Chapter 13: Conclusions and Next Steps

# Mini Abstract

1-2 paragraph chapter description. Should generally go over contents, expectations, and results. Abstracts are usually the last part of something to be written out since it is a summary of the article, but we can use them hear to help flesh out our ideas a bit for how to structure. Final abstract should be overhauled at the end of the chapter though, the chapter dictates the abstract, not the other way around.

We failed to meet the requirements given by USGS. Power draw did indicate it is possible. Simulation confirmed controllability of the system. Adjustments should be made in servo support and in the manufacturing process. The project did not meet the STRs, but it was shown in the work completed it is possible and worth pursuing. The team also makes reflections in this chapter about technical and personal experiences, and how the project functioned as an educational experience. Finally, the next steps are explored if the project is continued beyond the end of this course.

# 

# Chapter Outline

Develop the chapter outline here. Should become very detailed and broken down to paragraph level. Remember, if we invest time and effort into making a detailed outline, the actual writing will be far easier since we understand the flow and structure before we lay out the details. Before even writing a subsection, take the time to outline that subsection in the chapter outline. A lot of writing is in the layout. Remember to update this chapter in the Master Outline file so we can all keep track of the full outline of the report, it's large so breaking it up this way should help everyone keep track of each other's ideas and work.

Chapter 13 Outline:

* Section 1: Review of Technical Requirements
  + Go through each system level requirement only and determine if we did or did not meet requirements as a whole. Should be more of a summary and high level analysis since we do a detailed look at the verification in previous chapters.
* Section 2: Project Conclusions
  + State whether the project was successful or not, and why. This can be and should be a more complex answer. For example, our physical deliverable failed and so did some electrical components and limited progress in control and software design, but power draw analysis and simulation confirmed it is worth possible and can state it can be pursued and executed in the future
  + Conclusions:
    - Project wasn’t successful since none of the requirements were fully verified to be met, although some were verified to not be met
    - Many of the requirements were theoretically met but could not be demonstrated experimentally
    - Team made a lot of errors due to poor engineering and design decisions early on
* Section 3: Lessons Learned
  + Technical decisions learned, team management, all of that.
    - Verification of components before buying
      * Microcontroller, sensors
      * PCB component
    - Peer review of each other’s work
* Section 4: Personal Reflections
  + Each team member provide a detailed and thoughtful reflection on the project, their experience, their specific lessons learned, etc
* Section 5: Team Reflection
  + Reflections of the project as a team. Essentially this is the non-technical project conclusions and how it was as a learning experience.

# Chapter 13 Draft

Although considerations and theoretical solutions were thought of for most technical requirements, the end result of the project was unable to be tested experimentally to verify most of the system technical requirements. Lessons learned by each team member and by the team as a whole are detailed in this chapter. Overall, we failed to meet the requirements given by USGS, although power draw did indicate the extended flight time is possible. The simulation confirmed controllability of the system, although adjustments should be made in servo support and in the manufacturing process. Finally, the next steps are explored if the project is continued beyond the end of this course, including what to keep, what to change, and recommendations to incorporate.

## 13.1 Review of Technical Requirements

Below is a summary of each of our 11 system technical requirements and a high level overview of their progress and verification status:

1. The drone shall fly for at least 30 minutes with magnetometer payload during normal autopilot flight. May fly for one hour as a stretch goal. **Power Test Verified**
   1. This was verified through power tests of each individual part that 30 minutes shall be reached and 1 hour could be reached, but could not be demonstrated experimentally as a whole through a flight test for either the 30 minute or the 1 hour goal.
2. The drone shall be able to fly 5mph in 15mph winds. **Simulation Verified**
   1. This was verified within the simulation environment described in Chapter 8. It was shown the drone could reach 5mph when facing a 15mph wind. Verifying this requirement for our drones ideal shape, however when simulated with our fabricated shape the requirement was not met.
3. The drone should have RC control implementation to allow for direct control of the drone. The drone can start in this state, or be switched to from autonomous control. **Matlab Verified**
   1. Closed Loop Control was tested independently of other features of the full requirements under 4.0.0, and auto landing, auto-take-off, large angle error, and hover functions were all verified in MATLAB, but not VREP
4. The drone should be able to fly on its own to collect data. **Not Verified**
   1. No significant work done
5. The drone shall cost less than $10,000. Reach-The drone may cost less than $6,000

**Expected to be Met**

* 1. This requirement was verified with the current estimated costs of the drone to be $2,600, below both goals of the requirement. Even though the cost may change, it is very unlikely that the total cost will end up being above $10,000, fulfilling this requirement.

1. The magnetometer interference shall be less than 10 nT **Not Verified**
   1. This was not tested or verified because we were unable to get access to a magnetometer, but the test that would have been done was detailed. No analysis was able to be done to estimate the expected result as well.
2. The drone, its usage, and build should be safe to all individuals involved **Not Met**
   1. Safety precautions were taken for all considerations except for the safety of the propellers during a collision, causing this requirement to not be met. The safety of the electrical components and helium were secured through procedures in chapter 11.
3. The lift bag shall maintain 90% of its buoyancy over a one week period **Not Met**
   1. This was verified to not be fulfilled, as the drone lost 4.2% of helium in just half an hour, much more than what was allowed to escape.
4. The drone and team shall abide by all applicable laws for drone flight **Expected to be Met**
   1. FAA drone laws and registration process was researched, where it was seen that our drone would meet the requirements if registration was finished. Since the drone was not finished, it could not be registered with the FAA and this requirement could not be experimentally verified.
5. The drone should be quieter than 65dB **Not Met**
   1. This was only verified to not be fulfilled in an indoor environment at 72dB, but when the drone is completed and an outdoor test could be run, this can be tested again.
6. The drone should be able to be manufactured with equipment within our access **Not Met**
   1. Since manufacturing of the drone used 3d printing, a sewing machine, and soldering equipment, which were all available to the team, this requirement was verified.

Overall, only the flight time, drone speed and RC control of the project were verified, although the verification was not experimental. Rather, the verification was the result of simulation for the RC control and individual power tests for the flight time. There were 5 requirements that were verified to not be met, either due to fabrication errors or oversights in the project. The requirements that were expected to be met include the legal and cost requirements, which were expected to be met due to the confirmation that our drone would obey drone laws and the current costs of the system, respectively. The two requirements that were not verified include the autonomous design and the magnetometer interference. The autonomous design could not be verified because the effort was instead transferred to complete the RC control requirement and the magnetometer interference could not be verified due to the lack of equipment to test magnetic fields at the scale required.

## 13.2 Project Conclusions

The project faced a lot of challenges and obstacles, resulting in the failure of most requirements and the inability to experimentally test others. The physical prototype of the drone was only partly completed with only the servos and motors operational. Furthermore, the only physical flight test failed due to mishandling of the equipment, causing both lift bags of the drone to pop. Further testing was prevented by shipping delays and failure to complete certain systems for testing.

The simulation of the drone was also met with delays, causing the autonomous functionality of our drone to not be completed to ensure remote control simulation with controls implemented first. The PCB of our system had errors in the design that prevented its use, which also was unable to be fixed due to long shipping times beyond the constraints of the project.

The project was successful in a few areas. First, although the physical prototype failed to complete a flight, the motors were verified to supply sufficient thrust to lift the system when filled with helium by confirming both the thrust provided by the motors and the weight of the inflated system. Additionally, the flight time we hoped to achieve was proven possible through power draw testing of all of our systems components. Based on our power draw testing with our intended motors our minimum flight time would have not only been met but would have exceeded the flight time requirement by 33% and the hovering flight time goal would have exceeded the requirement by 58%. These power draw tests prove the plausibility of our primary requirement and could be considered the biggest success of this project.

Another success of our project was the creation of a simulation and control system. Although the closed loop remote control system was not able to be added to the simulation, the simulation was successfully able to verify that if our drone had the ideal shape it was designed for it would be able to meet our minimum speed requirement. The closed-loop control system for a unique and bespoke system was verified in MATLAB, although detailed simulations are needed to see if the design was correct. These are both large accomplishments that our team is proud of.

Despite our failures in many areas of the project several large accomplishments were made proving certain aspects of the project are viable and worth being persuaded by researchers and engineers in the future.

## 13.3 Lessons Learned

Throughout the three quarters of this project it is safe to say that every member of the team has learned more practical, technical, engineering skills and methods than any other single year.

The biggest lesson learned by the team was to check each other's work, which was gradually improved throughout the project through the increased work in sub-teams towards the end of the project. The environment created in smaller subteam meetings was better suited towards presenting and reviewing work to team members. Peer review is essential to any engineering project and needs to be done more by the team. We learned that the peer review process is done not because team members are not capable of doing work but because everyone makes mistakes and oversights, and by having their work questioned by other team members the vast majority of these oversights can be caught. This is especially true for larger projects where an oversight caused by one team member not considering others work will cause rippling effects throughout the project. Feedback can also help team members work more efficiently together as the project goes on through the improved teamwork and diverse thoughts considered.

Another lesson learned by the team was the tasks should never be exclusive to just one person. This is similar to the peer review lesson learned. If the team members are working together on issues more design considerations are made, especially if each member is working on multiple parts of the project. Tasks should not be assigned to a sole member as it will isolate them from the rest of the project. This is likely one of the largest mistakes we made as a team early on in the project. Each member was responsible for a chunk of work with little overlap. This meant that when it came time for the integration of the various systems. It was like trying to make 6 different projects fit together rather than 6 pieces of one project. To prevent this integration needs to be planned from the beginning of the project. This must be accomplished by the team being proficient in abstracting tasks that will be done later months ahead of time.

Something else learned is that working on a team assignment does not necessarily mean all at once. Early on in the project we would all try to create documentation at the same time, this was slow, ineffective, and even aggravating at times. When there are six competing ideas, communication can allow for a solution to be agreed on, but when communication fails it becomes impossible to find a compromise that makes everyone happy. Instead the compromises that were made to get the work done usually left everyone feeling unhappy and resulted in lower quality work. Even though every member's option should be considered on team assignments, by delegating individuals or smaller groups to work on assignments, foundations are laid much more efficiently. These foundations can then be peer reviewed by the other members of the team. This way there are less clashing ideas all at once but everyone's options are still heard and considered. Conversely, delegating someone to a task does not mean they alone should do it. When the team first started to not do team assignments all at the same time we sometimes ran into the opposite problem, where one person would essentially do the work on their own and the team would quickly give it a look over. This puts undue stress onto the individual assigned to this work and also results in work that is lower quality, completed slower, and has less design considerations made. Ultimately our team hit its stride in the latter half of the project when we started working more pairs and subteams, this is when we were able to get the most done as well as produce the highest quality work. For example, the physical testing of the drone was able to be attempted within a few days of meeting together to consolidate the envelope, gondola, and electronics needed.

The last thing the team learned was that organization tools like a Gantt chart or Trello boards are critical tools to use when completing a project. Completing a project without organization tools is like setting a nail without a hammer. Sure it can technically be done, but it would be so much faster and easier if the proper tools were used. Early on in the project the gantt chart was hardly used. We created it and then didn't look at it for weeks. This was the primary cause of our falling behind early on in the project. Once the gantt chart began to be used and checked on a regular basis more progress was made as people could better keep track of the due dates of their tasks as well as how delays in these tasks would affect the project as a whole. Additionally if a place in the project did fall behind schedule, it was able to be easily identified. The identification of these cracks allowed us to delegate extra assistance to these areas and help keep progress on the critical path moving forward. For example, When sensor programming started to fall behind team members who were familiar with the protocols that needed to be implemented were assigned hours to assist with this which allowed this work to be completed. Without the use of the gantt chart this crack would not have been detected and a fix could not have been applied.

These lessons learned have helped all of us grow as engineers. These lessons can be applied in any team based work environment, to see significant improvements in both the quality and efficiency of the team's work.

## 13.4 Personal Reflections

13.4.1 Dylan

This project has pushed me to and past limits I didn't even know I had. As an engineer, a teammate, and a leader.

As an engineer I learned a huge variety of skills more so then in any one class. By working in a project with so many different aspects I had to learn and give feedback on many different things. This varied from things I had some experience in and enjoyed such as coding or working with solidworks, to things I had some experience with but did not enjoy like analysis of torque or circuits, or to things I was clueless about like controls systems or V-REP simulation, as a member of the team I had to try my best to understand and help things things that I was unfamiliar or uncomfortable with.

As an engineer, I also learned that my biggest weakness is often my overconfidence. Sometimes this overconfidence is caused by laziness i.e. “I can put off that research because I can get it done in an hour”. Sometimes it is caused by prior experience i.e. “Oh I don't have to think about 3D printing stuff until the envelope is finished because I've printed a few things before and I do not need to learn anything new”. This destroyed me at every turn, from overlooking milestones at the second design review, to frantily spending night trying to fix 3D printer issues that I had no clue how to solve. These issues put an unneeded amount of stress on me that I was barely able to deal with. This stress made work even harder to complete as I now had to deal with my mental state as well as the work I had to do simultaneously. These stresses could have been avoided if I had been proactive in my acceptance that I may struggle with something. When I finally sucked it up and asked for help, whether it be from a teammate who knows more about 3D printing or from a peer or mentor outside the team who knows more about a subject than me, my stress was often greatly reduced. In order to become a better engineer I have to learn to not try and do everything on my own and ask for help before problems occur.

As a teammate I learned not to take things personally. I often become very defensive over my work, especially things I am struggling with. This is because I put a lot of effort into doing it and when it is questioned I often feel attacked. However this was clearly not the case. All members of the team just wanted to see the project go well and would often ask why simply to make sure I had a reason, or sometimes just because they were curious themselves. Even when the feedback was circular, I had to learn to swallow my pride and fix my mistakes not just for myself but for the good of the team. Once I got used to this I not only felt like I was better at maintaining a dialog about the work I had done, but I was better at asking questions to other team members about the work they were doing. This skill of being able to both take and give sometimes critical feedback to and from peers was without a doubt one of the most important skills I learned throughout this project.

Finally as a leader I feel like I have been pushed further than I thought possible. In the past I have had leadership experiences but In those experiences things often went well and when problems arose I was usually able to find a solution. This was not the case for this project. As a leader I felt I needed to come to every meeting with a can do and energetic attitude. In my past leadership experiences such as boy scouts where I needed to do this once a week this was easily doable. For a project that meets almost every day for close to nine months this was not feasible for me. Some days I was just tired and when I was I often felt like the meetings were not productive and this was on me. As a leader I needed to find a better way to have meetings run smoothly even when I am not at my 100%. This could have possibly been solved with better communication to the team of what needs to be done, or what with better delegation of tasks so that the team could still fully function without me. Additionally the mental toal being a leader of a project that has real, and difficult problems to overcome is much higher. The hardest parts of this project for me were not when I was getting roasted in a design review but when I had to sit and watch teammates be roasted. As the leader I often felt like any failure in any part of the project was on me. In a project that had so many failures this often took a heavy toll on me, this oftentimes made it even harder to bring the needed energy of a leader to team meetings, especially daily. I often found that when I was feeling out of it the meetings would often have long pauses where nothing got done. To remedy this I tried a new method. I stopped trying to put on an energetic mask at every meeting when it was not possible, instead I learned that sometimes being down to earth and honest with the team about how you are feeling often boosts team morale even if the feelings you are expressing are not positive ones. I believe this was effective because it reminded the team that we are all just people trying to do our best, and that we all need to have each other's backs if we want to succeed.

13.4.2 Leon

Looking back at the project, I realize just how little I knew starting out in the project. When I thought about Capstone in the past, I thought of it only as a year-long project with friends and nothing more. I didn’t realize just how much work and planning went into it, and how working with a team for a full school year would look like. I learned this the hard way the first two quarters of Capstone, where I took difficult classes along with Capstone and was not able to put in as much effort into Capstone as I would have liked. I changed this in the final quarter of Capstone, and saw the most progress and satisfaction from the project. In terms of technical skills, I also realized how unprepared I was to start a project from scratch. I had always thought that it was easy to think of some project idea, and to make design choices. This course taught me how punishing it can be to make bad design choices, as we saw in buying parts and only afterwards realizing they were not suitable for our needs, or when parts broke and we had to wait weeks for new ones to arrive. Overall, this Capstone project was grueling, but taught me to be a better engineer.

13.4.3 George

The first lecture of the year, we were asked what engineering was. I remember answers were all over the place and there wasn't much consistency, but, to be fair, it is a hard question. I think I have my answer now, since personally I did not care for the definition of engineering as given in the class. Engineering, in my understanding, is the identification, analysis, and optimization of TRADEOFFS. At every design decision, alternate solutions should be considered, the benefits should be identified, then those tradeoffs should be analyzed with the math and science skills we have worked to develop. The ideal solution also needs to be defined, or the order of importance of different traits so the optimal solution can be chosen among the infinite possibilities of tradeoffs. Also, my understanding of engineering is more general, because the business, management, public relations, documentation, financial and other aspects are inextricably linked to engineering projects. If the best engineering solution in history is created, but we lack the skill to communicate our solution well enough to get the information out, we fail as engineers, since, in the end, nothing changed. Engineering is tradeoffs, and understanding that is the most important thing I could have learned in school.

13.4.4 Jeremy

Overall, I wish I could have learned more from this project in person, as I did in the last few weeks. I feel I was restricted a lot from the rest of the team geographically and it was hard to keep the motivation at first to push myself with this project because of the lack of tasks I could do virtually at the beginning of the project. At first, I could really only work with datasheets for parts we found online, while other team members had some software they were experienced with that helped them plan their work. I spent most of the beginning of the project helping other team members with their design considerations and taking on managerial tasks because there were only a small amount of design tasks I could do by myself. After the parts were ordered, and were then worked on by Leon, who lived closer to me than the rest of the team but there honestly was no thought of me driving to his house so I could test the parts that had already arrived. Another thing I struggled with was the engineering design considerations and the documentation that could have been written that described the different choices I could have made. I found a lot of my decisions could have been done better at the beginning of the project, even though they ended up working out in the end, such as the battery choice and the justifications for it.

The last month of the project, the idea came up that I should drive to his house to test the power draw of all the parts. In the last month, I was more interested and learned more than the rest of the time because I was physically there and working with the hardware. The physical verification of the parts that we had and the comparison of their expectations were able to be done, but they could have been done sooner if I had gotten the idea to go to another team member’s house for physical testing of the parts they already had. The last week of the project, I wanted to help a lot because I definitely felt like I was the one on the team who had been doing the least amount of work. With my help, the physical testing of the drone was attempted but still failed due to some oversights. Overall, I really wish I would have been able to physically be with other members of the team earlier on in the project, because I struggled a lot with the motivation for a virtual project until it became physical.

13.4.5 Isaac

This design project challenged me to be responsible for work that my team is held accountable for. Whether I ended up completing a task or not meant less if the team were not able to achieve the same goal we had set for ourselves. Since the team’s work relied on all sections to be completed in order for us to move forward, I learned the importance of labor distribution and the necessity to work on all parts of the project equally. Throughout this year, I also learned more of why having a large team did not necessarily make the project any easier; in fact, when everyone is required to perform and contribute equally well towards an end product, our project became the perfect example of how much more difficult making a product innovative and simple can be, given the task at hand. The main issue we ran into, trying to create the perfect product, was that we intentionally convoluted parts of our problem to generate more work to satisfy project requirements. Overall, I learned a lot more about simulation than I thought possible in an engineering project and learned to value the work that I did over the course of the year.

13.4.6 Ryan

Being the sole board designer of the team has been an immense challenge and I feel responsible for letting the team down on not being able to deliver my design to the team. I have made some critical mistakes in my design and resulted in a major change in the electrical side of the design. I learned to use textbooks and Appnotes for standardized board design in the wrong chronological order. But those mistakes have been realized and I know how to recover from my mistakes now.

During the fall quarter of the SDP, I felt confident in PCB design since I had prior hobbyist knowledge of the design process and that is why I chose the role. A lot of documentation and brainstorming was involved, and in retrospect, I wish we could finish brainstorming our idea earlier so we could put more time into System Technical Requirement. I was pretty proactive in weekly meetings and gave out a lot of ideas as to what components we could choose, but now I think I should have done more pugh charts for all the components we’ve chosen for our electrical specifications.

Winter quarter was very intense as I was also taking my design class along with SDP. The design class took up more time than I expected and I did not put enough time into researching as I needed to. If I was to design the PCB again I would have gathered my sources first on good PCB practices for our specific system technical requirements and gone in that direction.

Spring quarter was difficult in a different way, I was not a part of the fabrication process due to my location out of the U.S. Instead I worked on troubleshooting shipment delays due to concerns and geo restriction of certain components that were ordered on online electronic retailers. If I knew there were restrictions on exporting electronics outside of the U.S. I would have asked someone else to order it to not delay the shipping times. I am also taking 3 major ECE classes which took more time off SPD, similar to the situation in winter quarter and seeing my team working together on location placed some mental strain in my mind because I wish I was there to work with them and prove my engineering skills to the team. Instead I am stuck in a different location without the hindsight of knowing my design had some critical errors, which meant my team members could not implement my design. I think I would have shipped the components to myself and soldered it and found out sooner about my problems and I would have shipped it off after to the team when I completed verifying the board. Giving more work to my teammates was unfair to them and put them in more stress than they needed.

Going into this project, I knew I wanted to be responsible for board circuitry because I had novice experience with it personally and I wanted to apply my engineering design skills to this field. However I did not work closely enough with Leonid and Jeremy on the wiring schematic. This resulted in a disconnect between my design with PCB and the implemented design with development boards. Looking back at it I would have prepared and done my research more before submitting my work without thorough verification and should have more frequent subteam meetings with Leonid and Jeremy to keep.

## 13.5 Team Reflection

The project as a whole provided further experiences to the team beyond the technical field, in areas that we had not considered before. For example, our ability to present material while receiving immediate technical feedback, from both peer and professor, and having to expand our perspectives to ask questions such as why we chose a design over another or where responsibility lies within the team and where it is being ignored. Simply working as a team brings many of its own challenges. In order to move forward as a team we have learned to negotiate around some of these challenges or address the problems within our team. Communication being the key element we have continually found to be worth improving. This is especially true as engineers who are in charge of design decisions; it is imperative that we take the necessary amount of time to explain and discuss our thought processes we have about certain topics with a level of professionalism and practicality, so that we might catch any errors before they are seen on the product.

In the same vein, accountability with our peers and most importantly ourselves is something we have learned to foster. After all, every sprint meeting is a reminder to keep ourselves accountable and productive so that we might have something to show for it at the end of a sprint or occasional design review.

Taking time to review information before meeting would also have been greatly beneficial and should be incorporated in the future. In addition to saving meeting time, it also would help everyone have ideas and thoughts going into the meetings and prepare us for more informed and thoughtful discussions.

## 13.6 Next Steps

13.6.1 What to Keep

One of the successes of the project was the creation of a simulation environment for testing the dimensions and movement of the drone. This simulation can take a variable wind speed, motor throttle, and motor angle. RC control was implemented into the simulation, but work needs to be done with integrating autonomous control.

The power budget of the system consists of estimated and verified power requirements of each part used, the voltage each part requires, and estimated heat losses. The power required is also variable depending on a performance factor for the motors and servos across a pre-set flight time on the power budget, allowing fast simulation of flight time.

The remote control system is verified in MATLAB and performs well, staying within all the technical requirements, even without fine tuning the system. The decoupling of the x and z components of forces and converting those forces back to the servo angle and thrust commands is, at least with current tests, a valid way of implementing a linearized control system. The tuning specifically will need to be adjusted with the aid of more detailed nonlinear simulations, but the integral path of the regulator will help maintain controllability. Also, a faster servo may want to be considered to help the control system react faster to the environment and help system stability.

The system's programming code was unfortunately not completed, but the layout is given in the flow chart and state machine in Fig 6.1 and 6.2-3 respectively. The layout provides a good base for developing the system behavior and can be adopted or further elaborated on in the continuation of the project.

13.6.2 Points of Failure to be Improved

Extra considerations need to be taken into account when fabricating the next iteration of the envelope. The envelope shape was not only fabricated to the incorrect shape, but the lift bag was punctured repeatedly. Future iterations of the envelope could experiment with an internal frame to provide protection for the lift bag as well as better support the weight of the propulsion system. Although this method would likely see benefits in structural stability it would likely increase the the effectiveness of the system, this would mean that either the system would have to increase

Future PCB design needs to be iteratively verified to ensure signal bus as far away from power traces as possible. Increasing PCB footprint from 4 by 4 inches to a larger size can help improve signal and power trace separation and a ground plane bridge needs to be implemented for the GPS module and the antenna.

Soldering components to the PCB should be done with reflow solder because the resistors and some of the IC’s had only have solder pads on the bottom of them, using reflow solder would make it much easier.

13.6.3 Considerations of New Technologies

ZeRONE’s blade-free propulsion drone uses ultrasonic vibrations of piezoelectric elements as propulsion. Each propulsion system is called a microblower, and each of the microblower’s piezoelectric elements operate at ultrasonic frequency ranges which generate less noise than conventional quadcopter drones. The microblower flaps a diaphragm at ultrasonic speeds instead of using conventional spinning propellers, removing the risk of injury by propeller blades[4]. The ZeRONE drone uses a 24- inch aluminum-metallized film balloon filled with helium gas making it a neutrally buoyant drone. The total weight without helium uplift of the ZeRONE drone is 106.4g including the balloon, microblower, carbon rods, drive circuit, receiver, battery, joint, screws, etc. The drone can be used as advertisement billboards in indoor crowds or halls. The drone also has been tested with a camera for crowd monitoring, human flow analysis and security. However, the microblowers cannot provide enough thrust beyond 1 meter per 7.5 second upwards and downwards. ZeRONE is prone to drift caused by slight winds, either by people walking past it or areas with air conditioning. [3]

Although the drone uses low noise microblowers to provide lift, it cannot counteract external forces such as slight breeze which makes it not ideal for precise sensor data collection. ZeRONE cannot add IMU and GPS sensors for autonomous flight control without increasing the balloon diameter and adding more microblowers. The technology is not advanced enough yet to be used to solve researchers problems with data collection, but can be useful with further development and should be watched.

13.6.4 Recommendations for Proceeding with Project

If someone was to continue working on this project there are several recommendations that can be made. First, future iterations of the physical prototype could experiment with an internal frame to provide protection for the lift bag as well as better support the weight of the propulsion system and maintain system shape, especially if the lift bag deflates. Although this method would likely see benefits in structural stability it would likely increase the effective weight of the system without adding additional helium, but this will also increase drag. An optimization problem should be written and solved containing the information developed throughout this report to weigh the effects of all these factors and help with a more optimized drone. For the physical implementation of the system, finding the balance between the weight and size of the system is the primary problem that needs to be solved. Our main recommendation is that support be added to the mechanical system for better structural integrity and the balance of weight vs size of the system be reconsidered.

The best part of the system that future work could continue on would be the simulation. We were able to create an environment that is able to support real time simulation of aerodynamics on our system. We were also able to design some control systems. By finishing the work of implementing the controls system into the V-Rep simulation using Remote API these control systems could be verified and improved upon through better guided fine tuning. The simulation phase should be the focus of incremental testing due to the difficulty and costs of building the drone, and working more with simulation may have helped us identify certain problems earlier. The VREP simulation used should not be the only one, since simulation of the system’s structural rigidity as the lift bag deflates would have helped us identify the problem that caused the second flight test to fail.

Finally through power draw testing we were able to successfully verify a longer flight time of our system was theoretically possible for up to 40 minutes, however, since our PCB design was unsuccessful, the circuitry layout was not optimized for efficiency. By finishing the implementation of an efficient PCB that takes advantage of the switching regulators the heat loss of our system can be minimized allowing for the possibility of even longer flight times.

Although this project failed in many respects, the parts that were verified prove a valuable foundation for future continuations of an extended flight time buoyant system for data collection. Since the idea for this project was conceived around a buoyant system this likely limited our considerations for other methods of improving flight time. Methods of extending flight time other than buoyancy could be explored as technology improves and as helium supplies run low, but we feel we showed, even with drone technology that changed how researchers collect data, there is still room to improve. These methods could still be explored using the aerodynamics simulation as well as our unique propulsion system that could allow more payload stability in flight of non buoyant drones, since the drone would no longer depend on having a tilt angle to maneuver.

We hope that future work is persuaded on the creation of a long flight time system as it would greatly benefit many researchers, and could pave the way for future breakthroughs in the fields of aviation.

# 

# Chapter Bibliography

We do have a full bibliography that should absolutely be updated with all content here. The point of the chapter bibliography is to help keep track of citations in the chapter since the numbering may change in the full bibliography with changes and additions. This way will isolate the sources in this section so you can cite here without having to worry about it, and can use a simple find and replace on your citations to update the new numbering when we combine everything in the final report.