Project
Autonomous Mini-Blimp

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Table of Contents

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1 Concept of Operations

The purpose of this project is to design a proof of concept of a semi-autonomous blimp that will fly around an office space which is our Minimum Viable Product (MVP). The craft uses helium as its primary lift mechanism, the craft must be remotely operable by a typical hobby controller, and all power sources, radios, sensor control systems are subject to a weight restriction depending on the blimp helium and shape. Manual control from a remote will allow the user six-degrees of freedom. Galois will use the final designed blimp to be used in an office environment for various tasks and for a team competition between blimps.

1.2 Need Statement

Blimps have been used mainly for outdoor activities and there are plenty of options for that market, not so much for Blimps that are small and maneuverable to be used in enclosed settings such as an office, warehouse, or a gymnasium. Also, the use of autonomy hasn’t been explored upon blimps as they do for the drone market, airplanes, and other vehicles. Blimps do not need a significant amount of energy to maintain stable hovering.

1.3 Objective

Our objective is to design and build an easy to use, maneuverable, and autonomous blimp that is capable of performing various tasks. The blimp will be controllable by the user. The product will be safe and easy to use.

1.4 General Plan

Throughout the course of two semesters, the team plans to investigate the topics of overall blimp functionality (e.g., efficiency, handling, battery life, etc).The usage of a Gantt chart is to ensure the milestones are completed by the end of the term in the spring semester. The team envisions a simplistic prototype to be completed by the end of the winter term semester and a more refined prototype by the end of the spring semester. The criterion for these prototypes are outlined below.

The implementation of Kanban principals will be employed to ensure proper efficiency with time and tasks towards the overall objective. The primary principal that is going to be employed is having incremental improved changes on the design. This is to help reduce any sort of design flaws in the end product. These principles will be to try to mitigate bottle necking by balancing capacity and demand. We hope to show a visual representation of our working processes with the Gantt chart.

1.5 Risks

We believe that one of the most challenging portions of this project is the integration of electrical and mechanical engineering. As this project is a joint venture, we will be relying on each other to perform in our fields but also crossing over. Since we don’t have the same academic background in engineering, we believe this will be one of the most challenging for us, as well will have to fill in the gaps of knowledge. Some of the topics in which ME students need to become familiar are: Mechatronics, power source, autonomous integration. This challenge can be primarily solved with additional time dedicated to learning functions of electrical engineering and communication with our team members. We can also rely on our team members from EE to help us learn more about these topics.

I believe some of the constraints we have for the blimp is the payload, electronics like a motor, microcontroller board, battery, to begin with, add to the weight and in the future, (W. E. Green, K. W. Sevcik and P. Y) we might need to integrate a camera and altitude sensor and we develop the autonomy for the blimp. Also depending on the design, we might need to sacrifice components or mobility due to the weight constraint as we do not want an oversize blimp and need to keep under the project constraint of 40 cubic ft of helium for the blimp envelope. Last but not least important is the programming code to control the blimp, at the beginning we just want to perform the basics but as we progress towards autonomy, code and processing will get more complicated. (Jinjun Rao, Zhenbang Gong, Jun Luo and Shaorong Xie)

Another challenge that we see is that of designing and assembling a prototype for our client. This challenge comes from the inability to physically meet and test our designs or to physically test our prototypes in the environment that they are expected to perform. We have discussed possible solutions to these challenges. For example, having several team members testing individually, or having one person in charge of designing parts and prototyping them (3D printing) to make sure the fit and finish is what is desired.

The most challenging portion of this project is the concept of developing a blimp for autonomous use. This is because of a lack of knowledge in these topics and the time that it takes to develop a reliable system. This was a major criterion that we have had to scale back to make the project more plausible by focusing our efforts on first completing a working prototype. Upon the accomplishment of a working prototype, further investigation can be devoted to an autonomous integration into the system.

Rigid vs Semi-rigid vs Non-Rigid

There is a difference between what we know as a zeppelin and a blimp; both are similar but a zeppelin has a rigid frame that is internal and gives its shape (keel), a blimps shape is due to the pressure of the gas that fills the envelope of the blimp and last a semi-rigid that is a combination of the two previously mentioned airships. One of the advantages of using a blimp is that it is lightweight and easier to handle but one of the dowsinsize is that post the risk of accidentally being damaged and being unusable adding to the cost. One other possibility is using a semi-rigid blimp, although not the same as a semi-rigid zeppelin the semi-rigid structure around the blimp can be use to attach components to the blimp and shield/help the blimp in case of accidental collision and object that can damage it, on the downside adding a structure to the blimp will increase the weight that the blimp needs to lift and probably make it slower. We will consider the options and come up with a balance where we can protect the blimp from collisions and be light enough to carry the components needed to function.

Brush motor vs Brushless motor

Brushless motors provide enough power and torque for my airship but there is also a risk that high-speed motors require more precise control to avoid losing control of the airship by providing more power. Brushless motor anti-jamming capacity is insufficient. Brushless motor pits may lose some power due to high winds or strong convective air, which requires predicting the loss of motor power in advance in order to obtain a more accurate power output.

In other ways, Because of the structural reasons of brush motor, the contact resistance of brush and shifter is very large, which causes the overall resistance of the motor is larger, easy to heat, and permanent magnet is a thermal element, if the temperature is too high, the magnet will demagnetization, so that the motor performance is reduced, affecting the life of brush motor.

2 Recently Learned Concepts

The blimp’s helium envelope will be in the shape of an ellipsoid. This shape will provide maximum helium volume while still allowing the blimp to move through a standard door frame. A good material for the envelope is mylar; it is a cheap light material with sufficient tensile strength to contain helium. These properties will provide maximum lift for a given volume, without compromising functionality or cost.

Based on our research we realized that there are no real blimps that can be used indoors and that initial research has been developed on this topic, as the majority of blimps are for outdoor use and their dimensions are not suitable for indoor use. One of the main topics of research for our project and the subject of newly learned concepts is the autonomy and control of unmanned aerial robots, as we progress on the design and construction of our blimp we plan to incorporate this feature. To achieve maximum movement control, as many degrees of freedom will need to be maintained as possible. Ideally, this would mean all six, however, trade-offs will need to be made to reduce weight. A successful blimp needs to be light and dynamic in order to carry the components that will power and guide it, so the materials we choose for the blimp are key, based on the peer-reviewed documentation read, most of the blimps researched were made out of already existing envelopes that are common use as party balloons and few are made of more resisting material as polyurethane and we will look into the best materials for our blimp. We will avoid using regular mylar balloons and seek a more durable material for the envelope, as they could get punctured easily and damage beyond repair. The shape is very important and we will use some of the research shapes suggestions of a regular known blimp as a just round shape is not stable enough. There is a widely different approaches on the peer-reviewed papers in terms of components used to power and control a blimp, from simple RC control to autonomous control the components vary depending on the use of the blimp, most of the literature is a few years old and new better components are being developed every day, we will research into the best components for our blimp.

3 Stakeholders

Stakeholders are Galois (sponsor), ECE412 team, Galois customer, Hobbyist, Cyber-physical, surveillance operators

4 Requirements

- Must
  - Be remotely operable (six degree axis of manual movement)
  - Use Helium as primary lift
  - Use less than 40 ft^3 of helium
  - All power sources, radios, sensors, control systems, etc., must be attached to the craft, and are thus subject to the weight restrictions created by the helium budget, above

- Should
  - Sporty Design
  - Survive Nerf Darts
  - Fit through a standard office door frame
  - Semi-Rigid frame

- May
  - Automatic recharging
  - Level 2 Autonomy
  - 1-hour battery life
  - Modularity in chassis and design considerations for future iterations
  - Prototype with higher-level autonomy

5 System Architecture

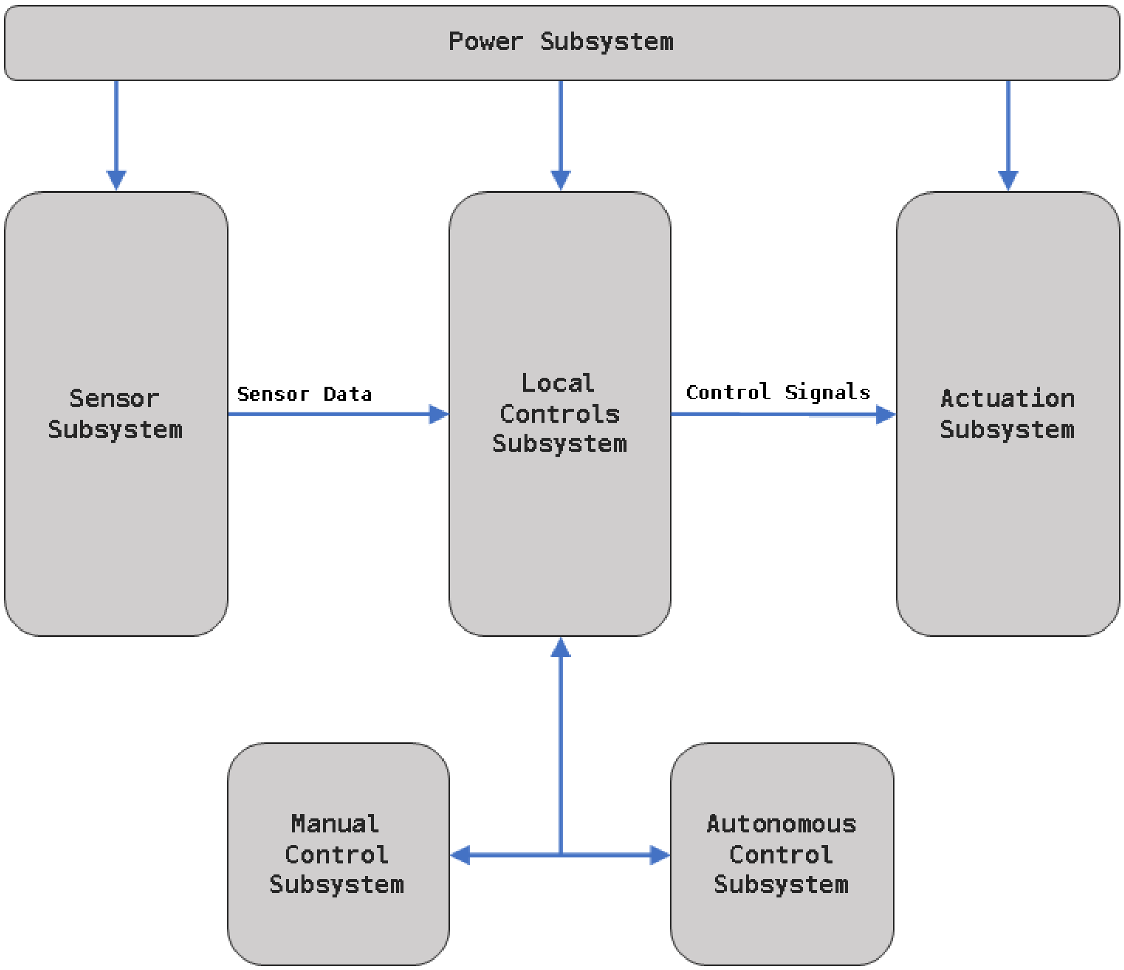

Figure 1: High level block diagram

5.1 High Level

The high level view of the blimp's architecture (Figure 1) consists of a local control subsystem that receives data from the sensor suite and the remote controls subsystems and acts on that input to drive the actuators. The power subsystem supplies power to the sensors, the actuators, and the processing core.

The remote control subsystems provide directional commands to the local control subsystem. These commands can be from either a manual remote control or, in a potential future expansion, an autonomous control subsystem.

5.2 Sensor Subsystem

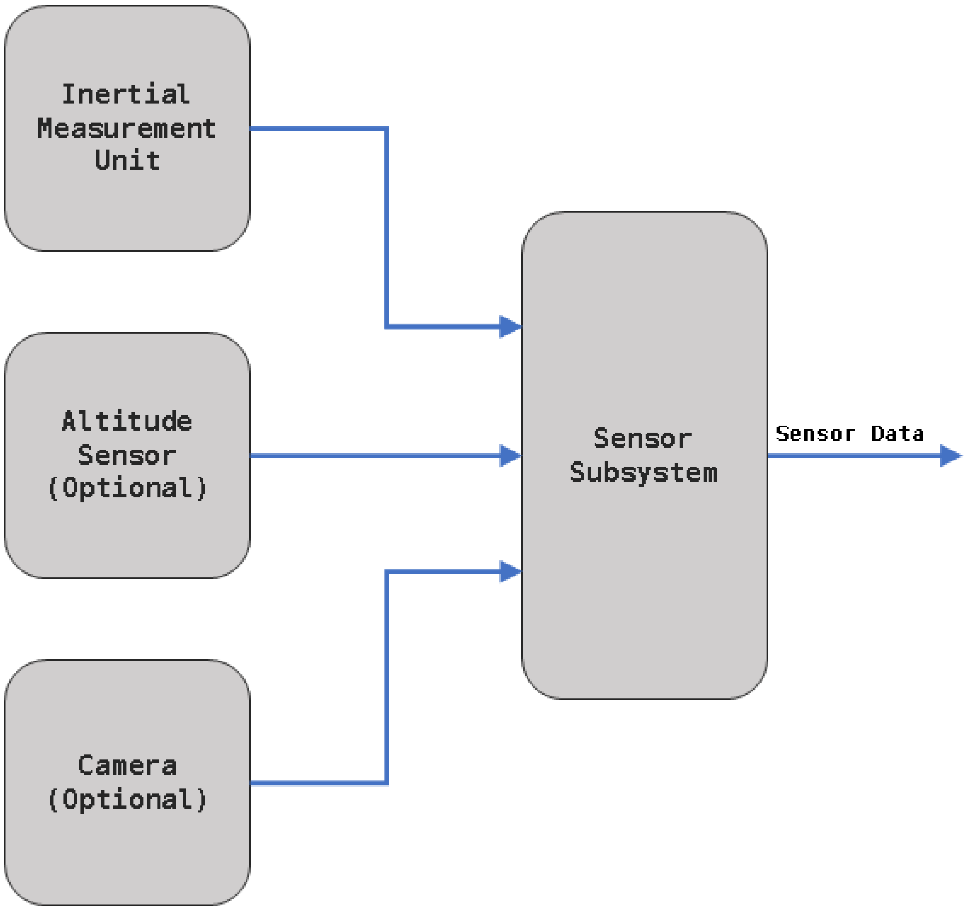

Figure 2: Sensor subsystem

The sensor subsystem (Figure 2) consists of an inertial measurement unit (IMU), an optional altitude sensor, and an optional camera. The IMU is necessary for maintaining a position in space by opposing changes to rotation and acceleration due to impacts.

The altitude sensor would mainly be used as a sanity check against the data from the IMU. The resolution of small form factor altitude sensors is not great enough to give a precise measurement of altitude for the range of altitudes the blimp will operate in.

The camera would be used to provide visual feedback for a remote operator, and has the potential to allow for object sensing with machine learning algorithms for autonomous control.

6 Design Specification

6.1 Electronic Components

- 1.7 - 1.8 Meter Blimp (Possibly a good base to work from)
    - Payload 450 grams

- Processor
    - ESP32 Feather Board - A powerful microcontroller development board with an established modular ecosystem.
        - Operating frequency: 240 MHz
        - Integrated WiFi and Bluetooth
        - Plenty of code space and RAM
        - Multiple communication interfaces
- IMU
    - Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout - Necessary to allow for auto-leveling and other orientation control
        - Processing on raw data completed in the module
        - Outputs parameters in units, rather than raw data
        - 3.3V I2C interface

- Motors (Movement)
    - Crazepony 8520 Brushed 15000KV Motors
        - Lightweight
        - 3.3 V compatible

- Electronic Speed Control (ESC)
    - Brushed Micro 1S 20A Bare Board
        - Can supply up to 20A; will be suitable for almost any size of 1S motors chosen

- Battery
    - FancyWhoop 3.7V 1800mah Lipo Battery 25C
        - 1S; compatible with all other equipment
        - Lightweight

- Altitude Sensor?
    - Accurate z-axis positioning

6.2 Mechanical Components

- Mylar
    - Light
    - Thin and flexible
    - durable and strong
    - Resistant to heat
    - Electrical insulator
    - Much lower leakage of helium vs polyester or latex

- Foam 3D Printer Filament
    - Lightweight plastic which foams, creating a low density solid structure
    - Foam density can be changed to fit design strength and weight requirements

6.3 Chassis Design Iteration

Design A

Design A shown in Fig. 4 uses 3 motors in a cartesian orientation. This design allows for maximum forward and backward motion. All components are mounted to a main body either directly, or through another component. Using a single main board saves weight The vertically mounted motor allows for continuous altitude control while moving, or stopped. Chassis design A is connected to the blimp envelope using 2 brackets attached with 4 foam adhesive pads.

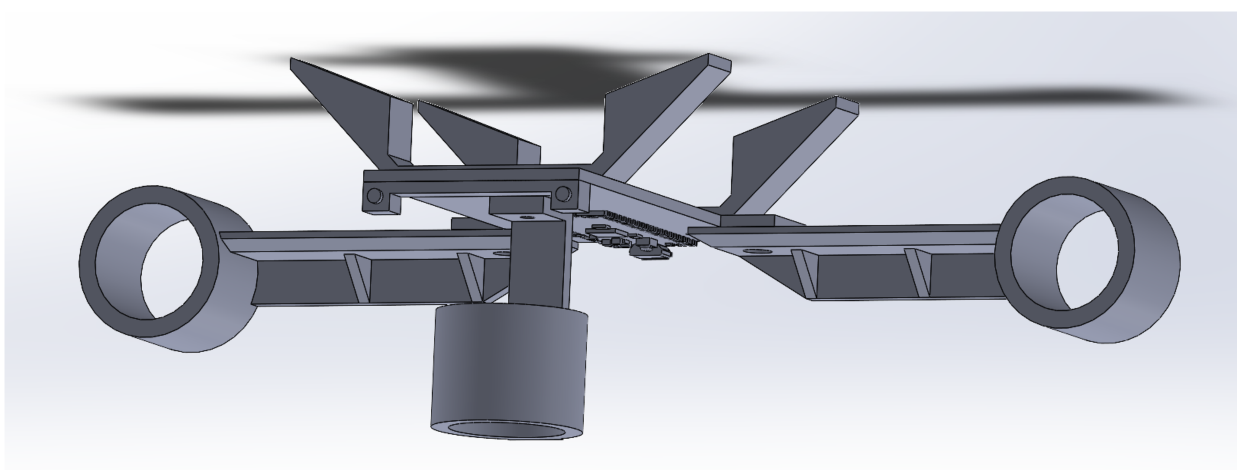

Figure 4: Chassis Design A

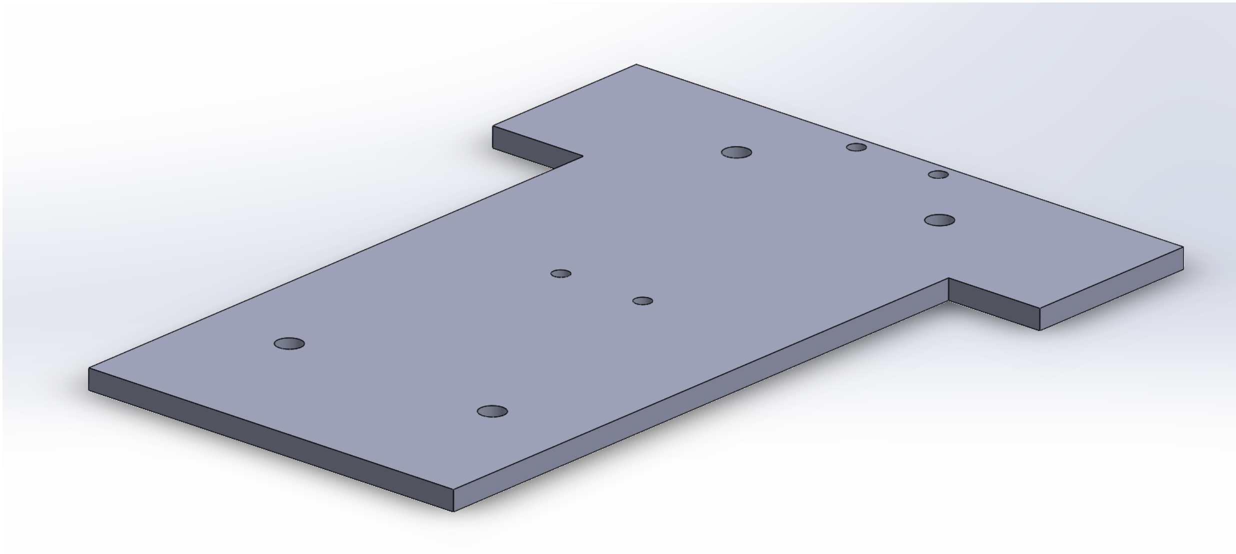

Figure 5: Main body

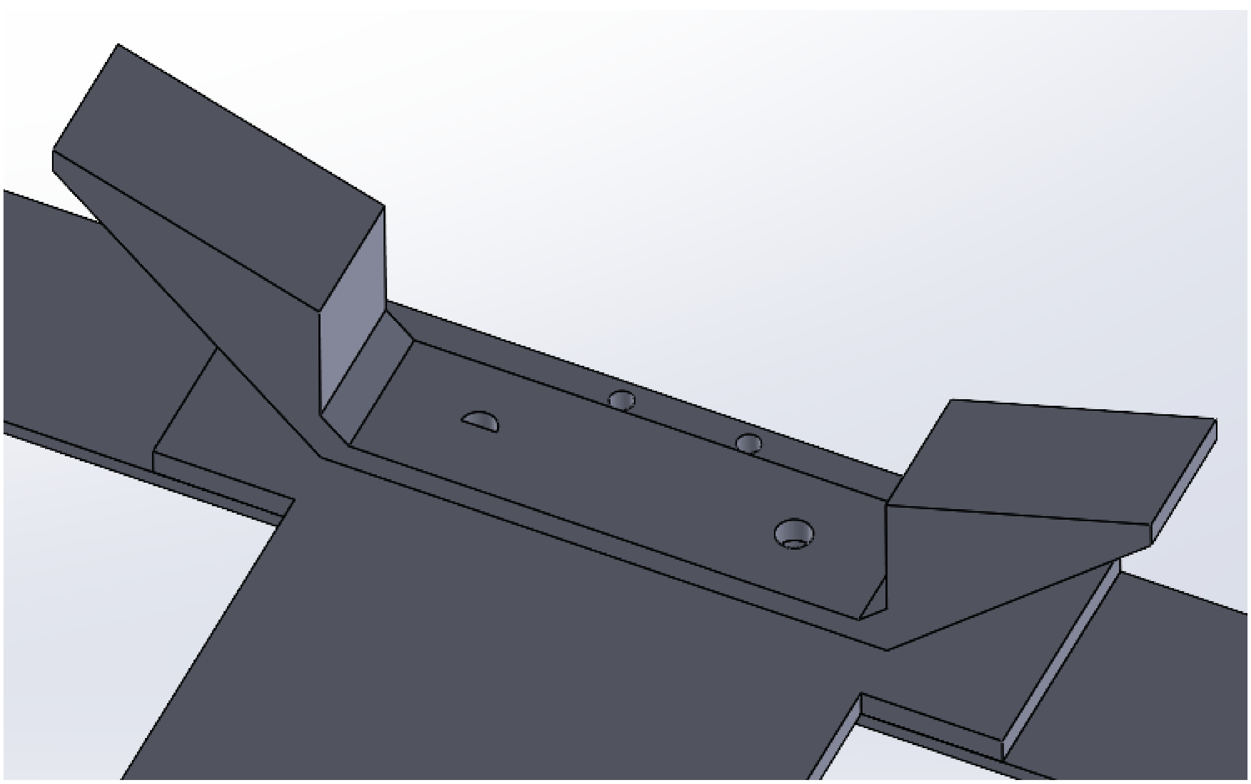

Figure 6: Mounting bracket

Pros:

- Intuitive control method

- Simple replaceable mounting bracket
- Easy access to controller board

Cons:

- Components must be considered before fabrication; adding components requires new model
- Relatively heavy motor stalks

Design B

Design B purpose is to explore the concept of a more modular design, in which placement of motor segments, internal electronics and mounting could be moved. This design is to have the possibility of the placement of these components change as the other components change.
This design also takes into account the customer's requirements of being able to fend off nerf darts being fired at it. The hexagonal shape of the holes are too small for the nerf darts to penetrate the interframe.

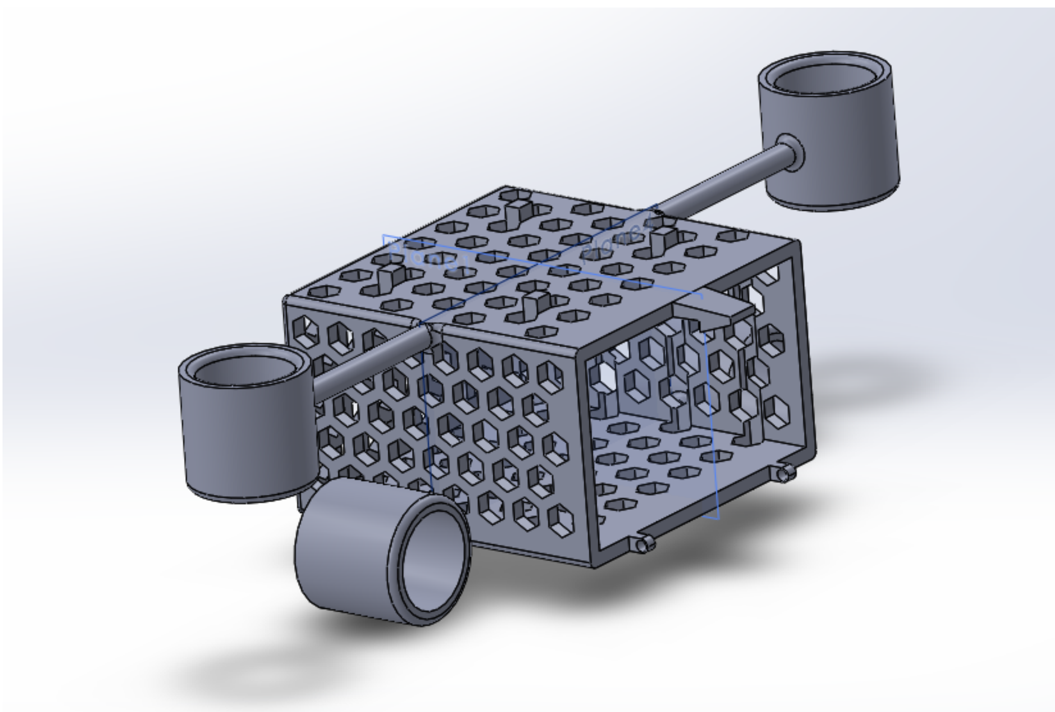

Figure 7: Caged Design

Pros:

- Very easy to swap components
- Fragile components will be well protected from environment
- Additional forward propellers allow for higher top speed

Cons:

- Very heavy due to inefficient use of chassis material and extra motor

Design C

Design C shown in Fig. 8 uses a single main board similar to Design A. It employs two rotating coaxial motor stalks which can independently adjust the direction of two motors to provide thrust which will compensate for non-neutral buoyancy, and provide directional thrust. The design uses two servo motors to control the rotation of each axle, although other methods, such as stepper motors could be used instead. By separating the axle at the center, each motor can be moved independently from one another. This allows the craft to rotate at full speed while moving at slow speed or while stopped, without sacrificing altitude control. Design C uses a thin flexible cross shaped mount, which provides ample surface area for adhesive to connect to the envelope.

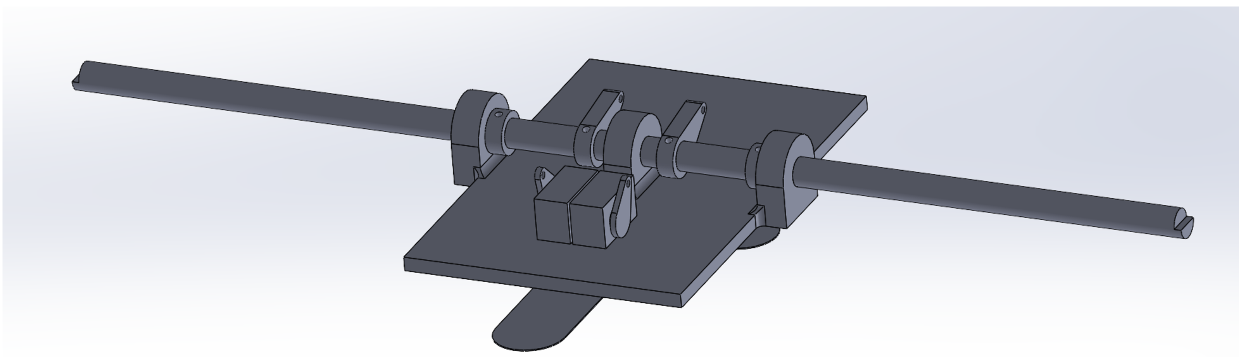

Figure 8: Chassis Design C

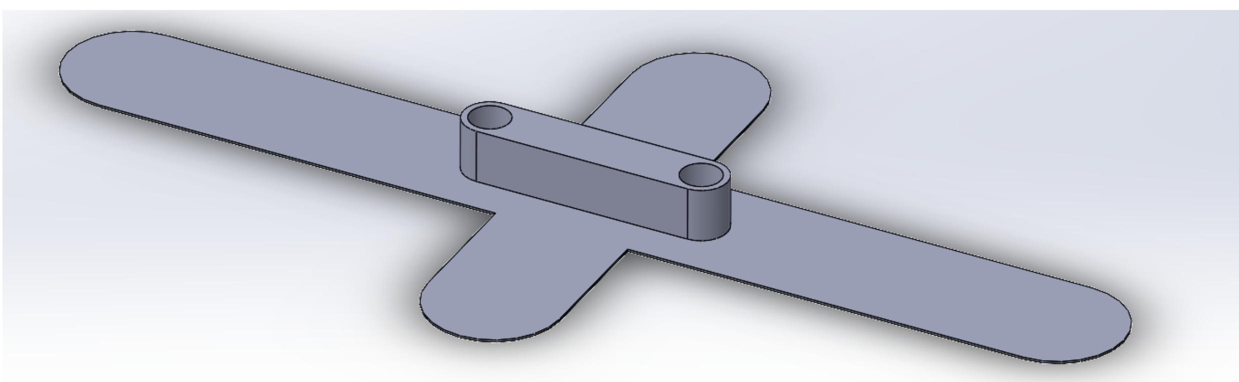

Figure 9: Chassis Design C Mounting Bracket

Pros:
- Lightweight due to fewer motors
- Lightweight minimalist mount

Cons:
- Complicated thrust vectoring method will require more robust controller
- Mount adhesion may not be robust enough

7 Deliverables

- Airship Documentation
- Code Documentation
- Simulations Model
- Airship

8 Timeline (rough)

Winter term 2021

- Testing blimp buoyancy -- February, March
  - Determine if RC blimp is a viable base to work off of
  - Custom Airship shape (Test if that floats)
- Designing envelope and gondola -- March
- Get all electronic components -- February
- Start development/building blimp -- March

Spring Term 2021

- Continue building blimp -- April
- Testing and Improvement -- May
- Documentation and presentation -- June

9 Citation

[Autonomous Blimp Control using Model-free Reinforcement Learning in a Continuous State and Action Space]

A. Rottmann, C. Plagemann, P. Hilgers and W. Burgard, "Autonomous blimp control using model-free reinforcement learning in a continuous state and action space," 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems, San Diego, CA, 2007, pp. 1895-1900, doi: 10.1109/IROS.2007.4399531.

[Parameter Identification of Blimp Dynamics through Swinging Motion]

Q. Tao, J. Cha, M. Hou and F. Zhang, "Parameter Identification of Blimp Dynamics through Swinging Motion," 2018 15th International Conference on Control, Automation, Robotics and Vision (ICARCV), Singapore, 2018, pp. 1186-1191, doi: 10.1109/ICARCV.2018.8581376.

[A competition to identify key challenges for unmanned aerial robots in near-earth environments]

W. E. Green, K. W. Sevcik and P. Y. Oh, "A competition to identify key challenges for unmanned aerial robots in near-earth environments," ICAR '05. Proceedings., 12th International Conference on Advanced Robotics, 2005., Seattle, WA, 2005, pp. 309-315, doi: 10.1109/ICAR.2005.1507429.

[A Flight Control and Navigation System of a Small Size Unmanned Airship]

Jinjun Rao, Zhenbang Gong, Jun Luo and Shaorong Xie, "A flight control and navigation system of a small size unmanned airship," IEEE International Conference Mechatronics and Automation, 2005, Niagara Falls, ON, Canada, 2005, pp. 1491-1496 Vol. 3, doi: 10.1109/ICMA.2005.1626776.

Revisions

Revision 1.0: Initial document 01/02/2021
Revision 1.1: Added sections 01/09/2021
Revision 1.2: Added block diagram 01/26/2021
Revision 1.3: Corrected grammar, added risks 02/04/2021
Revision 1.4: Added more detail 02/05/2021
Revision 1.5: Added table of contents, Image 02/08/2021
Revision 1.6: Added sub-section in design spec, formating

Formal Sign Off