Volantem Machina

Submitted in Response to the 2019 EXPOFest

Submitted By:

ΣSUMS

$\sum (i)^3$ imagine, investigate, invent

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Table of Contents

Abstract

Our company is going after a contract, released by a city in the United States of America, seeking designs for an Unmanned Aircraft System (UAS) to be used for surveying in urban environments. The city is requesting bids for a pilot program to test the feasibility of safe UAS operation within the city to perform the surveying tasks. For this challenge, you will assume that the city has received the necessary waivers from the FAA to operate UAS in the city. In order to obtain the waivers, our UAS design must meet a set of safety requirements to operate within the city. In addition to the requirements, the contract is requesting for the system to perform certain survey tasks effectively. Winning the contract will be based on the most competitive bid or in other words, the most reasonable price.

The safety requirements that will allow the drone to fly through the city include: Being able to take off in a 3-meter by 3-meter space. The city cannot designate an entire runway or large area for the drone, as cities are already extremely crowded as is. The drone must also be able to guide itself around the city without the assistance of GPS. GPS can be extremely unreliable in an urban canyon environment. The guidance system should also be able to detect obstacles in its way, stationary or not and evade them sufficiently. As the drone is operating in an urban environment, it must also be able to operate beyond line-of-sight so that it can be flown behind buildings and other plentiful obstructions. Finally, the drone has to be able to sufficiently land itself in the event of an engine failure in order to prevent injuries on the ground. Bird strikes and other obstacles could be common, so this will be one of the most important systems on the drone. Whilst doing this, the design also has to be cost effective both to appeal to the contractual bid and make a profit for our company.

Specifications Sheet

Criteria	Value	Regulation	Compliance Y/N
Empty Weight	7.242 lbs	N/A	N/A
Flight Takeoff Weight	13.04 lbs	Unmanned aircraft must weigh less than 55 lbs (25 kg).	Y
Diameter (end of propeller to end of propeller on opposite side)	10 cm	N/A	N/A
Max. Airspeed	30 mph	Maximum airspeed of 100 mph (87 knots).	Y
Max. Operating Altitude	50 ft	Maximum altitude of 400 ft above ground level.	Y
Max. Flight Time	46.5 min.		
Distance Traveled			
# of Aircraft per Operators	1	No person may act as an operator or VO for more than one unmanned aircraft operation at one time	Y
		Visual line-of-sight (VLOS) only; the unmanned aircraft must remain within	N

		VLOS of the operator or visual observer. At all times the small unmanned aircraft must remain close enough to the operator for the operator to be capable of seeing the aircraft with vision unaided by any device other than corrective lenses.	
		Small-unmanned aircraft may not operate over any persons not directly involved in the operation	N
		Daylight-only operations (official sunrise to official sunset, local time)	Y
		Must yield right-of-way to other aircraft, manned or unmanned	Y
		Minimum weather visibility of 3 miles from control station	
		No operations are allowed in Class A (18,000 feet & above) airspace	Y

1. Document System Design

1.1 Mission Design

1.1.1 FAA Regulations:

The proposed theory of operation for the UAS solution documented in this design notebook complies with the following elements of the Part 107 regulations:

- The vehicle may only operate in daylight or twilight
- The vehicle may not be flown under covered structures or vehicles
- The vehicle must stay within 400 feet of the ground
- The vehicle may operate in Class G airspace without air traffic control (ATC) permission.
- The vehicle must not exceed an airspeed of 100 mph (87 knots)
- The vehicle must not weigh over 55 lbs
- External load operations are allowed if the object being carried by the unmanned aircraft is securely attached and does not adversely affect the flight characteristics or controllability of the aircraft.
- Most of the restrictions discussed above are waivable if the applicant demonstrates that his or her operation can safely be conducted under the terms of a certificate of waiver.

1.1.2 Justification of Regulatory Compliance:

The two areas of the FAA part 107 regulations in which case our solution violated the rules were; The aircraft must remain within the VLOS of the operator, and the aircraft must not operate above any persons not directly involved in the operation.

In the former case, the task we've been given makes it impossible for VLOS to be maintained at all times. In order to survey effectively, the UAS must operate behind buildings and other plentiful obstacles within the urban environment. Instead, the operator will use an external video source to keep track of the drone. The video will be stream from a camera mounted on the UAS to a laptop or other device.

In the latter case, the urban environment makes it impossible to comply with the regulation. This is because there will be dense populations of people walking throughout the city, so operating a drone within that area will inevitably result in the drone flying above persons on the ground not directly involved in the operation.

In both of these cases, we believe that the safety systems put in place will easily make us eligible for a waiver that allows us to operate despite the lack of compliance of these rules.

1.1.3 Design Operations

The UAS will be used for surveying missions. To improve safety, the aircraft will be fitted with a CCD/CMOS camera in order for the operator to be able to see and avoid obstacles if necessary.

In order to survey as needed, the UAS will be equipped with radar sensors to detect whether it is too close to a building or not and automatically avoid it without input from the operator. The health of the plant life will be determined by purely visual means via a gimbal camera mounted on the bottom of the drone. The redundancy between radar and cameras will allow for the drone to automatically intervene if it approaches too close to a building while also allowing the operator to avoid collisions as best they can in addition to the essential survey role.

As for the part 107 regulations, the group made their best attempts to design the UAS within them as much as possible. However, the nature of the mission meant that we had no choice but to operate our solution outside of two of the part 107 regulations. Flying behind buildings and over people is completely unavoidable when operating in a city.

1.2 Conceptual, Preliminary, and Detailed Design

Using the model of the engineering design process, we separated our solution into parts and went about finding what we believe what the best parts would be for our design solution. The parts that we chose were selected with other aspect and parts of the drone in mind, since choosing them individually could result in an unbalanced design.

1.2.1 Engineering Design Process:

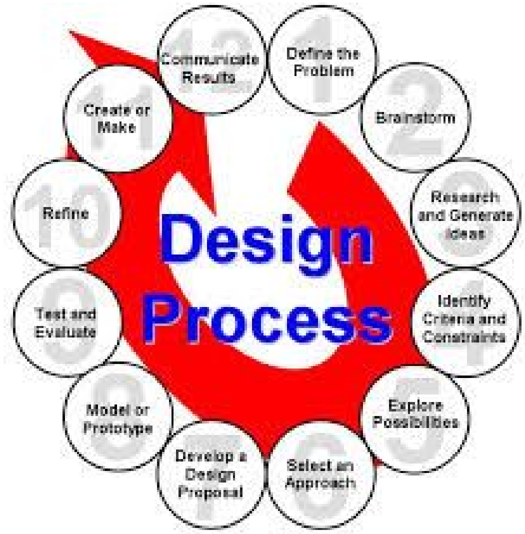

Figure 1: Engineering Design Process graphic

Our first step in developing our system was to define the problem and figure out what kind of solution we would need to develop. We quickly came to the conclusion that our drone's main purpose was to survey and take pictures, with the biggest obstacle being navigating the hazardous urban environment. With this, we got to work on brainstorming and research.

The first thing our team did was decide what type of design would be best suited for the task at hand. Choosing that correct platform for our solution was the most important part of our brainstorming, as it would decide the premise of the entire project from thereon. We did this by comparing the pros and cons of different types of unmanned aerial systems, and through an in-depth analysis decided which one would be best suited for the task. After this, we went through a similar comparison process in regards to more specific parts of the drone, such as frame type, propeller type, camera type, etc. For this, each person was assigned certain parts to research in order to maximize the efficiency of the research. We all then returned in a group to discuss our findings and come to conclusions on which parts should be used, which involved not only deciding what individual parts would be best but how they all fit together as a whole. Once this was decided, the team began to make 3D models of each type of part being used so we could begin to put the design together.

1.2.2 Conceptual Design

Important Criteria

- *Must be maneuverable* → Maneuverability is crucial when navigating a city. There will be far more obstacles than in other environments such as buildings, trees, vehicles people, as well as strong wind currents created by the various structures. If the drone is too sluggish, it will not be able to perform the task effectively.
- *Must be relatively small* → The drone does not necessarily have to be tiny, however, it should not be large and cumbersome. A large surface area could see issues with the previously mentioned wind currents, and if the drone fails then it could be potentially lethal to persons on the ground if there is a catastrophic systems failure.
- *Must handle in crosswinds and bad weather* → The drone should be able to operate in bad weather conditions. It is not ideal nor intended that the drone operate as normal in heavy rain, however, if the weather makes a sudden shift, it's a scenario that we must be prepared for.
- *Must have mounted camera for pictures and remote operation* → A remote visual camera is an absolute necessity when it comes to the drone. It will almost certainly be operating out of line-of-sight of the user seeing as there are so many view-obstructing obstacles in urban environments, so there has to be some way for the operator to remotely see where the drone is and operate it from that point. The camera is also necessary for the monitoring of plant life.
- *Must have procedure for emergency landings* → Systems failure due to a bird strike, bad weather or mechanical failure should be expected at some point during the operations of the drone, so an emergency landing procedure of some sort is necessary. It is imperative that we minimize the risk of any persons on the ground being harmed.

- *Must be able to detect and avoid large stationary objects such as buildings* → It is unrealistic to expect for pilots of the drone to be perfect, so there should be precautions put into place in order to protect the drone from crashing into easily avoidable obstacles. This will more than likely be done in the form of relatively simple sensors that will simply transmit data to the drone if it's too close to an obstacle.

Fixed-wing

Advantages:

- *Faster travel* → Fixed-wing aircraft are indisputably faster than VTOL aircraft. Achieving higher speeds could get the task done more quickly and save fuel.
- *Less moving parts* → The only external moving part of a fixed-wing drone is its single propeller. This leaves far less to go wrong mechanically, and it will also make the drone far more simple to construct compared to VTOL.
- *Quieter travel* → VTOL unmanned aerial systems tend to use four or more propellers, which will be louder than the one that a fixed-wing aircraft requires. This means that the drone will disturb or distract people on the ground far less.

Disadvantages -

- *Harder to fly, both manually and autonomously* → Fixed-wing aircraft take a much higher skill set to operate than VTOL aircraft. Normal VTOL drones have advanced autopilot systems that make them exceptionally easy to fly since when the controls are released, the drone automatically stabilizes. With fixed-wing aircraft, that is not the case. The aircraft must constantly be in control, and usually, an expert pilot is required.
- *Restricted range of motion* → Fixed-wing aircraft do not have the spherical range of motion that VTOL aircraft do. In an urban environment, this is a big issue, as avoiding obstacles such as birds become far more difficult.

VTOL

Advantages:

- *More maneuverable* → As previously mentioned, VTOL drones have a spherical range of motion. This allows the UAS to avoid obstacles in any direction very easily compared to fixed-wing aircraft, which have to rely on their turning radius and such.
- *Easier to fly* → As previously mentioned, VTOL drones tend to be equipped with advanced autopilot systems that make the drone extremely intuitive and easy to fly. Using these kinds of drones opens up the possibility of not needed a professional pilot.
- *Additional stability for taking pictures* → With a fixed-wing aircraft, taking pictures or video is far, far more difficult as you must always be moving at a relatively high velocity in order to maintain lift. With a VTOL aircraft, it is extremely easy to stop and take a picture or video, allowing the plant life to be surveyed in far greater detail.
- *Precise positioning for best angles* → To go along with the previous point, a VTOL drone can get extremely close to the plant life and also look at from various different angles, something a fixed-wing craft cannot do since it's in constant motion
- *Easier to program* → Programming a VTOL aircraft required far less complex instructions than with a fixed-wing aircraft since there is no need to take into account that the craft always has a forward velocity.

Disadvantages:

- *Slower* → Fixed-wing aircraft are far faster and more efficient than VTOL aircraft. The VTOL aircraft will probably need bigger, heavier batteries to operate as a result since it will be using pure engine power to create lift, and not a fixed, completely unpowered surface.
- *Would need parachute system to combat engine failure* → Whilst fixed-wing aircraft can glide in the event of an engine failure, VTOL aircraft cannot. A parachute system will have to be added at an extra cost if the VTOL design is chosen for our solution.

Final Design Idea Type: VTOL

The VTOL design is simply more fitting for this task than a fixed-wing ever could be. It's far easier to fly in this non-open environment and more resistant to the harsh winds the city has to offer. The reason fixed-wing designs are much more difficult to fly is because of the requirement for constant speed to generate lift, meaning they can never be still. Additionally, in an emergency situation, a fixed-wing design would be more complicated, as adding safety systems such as a parachute is harder to mount on a body which has to be sleek and smooth to fly. The same problem makes it harder to mount a camera anywhere on the frame for a fixed-wing design. We would have to find a camera that is both competent but still aerodynamic. Assuming we didn't want to mount a parachute system, the aircraft could glide. However, gliding runs the additional risk of hitting other people, and in the event of colliding with an obstacle, the aircraft may not be fit to glide. Additionally, the 3m x 3m landing space is a nearly impossible space to land a fixed-wing aircraft in unless the aircraft is extremely small.

1.2.3 Preliminary Design

Frame

Quadcopter:

Advantages:

- *Inexpensive* → Quadcopters are very common among the drone market and are not very complex to build, making them relatively cheap compared to other frames.
- *Easy to construct/repair* → Because the frame is so popular, replacement parts will be extremely easy to find and install.
- *Large market* → easy to find parts for it

Disadvantages:

- *Not extremely heavy-duty* → Quadcopters are typically used recreationally and aren't designed to carry even moderately heavy loads. Our design will have to carry a camera and parachute, so this would cause some issues.

- *Unsafe in the event of an engine failure* → If even one engine fails on a quadcopter, the drone becomes entirely incapable of flight, meaning that any mechanical failure regarding the engines will force the parachute system to be used every time.
- *Less natural stability* → Quadcopters are reasonably stable, however seeing as we are operating in an environment which has very strong winds and such caused by buildings, more propellers could be more helpful in this case.

Hexacopter:

Advantages:

- *Safe in event of single or double engine failure* → Upon some quick research, we found that hexacopters could fly even if one engine is not producing thrust. This is extremely helpful as it means that even if an engine fails, the drone could possibly make it back to its landing area, or if that is impossible, land somewhere safely without the need to use the parachute system. In the event of a dual symmetrical engine failure, the drone would also be flyable since the center of thrust would still be in the middle, and there would more than likely be enough thrust total to make a safe landing.
- *Can lift very heavy loads* → Hexacopters, having two more propellers than quadcopters, have 1.5 times the thrust and therefore 1.5 times the lifting capacity. Seeing as we will be carrying a parachute and a heavy camera, this will increase the performance of the aircraft as well as allow the aircraft to more easily land in the event of an engine issue.
- *More stable due to more props* → Having more propellers, the hexacopter will be more stable than the quadcopter in the crosswinds of the urban environment.

Disadvantages:

- *Expensive to build* → Hexacopters are not as common as quadcopters, so finding parts will be more difficult and likely more expensive as well. Additionally, the design being a hexacopter means that we need two extra motors, which increases initial and maintenance costs.

- *Difficult to construct/repair* → Hexacopters are not nearly as common on the market as quadcopters, so finding parts will be more difficult, making construction and repair more difficult.
- *Harder to find parts* → Market is smaller

Final Frame Type: Hexacopter

Hexacopters provide benefits over quadcopter designs that outweigh any possible detriments. Hexacopters, hence their name, have six propellers as opposed to a quadcopter, which has four. This makes the design far more stable, as lift is distributed in more places. The lift being distributed in more locations also increases lift in comparison to a quadcopter. This allows the design to lift the heavy cameras and safety systems that must be attached to the drone. Some quadcopters may be able to do this as well, however, in the event of a partial loss of power to the drone caused by low battery or any other factor, a hexacopter will be far safer as it will have an easier time maintaining altitude. Regarding safety, a six propellor design takes a distinct advantage over quadcopters in that it is flyable in the event of an engine failure. Assuming one engine fails on any side, the other five engines will produce enough lift to safely land the drone, and possibly even fly it all the way back to the landing area. In theory, if two engines failed on opposite sides it could even remain stable under a dual engine failure.

Propellers

Dual-Bladed:

Advantages:

- *Less expensive* → Dual bladed propellers use fewer materials and are more common and are therefore less expensive than other blades.
- *More common on the drone market* → Lower maintenance costs

Disadvantages:

- *Minimal lift produced compared to other propellers* → Two-bladed propellers have minimal surface area compared to propellers with more blades, decreasing their lift.

Tri-Bladed:

Pros:

- *More lift produced compared to dual-bladed props* → Three blades means that there is more surface area to create lift, which helps the performance of our drone.

Cons:

- *More expensive* → Tri-bladed propellers are less common and use more materials, so they will cost more to buy than dual-bladed.
- *Less common on the drone market* → Higher maintenance costs

Final Propeller Type: Tri-Bladed

The tri-bladed design holds some distinct performance advantages over the dual bladed design. Whilst dual blades may be sufficient in order for the drone to achieve flight, more blades on the propeller means that there is more lift to play with. This will allow the drone to carry the heavy payloads of the camera and parachute even more easily, and will also increase the flyability of the drone in the event of a partial loss of power or engine failure.

Additionally, the propeller will be fixed pitch and variable speed, not vice versa, since the vice versa is very difficult to do with drones.

CCD/CMOS Camera

Fixed Camera:

Advantages:

- *Less expensive* → Gimbals on cameras are extremely expensive, so if necessary a fixed camera is a much more cost-effective option.
- *Easier to find and replace* → Gimbal cameras are very difficult to make and therefore very difficult to find as well. If the camera breaks, then fixed would be much easier to replace.

- *Lighter* → Gimbals are heavy, and weight is something we don't want on our drone. A fixed camera would thus undoubtedly increase the performance of the drone.

Disadvantages:

- *The camera is forced to face where the drone is* → A fixed camera can't be remotely adjusted, so taking pictures is far more difficult, especially if the drone is moving.
- *The camera is only as stable as the drone is* → If the drone has even a minor stability issue, it could make the image blurry and useless. Gimbals usually automatically adjust to always be upright, so that problem only exists with fixed cameras.

Gimbal Camera:

Advantages:

- *The camera has automatic stability assistance* → As previously mentioned, gimbaled cameras have gyroscopes that allow them to automatically stabilize so smooth pictures are always taken.
- *The camera can face anywhere, regardless of drone orientation* → Even if the drone is moving in one direction, the camera can rotate to face another and get a different view of the plant life.

Disadvantages:

- *More expensive* → Gimbals are extremely expensive things to put on cameras, so having one would drive up maintenance costs significantly.
- *Harder to find and replace* → Gimbal cameras are not as common as they are difficult to make, so replacing them is not only more expensive but more difficult as well.
- *Heavier* → Gimbals have significant weight to them, which could affect the performance of the drone significantly.

Final Camera Type: Gimbal Camera

A gimbaled camera does, admittedly, have some issues. Cameras like these are extremely expensive and tend to be heavier than fixed cameras, as they need additional equipment to support their gimbal. However, the advantages that a camera like this presents far outweigh any drawbacks. With a gimballed camera, even if the drone is performing a maneuver, the camera will stay entirely level, ensuring that a clear photo or video is always taken, even when moving at speed. If there are strong winds that affect the stability of the drone, causing vibrations or small movements, the camera would hardly notice and compensate entirely for the movement. If we decided to use a fixed camera, the task would be completed less well and take more time, which is why we didn't use it for our design.

Parachute System

A parachute system was an obvious addition to the drone for us. It was previously mentioned before, but we would like to go more in depth about it. The parachute system will be very similar to the ParaZero safety system. It will activate automatically if a problem is sensed, and can also be activated manually if deemed necessary. It will also have safety pins so that there is no unintended activation, which could compromise the drone by getting the propellers tangled. The design will also be as lightweight as possible for obvious performance advantages.

1.2.4 Detailed Design

Our final design based on the selections from section 2.1.3, is a hexacopter VTOL drone with tri-bladed propellers, a gimbaled camera, and a parachute system. We decided on our design because all of the individual parts to the design worked together very well. The heavy camera and parachute equipment are held up by the six, tri-bladed propellers. Our whole team agreed that this was the best solution.

1.2.5 Lessons Learned

Throughout our design, the team learned how to brainstorm together in order to work towards different design solutions. In the conceptual design phase, we all worked together and pitched in our individual ideas to come up with a compromise that would best fit the Real World Design Challenge. In the preliminary design phase, we all split off and learned how to do our own research individually, and then used all of our individual ideas to come to another compromise. Overall, every group member learned valuable lessons in research and teamwork.

1.3 Selection of System Components

Parts selection for our drone will take into account multiple factors. The part must be high quality and able to function well at its task, and must also display durability. The part must also be relatively cheap for what it's giving, as we are trying to win a contract bid and make a profit off of this endeavor. The parts that we selected for this drone are thoroughly researched and compared to accomplish these goals.

Name	Quantity	Cost	Total Cost
DYS 3-Axis SMART Gopro Brushless Gimbal	1	$195.99	$195.99
GoPro Hero 7 White Action Camera	1	$199.99	$199.99
Tarot 690 Folding Carbon Fiber Hexacopter Frame	1	$99.00	$99.00
Lumenier LU5 400kv Professional Motor	6	$125.99	$755.94
Turnigy High Capacity 20000mAh	1	$193.08	$193.08

6S 12C Multi-Rotor Lipo Pack			
Castle Creations 20A BEC Pro	1	$34.99	$34.99
TF03 LiDAR Rangefinder (180m)	7	$229.00	$1603.00
Graupner E-Prop 10x5 (3 Blade) - 10 x 5 Propeller Well Balanced	6	$12.89	$77.34
Pixhawk 4 Open Source Autopilot	1	$179.00	$179.00
Lumenier 35A BLHeli_S ESC OPTO (2-6s) DSHOT	6	$18.99	$113.94
DroneFever Hexacopter Power Distribution Board - Assembled	1	$19.99	$19.99
X68 Pro Parachute for 4-20 kg SUAV	1	$568.64	$568.64
TBS Crossfire Micro TX	1	$69.99	$69.99

Dark Knight Radio Nirvana	1	$179.00	$179.00
Ultra Power UP-S6 1S Battery Charger	1	$22.99	$22.99
Total Cost:	**1**	**N/A**	**$4,312.88**

1.3.1 Payload Selection

Camera/Gimbal Options

DYS Marcia 3 Axis Brushless Gimbal for GoPro:

- Cost: $315.99

Reasoning: This gimbal is designed for the GoPro series of cameras, the most likely to be used. Allows for incredibly steady photographs to be taken, as more expensive Gimbals are much better stabilized.

Figure 2.1: DYS Marcia 3 Axis Brushless Gimbal for GoPro

DYS 3-Axis SMART GoPro Brushless Gimbal:

- Cost: $195.99

Reasoning: Designed for multi-rotor platforms making it perfect for our use. Designed to use the GoPro series of cameras, the most likely to be used. This is a cheaper gimbal but should provide ample stability. More expensive gimbals are often heavier, as it is difficult to shake something that is heavy, but for our purposes, we would want the lighter option.

Figure 2.2: DYS 3-Axis SMART GoPro Brushless Gimbal

GoPro Hero 7 White Action Camera

- Cost: $199.99

Reasoning: GoPro is incredibly reputable for their cameras, this should provide ample quality in relation to size and weight.

Figure 2.3: GoPro Hero 7 White Action Camera

Final Camera/Gimbal

- DYS 3-Axis SMART Gopro Brushless Gimbal
- GoPro Hero 7 White Action Camera

1.3.2 Air Vehicle Element Selection

Frame

Tarot 690S Folding Carbon Fiber Hexacopter Frame:

- Cost: $99.00

Reasoning: The drone being a hexacopter, size and weight present more prominent concerns than with other types of drones. Getting a carbon fiber frame was therefore essential for our purposes, as gimballed cameras, large batteries, and parachutes are heavy. This frame allows the drone to have better-suited parts for the purpose, without sacrificing size or quality.

Figure 2.4: Tarot 690 Folding Carbon Fiber Hexacopter Frame

Motor

6 x Lumenier LU5 400kv Professional Motor:

- Cost: 6 x $125.99*1

Reasoning: These motors are designed with aerial mapping, photography, and agriculture surveying in mind. As size and weight are an issue, we need motors that can lift a heavier than usual drone, which these motors are designed for. These motors are also water and dust resistant, which will allow the drone to operate in the city more effectively, and more often. As they are designed for photography drones they produce minimal vibrations in the drone, allowing for much better image quality.

Figure 2.5: Lumenier LU5 400kv Professional Motor

Battery Options

Relevant Calculations for Power Draw

$Weight = 5,914\ g$ $Thrust_{hover} = Weight$ $Thrust_{hover} = 5914\ g_{force}$ $Thrust_{hover_{single}} = \frac{Thrust_{hover}}{6}$

$Thrust_{hover_{single}} = 985.67\ g_{force}$ $P_{hover_{single}} = 95.46\ Watts$ $P_{hover} = 6 * P_{hover_{single}} = 572.76\ Watts$

Figure 2.6: Turnigy High Capacity 20000mAh 6S 12C Mult-Rotor Lipo Pack

Turnigy High Capacity 20000mAh 6S 12C Multi-Rotor Lipo Pack:

- Cost: $193.08

Reasoning: This battery is designed for multi-rotor aircraft, especially those with aerial video. With a capacity of 20000mAh, it should provide enough power for flight lengths of approximately 46.5 minutes.

Lumenier N2O 5200mAh 4s 120c Lipo Battery:

- Cost: $89.99

Reasoning: This battery has a very high C rating, thus it should provide ample current for our non-racing large drone. Its lighter weight also means the rotors can spin at lower speeds, decreasing power draw.

Figure 2.7: Lumenier N20 5200mAh 4s 120c Lipo Battery

Lumenier 5200mAh 4s 35c Lipo Battery:

- Cost: $59.99

Reasoning: Uses a much more common connector, making it cheaper to charge and run the drone. Similar advantages of light weight with the other 5200 mAh battery.

Figure 2.8: Lumenier N20 5200mAh 4s 35c Lipo Battery

Final Battery:

- Turnigy High Capacity 20000mAh 6S 12C Multi-Rotor Lipo Pack
    - This battery was the most expensive, but it was the only one which could provide the requisite current with more than enough capacity to keep the drone flying for the target time of 30 minutes.
    - $P = V * I$ $V = 22.2\ volts$ $P = 572.76\ watts$ $I = \frac{P}{V}$ $I = 25.8\ amperes$
      $Capacity/current = runtime$
      $20,000\ mAh * 3600\ \frac{s}{h} * \frac{1\ A}{1000\ mA}/25.8\ A = 2790.70\ s = 46.5\ min$

Battery Eliminator Circuit:

Castle Creations 20A BEC Pro

- Cost: $34.99

Reasoning: This battery eliminator circuit is more than enough for our task, and its excess output means it will be less strained. This makes its failure far less likely and makes the drone more reliable, an important factor to optimize.

Figure 2.8: Castle Creations 20A BEC Pro

LiDAR Sensors

TF03 LiDAR Rangefinder (180m)

- Cost: 7 x $229.00

Reasoning: These sensors have extremely long maximum range for their size and have a small 10cm deadzone. This makes collision avoidance more precise and the expense is more than fair for protecting the drone from damage.

Figure 2.9: TF03 LiDAR Rangefinder (180m)

Propeller Options

Master Airscrew 3-Blade - 10 x 7 Propeller Factory Balanced:

- Cost: 6 x $9.77 = $56.82

Reasoning: Three-bladed propellers provide more lift than similarly sized two bladed counterparts. These are balanced at the factory reducing the time before they can be mounted. The extra lift provided will help in the case of an engine failure, making it easier for the remaining engines to make up for the lost lift.

Figure 2.10: Master Airscrew 3-Blade - 10 x 7 Propeller Factory Balanced

Graupner E-Prop 10x5 (3 Blade) - 10 x 5 Propeller Well Balanced:

- Cost: 6 x $12.89 = $77.34

Reasoning: Three-bladed propellers provide more lift than similarly sized two bladed counterparts. These propellers are made well balanced, only requiring minor tweaks before installation. This propeller's e-prop design makes it optimized for being electrically driven due to a different profile.

Figure 2.11: Graupner E-Prop 10x5 (3 Blade) - 10 x 5 Propeller Well Balanced

Graupner E-Prop 10x5 (2 Blade) - 10 x 5 Propeller Well Balanced:

- Cost: 6 x $11.29 = $67.74

Reasoning: These propellers are made well balanced, only requiring minor tweaks before installation. These propellers are reinforced with carbon fiber, making them strong, but not heavy. This propeller's e-prop design makes it optimized for being electrically driven due to a different profile.

Figure 2.12: Graupner E-Prop 10x5 (2 Blade) - 10 x 5 Propeller Well Balanced

Final Propeller:

- Graupner E-Prop 10x5 (3 Blade) - 10 x 5 Propeller Well Balanced
    - Despite this propeller's higher cost, its e-prop design makes it more efficient when used with electric motors. This optimization does not apply to the other 3-bladed option and although the 2-bladed propeller up for consideration is an e-prop, the extra lift of 3-bladed propellers will lead to longer flight times.

Flight Controller

Pixhawk 4 Open Source Autopilot:

- Cost: $179.00

Reasoning: This flight controller does everything we need it to do, and it does so fast. Its open source status makes it flexible in its tasks and compatible with numerous configurations.

Figure 2.13: Pixhawk 4 Open Source Autopilot

ESC Module Options

Lumenier 35A BLHeli_S ESC OPTO (2-6s) DSHOT:

- Cost: 6 x $18.99 = $113.94

Reasoning: Single ESC. Allows for fast and smooth response from motors. Very high PWM frequency, granting high precision in thrust modulation. Lightweight and compact design helps us fit the need number of ESCs in a smaller space.

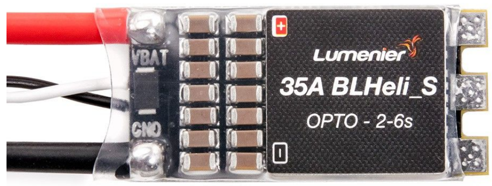

Figure 2.14: Lumenier 35A BLHeli_S ESC OPTO (2-6s) DSHOT

Flycolor Raptor 20A 2-4S OPTO ESC:

- Cost: 6 x $12.99 = $77.94

Reasoning: Single ESC. Designed for multi-rotor drones. Small, lightweight design allows us to fit more ESC's in a smaller area, freeing up more space on the drone.

Figure 2.15: Flycolor Raptor 20A 2-4S OPTO ESC

Final ESC Module

- Lumenier 35A BLHeli_S ESC OPTO (2-6s) DSHOT
    - This ESC, although not stated to be designed for multi-rotor drones, offers more current and therefore power to our motors. It is preferable to be stressing the ESCs less compared to their maximum load, so the excess current capacity this ESC maintains should increase reliability. Further, the higher PWM frequency provides for more precision and quicker reactions from the motors to human and autopilot input alike.

PDB

Drone Fever Hexacopter Power Distribution Board - Assembled:

- Cost: $19.99

Reasoning: This board is designed for hexacopters, and has 6 separate ESC power outputs while still being able to power the flight controller.

Figure 2.16: Drone Fever Hexacopter Power Distribution Board - Assembled

Parachute

X68 Pro Parachute for 4-20 kg SUAV:

- Cost: $568.64

Reasoning: Parachutes are necessary to minimize collateral impact from any complex failure in the case that they do occur. The X68 Pro supports a wide range of masses and the option we chose spans 4-11 kg. The option is always present for 8-20 kg, supporting heavier payloads at the expense of not working as well for lighter payloads. However, the X68 Pro is also lighter than the XL, which is used for weights 8-20 kg. This makes the drone lighter and allows for more useful payload.

Figure 2.17: Skycat Parachute Launcher

1.3.3 Command, Control, and Communications (C3) Selection

Radio

TBS Crossfire Micro TX:

- Cost: $69.99

Reasoning: This radio comes with a ground transmitter, and a receiver to mount on the drone. This radio has a range of 40km, which should be more than enough for our application.

Figure 2.18: TBS Crossfire Micro TX

Controller

Dark Knight Radio Nirvana:

- Cost: $179.00

Reasoning: Compatible with TBS Crossfire radios. High-quality construction. Internal battery.

Figure 2.19: TBS Nirvana

1.3.4 Support Equipment Selection

Battery Charger

Ultra Power UP-S6 1S Battery Charger:

- Cost: $22.99

Reasoning: Has a large array of charging ports. Able to charge multiple batteries at the same time.

Figure 2.20: Ultra Power UP-S6 1S Battery Charger

1.4 Component and Complete Flight Vehicle Weight and Balance

The drone is a symmetrical hexacopter on the x and y-axis looking top-down (or vice versa), and symmetrical on the y-axis looking from the side. This puts the center of mass exactly in the middle of the drone from a top-down perspective (or vice versa), which is where we want it to be to ensure stability at all times.

Name	Quantity	Weight (g)	Total Weight (g)
DYS 3-Axis SMART Gopro Brushless Gimbal	1	262	262
GoPro Hero 7 White Action Camera	1	92.4	92.4
Tarot 690S Folding Carbon Fiber Hexacopter Frame	1	600	600
Lumenier LU5 400kv Professional Motor	6	195	1170
Turnigy High Capacity 20000mAh 6S 12C Multi-Rotor Lipo Pack	1	2630	2630
Castle Creations 20A BEC Pro	1	40	40

TF03 LiDAR Rangefinder (180m)	7	77	539
Graupner E-Prop 10x5 (3 Blade) - 10 x 5 Propeller Well Balanced	6	15.6	93.6
Pixhawk 4 Open Source Autopilot	1	15.8	15.8
Lumenier 35A BLHeli_S ESC OPTO (2-6s) DSHOT	6	7	42
DroneFever Hexacopter Power Distribution Board - Assembled	1	10	10
X68 Pro Parachute for 4-20 kg SUAV	1	420	420
TBS Crossfire Micro TX	1	N/A	N/A
Dark Knight Radio Nirvana	1	N/A	N/A
Ultra Power UP-S6 1S Battery Charger	1	N/A	N/A

Total Cost:	**1**	**N/A**	**5,914.8**

1.5 Three-Dimensional View of Final Design

Figure 3: Three - View of Final Cad Model

2. Document the Missions

2.1 Mission Requirements

The challenge stipulates that our drone must be able to navigate an urban environment and conduct a full survey of plant growth. It must also be able to fly without GPS and beyond the operator's line of sight. Lastly, it must also be able to launch in a 3m by 3m space, avoid obstacles, and perform emergency landings. To accomplish this we equipped our drone with a carbon fiber hexacopter frame and LU5 Lumenier Professional motors. The carbon fiber frame was important as it contributed to a more lightweight drone, but with the necessary strength as well. The motors we chose we specifically designed for aerial mapping and providing more torque, as will be necessary with cameras onboard. In order to accomplish the most vital part of the mission, our UAS had to be equipped with a GoPro Hero 7 White Action camera. This added weight to our UAS, but this was offset by the aforementioned motors.

2.1.1 Launch and Recovery

Our UAS will be able to land and take off in a 3-meter by 3-meter space. This was ensured by the decision to use 400kv motors and our hexacopter design. The motors provide the necessary power and lift to enable the drone to raise itself out of the 9 square meter space, as well as rapidly land (as being able to emergency land is a requirement). The hexacopter design was vital so as to ensure greater maneuverability and control within the tight confines of an urban setting. Similarly, this also enabled our drone to be able to take off and land with a limited space constraint. The hexacopter design will also contribute to greater reliability in the event of an emergency (say if one or two motors fails, the UAS will still be able to operate).

2.1.2 Guidance without GPS

Our UAS guidance system will be designed to include an auto-fly and homing function. Originally we wanted or drone to simply fly up to above the building skyline, however, the 400 ft FAA limit on height prevented this. Instead, the team decided to have the drone retrace its steps; with a protocol to emergency land should an obstacle come in its way. Before emergency landing, the drone will attempt to backtrack 3 meters, fly upwards 5 meters, and then move forward and continue its flight path. However, should this prove impossible, an emergency landing will be performed. Upon landing, we would simply follow the drone's pre-recorded flight path until we came across it. An obvious difficult this leaves is if a citizen or town worker comes across the drone. However, since we will need the town's pre-approval anyway, we would simply stipulate that should the drone be found to have it returned to us.

2.1.3 Obstacle Avoidance

A vital part of navigating in an urban environment will be obstacle avoidance. Our camera will be active throughout our drone's flight time, thus providing a way to identify stationary objects that the drone needs to avoid. Once the camera identifies something as within 1.5 meters, it will immediately signal this information to the operator. This will ensure the drone is always at least 1 meter away from objects, as required. In the case that the UAS is operating beyond the operator's line of sight, a protocol will be in place. Autopilot will engage and the drone will attempt to backtrack 3 meters, fly 5 meters up and attempt to fly forward and return to its flight path. In the event that it continues to hit an obstacle or reaches the 400 ft height limit, the drone will perform an emergency landing and the operators will retrieve it.

2.1.4 Beyond Line of Sight

When the aircraft is beyond the operator's line of sight, there will be two circumstances when this happens. Circumstance one is when the drone goes beyond the operator's line of sight unintentionally and radio connection is lost with the drone. What happens next has been enumerated above, but will be repeated for clarification sake. The drone will attempt to backtrack its flight path, while following the rules of obstacle avoidance noted above, and return to the operator's line of sight and radio contact (at which point the operator can regain control). The second circumstance is when the drone is purposely sent out into the field beyond the operator's line of sight. This mode will be activated specifically to ensure the drone does not believe circumstance one's mode is in effect. The drone will be therefore operating in an area operators are fairly certain has no obstacles and radio contact can be maintained throughout the entire mission. The drone will fly forwards and turn when and how is required by the area it is surveying. Should the drone come across an obstacle (as the obstacle avoidance system is always latently active) it will simply stop where it is and notify the operator. At this point, the operator will be able to retake control of the drone and safety relocate and orient the UAS for further survey

2.1.5 Emergency Landings

In the above sections our drone is frequently cited as performing an "emergency landing", however, as of yet, what this means has not been clearly discussed; we aim to do that here. An emergency landing will be triggered either automatically, as in the circumstances described, or manually by the operator. Once this happens, after all attempts at backtracking its steps to its starting point are exhausted, the drone will begin to survey. Using the same technology it uses to analyze plant growth it will choose the flattest and most plant dense area in its field of view. The drone will then begin to lower itself onto this point. These protocols ensure the drone is a landing friendly area (flat) and also unpopulated with both people and expensive machinery (dense plant growth). The team will attach miniature safety visual and auditory indicators. These will be activated upon emergency landing and the drone will descend extremely slowly to ensure no one is injured. To this end, the propellers will also be equipped with buffers to ensure they are enclosed on the bottom and not at all potentially harmful to bystanders. Furthermore, the propellers will stop completely upon landing and the drone will almost entirely shut off (except for the radio transmitter, which will continue transmitting or attempting to transmit radio signals to the operators). The drone will hopefully never be required to do this, but if so an operator will be nearby and able to retrieve the drone immediately.

2.2 Survey Plan

Our drone will be using a GoPro 7 White Action to conduct the survey of the objective areas of the city. The team will be using a LiDAR (Light Detection and Range) technology to conduct the main survey of the objective plant growth areas. LiDAR works by sending a light pulse to the ground and awaits its return. This active remote sensing allows for elevation detection, detection of light intensity, and the creation of a Canopy Height Model (CHM). Specifically, we will be using small footprint LiDAR; alternating between topographic and bathymetric depending on the demands of each particular mission. We want to use full and discrete wave LiDAR to test the relative strengths and weaknesses of each. However, we will likely decide to go with discrete wave LiDAR for simplicity's sake, but are still actively considering using full length should the need arise. Discrete wave LiDAR will enable us to count the number of pulses it takes the light rays to reach the ground which will allow us to calculate plant density of coverage of forested or plant covered areas.

2.2.1 Survey Theory of Operations

The survey mission will require a minimum of two people to operate. One will monitor the data and serve as a backup pilot, while the other acts as the principal pilot. Optimally we would like to have three or more members to have at least one person in the field should something go wrong. The time required to complete each survey will depend entirely on each mission's area and the inconsistencies we encounter amongst each mission. However, we would like to have at least 5 minutes for setup and then 10 minutes for testing. This would allow us to have ample time to ensure our apparatus is intact and nothing is amiss with our UAS. The testing also ensures the pilot is ready and able to fly effectively on that day, and not endanger the mission or bystanders. Operation will also depend on location and season. In areas that are warm year-round, our prime concern would be overheating. This can be accommodated by providing our drone mandatory thirty-minute breaks or, eventually, get a second drone. In colder climates, we would likely need to focus on storage and make sure the drone is stored at room temperature to ensure the device can be started up as soon as needed. Additionally, in stormy weather, the drone's hexacopter design will enable it greater stability and maneuverability despite any wind or precipitation. Nonetheless, it will still be our policy to avoid operating in poor conditions to reduce the risk of damage to the drone or any accidents in general.

2.2.2 Survey Considerations

To enable our detection strategy, we incorporated our GoPro Hero 7 as our principle camera and data recording device. We will combine it with LiDAR (Light Detection and Range) software, as described, and record ample data via that medium.

Our system is beneficial to our company due to its low cost and diverse applications. That is it can be applied to a variety of surveying styles; including urban monitoring, commercial monitoring, and farming survey. Our final cost is XYZ, this makes us more attractive to competitors and allows for a greater profit margin. This is beneficial for our company for two reasons. It enables us to get a greater number of offers and to earn a greater profit with each mission.

The main features of measuring plant health would likely be plant-height; lateral plant size; the amount of apical or lateral dominance exhibited in shoots and roots, which represents nutrient spread and plant hormones; and leaf color, an indicator of which nutrients may be in deficiency. For example, a common problem in urban environments is lack of sunshine, which can cause wilting if development of noxious gases occurs from the inability of releasing these gases through photorespiration and evapotranspiration. Moreover, another common problem is a lack of magnesium, a principal component of the metallic coordination complex known as chlorophyll, which is required for photosynthesis; such a deficiency causes the yellowing of the leaves and the fragmentation of leaves along veins of tracheids and sieve tube members in the vascular tissue. These would likely be the primary indicators of plant health in the survey.

These can easily be measured using LiDAR part choices, which are renowned worldwide and are commonly used in contemporary surveying techniques. Outfitting the sUAS with these capabilities would enhance performance while making it competitive with products on the market. LiDAR part choices, in tandem with the aforementioned cameras, can be combined together with a holistic data analysis approach that sequences acquired data over time and makes reliable extrapolations for the directions of plant health for certain regions of the designated urban environment, letting operators better evaluate how to systematically prioritize certain plants over others and how to approach plant health issues most efficiently using data from the components.

2.3 Regulations and Additional Safety

FAA regulations on small unmanned aircraft (Part 107) require that the entirety of the airborne apparatus, including the drone, attached systems, payload, and cargo weigh less than 55 pounds or approximately 25 kilograms. Our components have been specifically selected with careful deliberation in order to minimize the total weight of our design to comply with these standards without compromising efficiency or quality. As such, our drone has an aggregate weight well under the designated limit of 55 lbs thus satisfying the standards for safe aircraft weight. Furthermore, regulations require that any additional loads must be securely attached and not adversely affect the flight characteristics or controllability of the aircraft. Our auxiliary components, specifically the batteries, the gimbal, and the camera, will be securely fastened to the drone. Due to their centralized placement and relatively low mass as well as the strong lifting power of our motors, the presence of this additional load will not result in significant disruption to the balance or flight capability of the drone.

Moreover, FAA regulations mandate a maximum flight speed of 100 mph (approximately 87 knots). Our drone's functions do not require extremely high flight speeds in order to execute, and so it was not difficult to satisfy this stipulation. In fact, our missions do not necessitate our drone to achieve an airspeed of over 30 mph to complete sufficiently, and thus we are well within the imposed FAA regulations. FAA regulations also impose a maximum allowable altitude of 400 feet above the ground (or higher, as long as the drone maintains a maximum distance of 400 feet from the nearest structure). Our chosen surveying technique does not require high operating altitudes and actually benefits from lower operating altitudes; thus, our drone is able to perform its surveillance while maintaining a maximum normal operating altitude of 50 feet above the ground. Although measures for obstacle avoidance are put into place that would theoretically allow the drone to reach altitudes above 400 feet, such situations are highly unlikely to occur and emergency measures are put into place anyways that force an emergency landing if the object were to ever exceed the maximum altitude of 400 feet.

FAA operating requirements further demand that all drone operations occur either during daylight (defined as a period beginning thirty minutes prior to official sunrise and ending thirty minutes after official sunset), or during twilight (with appropriate anti-collision lighting). These requirements are observed by our drone's surveillance process, as our intended operation time would be midday in order to maximize visibility of the drone, as we would be unable to see and control the drone effectively and safely during darkness in the nighttime period. Additional requirements prohibit small unmanned aircrafts from being flown under covered structures, from being flown inside a covered stationary vehicle, and from being controlled by an operator located within a moving vehicle (unless operation is occurring over a sparsely populated area). As our drone is designed to conduct surveillance solely on outdoor plants, it will never be necessary for us fly it under any covered structures or inside any covered stationary vehicles. Furthermore, due to the lack of such structures of vehicles at the height the drone will be operating, there will be little difficulty in complying with these regulations. Furthermore, we will not be controlling the drone from within a moving vehicle as a large amount of safety risks would arise due to an inability to effectively maintain a focused line of sight on the drone when necessary, and the infeasibility of precisely directing the drone on its intended flight path while nonstationary.

FAA regulations also forbid small unmanned aircrafts from being flown over individuals not participating directly in the operation of the machine. Due to the drone's operation in an urban setting, there is no feasibly way to completely avoid flying the drone over uninvolved persons. However, this will only occur in brief, infrequent spans of time and maintaining this safe altitude of 50 feet will mitigate any risk of danger to any civilians that would happen to cross below the drone's path of flight. Furthermore, if the drone detects any deficiencies in its systems or other potentials for danger such as a malfunctioning motor, it will automatically perform an emergency landing which will cause it to safely and slowly land in an area of dense plant growth, away from human-populated areas, before shutting off its systems. Additionally, buffers are placed around the propellers to prevent them from being able to cause significant physical harm, especially if the drone were to spontaneously and irrecoverably crash. Finally, in the extreme event that the drone's flight systems are completely disabled or at least disabled to a point where recovery would be impossible, an emergency parachute is rigged to activate. Thus, despite the drone's significant size and weight, its slow descent will prevent it from being able to cause significant impact injury to any nearby bystander, mitigating any risk of danger to humans in the area. Thus, while we are unable to comply with the regulation demanding that sUAs do not fly over any part of a non-participating human being, we will still maintain high quality of safety standards in order to maximize our device's ability to take appropriate action in emergency situations and minimize any possible threat our drone may pose to nearby humans.

Moreover, FAA regulations mandate that the aircraft remain constantly within the operator's direct line of sight. However, in order for the drone to be able to survey large spans of areas with high speed, we will be unable to maintain a line of sight while the drone is conducting standard surveillance procedures. To ensure that our drone is still able to safely avoid obstacles, as mentioned above, it has an integrated obstacle avoidance system. If the camera detects an obstacle or object within proximity, the drone will attempt perform the necessary maneuvers in order to avoid collision with the obstacle in question, before continuing on its intended flight route. We will also be able to monitor the drone's flight path, as well as positional components such as position, altitude, attitude, and movement through communication with the onboard transmitter. Thus, while the drone will not be physically visible, we will still be aware of its whereabouts and surrounding obstacles while it is outside our line of sight through its mounted camera. In event of any emergency situations that would either lead to our inability to fully monitor or control the drone's movements, it will be instructed to execute its emergency protocol and conduct a safe emergency landing so that no harm occurs and we can safely retrieve the drone.

3. Document the Business Case

3.1 Market Assessment

3.1.1 Market Comparison

One of the main competitors the Volantem Machina will face is the DJI Agras MG-1. This aircraft is best known for its spraying ability, which is now 40-60 times faster than manual spraying. The system allows the aircraft to carry up to 10 kg liquid payloads, including pesticides and fertilizers. It takes about 10 minutes to cover an area of 4,000 m^2. Their spraying system adjusts its spray depending on the flying speed, ensuring an even spray. This allows for the amount of pesticide or fertilizer is precisely regulated to avoid pollution and economize operations. It has an interchangeable nozzle to spray at different volumes. Even though our drone is not designed to spray, they can still be considered a main competitor, for the fact that a consumer may choose their product over ours.

However, there is one main issue with the DJI Agras MG-1 for the potential consumer: its extreme price. At around $15,000, it will cost a significant amount to any person and/or corporation willing to purchase the drone. However, our drone is available for $4,312.88, which is significantly less than the DJI Agras MG-1. This gives us a much bigger advantage over any competitor, for any consumers shopping for price. We will also have more than four times the flight time, meaning, not just is our drone significantly less expensive, but has a significantly better cost to flight time ratio than the DJI Agras MG-1.

3.1.2 Target Market Assessment

The environment in Urban cities is extremely overlooked, as most people would focus only on the landscaping. All plant life in urban areas are not being monitored, and this has been a growing problem. Densely populated cities such as New York City and Los Angeles are rarely surveyed, and designing a drone specifically for them would allow this untapped market to be put into the limelight. Our drone perfectly appeals to these areas, along with any cities that are too densely populated for regular field-survey drones to investigate. By purchasing our drone, we will work towards a more developed society, giving nature a chance to unleash its full potential.

3.2 Profitability Analysis

Our proposed hexacopter has several advantages over similar products available on the market, despite having a higher initial cost. The increased durability and reliability, included within our initial cost, offset the long-term costs incurred for repairs and unit replacements which plague the traditional quadcopter models. Our six propellered design is safe in the event of a single or double engine failure, particularly critical in urban environments where a drone crash would likely incur collateral damage, and stable in flight. These added benefits of our product should easily outweigh the relatively expensive cost per unit.

3.2.1 Fixed (Initial) Costs

The estimated cost of just the parts of our hexacopter comes to approximately $4,312.88 per full unit while buying individual parts from retailers. The cost of parts will ultimately be decreased once our drones are being manufactured on a larger scale since the quantity should keep costs law and sales to manufacturers are consistently cheaper than sales made to consumers. All individual parts costs can be located in *2.3 Selection of System Components* and broken down by purpose and quantity. Each component of the design is also selected as a balance between quality (encompassing durability, power, and maneuverability) and cost. Therefore, the choice of each component can be justified by identifying the purpose and selecting a part to purchase which can adequately perform this function in the context of our design.

Some of the more expensive parts include the Tarot 690 Folding Carbon Fiber Frame, available at $119. A carbon fiber frame is essential to our design because one of the relatively few drawbacks of a hexacopter design is the weight of additional propellers and motors. A carbon fiber frame is durable enough to support the weight of our design, so our team decided the large cost was warranted in order to preserve the benefits of our design (mainly consistency of motion and lack of repair costs). The overall most expensive single component of our design is the DYS Marcia 3 Axis Brushless Gimbal for GoPro available for $315.99. This cost is fairly standard for a GoPro gimbal and this gimbal is significantly steadier than earlier versions released for GoPro. A gimbal will be necessary for our drone to perform the tasks identified by the design problem, so other competitive designs will likely contain similar components. Additionally, the 6 motors combined account for $759.94, a majority of the cost in components of our hexacopter. These motors are necessary to ensure that our drone has redundancy in the case of motor failure. Each additional motor also provides for extra cargo capacity, enabling a more extensive sensor suite and enhancing our hexacopter's capability. Therefore, this incurred cost is likely shared by market competition and won't be influential in the cost analysis of each design.

As explained earlier, the initial cost of our design is specifically higher in order to produce a high-quality product which won't require frequent repairs or suffer significant malfunctions. The costly components will be ultimately offset by the cost which would be incurred by designs which need frequent repairs and last for shorter periods of time.

3.2.2 Operational Costs

Our product will require operational costs in the form of personnel to maintain the drone, fly the drone, and analyze the data obtained from the GoPro camera. Our product is specifically designed to require minimal repairs, but in the event of an unanticipated error, a technician onhand will be necessary while the drone is operating. However, this work should be relatively low cost, since the person making these repairs would likely be part of the design team responsible for constructing the drone, and this duty would only be a supplementary function of an otherwise full-time employee (paid approximately $20 an hour). The drone flight supervisor/pilot is the most costly employee required; however, a drone license is obtainable in the state of CT for anyone over the age of 16 at a price of only $150. While the specific legal requirement is easy to obtain, our pilot requires experience due to the volatile nature of flying in an urban environment, and this skill set is both more marketable and exclusive. Experienced drone controller in similar roles are typically paid between $30-40 an hour but only work part-time when flights are scheduled. The estimated cost for both these employees per year comes to $59,800. The data analysis role can be freelanced to experts online, saving costs for the company and bolstering community engagement with our project.

3.2.3 Pricing Analysis

Our unit pricing is based around the typical scale of mid-sized cities (population 100,000-175,000) in CT. Cities like New Haven (population 131,000), Hartford (population 123,000), and Bridgeport (population 147,000) are ideal candidates for Volantem Machina, seeing as the support midsized urban populations, as well as a blend of urban city streets and suburban communities. These cities also have large quantities of urban biomass to be surveyed and cataloged by our drone. The Volantem Machina has a range of 2 square miles, and can survey this area is approximately 4 hours of flight. Consequently, every week a single unit (flying every day for 8 hours per day) can survey 28 square miles. This time frame should be acceptable to the municipalities eligible for our project, and cities like new haven span under 28 square miles in terms of area, reducing time. If this timescale is acceptable, a single drone should be appropriate for each CT city; however, additional units can be introduced for cities looking to survey plantlife fast or with a larger area. Our plan is to begin in CT's major cities the first year, before expanding to part of MA and NY in the following years. This phased integration ensures our drone technology, operating teams, and management are effective and experienced before expanding to larger urban centers. Adding together the cost of personnel, the physical mechanics of the drone, and $500 for potential repairs, brings the entire cost of the project to $65,000 for a city (provided they intend to use Volantem Mechina for an entire year). Charging this initial deposit for repairs allows our team to provide replacement parts free of charge, and since it is extremely unlikely this entire $500 will be used, the remaining money in this fund can be allocated to the Volantem Machina company/design team.

3.2.4 Regulatory Analysis

Volantem Machina meets all federal and state regulations for the production and operation of UAS. These federal guidelines can be located in 14 CFR 107, and each regulation is thoroughly accounted for in our design plan. CT requires commercial drone operators to obtain a license to ensure competency in a variety of safety-related scenarios. In addition to this Connecticut requires commercial drone pilots to pass the FAA's

Aeronautical Knowledge Test to obtain a Remote Pilot Certificate. To fly a drone as a hobbyist in the state of Connecticut (i.e. for fun/pleasure) you are required to register your drone with the FAA and follow the FAA's Special Rule for Model Aircraft. To fly a drone as a government employee in the state of Connecticut (i.e., for a police or fire department) you may either operate under the FAA's Part 107 rule or obtain a federal Certificate of Authorization (COA). According to the Connecticut Department of Transportation and the Connecticut General Assembly, Connecticut has one statewide law concerning the use of drones in the state known as ***SB 975 // 2017.*** This law prohibits Connecticut municipalities from regulating drones, but it does allow a municipality that is also a water company to enact ordinances that regulate or prohibit the use or operation of UAS over the municipality's public water supply and land. ***DEEP §23-4-1 // 2017*** is the law instituted by the Department of Energy and Environmental Protection which states that the use of drones is prohibited at Connecticut State Parks, State Forests or other lands under the control of the Department of Energy and Environmental Protection unless specifically authorized by the Commissioner in a Special Use License. All drone pilots operating commercially in the state of Connecticut are subject to the FAA's Part 107 rules.

4. Conclusion

Volantem Machina is an optimal design for the 2019 Real World Design Challenge prompt. The drone, with its advanced onboard cameras, can easily survey plant life in any urban environment with utmost quality. Add that to its exceptional maneuverability made possible by its VTOL design, and there is truly no place that this drone can't go in order to perform its task. Volantem Machina can also perform its task extremely safely with its automatic parachute system and radar sensors, preparing it for potential catastrophe, and lowering the risk of a catastrophe occuring in the first place. And, even in the event that there is an issue, the drone is able to fly on less than its six normal engines. The price may be a relatively large five figures, however we sincerely believe that that is made up for in the sheer competency of our product.

References

1. “Dark Knight Radio - Nirvana.” GetFPV Learn, www.getfpv.com/dark-knight-radio-nirvana.html.
    a. *Used as the radio for communicating with the drone. See 2.3.3.*
2. “DYS Marcia 3 Axis Brushless Gimbal for GoPro.” GetFPV Learn, www.getfpv.com/dys-marcia-3-axis-brushless-gimbal-for-gopro.html
    a. *Used to swivel the camera as a mount. See 2.3.1.*
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    a. *6 required per drone. Standard propellers designed for electric motors with relatively low pitch. See 2.3.2.*
4. “Hexacopter Power Distribution Board-Assembled.” DroneFever.com, dronefever.com/Hexacopter-Power-Distribution-Board-Assembled.html
    a. *Power distribution board capable of providing power to all 6 motors. See 2.3.2.*
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    a. *6 required per drone. Durable and powerful motors with relatively high efficiency to provide high thrust to weight ratio. See 2.3.2.*
6. “Pixhawk 4 Autopilot.” GetFPV Learn, www.getfpv.com/pixhawk-4-autopilot.html
    a. *Flight Controller. Controls the speed of the motors. See 2.3.2.*
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    a. *Radio with long range suitable for city use in obstructed environments which necessarily decrease practical range. See 2.3.3.*
8. “Turnigy High Capacity 20000mAh 6S 12C Multi-Rotor Lipo Pack w/XT90.” Hobbyking, hobbyking.com/en_us/turnigy-high-capacity-battery-20000mah-6s-12c-drone-lipo-pack-xt90.html?___store=en_us

   a. *Batteries in order to support the drone's electronic. High capacity to power drone for extended period of time. See 2.3.2.*

9. "Ultra Power UP-S6 1S Battery Charger." GetFPV Learn, www.getfpv.com/ultra-power-up-s6-1s-battery-charger.html.
   a. *Battery Charger. Multiple charging ports allow for this to charge more than one drone at a time. See 2.3.4.*
10. "Lumenier 35A BLHeli_S ESC OPTO (2-6s) DSHOT." GetFPV Learn, www.getfpv.com/lumenier-35a-blheli-s-esc-opto-2-6s.html.
    a. *6 required per drone. Provides power to each motor through the flight controller from the battery and modulates engine power to the motors as flight controller requires. See 2.3.2.*
11. "RC DRONES." Hobby-Wing.com - The RC Drones and FPV Goggles Online Store, www.hobby-wing.com/tarot-fy690s-tl68c01-hexa-copter-frame.html
    a. *Hexacopter frame, serves as the base for all of the other parts. Carbon fiber design provides light weight and high strength as needed by the relatively heavy design. See 2.3.2.*
12. "Swipe Right. Or Left." GoPro - Cameras, shop.gopro.com/cameras/hero7-white/CHDHB-601-master.html?gclid=Cj0KCQiApbzhBRDKARIsAIvZue-ARH1jvZziIPFJpGmwiKnwPEg1sOFdi0_EplAcLwuvNnFiXvPxRlkaAtMtEALw_wcB&gclsrc=aw.ds
    a. *Camera, provides for user video feed. Designed to fit chosen gimbal and is rugged. See 2.3.1.*
13. "TF03 LiDAR Rangefinder (180m)." IR-LOCK, irlock.com/collections/rangefinders/products/tf03-lidar-rangefinder-180m?variant=15818687512627
    a. *LiDAR rangefinder, senses for obstacles. See 2.3.2.*
14. "Castle Creations 20A BEC Pro." *Motion RC*, www.motionrc.com/collections/battery-eliminator-circuits/products/castle-creations-20a-bec-pro

    a. *Battery eliminator circuit, provides power for electronics not powered through our ESCs which do not integrate a BEC. See 2.3.2.*

15. "X68 Pro Series for 4-20 Kg SUAV." Skycat.pro Parachute Launchers, www.skycat.pro/shop/skycat-x68
    a. *Parachute, an emergency option for preventing any injuries if a large-scale failure occurs. See 2.3.2.*
16. "3-Blade - 10x7 Propeller." *Master Airscrew*, Master Airscrew, www.masterairscrew.com/products/3-blade-10x7-propeller
    a. *Option for a propeller. Wrong profile, not being an E-Prop. See 2.3.2.*
17. "DYS Marcia 3 Axis Brushless Gimbal for GoPro." *GetFPV Learn*, www.getfpv.com/dys-marcia-3-axis-brushless-gimbal-for-gopro.html
    a. *Option for a gimbal. More expensive and less stabilized than chosen option. See 2.3.1.*
18. "Flycolor Raptor 20A 2-4S OPTO ESC." *GetFPV Learn*, www.getfpv.com/flycolor-raptor-20a-2-4s-opto-esc.html.
    a. *Option for an ESC. Less maximum current output. See 2.3.2.*
19. "Graupner E-Prop 10x5." *GetFPV Learn*, www.getfpv.com/graupner-e-prop-10x5.html
    a. *Option for a propeller. Less lift than chosen option. See 2.3.2.*
20. "Lumenier 5200mAh 4s 35c Lipo Battery." *GetFPV Learn*, www.getfpv.com/lumenier-5200mah-4s-35c-lipo-battery.html
    a. *Option for a battery. Too low energy capacity and too little current output. See 2.3.2.*
21. "Lumenier N2O 5200mAh 4s 120c Lipo Battery." *GetFPV Learn*, www.getfpv.com/lumenier-n2o-5200mah-4s-120c-lipo-battery.html
    a. *Option for a battery. Too low energy capacity. See 2.3.2.*