specified in section 2.2.1.1 making it a suitable choice. The only setbacks would be that the hovercraft segment still needs to be powered as well but there are no extra motors to inflate the skirt and no way to integrate that motor onto the pre-coded microcontroller used for the drone. An image of the drone is shown in Figure 9.

Figure 9 - 4DRC Drone

It was decided that the best way to control the motor that inflates the skirt would be with an ESP32. The ESP32 is a great microcontroller that allows for Wi-Fi and Bluetooth connection capabilities. The speed controller being used for the hovercraft segments motor is a speed controller known as the L9110 which can control 2 separate motors. The final drone used and repurposed was the Wipkviey T16 Mini Drone, an image is detailed in Figure 10. Motors from the 4DRC drone are still being implemented in other areas of the ARTEx.

Figure 10 - Wipkviey T16 Drone

4.2 CAD

The enclosure for the ARTEx has undergone several revisions. This is due to constant changes regarding the components and initial limitations in knowledge when developing the enclosure as a consequence of inexperience. This section will outline the changes that have been made regarding the enclosure of the ARTEx and explain why the changes were made along with any knowledge gained along the way.

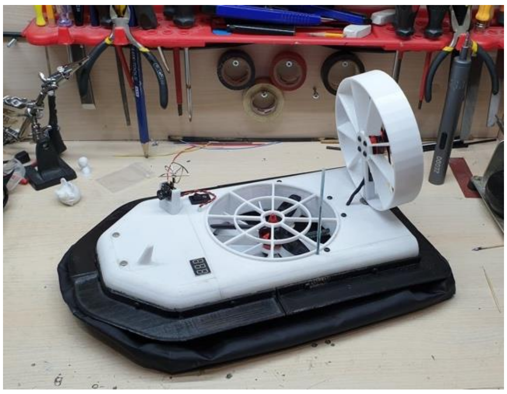


Figure 11 - Mosaves hovercraft build

4.2.1 Design 1

The initial design was always going to be the worst. With little to no experience on how to design 3D models, the easiest software to use at the time was TinkerCad. The thorough research conducted on hovercrafts inspired the creation of ARTEx v1. A creator/designer known as Mosave developed a simple hovercraft ready for production using a 3D printer. Mosave's hovercraft is depicted in Figure 11 and had the biggest impact on the design of the first version of the ARTEx. It uses two motors, one to inflate the skirts on the bottom of the hovercraft and another connected to the back. The motor on the back of his hovercraft is connected to servos which allow him to turn the motor for better directional control. This hovercraft has been tested and manoeuvres well on flat surfaces including snow.

Using the information and inspiration taken from Mosave and various other sources the enclosure was designed. The fully assembled enclosure and each component are documented in Figures 12 and 13. This design consists of three major parts:

- Top Segment: This part focuses on the protection of the components. It shields them from potential water damage. It also holds the turbine used to inflate the skirt at the bottom of the raft.
- Middle Segment: This holds the four rotors. Each one has its designated spot, ensuring a balanced and efficient setup.
- Base: This acts as a stable hovercraft foundation. It prevents any interference between the skirt and the drone's rotors. I've even tweaked how the skirt inflates from the bottom, deviating from normal hovercrafts to enhance overall performance and airflow for the drone rotors.

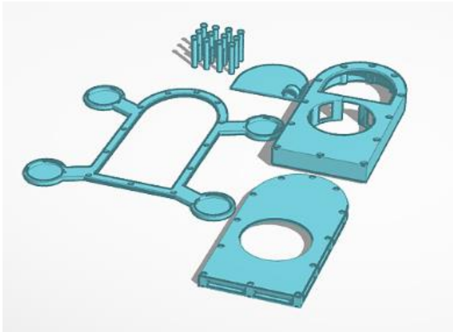


Figure 12 - ARTEx v1 split view

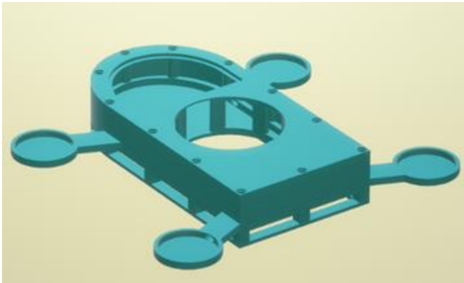


Figure 13 - ARTEx v1 Full Build

It is good to note that the turbine used to inflate the skirt should also retract the skirt back under barriers (on the base) by inverting the current flow and sucking the air back up from the skirt. The base's gaps also serve a dual purpose by reducing weight and optimising airflow for streamline-ability during travel in the air.

This design was not taken forward and discontinued due to factors mentioned in section 4.1 which underlines the limitations caused when sourcing different components for the ARTEx. These changes were made not only due to budget but also to expedite the development timeline by ensuring compatibility which should have minimised any technical challenges that would be faced further down the line. Furthermore, this body could no longer be used as it was designed for a significantly larger vehicle. Given the components that will be used, this design would no longer be valid.

4.2.2 Design 2

The following design was built in Fusion 360. The aim of this build was to see if a body could potentially connect to the bottom of a prebuilt drone and act as the hovercraft base. A massive flaw was identified. The first issue that became apparent was the base sketch used for the drone. The dimensions of the drone were inaccurate as the tools used to extrapolate the data weren't the best. Working with inaccurate measurements would lead to a world of issues down the line. The second issue was that the base would need to be long to hold the motors used (coreless motors) and this would cause major stability issues when the ARTEx would attempt to drive on land. It would be very susceptible to tipping due to wind and gravity would also tip the ARTEx. Figures 14 and 15 display images of the discontinued hovercraft integration bases with sketches below to show how the body of the drone was compiled on top of it.

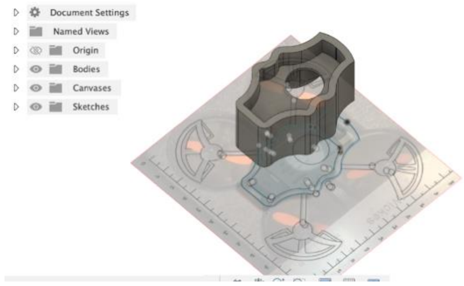


Figure 14 - ARTEx v2 Integration Base Top View

This design wasn't useless. The analysis of the build aided in deciding how to progress. The most important discovery was that there would simply not be a way to connect a standalone hovercraft base to a prebuilt drone. Second was the realisation that the motors that would be used for the ARTEx would be more coreless motors like the ones already used for the drone. This is due to the size of the motors and most importantly the cost of them compared to more heavy-duty motors such as a "Hawks Work A2212 Brushless Motor". One of these Hawk motors costs the same as 5 coreless motors. Due to these factors, a full body for the ARTEx would need to be developed so that all the internal components could fit and not create more challenges than they fix.

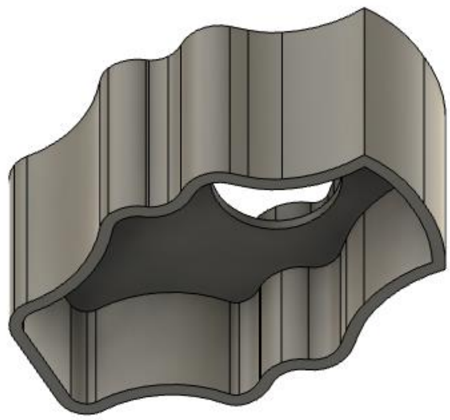


Figure 15 - ARTEx v2 Integration Base Bottom View

4.2.3 Design 3

Reverting to TinkerCAD, the following builds found in Figures 16 through 19 were designed. This build has space to hold all of the necessary components, namely, the drone PCB and motor used to inflate the skirts in the base. Focusing on the top segment depicted in Figure 17, there are 4 holes for the drone motor to slot into. The centre of the body holds the drone components. This iteration catered for the camera controller which has now screw-in holes.

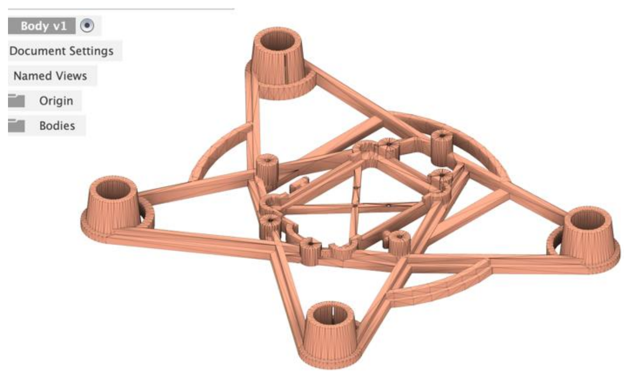


Figure 16 - ARTEx v3 Top Segment

The bottom connecting segment depicted in Figure 17 of the ARTEx v3 has a slanted nozzle entry for the motor to be put into. The idea was that the motor would slot into a motor holder (shown in Figure 18) that would allow the motor to blow air through the nozzle and down to the skirts.

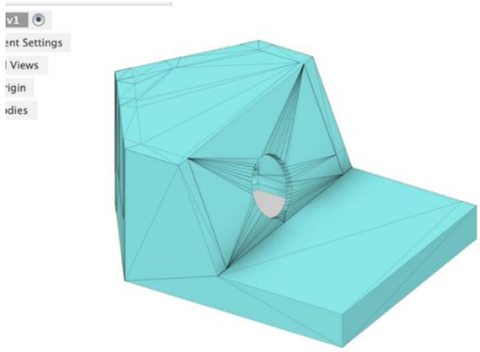


Figure 17 - ARTEx v3 Bottom Segment

The biggest issue was that there was an oversite when adding connecting holes to the base, so nothing could end up being connected. This was a massive and stupid oversight. Furthermore, the middle segment where the motor holder in Figure 18 would clip to was structurally unsound. The amount of landing and taking off would cause vibrations and would easily knock it out of place.

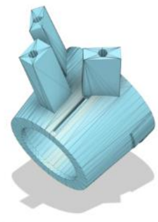


Figure 18 - Motor Holder

4.2.4 Design 4

Fusion 360 is the best option when it comes to developing models and 3D printing. Not only does it provide accuracy, detail, and the ability to create complex shapes compared to TinkerCAD, but once the learning curve is overcome it provides the ability to easily build upon work and collaborate. The updated version depicted in Figure 19 was a lot more sleek and fit each component perfectly. The central front end had a small cut-out to allow the camera to easily thread through the gap. The camera was later not implemented for a number of reasons. The biggest flaw in v3 was now rectified with the motor holder being supported by more stable, thicker segments. This was a very massive and inexcusable oversight in the first print.

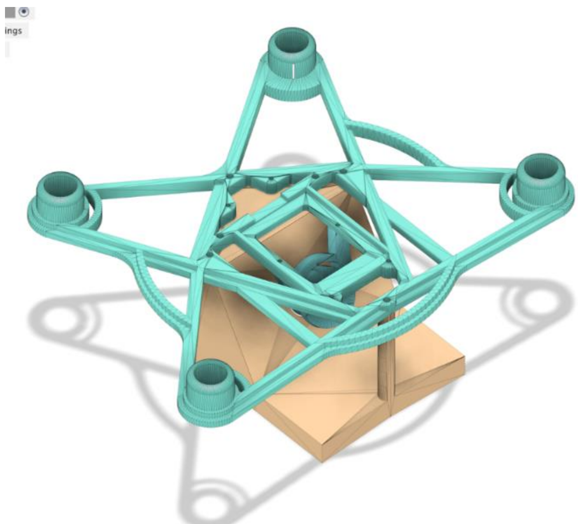


Figure 19 - ARTEx v4 Full Build

With this design, there were still a few drawbacks that could pop up down the line. The first drawback would be that the holder used to hold the motor that would inflate the skirt in the centre of the enclosure was not the best solution. This became apparent after a bit of testing where when attempting to put the propeller on the motor, it was difficult due to the dimensions of the propeller. This also drew attention to the biggest factor that would make or break the bottom segment used for the hovercraft being the air flow. If there is a lack of airflow, then the skirts will fail to inflate. The size of the motor used plays a big part along with how well air is pushed through the base. The ARTEx was also

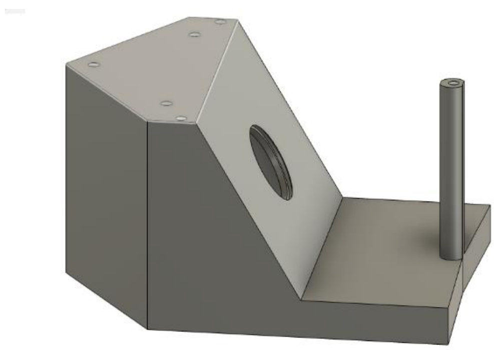


Figure 20 - ARTEx v4 Base

meant to have the functionality to drawback the skirts when the ARTEx leaves the ground to aid airflow to the top motors used for flight.

There are also issues with the base of the enclosure. One is that the slanted area where the motor would go in also wouldn't be great for airflow after testing and the other being the simple fact that the propellers just don't fit. I could have used smaller propellers but that again would reduce airflow and we want to generate enough air to inflate the skirt and keep the whole vehicle afloat. There was also a 3d printing error with the back pose that is connected to the rear end of the upper drone body so I would need to design a support with a larger surface area that can print well. There was also no bottom/clip for the base to hold the skirts in place. I was going to use a different method to keep it in place but it most likely would work out. Finally, the surface area of the drone is quite small and doesn't allow much space for expansion so a new body would have to be created.

4.2.5 Design 5 – Final Build

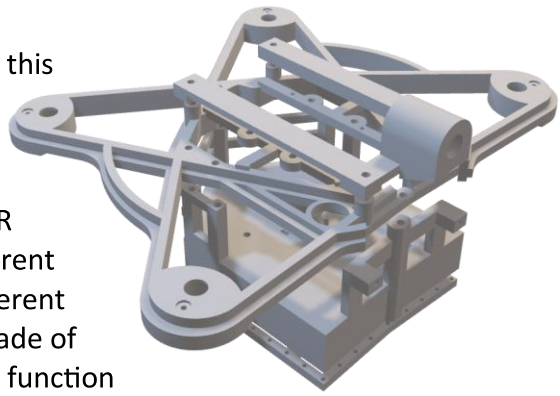


Figure 21 - ARTEx v5 Full Build

Taking into account all of the issues that happened before this build and adjusting accordingly, the following build displayed in Figure 21 is the sprog. This build is smaller in height than and allows for the addition of multiple components such as the BMP280, ADXL345 and even an IR sensor. This version (version 5/v5) is constructed of 6 different major components which can be referred to in their 3 different segments. One segment aids the flight. This segment is made of one piece. Another segment is what allows the hovercraft function to be carried out in the ARTEx. This segment is made of 4 pieces. The final segment which is the most important is the battery holder. Without power, the ARTEx isn't going anywhere. This is only made of one piece. The structure of this build will be segmented into different sections and discussed below.

4.2.5.1 Top Segment – Drone

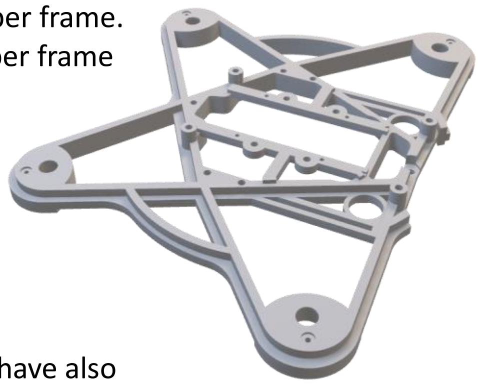


Figure 22 - v5 Upper Frame

The first changes to make note of would be the updated upper frame. A focused view of this part is displayed in Figure 22. The upper frame implements a number of components such as the motors, ESP32, L9110, etc. The implementation of these components will be discussed in section 5 entitled Implementations. The images of how components will be connected to the upper frame can be found in Appendix B1 entitled Upper Segment Implemented Components.

The holes which are used to connect to the lower segment have also been altered to allow more stability and firmness when connecting. The rear end depicted in Figure 23 shows how the lower segment connecting the pole joins with the upper frame. This has slightly extruded bezels to help hold the connecting pole from the base stay in place. It also dips in from the top allowing the screw to remain flush with the upper frame and allows a larger surface area of the screw to entrench itself into the pole.

Furthermore, the motor holders on this design no longer protrude out as it was deemed unnecessary and would only add to the weight of the vehicle. These motor holders support larger propellers which have now been implemented from the Wipkviey T16 Drone. These larger propellers heavily aid thrust and efficiency. Larger propellers generate more thrust making them more efficient. Although they may weigh more than smaller propellers, the increased efficiency means more thrust for the same power or alternatively the same thrust at a lower power output.

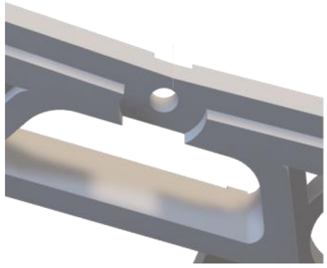


Figure 23 - v5 Upper Frame Connection Example

4.2.5.2 Bottom Segment – Hovercraft

4.2.5.2.1 Hovercraft Body

The base holds the components used for the hovercraft functionality. The body can be seen in Figure 24. In the centre of the body, a large circular hole can be seen. This holds the motor used to inflate the skirt in place. There are holes surrounding this motor holder to aid air intake. Several holes can also be seen around the body. The 5 elevated holes on the front of the body and the singular elevated hole at the back which faces are used for securely connecting the base to the upper body. The rear hole is 1mm higher than the other holes. This is because it fits in place between two extruded pieces as mentioned earlier in section 4.2.5.1. The holes found on the body are used to connect the different components in place such as the IR sensor, ADXL345 and BMP280. Lastly, the 2 holes on the rear end of the body are used to keep the back segment of the ARTEx in place (this will be discussed further in section 4.2.5.3).

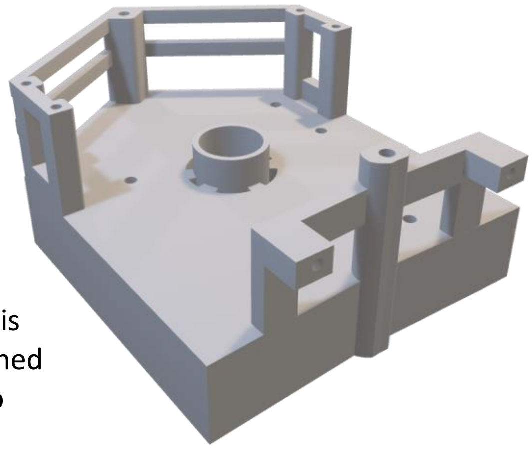


Figure 24 - v5 Lower Body

On the bottom of the body, holes are segmented around the edge. These are used to connect the body to the skirt clips and in turn the skirt (this will be discussed further in section 4.2.5.2.2). The central motor holder also protrudes out of the centre. This is to make sure that the propeller connected to the motor won't scratch the surface above it and damage the ship internally. More images of this body can be found in Appendix B2 entitled Lower Segment Body View.

4.2.5.2.2 Skirt Clips

After researching more in-depth examples of how other creators have made hovercraft, it was decided that the best thing to do moving forward would be to design skirt clips to properly aid the functionality of the hovercraft. On a hovercraft, as mentioned in section 2.2.2 and slightly displayed in Figure 8, air should be pushed out through the centre of the skirts to cause a hovering effect. This wasn't going to be possible in previous versions due to how the skirt was connected to the base and was a massive oversight. To implement this, two pieces were created. The images of these pieces are depicted in Figures 25 and 26 and images of how the two pieces connect to each other can be found in Appendix B3 entitled Skirt Clips Connection Diagram.

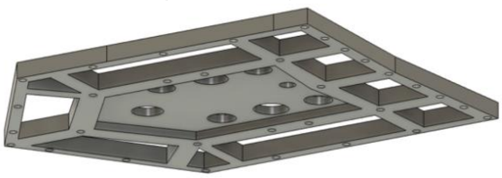


Figure 25 - Skirt Upper Clip

The holes in the upper clip allow for air to flow down and out under the skirts to aid the floating process. The rectangular holes around the side allow air to travel to the skirts when the central motor is on. The skirt sits between the body used for the lower segment of the hovercraft and this upper skirt clip. The holes inside the upper clip then allow for the skirts to be secured in place. The lower clip secures the other end of the skirt in place out of the way of the holes in the upper skirt clip so that air can still travel through. The upper skirt clip also protrudes out slightly past the segment where the holes are to allow for easier skirt securing and a stronger frame.

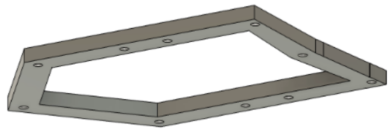


Figure 26 - Skirt Lower Clip

4.2.5.3 Back Segment – Battery Holder

The final segment is the back. It is comprised of a battery holder which connects to the body at the base. This battery holder is depicted in Figure 27. It simply holds the battery and allows for quick and easier inserts and removal. The upper frame has also been redesigned due to this holder to allow it space to sit comfortably without any disturbances. The battery holder doesn't sit below the base otherwise it may affect the skirts and in turn the skirts that need to inflate.

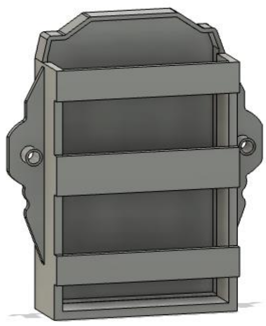


Figure 27 - Battery Holder

Previous versions of the ARTEx did not implement a battery holder which again is a problem as a loose battery could fly out and disconnect the components from power during movement. Since the ARTEx was intended to operate at high speeds this would have been a massive issue as it would greatly increase the risk of an issue. When deciding where to put it, it was initially going to be placed on the upper frame. After some reflection, this wasn't deemed as a smart idea as it would again increase the height of the ARTEx and make it more susceptible to imbalances when carrying out the hovercraft functionality.

4.3 Printing/Application

4.3.1 Print 1

When it came to printing the ARTEx there were several issues. In the first print, the upper frame had weak and flimsy central supports. This was due to the width of the supports. On top of this, the motor holders were much too big for the motors and a supporting clip had to be used to put the motors in place. Even when the motors were held in place, they wouldn't allow the motors to go high enough meaning that when the propellers were attached to the motor, the propellers would end up scratching the frame. This most certainly wasn't going to be okay. An image of the upper frame can be seen in Figure 28.

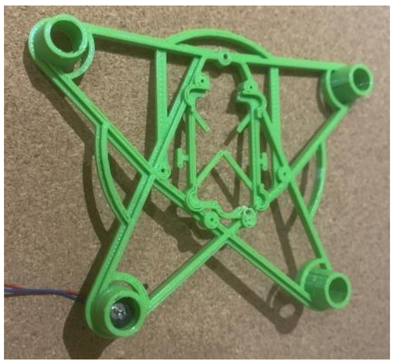


Figure 28 - Upper Frame Print 1

Then the base. The base had the majority of the issues. There was only one connecting hole which was located in the rear end. Furthermore, the holes that were implemented weren't usable as they were too close to the edge of the base. This issue wasn't a human error but more a machine one. The machine's filament placement precision was too big and in turn, wasn't able to add filament to the surrounding edge of the hole. This meant that the screw holes weren't usable. Moreover, the flat base was very thin and permeable. If one were to hold it up, they would be able to see through the base. The base can be seen in Figure 29.

Figure 29 - Base Print 1

4.3.2 Print 2

The second print was a lot better. Appendix B4 entitled images of 2nd print shows all of the printed pieces. It implemented the design from version 5 of my ARTEx CAD designs. There again were minor errors when printing due to the filament printing precision of the 3D printer. With regards to the upper frame, some holes didn't have all edges filled but it was usable. On the other hand, the lower segment pieces suffered severely from the precision of the 3D printer. Figure 30 depicts the condition of the upper skirt clip. It can be seen with missing pieces compared to what was intended in Figure 25. There were also major errors with the base leading to exposed connecting holes in the upper and lower side of the body. The lower skirt clip faced these issues as well but the errors much like the upper frame were also bearable due to the thicker width of each section. Please view Appendix B4 for images of the pieces.

Figure 30 - Upper Skirt Clip Print

A suggestion to negate the effects of the bad printing was given by one of the technicians that were familiar with the 3D printer. The technician suggested that the holes on the body be made smaller so that the 0.7mm precision of the 3D printer can handle the task and not cause any more errors.

4.3.3 Print 3

Taking the suggestion forward, the print finally came out well. An image of the fixed components can be seen in Figure 31. The upper frame and lower skirt clip weren't reprinted as they were okay for use.

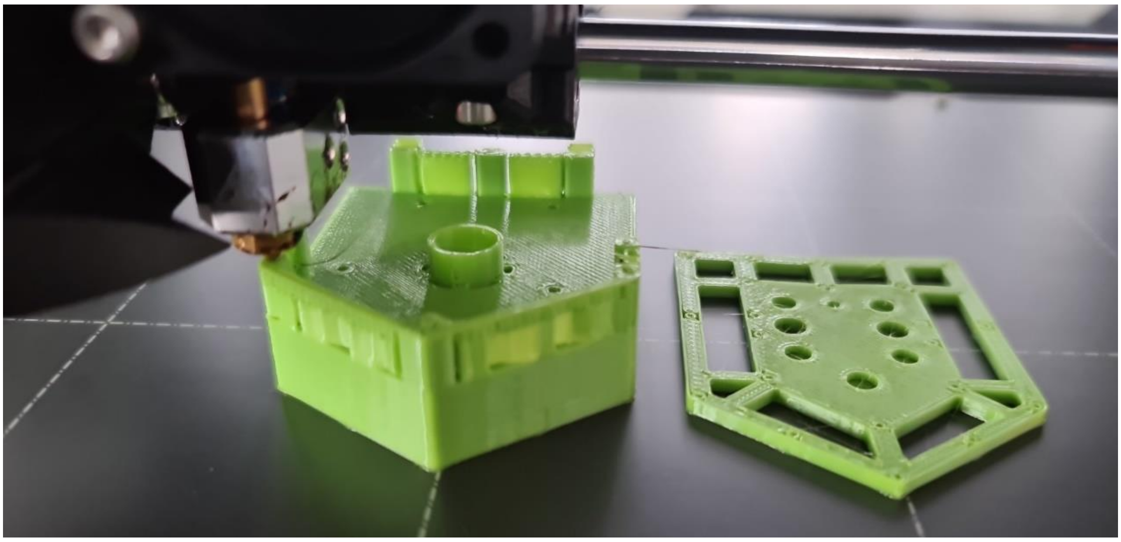


Figure 31 - Fixed Components Printed

4.4 Wiring and Testing

The wiring of the ARTEx was no easy feat. The top segment of the ARTEx simple to wire together as there was just about enough breathing room for the wires to move around. With regards to the base there was a lot of issues. Due to the vast number of components namely the BMP280, ADXL345 and IR sensor, wiring was a struggle due to their close proximity. Figure 32 displays an image of the muddled wiring. For this reason exactly a PCB would be a significantly better option when using a number components, but sadly it couldn't be implemented. The rationale behind why a PCB wasn't used can be found in section 5.2 – Excluded Component, Rationale. While all components fit well and work, due to the chaotic and exposed wiring, it was decided to only use the IR sensor for this prototype version.

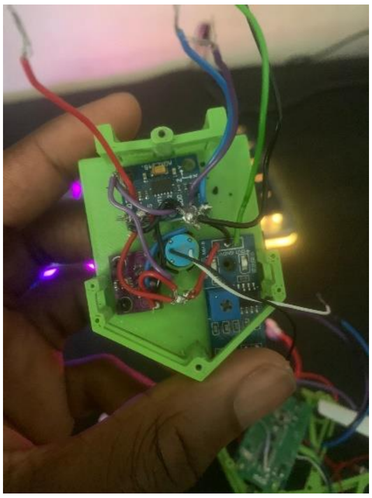


Figure 32 – Wiring of the Base

Not enough air was being pushed to the propeller in the base as well. The issue was tested and solved with the conclusion that the initially implemented vents were simply not wide enough. This means not enough air on the intake being pushed to the skirts. The issue has since been fixed.
There were some unplanned benefits in the design. For example, there was a fear that the button used to turn on and off the drone would both interrupt how well the ESP32 is screwed down and not be accessible due to its positioning. On the contrast, while screwing

down the ESP32, as long as the screws are too tight, the ESP32 will be able to rest at a good height securely while also being able to be pushed down to activate the button below it and turns on drone. The design of the top segment also has a wire holder which can be seen in figure 33. This segment was purposely added but works perfectly in the ARTEx's favour.

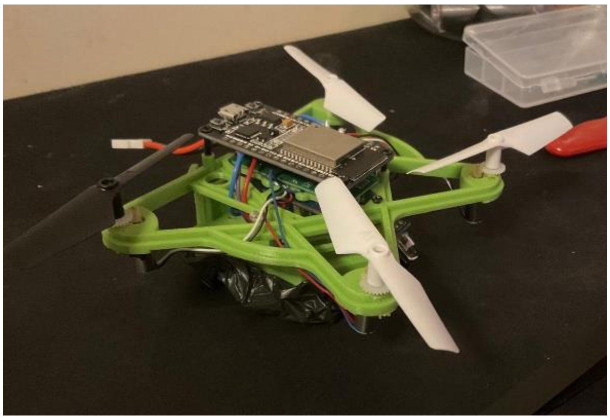


Figure 33 - Full Build

4.5 Code

All code is documented in Appendix C for ease of viewing. All code is pertaining to the functionality of the ESP32. Appendix C1 shows the Arduino code used for the onboard functions. Appendix C2 - C4 Document the code used for the webpage. This section will serve as an explanation for the different codes and their uses in the functionality of the ARTEx.

SPLIFFS was implemented to allow the use of separate HTML, Java, and CSS code. When the ESP32 is turned on data is sent to the webpage depicted in Figure 34. Buttons on the webpage also become useable so that the user can manually turn on and off the ARTEx's motor which is used to inflate the skirt. The functionality of the code is the control the inflation and deflation of the skirts on the hovercraft. An IR sensor is used to detect if the ARTEx is close to the ground. If the ARTEx is close to the ground within the IR sensor's specified range, then the light on the sensor will turn on and the motor will begin to push air down to the skirts. When the IR sensor doesn't detect anything, the motors will spin in the opposite direction to retract the skirts. The motors will only spin in the opposite direction for a few seconds and then turn off.

The code also enables the ESP32 to send data from the various microcontrollers and sensors back to the webpage. This way the user can have a reading on the specific temperature, pressure, and altitude of the ARTEx. The camera was also supposed to be implemented to enable better visualisation and computer vision capabilities like obstacle detection, but the camera could not be used. The web server also allows the user to see if the skirts are inflated or not and manually change whether it should be on or off.

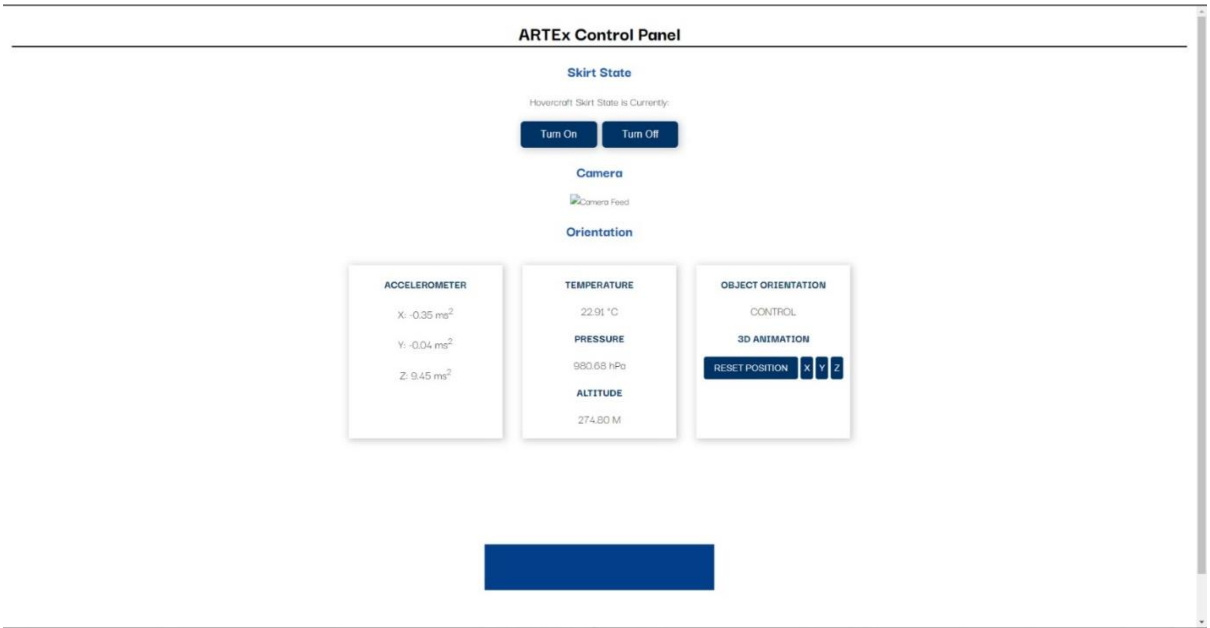


Figure 34 - ESP32 Webserver

5. Implementations

5.1 Components

The ARTEx has gone through several changes. A variety of components that were initially thought to be plausible have been withdrawn for a number of reasons. Components and the rationale behind why they were not taken forward will be discussed in the next section (section 5.2 – excluded component rationale). Components that have been used will be discussed here.

The first component to consider is regarded as the heart of the build, it is the ESP32. The ESP32 is a low-cost microcontroller that has integrated WI-FI and Bluetooth functionalities. Currently, in the ARTEx, the ESP32 is responsible for connecting to the motor that inflates the skirts in the lower centre of the body using a speed controller. The speed controller is a L9110. The speed controller allows for the control of 2 separate motors, having full control of airflow in both directions and even for the control of 4 motors. There is also the ADXL345 and BMP280 which have readings that are displayed to the ESP32's webserver. Having readings allows for the monitoring of the conditions that the ARTEx is navigating through so that the controller of the vehicle can adjust accordingly.

Then the components for the flying functionality. It consists of 4 motors which are connected to a microcontroller. This microcontroller is then connected to a controller via an antenna cable.

5.2 Excluded Component Rationale

A PCB was in development with the intent of implementing it as the ARTEx's primary control circuit board. This would not only clean up the clutter caused by the numerous components used and but also make the entire vehicle lighter. This PCB was not progressed however due to the size. An image of the PCB and the schematic up until the point of discontinuation can be seen in Figures 35 and 36. The PCB was far too big and was at risk of interfering with the components that had to remain there (being the motors, their accompanying propellers, and the battery). An attempt was made to make the PCB into a small form factor as well, but it proved difficult as the routing paths for the components were deemed impossible.

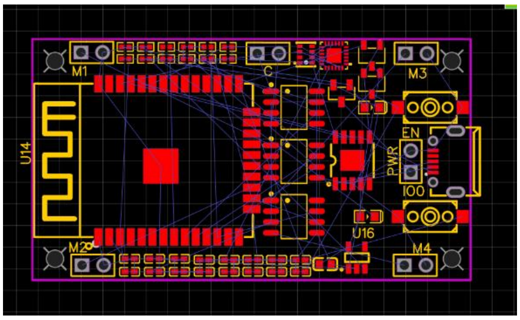


Figure 35 - PCB

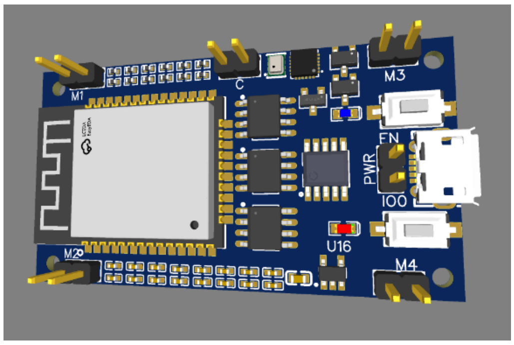


Figure 36 - PCB 3D View

Looking at figure 36 it is clear that the PCB looked far too cluttered and was simply not going to work. On top of that, the cost to buy and install the components would have far exceeded the budget given, not because each PCB was too expensive but because of the amount of money already used. The pricing for the PCB up until the point of discontinuation came to £8.29 per PCB. The BOM and schematic for the PCB can be found in Appendix B5 (these prices are subject to change for the completed PCB). For these reasons, the PCB was discontinued.

There was also going to be a mini-OLED display integrated into the ARTEx. However, it has not been taken forward as it was deemed unnecessary. While an OLED display can display different information, it would add redundant weight. The information that would be displayed on the OLED display can also be displayed on a webserver thanks to the ESP32. An ESP32 would be significantly better as the data wouldn't be readable from the OLED display when the ARTEx is in motion. All in all, it was useless.

A component that would not have been useless but contrarily very helpful is the camera sourced from the initial drone. Sadly, during the testing phase, the camera was unable to connect to the ESP32 board. The camera kept constantly sending unknown serial and connection errors making it difficult to work with. In the end, it wasn't taken forward due to the constant errors. The camera could have allowed for computer vision applications and would have given the pilot a better sense of direction and understanding when controlling the ARTEx.

6. Results and Discussion

6.1 *Discussion of Results*

Even though the ARTEx inflates its skirts, it struggles. More powerful motors would need to be implemented to make the ARTEx work at full performance. The implementations of powerful motors on a vehicle of this size will simply not be possible. Therefore, the whole build needs to be scaled up significantly to accommodate. This build was still a good prototype. The build is also heavy. Making the ARTEx bigger would help but the addition of a PCB would also make the entire system cleaner and lighter.

6.2 *Project Management and Progress*

The time taken for the project to be completed was a lot longer than initially expected. Unfortunately, due to a number of unforeseen challenges during the course of the project, the scope of changes, availability of resources such as funds and components that could fit the project, the time to complete the project was hindered.

Project was managed well. Making sure that everything was complete before the deadline was possible due to the Gantt chart. If it seemed like a section was going to continue for a long amount of time, the Gantt chart would be adjusted accordingly so that the remaining time could easily be identified. This meant extending sections and even removing some phases in the Gantt chart. This helped especially when it came to deciding which components to still implement. For example, testing and trying to get the camera module to work with the ESP32 was taking far longer than expected. The Gantt chart helped when deciding not to progress with using it due to the number of problems it was causing and the uncertainty with when the issues could be solved. Several steps during the development of the ARTEx have been taken to mitigate the impact of these delays.

7. Conclusions and Further Work

7.1 *Conclusions*

For application in the medical industry, whereby the ARTEx carries and delivers products to people's homes or (in third world countries) to the hospitals themselves, the ARTEx would need to be scaled up significantly. This is to allow the use of stronger motors and the ability to carry a lot more weight in an area of the body where it won't affect the functionality of the drone or hovercraft. For third world countries where the ground is very tough, the implementation of wheels over a hovercraft skirt would most likely be better. So the implementation of movable wheels could be used. The second reference displays examples of these manoeuvrable wheels.

To conclude, the ARTEx is an amazing prototype. It can currently be implemented in smaller applications such as taking readings in the environment such as temperature, altitude etc. With the use of different components it will also be able to read different values.

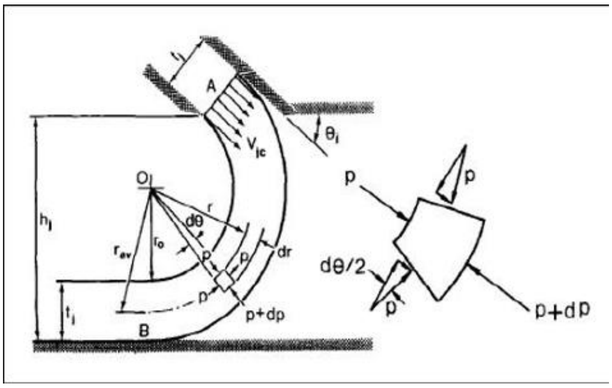
7.2 *Suggestions for Further Work*

For further work, it would be good to:

- Scale up the ARTEx
- Implement a camera so it can use CV
- Implement a working PCB
- Use stronger motors and test its ability to carry different products.

Appendix A

A1 – Hovercraft Equations



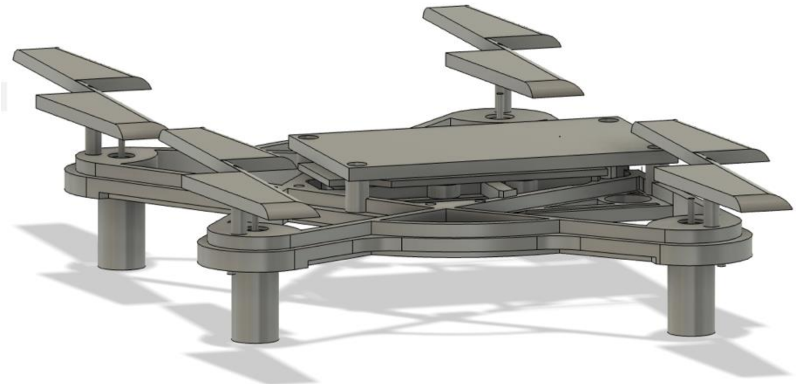
General Equations:

$Fc = W = Pc\ Ac + Jj * Lj * Sin\ \theta j$

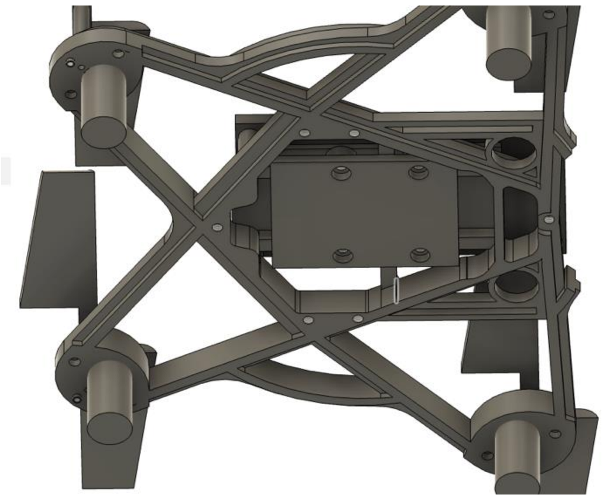
- *Fc* = Lift force (N)
- W = Weight of the model (N)
  - $W = \text{Mass} * \text{Gravity}$
  - *W* = Pc Ac + Jj Lj sinθj
  - *W* = Pc Ac + r * Pc (Lj) sin 45º = Pc (Ac + (r * Lj * sinθ))
- Ac = Area of cushion (m²)
  - Ac = Length * Width
- Jj = Momentum flux of air jet per unit length of the nozzle (Kg/s²)
- Lj = Nozzle perimeter (m)
  - *Lj* = π x tj
- θj = Angle of the nozzle from the horizontal (º)
- *r* = The average radius of the curvature of the length (m)
  - *r* = hj / (1 + cos θj)
- *Pc* = Cushion pressure (Pa)
- *hj* = The lift height (m)
- *Paj* = Power required (W)
  - *Paj = Pj Qj*
- *Qj* = Total volume flow per second into the skirt
  - $Qj = \frac{\text{Ljhj}}{1+\cos\theta j}\left(\frac{2\text{Pj}}{\rho}\right)^{\frac{1}{2}}(1-(\frac{Pc}{Pj})^{\frac{1}{2}})$

Appendix B

B1 – Upper Segment Implemented Components



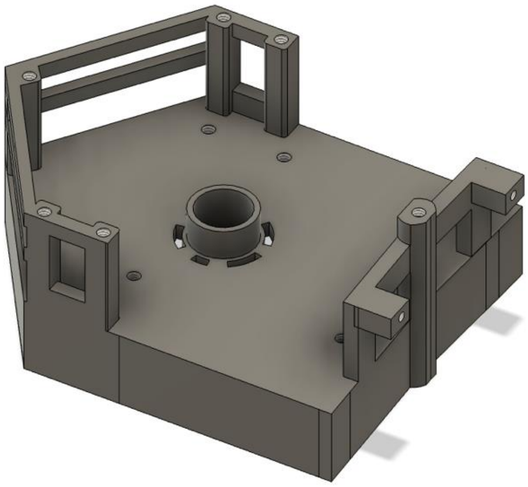
This image displays the full body from a top-view angle. The motors and propellers can be seen on the four corners of the upper frame. The ESP32 can be seen secured into place above the PCB used for the motors.



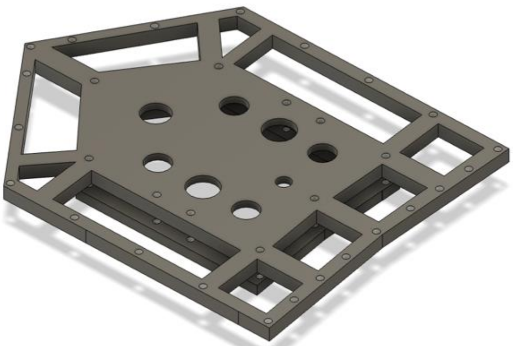
This image depicts the bottom angle of the body having its main focus on the central components. On the bottom is the L9110 microcontroller which is being used as a speed controller for the central motor which inflates the skirt in the base.

B2 – Lower Segment Body View

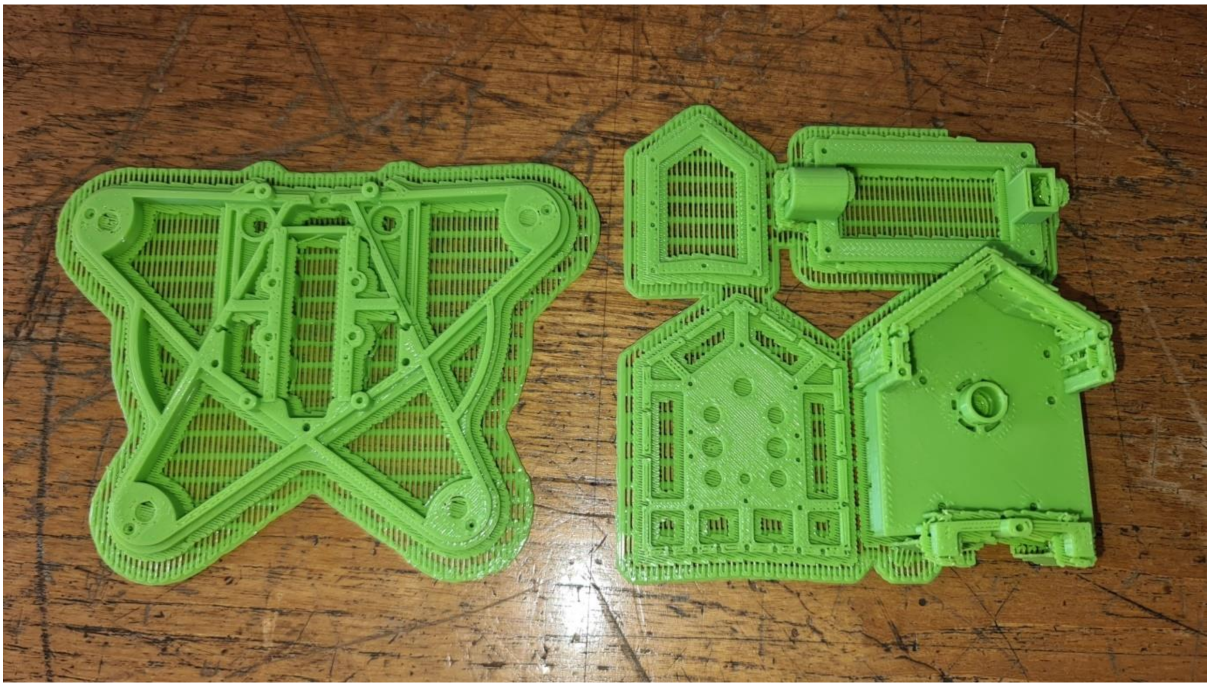
Base with gaps to aid airflow as well as connector holes to attach to the skirt clips. Dipped motor holder.



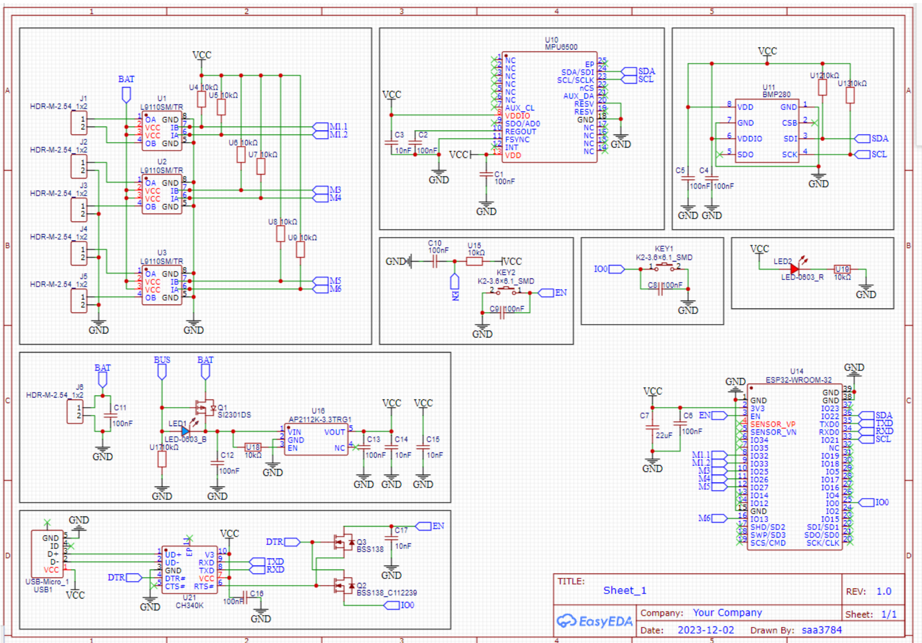
B3 – Skirt Clips Connection Diagram



B4 – Images of 2nd Print



B5 – Schematic & BOM (discontinued PCB)



ID	Name	Designator	Footprint	Quantity	Manufacturer Part	Manufacturer	Supplier	upplier Pa	Price
1	100nF	C1,C2,C4,C5,C6,C8,C9,C10,C11,C12,C13,C16	C0402	12	CL05A104KA5NNNC	SAMSUNG(三星)	LCSC	C100072	0.002
2	10nF	C3,C14,C15,C17	C0402	4	CC0402KRX7R9BB103	YAGEO(国巨)	LCSC	C60133	0.001
3	22uF	C7	C0603	1	CL10A226MQ8NRNC	SAMSUNG(三星)	LCSC	C59461	0.008
4	HDR-M-2.54_1x2	C,M1,M2,M3,M4,PWR	HDR-M-2.54_1X2	6			LCSC	C124375	0.022
5	K2-3.6×6.1_SMD	IO0,EN	KEY-SMD_2P-L6.2-W3.6-LS8.0	2	K2-1107ST-A4SW-06		LCSC	C118141	0.054
6	LED-0603_B	LED1	LED0603_BLUE	1	19-217/BHC-ZL1M2RY/3T	EVERLIGHT(台湾亿光)	LCSC	C72041	0.02
7	LED-0603_R	LED2	LED0603_RED	1	19-217/R6C-AL1M2VY/3T	EVERLIGHT(台湾亿光)	LCSC	C72044	0.017
8	SI2301DS	Q1	SOT-23-3_L2.9-W1.3-P1.90-LS2.4-BR	1	SI2301DS	TECH PUBLIC(台舟)	LCSC	C2841444	0.056
9	BSS138_C112239	Q2	SOT-23-3_L2.9-W1.6-P1.90-LS2.8-BR	1	BSS138	SHIKUES(时科)	LCSC	C112239	0.018
10	BSS138	Q3	SOT-23-3_L2.9-W1.6-P1.90-LS2.8-BR	1	BSS138	SHIKUES(时科)	LCSC	C112239	0.018
11	L9110SM/TR	U1,U2,U3	SOP-8_L4.9-W3.9-P1.27-LS6.0-BL	3	L9110SM/TR	HGSEMI(华冠)	LCSC	C725348	0.177
12	10kΩ	U4,U5,U6,U7,U8,U9,U12,U13,U15,U17,U18,U19	R0402	12	RAT021002FTH	RALEC(旺诠)	LCSC	C5119777	0.003
13	MPU6500	U10	QFN-24_L3.0-W3.0-P0.40-BL-EP	1	MPU-6500	TDK InvenSense(应美盛)	LCSC	C50278	2.484
14	BMP280	U11	LGA-8_L2.5-W2.0-P0.65_AMP6127	1	BMP280	Bosch(博世)	LCSC	C83291	1.641
15	ESP32-WROOM-32	U14	WIFIM-SMD_ESP32-WROOM-32-N4	1	ESP32-WROOM-32-N4	ESPRESSIF(乐鑫)	LCSC	C82899	3.012
16	AP2112K-3.3TRG1	U16	SOT-25-5_L2.9-W1.6-P0.95-LS2.8-BL	1	AP2112K-3.3TRG1	DIODES(美台)	LCSC	C51118	0.076
17	CH340K	U21	ESOP-10_L4.9-W3.9-P1.00-LS6.2-BL-EP	1	CH340K	WCH(南京沁恒)	LCSC	C968586	0.622
18	USB-Micro_1	USB1	MICRO-USB-SMD_5P-P0.65-H-F_C10418	1		ValuePro	LCSC	C10418	0.056
			TOTAL						8.287

Appendix C

C1 - Arduino Code (.ino)

```
#include <WiFi.h>
#include <Wire.h>
#include <Arduino.h>
#include <Arduino_JSON.h>
#include <AsyncTCP.h>
#include <ESPAsyncWebServer.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_ADXL345_U.h>
#include <Adafruit_BMP280.h>
#include "SPIFFS.h"

#define ssid "******"
#define password "***********"

AsyncWebServer server(80);
AsyncEventSource events("/events");
JSONVar readings;

Adafruit_BMP280 bmp; // I2C
#define sensor 33 //IR-Sensor
#define motorA1 26 // Motors
#define motorA2 27
#define motorB1 12
#define motorB2 13

bool go;
String header;
String skirtState = "off";
const long timeoutTime = 2000;
unsigned long previousTime = 0;
unsigned long lastTimeTemperature = 0;
unsigned long lastTimeAcc = 0;
unsigned long temperatureDelay = 1000;
unsigned long pressureAltitudeDelay = 1000;
unsigned long accelerometerDelay = 200;
unsigned long currentTime = millis();

Adafruit_ADXL345_Unified adxl;

sensors_event_t a;
float accX, accY, accZ;
float temperature, pressure, altitude;

void initADXL(){
  if (!adxl.begin()) {
    Serial.println("Failed to initialize ADXL345 sensor!");
    while (1);
  }
  Serial.println("ADXL345 sensor initialized successfully!");
}

void initBMP(){
  if (!bmp.begin(0x76)) {
    Serial.println("Could not find a valid BMP280 sensor, check wiring!");
    while (1);
  }
  Serial.println("BMP sensor initialized successfully!");
}

void initSPIFFS() {
  if (!SPIFFS.begin()) {
    Serial.println("An error has occurred while mounting SPIFFS");
  }
  Serial.println("SPIFFS mounted successfully");
}
```

```
// Initialize WiFi
void initWiFi() {
  WiFi.mode(WIFI_STA);
  WiFi.begin(ssid, password);
  Serial.println("");
  Serial.print("Connecting to WiFi...");
  while (WiFi.status() != WL_CONNECTED) {
    Serial.print(".");
    delay(1000);
  }
  Serial.println("");
  Serial.println(WiFi.localIP());
}

String getAccReadings() {
  adxl.getEvent(&a);
  accX = a.acceleration.x;
  accY = a.acceleration.y;
  accZ = a.acceleration.z;
  readings["accX"] = String(accX);
  readings["accY"] = String(accY);
  readings["accZ"] = String(accZ);
  String accString = JSON.stringify (readings);
  return accString;
}

String getTemperature(){
  temperature = bmp.readTemperature();
  return String(temperature);
}

String getPressure() {
  pressure = bmp.readPressure() / 100.0;
  return String(pressure);
}

String getAltitude() {
  altitude = bmp.readAltitude(1013.25);
  return String(altitude);
}

void setup() {
  Serial.begin(115200);
  initWiFi();
  initSPIFFS();
  initADXL();
  initBMP();
  pinMode(sensor, INPUT);
  pinMode(motorA1, OUTPUT);
  pinMode(motorA2, OUTPUT);
  pinMode(motorB1, OUTPUT);
  pinMode(motorB2, OUTPUT);
  digitalWrite(motorA1, LOW);
  digitalWrite(motorA2, LOW);
  digitalWrite(motorB1, LOW);
  digitalWrite(motorB2, LOW);

  server.on("/", HTTP_GET, [](AsyncWebServerRequest *request){
    request->send(SPIFFS, "/index.html", "text/html");
  });

  server.serveStatic("/", SPIFFS, "/");

  events.onConnect([](AsyncEventSourceClient *client){
    if(client->lastId()){
      Serial.printf("Client reconnected! Last message ID that it got is: %u\n", client->lastId());
    }
    // send event with message "hello!", id current millis
    // and set reconnect delay to 1 second
    client->send("hello!", NULL, millis(), 10000);
```

```
  });
  server.addHandler(&events);

  // Turn skirt on
  server.on("/turnSkirtOn", HTTP_GET, [](AsyncWebServerRequest *request){
    turnSkirtOn();
    request->send(200, "text/plain", "Skirt turned on");
  });

  // Turn skirt off
  server.on("/turnSkirtOff", HTTP_GET, [](AsyncWebServerRequest *request){
    turnSkirtOff();
    request->send(200, "text/plain", "Skirt turned off");
  });

  server.begin();
}

void loop() {

  if ((millis() - lastTimeAcc) > accelerometerDelay) {
    // Send Events to the Web Server with the Sensor Readings
    events.send(getAccReadings().c_str(),"accelerometer_readings",millis());
    lastTimeAcc = millis();
  }
  if ((millis() - lastTimeTemperature) > temperatureDelay) {
    // Send readings to webserver
    events.send(getTemperature().c_str(),"temperature_reading",millis());
    lastTimeTemperature = millis();
  }
  if ((millis() - previousTime) > pressureAltitudeDelay) {
    events.send(getPressure().c_str(), "pressure_reading", millis());
    events.send(getAltitude().c_str(), "altitude_reading", millis());
    previousTime = millis();
  }
  if (digitalRead(sensor) == LOW) {
        go = true;
        while (go == true) {
            turnSkirtOn();
            if (digitalRead(sensor) == HIGH) {
                turnSkirtOff();
                go = false;
            }
        }
    }
}

void turnSkirtOn() {
  digitalWrite(motorA1, HIGH);
  digitalWrite(motorA2, LOW);
  digitalWrite(motorB1, HIGH);
  digitalWrite(motorB2, LOW);
}

void turnSkirtOff() {
  digitalWrite(motorA1, LOW);
  digitalWrite(motorA2, HIGH);
  digitalWrite(motorB1, LOW);
  digitalWrite(motorB2, HIGH);
  delay(2000);
  digitalWrite(motorA1, LOW);
  digitalWrite(motorA2, LOW);
  digitalWrite(motorB1, LOW);
  digitalWrite(motorB2, LOW);
}
```

C2 – Webpage Code (index.html)

```html
<!DOCTYPE HTML>
<html>
<head>
  <title>ARTEx Control Panel</title>
  <meta name="viewport" content="width=device-width, initial-scale=1">
  <link rel="icon" href="data:,">
  <link rel="stylesheet" type="text/css" href="style.css">
  <link rel="stylesheet" href="https://use.fontawesome.com/releases/v5.7.2/css/all.css" integrity="sha384-
fnmOCqbTlWIlj8LyTjo7mOUStjsKC4pOpQbqyi7RrhN7udi9RwhKkMHpvLbHG9Sr" crossorigin="anonymous">
  <script src="https://cdnjs.cloudflare.com/ajax/libs/three.js/107/three.min.js"></script>
</head>
<body>
  <div class="topnav">
    <h1>ARTEx Control Panel</h1>
    <h2>Skirt State</h2>
    <p>Hovercraft Skirt State is Currently: <span id="skirtStatePlaceholder"></span></p>
    <button id="turnOnButton" class="custom-button" onclick="turnSkirtOn()">Turn On</button>
    <button id="turnOffButton" class="custom-button" onclick="turnSkirtOff()">Turn Off</button>
    <h2>Camera</h2>
    <img id="cameraFeed" alt="Camera Feed">
    <h2>Data</h2>
    <div class="content">
      <div class="cards">
        <div class="card">
          <p class="card-title">ACCELEROMETER</p>
          <p><span class="reading">X: <span id="accX"></span> ms<sup>2</sup></span></p>
          <p><span class="reading">Y: <span id="accY"></span> ms<sup>2</sup></span></p>
          <p><span class="reading">Z: <span id="accZ"></span> ms<sup>2</sup></span></p>
        </div>
        <div class="card">
          <p class="card-title">TEMPERATURE</p>
          <p><span class="reading"><span id="temp"></span> &deg;C</span></p>
          <p class="card-title">PRESSURE</p>
          <p><span class="reading"><span id="pressure"></span> hPa</span></p> <!-- Changed unit to hPa -->
          <p class="card-title">ALTITUDE</p>
          <p><span class="reading"><span id="altitude"></span> M</span></p> <!-- Changed unit to M -->
        </div>
        <div class="card">
          <p class="card-title">OBJECT ORIENTATION</p>
          <p><span class="reading"><span id="altitude"></span>CONTROL</span></p>
          <p class="card-title">3D ANIMATION</p>
          <button id="reset" onclick="resetPosition(this)">RESET POSITION</button>
          <button id="resetX" onclick="resetPosition(this)">X</button>
          <button id="resetY" onclick="resetPosition(this)">Y</button>
          <button id="resetZ" onclick="resetPosition(this)">Z</button>
        </div>
      </div>
      <div class="cube-content">
        <div id="3Dcube"></div>
      </div>
    </div>
  </div>
  <script src="script.js"></script>
</body>
</html>
```

C3 – Javascript (script.js)

```javascript
let scene, camera, rendered, cube;

function parentWidth(elem) {
  return elem.parentElement.clientWidth;
}

function parentHeight(elem) {
  return elem.parentElement.clientHeight;
}
```

```
function init3D(){
  scene = new THREE.Scene();
  scene.background = new THREE.Color(0xffffff);

  camera = new THREE.PerspectiveCamera(75, parentWidth(document.getElementById("3Dcube")) /
parentHeight(document.getElementById("3Dcube")), 0.1, 1000);

  renderer = new THREE.WebGLRenderer({ antialias: true });
  renderer.setSize(parentWidth(document.getElementById("3Dcube")),
parentHeight(document.getElementById("3Dcube")));

  document.getElementById('3Dcube').appendChild(renderer.domElement);

  const geometry = new THREE.BoxGeometry(5, 1, 4);

  var cubeMaterials = [
    new THREE.MeshBasicMaterial({color:0x03045e}),
    new THREE.MeshBasicMaterial({color:0x023e8a}),
    new THREE.MeshBasicMaterial({color:0x0077b6}),
    new THREE.MeshBasicMaterial({color:0x03045e}),
    new THREE.MeshBasicMaterial({color:0x023e8a}),
    new THREE.MeshBasicMaterial({color:0x0077b6}),
  ];

  const material = new THREE.MeshFaceMaterial(cubeMaterials);

  cube = new THREE.Mesh(geometry, material);
  scene.add(cube);
  camera.position.z = 5;
  renderer.render(scene, camera);
}

function onWindowResize(){
  camera.aspect = parentWidth(document.getElementById("3Dcube")) /
parentHeight(document.getElementById("3Dcube"));
  //camera.aspect = window.innerWidth /  window.innerHeight;
  camera.updateProjectionMatrix();
  //renderer.setSize(window.innerWidth, window.innerHeight);
  renderer.setSize(parentWidth(document.getElementById("3Dcube")),
parentHeight(document.getElementById("3Dcube")));

}

window.addEventListener('resize', onWindowResize, false);

// 3D ARTEx rep
init3D();

if (!!window.EventSource) {
  var source = new EventSource('/events');

  source.addEventListener('open', function(e) {
    console.log("Events Connected");
  }, false);

  source.addEventListener('error', function(e) {
    if (e.target.readyState != EventSource.OPEN) {
      console.log("Events Disconnected");
    }
  }, false);

  source.addEventListener('temperature_reading', function(e) {
    console.log("temperature_reading", e.data);
    document.getElementById("temp").innerHTML = e.data;
  }, false);

  source.addEventListener('pressure_reading', function(e) {
    console.log("pressure_reading", e.data);
    document.getElementById("pressure").innerHTML = e.data;
  }, false);
```

```
  source.addEventListener('altitude_reading', function(e) {
    console.log("altitude_reading", e.data);
    document.getElementById("altitude").innerHTML = e.data;
  }, false);

  source.addEventListener('accelerometer_readings', function(e) {
    console.log("accelerometer_readings", e.data);
    var obj = JSON.parse(e.data);
    document.getElementById("accX").innerHTML = obj.accX;
    document.getElementById("accY").innerHTML = obj.accY;
    document.getElementById("accZ").innerHTML = obj.accZ;
  }, false);
}

function resetPosition(element){
  var xhr = new XMLHttpRequest();
  xhr.open("GET", "/"+element.id, true);
  console.log(element.id);
  xhr.send();
}

function updateCameraFeed() {
    fetch('/camera-feed') // Fetch the camera feed from the server
        .then(response => {
            if (!response.ok) {
                throw new Error('Network response was not ok');
            }
            return response.blob(); // Get the response as a blob
        })
        .then(blob => {
            // Convert the blob to a data URL
            const reader = new FileReader();
            reader.onload = () => {
                const dataUrl = reader.result;
                // Update the src attribute of the image element with the data URL
                document.getElementById('cameraFeed').src = dataUrl;
            };
            reader.readAsDataURL(blob);
        })
        .catch(error => console.error('There was a problem with fetching the camera feed:', error));
}

function turnSkirtOn() {
  sendRequest('turnSkirtOn');
}

function turnSkirtOff() {
  sendRequest('turnSkirtOff();');
}

// Call updateCameraFeed()
setInterval(updateCameraFeed, 1000);
```

C4 - Webpage Styling (style.css)

```
@import url("https://fonts.googleapis.com/css2?family=Darker+Grotesque:wght@400;600;800&display=swap");

html {
  display: inline-block;
  text-align: center;
}
code {
  font-family: source-code-pro, Menlo, Monaco, Consolas, "Courier New",
    monospace;
}
body {
  margin: 15px;
```

```css
  font-family: "Darker Grotesque", -apple-system, BlinkMacSystemFont, "Segoe UI",
    "Roboto", "Oxygen", "Ubuntu", "Cantarell", "Fira Sans", "Droid Sans",
    "Helvetica Neue", sans-serif;
  -webkit-font-smoothing: antialiased;
  -moz-osx-font-smoothing: grayscale;
}
h1 {
  font-size: 32px;
  border-bottom: 2px solid black;
}
h2 {
  font-size: 24px;
  color: #145ab6;
}
a {
  text-decoration: none;
}
p {
  font-size: 18px;
}
.content {
  padding: 20px;
}
.card {
  background-color: white;
  box-shadow: 2px 2px 12px 1px rgba(140,140,140,.5);
}
.card-title {
  color:#003366;
  font-weight: bold;
}
.cards {
  max-width: 800px;
  margin: 0 auto;
  display: grid; grid-gap: 2rem;
  grid-template-columns: repeat(auto-fit, minmax(200px, 1fr));
}
.reading {
  font-size: 1.2rem;
}
.cube-content{
  width: 100%;
  background-color: white;
  height: 300px; margin: auto;
  padding-top:2%;
}
#reset{
  border: none;
  color: #FEFCFB;
  background-color: #003366;
  padding: 10px;
  text-align: center;
  display: inline-block;
  font-size: 14px; width: 150px;
  border-radius: 4px;
}
#resetX, #resetY, #resetZ{
  border: none;
  color: #FEFCFB;
  background-color: #003366;
  padding-top: 10px;
  padding-bottom: 10px;
  text-align: center;
  display: inline-block;
  font-size: 14px;
  width: 20px;
  border-radius: 4px;
}
.custom-button {
    background-color: #003366;
    border: none;
```

```
    color: white;
    padding: 12px 32px;
    text-align: center;
    text-decoration: none;
    display: inline-block;
    font-size: 16px;
    margin: 2px 2px;
    cursor: pointer;
    border-radius: 6px;
    box-shadow: 2px 2px 12px 1px rgba(140,140,140,.5);
}
```

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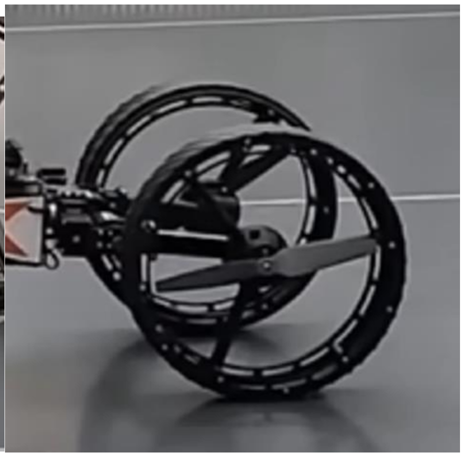
[2] – Alternative version for ARTEx(timestamp 1:08) - https://www.youtube.com/watch?v=m1FNcNvboSg&ab_channel=TechPlanet – Images

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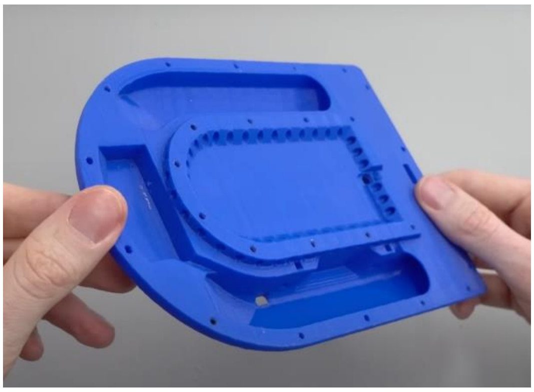

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