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Eye in the Sky

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ABSTRACT

This project is separated into two parts: an unmanned aerial vehicle (UAV) and a corresponding capsule. The UAV will be stored in the capsule as the pair is released from underwater and floats to the surface where the capsule will autonomously open and discharge the drone. Following release, the UAV will fly up and record video surveillance of the surrounding area. Finally, the UAV will record the data onto a micro SD card inserted in the monitor that shows the camera's live feed. The objective is to design, build, test, and finalize a UAV and capsule that meet NUWC's, the customer, specifications as much as possible. The overarching design for this system consists of a cylindrical capsule with chambers for the drone, electronic controls, controlled air flow, and the tank of compressed air. An Arduino UNO is programmed to trigger the flow of air that pushes the drone out after a certain number of seconds. The UAV is a quadcopter whose arms spread open by a simple spring mechanism once ejected from the capsule but sits linearly while inside the capsule. The capsule has been manufactured from aluminum and the drone uses the Vortex 250 Pro as a base but has been modified to feature the required fold-able arms. Testing has shown that the capsule functions as expected. It floats to the surface, maintains a vertical position, and ejects the UAV after the programmed number of seconds. Testing has also shown that the UAV's physical body also functions as expected in terms of its arms springing open when no longer constrained within the capsule. Photos and videos have been successfully recorded onto the monitor. The drone's flight was not tested due to unforeseen and currently unresolved software issues. Overall, if the drone was capable of flight, the team would expect the system to work well as a whole.

CONTENTS

1	Introduction	1
2	Patent Search	1
3	Evaluation of the Competition	2
4	Specifications Definition	4
5	Conceptual Design	7
5.1	Jeffrey's List of Concepts Generated	7
5.2	Jeffrey's Evaluation of Each Concept	10
5.3	Robert's List of Concepts Generated	11
5.4	Robert's Evaluation of Each Concept	13
5.5	Daynamar's List of Concepts Generated	13
5.6	Daynamar's Evaluation of Each Concept	15
5.7	Hannah's List of Concepts Generated	16
5.8	Hannah's Evaluation of Each Concept	18
6	QFD	18
7	Design for X	21
8	Project Specific Details & Analysis	21
9	Detailed Product Design	21
10	Engineering Analysis	24
11	Build/Manufacture	30
11.1	Capsule	30
11.2	Drone	32
12	Testing	33
12.1	Capsule Tests	33
12.1.1	Performance Testings	33
12.1.1.1	Vertical Ascending Trajectory and Surface Position	33
12.1.1.2	Recoil and Payload Expulsion	37
12.1.2	Design Specification Compliance	40

12.1.2.1 Watertight	40
12.2 UAV Tests	41
12.2.1 Performance	42
12.2.1.1 Redesigned Body	42
12.3 Test Matrix	43
13 Redesign	44
13.1 Performed Redesign	44
13.2 Recomend Redesign	45
14 Project Planning	46
15 Financial Analysis	48
16 Operation	50
17 Maintenance	51
18 Additional Considerations	52
19 Conclusions	53
20 References	54
21 Appendix A - Concept Designs	55
22 Appendix B - UAV and Capsule Drawings	96
23 Appendix C - Project Charts	103
24 Appendix D - Assembly and Operations Manual	105
24.1 Item List	105
24.2 Initial Assembly Instructions	106
24.3 Operation Instructions (including rest of assembly)	106
24.4 Binding Instructions	111
24.5 Troubleshooting Guide	112

NOMENCLATURE

a	Acceleration
A	Area
$AECA$	Arms Export Control Act
C_D	Coefficient of Drag
d	Distance
D	Diameter
DoD	Department of Defense
DVR	Digital Video Recorder
EC	Engineering Characteristics
F_B	Buoyant Force
F_D	Drag Force
FAA	Federal Aviation Administration
FMS	Foreign Military Sales
FPV	First Person View
g	Gravity
GPS	Global Positioning System
h	Depth or Height
HOQ	House of Quality
m	Mass
$NUWC$	Naval Undersea Warfare Center
P	Pressure
P_o	Atmospheric Pressure
PLA	Polylactic Acid
PSI	Pounds per Square Inch
PVC	Polymerizing Vinyl Chloride
QFD	Quality Function Deployment
t	Thickness
t_1, t_2	Time
UAV	Unmanned Aerial Vehicle
V	Velocity
V_f	Final Velocity
V_o	Initial Velocity
W	Weight

x	Distance Traveled
ρ	Density
σ_c	Hoop Stress
σ_y	Tensile Yield Stress

LIST OF TABLES

1	Engineering Characteristics	3
2	Design Specifications	6
3	Vertical Surface Position Test Results	36
4	Recoil and Payload Expulsion Test Results	40
5	Watertight Test Results	41
6	Drone Performance	43

LIST OF FIGURES

1	Robert's Concept Evaluation for each design	13
2	Flute Capsule	16
3	Sphere Drone	16
4	Folding arm quadcopter	18
5	Cylindrical Capsule	18
6	QFD Chart	20
7	Model of Final UAV Capsule	22
8	Drone Final Design: Open position	23
9	Drone Final Design: Folded position	23
10	Complete Final Design	24
11	Launch Angle vs. Launch Height	29
12	Trial 1	34
13	Trial 7	35
14	Trial 11	36
15	Dummy Load Drone	37
16	Dummy Load Drone Top View	37
17	Recoil Test Visual 1	38
18	Recoil Test Visual 2	39
19	Watertight Test setup	40
20	Pressurizing the Test Vessel	41
21	Original Model: Vortex 250 Pro out-of-box	42
22	Test Matrix	43
23	Project Gantt Chart	47
24	Project Completion Percentage Report	48
25	Jeffrey's Concept 1-2	55
26	Jeffrey's Concept 3-5	56
27	Jeffrey's Concept 6	57
28	Jeffrey's Concept 7-8	58
29	Jeffrey's Concept 9-11	59
30	Jeffrey's Concept 12-13	60
31	Jeffrey's Concept 13 Continued	61
32	Jeffrey's Concept 14	62
33	Jeffrey's Concept 15-16	63

34	Jeffrey's Concept 17-18	64
35	Jeffrey's Concept 19-20	65
36	Jeffrey's Concept 21-22	66
37	Jeffrey's Concept 23-24	67
38	Jeffrey's Concept 25-26	68
39	Jeffrey's Concept 27-28	69
40	Jeffrey's Concept 29-30	70
41	Jeffrey's Pugh Chart	71
42	Robert's Quadcopter	72
43	Robert's Collapsed Quadcopter	73
44	Robert's Quadcopter exiting the launch tube	73
45	Robert's rapidly Changeable Motor Mount	74
46	Robert's Arduino Placement	74
47	Robert's Compressed Gas System	75
48	Robert's Complete Sabot System	75
49	Robert's Dual Tilting Rotor Copter	76
50	Robert's UAV and control system Stand Off Device	76
51	Robert's UAV retention device that removes the end cap during launch	77
52	Robert's Dual-Rotor, counter rotating Copter with Gyro Cam	77
53	Robert's Rotating Swing Wing	78
54	Robert's Swing Wing Plane exiting the launcher	79
55	Robert's PVC Drone Cannon	80
56	Robert's Launch Canister System	80
57	Robert's Inner Launcher Retention System	81
58	Robert's Inner Launcher Ejection System	81
59	Daynamar's Concept: Hockey Puck	82
60	Daynamar's Concept: Conical Lid	82
61	Daynamar's Concept: "Lego" Capsule	83
62	Daynamar's Concept: Buoyant Canister	83
63	Daynamar's Concept: Starwars All Terrain Armored Transport	84
64	Daynamar's Concept: Sphere Capsule	84
65	Daynamar's Concept: Double Cone	85
66	Daynamar's Concepts page 1	85
67	Daynamar's Concepts page 2	86
68	Daynamar's Concepts page 3	87

69	Daynamar's Pugh Chart	88
70	Hannah's Concept Designs 1-6	89
71	Hannah's Concept Designs 7-10	90
72	Hannah's Concept Designs 11-14	91
73	Hannah's Concept Designs 15-22	92
74	Hannah's Concept Designs 23-26	93
75	Hannah's Concept Designs 27-30	94
76	Hannah's Pugh Chart	95
77	Drone Housing	96
78	Barrel End Cap	97
79	Joining Fixture	98
80	Pressure Vessel	99
81	Pressure Vessel End Cap	100
82	Dummy Drone	101
83	Bill of Materials for a Single Unit	102
84	Remaining Critical Tasks	103
85	Work Completed	103
86	Work breakdown	104
87	Capsule Items	105
88	Drone Items	105

1 INTRODUCTION

In today's contested and highly dynamic battle space environments, security is paramount to any war-fighting organization. The Naval Underwater Warfare Center, NUWC for short, pitched this project with the purpose of creating a new and improved way for people, specifically those aboard submarines, to gather information and other intelligence about their surroundings above water. This equipment must be both compact and rugged. The deployment system must be able to withstand the crushing pressure at depth, be able to rise to the surface, and deliver the unmanned aerial vehicle (UAV). The deployment system has to be compact and compatible to be used in handling systems that are already in use. Currently, larger drones are used in a similar manner to what is expected of the project. However, the ultimate goal with this project is to minimize both the cost, since the UAV is meant to be used only once, and the size of the drone as well as the capsule, to make storage easier, while maintaining the same function and ease of use as existing models. This UAV will give the war-fighters the requested imagery, surveillance, and reconnaissance capabilities. NUWC has allotted a \$1,500 budget to complete this task.

The goal for this project is to create a design, build a prototype, test, make any necessary adjustments, retest, and finalize a UAV housed in a waterproof capsule. The UAV, or drone, itself must be no larger than 2.75 inches for it to fit within the capsule which must be a maximum of 3 inches in diameter in order to fit inside the ideal launch space. The capsule with the drone inside will be deployed from subsurface. For testing purposes, the capsule will simply be held underwater and released with no added launch force. The capsule is required to float upwards and open once it reaches the surface of the water. Then, the drone must turn on and fly to a designated height no more than 400 feet up where it will then survey the local vicinity using a camera to obtain photos and/or videos. The drone must then return to the ground and deliver the data on a micro SD card. The additional challenge is that both the drone and the capsule are expected to be as autonomous as possible. Other features such as accuracy of the altitude hold, stability of hovering, recording GPS fixes of the UAV, and determining compass direction are not necessary for the design, but would be appreciated if functional.

2 PATENT SEARCH

When creating a new product, it is crucial to be aware of existing products that have the same or similar function in order to avoid patent infringement. The physical shape, tech-

nical code, and even ideas can all be protected and owned under patent law. If someone produces an invention without verifying if there is already a patent for it, legal issues may arise and businesses may be destroyed. Each member of the team conducted searches to understand what preexisting designs are in the market to evade copying another product. Related topics included waterproof unmanned aerial vehicles, underwater capsules, aerial photo instruments, and more.

The only patent that helped influence the current design of the project is Patent 8091461 entitled "*System for water-based launch of an unmanned aerial vehicle*" [1]. The patent describes a compressed air tank within a tube coupled to a support structure. There is also an outlet in which the air travels controlling the airflow to the launch tube. The team's current design uses a compressed air tank as the main source of power to eject the UAV from the capsule. Using a compressed spring to launch the UAV from the capsule was originally considered, but the discovery of compressed air changed the idea to something proven to work and more easily controllable.

Other patents were helpful to begin the process of generating concepts as solutions to the problem, but have not been directly influential in the final design. A couple of patents such as Patent 9905860 entitled "*Water activated battery system having enhanced start-up behavior*", which describes a lithium battery activated by contact with water, and Patent 7302316 entitled "*Programmable autopilot system for autonomous flight of unmanned aerial vehicles*", which describes a system that is able to be programmed to maintain the UAV's altitude as well as orbit around a fixed point in space, may be helpful in the future if the current design fails [2] [3]. The Arduino UNO is the planned source of power to activate the capsule, but a water activated battery may be a better solution. The UAV may also be programmed by an Arduino UNO, but a new system such as the one described in Patent 7302316 could be implemented instead.

3 EVALUATION OF THE COMPETITION

To develop the Quality Function Deployment (*QFD*), different sectors regarding the requirements, characteristics, and competition are put in a House of Quality (*HOQ*) configuration [4, 5]. For this project the first section begins with the customer requirements for the UAV. These customer requirements are:

- Reliable

-
- Flight Time (≤ 15 min)
 - Programmable
 - Ease of Use
 - Safe
 - Width less than 3"
 - High Definition Camera
 - Low cost to run
 - Bluetooth

To measure the product performance the Engineering Characteristics (*ECs*) chosen are displayed in Table 1:

Table 1: Engineering Characteristics

Characteristic	Limit Value
Length	39 inches
Width	3 inches
Height	3 inches
Noise	40 dB
Camera Quality	720P
Power	Watts
Semi-Autonomous	Programmable
Flight Time	15 minutes
Weight of Vehicle	Lbs
Waste Produced	Wasted Materials
Housing	Machinable
Materials	Availability
Life Cycle	Serviceability

The main objective for the HOQ is to determine the critical engineering characteristics that need to be satisfied. The ECs are to be ranked in order of which ones will have the greatest effect in customer satisfaction. A way of increasing the capabilities of the HOQ is to conduct a competitive assessment. Five products compete with the UAV for this project. These are: Blackwing, Raven, Puma, Wasp, and Axis Vidiu. The product that presents the most competition to the team's UAV design is the Blackwing. This product is the most similar to the UAV design requirements. When looking at the finalized QFD, see Figure 6, the constraints are primarily the method of powering the capsule and the programming for the UAV and capsule to be autonomous. All the constraints are taken into account to serve as a guide for the determination and selection criterion for the final design.

4 SPECIFICATIONS DEFINITION

The design portion falls in two different elements, the underwater capsule and the UAV. For the underwater capsule, one of the main priorities is for it to be waterproof in order to protect the payload. This capsule must be able to withstand the salt water pressure at a maximum of 200 feet in depth, that is 100 psi. One of the biggest constraints for this capsule element is the dimensions. The capsule must not have an outer diameter (*OD*) larger than 3 inches. The final design satisfies this requirement by due to its *OD* equal to 3 inches. The length of it must not exceed 39 inches. In the final design this length was exceeded by 1/8 of an inch. Taking this issue to the advisor it was concluded that the surpassing of the length is acceptable. The material and shape were free for the team to decide. Therefore, Aluminum 6061-T6 was selected because of its easy handling for manufacturing and mechanical properties. To maintain the capsule with a positive buoyancy, the hardware selected is made out of stainless steel and the electronics carrier out of polylactic acid (*PLA*). For the second element of the design section, a UAV was created. The Vortex 250 Pro from Immersion RC was taken apart and redesigned with the some of its original body components along with 3D printed components. The final dimensions for the drone in its collapsed and open position can be seen in Table 2. The UAV is autonomously deployed by the capsule and once in the air, the Spektrum DSMX controller is used to start its motors. The UAV reaches the designated altitude of 30 feet and the Digital Video Recorder (*DVR*) monitor records the live video transmitted by the first person view (*FPV*) camera and 5.6 Ghz antenna on the UAV to a micro SD card. The altitude chosen is lower than 400 feet since the Federal Aviation Administration (*FAA*) limits the maximum altitude to 400

feet above the ground or water. When the video capture is complete, the UAV can land at the desired landing spot. Table 2 shows all the specifications that were given by NUWC and met for the development of the capsule and the UAV. All designs are meant for ideal atmospheric conditions, calm water and no wind.

Table 2: Design Specifications

	Capsule	UAV
Features and Objectives	<ul style="list-style-type: none">• Positive buoyancy• Maintain 90°+/- 15°angle from the surface• Air valve releases 100 psi instantaneously by a Blue-tooth command	<ul style="list-style-type: none">• Fold able arms• Altitude hold of 30 '• 30 sec recording of panoramic video on DVR monitor• Spektrum DSMX controller
Dimensions	<ul style="list-style-type: none">• OD = 3"• ID = 2.87"• Length = 39 1/8"	<ul style="list-style-type: none">• Collapsed: (LxWxH)<ul style="list-style-type: none">– 12.375" x 2.625" x 2.375"• Open (LxWxH)<ul style="list-style-type: none">– 9.875" x 7.5" x 2.375"
Power Supply	<ul style="list-style-type: none">• 8 AA Duracell batteries	<ul style="list-style-type: none">• 1300 mAh 3 cell 6c Lipo battery
Environment	<ul style="list-style-type: none">• Sea State 1 (<i>0-0.1m waves</i>)• Sustain pressures of up to 200' below sea level (<i>100 psi</i>)	<ul style="list-style-type: none">• Calm, no wind or rain
Materials	<ul style="list-style-type: none">• Aluminum 6061-T6• Stainless Steel Hardware• 3D printed PLA electronics carrier	<ul style="list-style-type: none">• Carbon fiber/polymer composite body with 3D printed PLA arm components• 3D printed PLA UAV carrier

5 CONCEPTUAL DESIGN

Each person on the team was tasked with generating at least thirty design concepts that provided a solution to the problem at hand. Since there are four members of Team 9, a total of 120 concepts were created with about an even split of UAV and capsule designs. This section will briefly describe each of the creator's concepts and which combination he or she thought would best deliver a proper solution. Refer to Appendix A to see a complete list of concept designs in Figures 25 through 76.

5.1 Jeffrey's List of Concepts Generated

The thirty designs and concepts generated by Jeffrey for this project can all be seen in Appendix A. The descriptions of each of these designs are detailed in the following manner.

1. Design 1 is of the capsule unit. The lid is held on using nylon nails which are strong enough to hold the lid in place but can easily be broken through shearing forces. A plate with posts holds the drone and a pressurized canister will cause the plate and the posts attached to force the lid off with no damage to the drone when the pressure is released.
2. Design 2 is similar in form to design 1 except for the fact that the material used would be aluminum in place of a 3D printed material. The 3D printed material could be water resistant but not water proof and it is possible it would not withstand the pressures that are induced so far below sea level. Aluminum is corrosion resistant, light, inexpensive, and machinable.
3. Design 3 is of the capsule unit using a hinged lid with a spring base. The base also has posts attached which would be the contact point to open the door, thus leaving the drone untouched during that opening of the capsule.
4. Design 4 is of the capsule unit using a square design with rounded corners. The lid is also one unit being held on with an adhesive which is water soluble. Therefore the adhesive would slowly start to dissolve once the unit is deployed, and can later be opened with ease.
5. Design 5 is of the drone. The drone has a rounded spherical body with four motors. Each is mounted on a rod extending away from the body and is connected using spring loaded hinges. In the storage configuration, the motors are folded in to minimize volume taken up. Once deployed, the wings will unfold to an X shape.

-
6. Design 6 is of the drone. This is a simple nano-sized drone where there are no moving parts and the drone is always in a configuration which is ready for flight. The drone must fit within the size specifications of 2.75 inches though.
 7. Design 7 is of the capsule unit. This design is considering extending the height of the capsule to maximize the length or height of the drone itself. It also uses a hinged lid to open the top.
 8. Design 8 is that of the capsule unit. This design also considers a long height, though the key feature is the lid positioning, which is on the side of the unit. This would allow for a long drone to achieve flight right from the capsule unit.
 9. Design 9 is that of the capsule unit. This design considers the characteristics of design 7 but using PVC instead of Aluminum. PVC is strong, light weight, corrosion resistant, and easy to machine. Aluminum is less corrosion resistant and can be more costly to machine.
 10. Design 10 is that of the capsule unit. It is similar to design 8 but considering the use of PVC instead of Aluminum. The PVC is strong and lighter than the aluminum and it can still withstand the pressures it would be under while deployed beneath sea level.
 11. Design 11 is that of the capsule unit. It utilizes a mild strength adhesive to seal the lid from water. It also uses a base platform that is spring loaded to help force the drone out of the unit.
 12. Design 12 is that of the capsule unit. This design focuses on the lid and utilizes a lid which has overlapping edges. This could help with the waterproofing of the unit to protect the drone and require less sealant.
 13. Design 13 is of the drone. This design uses propeller blades which are fitted to the body of the drone. They thus allow for the drone to slide into the capsule unit and minimize the size of the drone. They then fold out for flight and the motor can spin them at the top to achieve flight, such as a helicopter.
 14. Design 14 is of the drone unit. This drone is water tight and therefore it does not need its own designated capsule unit for deployment. It also utilizes propellers which fold into the body for storage and out for flight. They could also be used to help the drone surface from underwater. The camera is integrated to the bottom with a small cover for waterproofing.

-
15. Design 15 is that of the drone using a balloon and a pressurized canister of helium. The helium canister fills the balloon which lifts the drone and camera out of the water when at the surface.
 16. Design 16 is that of the canister for the drone. It is designed with a buoyant material such as foam or cork in order to provide increased stability when the lid is opened.
 17. Design 17 is a drone concept. The propeller blades are hinged upward so they can more easily fit within the canister. Once the blades slide out they will fall down into position for operation. The camera is positioned at a 45 degree angle to provide a better viewing angle.
 18. Design 18 is a concept of the drone. This concept utilizes only two propeller blades which are fixed to provide lift for the drone.
 19. Design 19 is a drone concept, in which the motor shaft is extended higher above the drone body. This allows for longer propeller blades to be attached to the drone. The blades would be hinged and as the motor turns the blades would lift up.
 20. Design 20 is of the drone which possesses two motors and two cameras to provide enhanced viewing capabilities.
 21. Design 21 is based off of design 20, but using a 3D printed body instead of a machined aluminum body for the drone. This would be faster to produce and cheaper and would reduce the weight of the drone. For the drone, such a durable material is not needed as well.
 22. Design 22 is of the capsule and a potential flotation device. An airbag type system wraps around the upper section of the capsule and could be activated at any depth to assist in the acceleration to the surface. This could also be used to help stabilize the canister from tipping in rough seas.
 23. Design 23 is of a potential drone configuration where the propellers are integrated into the body of the drone and not fixed on an arm. The camera is also recessed into the body of the drone.
 24. Design 24 is of a drone with a cylindrical body and a camera on the bottom. The motors fold up over the top of the drone for storage in the capsule. These will drop down and out once the drone begins to come out of the capsule.

-
25. Design 25 is that of a capsule configured with a split and folding lid with two hinges. There is a piston at the bottom of the capsule with a platform which the drone would sit on. The piston would push up and force the drone out of the capsule.
 26. Design 26 is of a drone with a square body and four folding arms, each with their own motors. A camera is mounted at the bottom at an angle to help optimize viewing capabilities.
 27. Design 27 is of a drone using two different motors positioned on opposite ends of the drone. These motors have extended shafts so the propeller blades can be longer. The camera is mounted on the bottom at an angle.
 28. Design 28 is of a drone with a triangular geometry to try and reduce issues with wind. A small solar panel is mounted on the top to charge the battery and increase flight time. Three motors are used and a camera is mounted on the bottom.
 29. Design 29 is of the drone within the canister. The drone would be deployed using a spring so it would reach a point to which the propeller blades could be deployed. It would then be assisted by a discharge of compressed gas.
 30. Design 30 is of a canister with a conical shaped lid. The cone has a rubber membrane attached so when it opens the membrane stops water from going in.

5.2 Jeffrey's Evaluation of Each Concept

A Pugh chart was generated in order to assist with the analysis of these thirty design concepts, which can be seen in Appendix A Figure 41 . Upon review of these concepts, it was found that some of these ideas, concepts, or designs had some innovative, creative, and unique ideas, while others were somewhat unrealistic, over complex, or difficult for us to develop with our knowledge and resources. Design concept 14 was chosen to be the reference design for the Pugh chart because it was one of the most innovative ideas and it removed the need to have a capsule entirely simply by designing the drone to be water-proof and cylindrical. The camera was designed to be integrated into the bottom of the drone, and with the propellers folding into the body, it provided a cylindrical shape for flowing through the water. From the Pugh chart, it can be seen that designs 8, 12, 22, and 24 each had the most number of positive attributes, when compared to the other designs, and concept 13 was the most similar, yet had one negative attribute.

When analyzed by the entire team, a permutation of design concept 8 was generated, using the cylindrical capsule with the side opening hatch design. The generated permutation went on to the next stage of consideration and further analysis.

Design 12 was found to be restrictive of the amount of room the drone would have to exit the capsule. Also, such a large overlap at the edges could promote unwanted binding of the lid during removal. Any binding could prevent drone deployment. This design was therefore removed from consideration.

Design 22, though innovative and potentially effective, is a somewhat complex task to design, build, and test. It was also found that such a device would require a lot of room in the walls of the capsule, thus reducing the amount of room for the drone. Placing this at the bottom could also make the unit top heavy and unstable. For these reasons, this design was not chosen for further consideration.

The final design analyzed in-depth was design 24. This design was not chosen largely due to its motor arm design. The motors would fold down and into position on the drone. A locking mechanism would be required to prevent the motor arms from folding up again during flight. Even if a solution was found, there would be a chance that this system could fail and the drone could be lost. The team decided that the flaw was significant enough to not consider the design further.

5.3 Robert's List of Concepts Generated

1. Electro Optic Infrared Camera system (EoIR)
2. Inner Sabot made of aluminum
3. Outer Launch Tube of Aluminum
4. High Rotational Velocity short rotor blade
5. Integrated motor hub and transmission
6. Outer Sabot Base made of Aluminum that is also the Compressed Gas Cylinder
7. Tilt Rotor Copter Body
8. Tilt Rotor housing, hub and transmission

-
9. Swing Wing Concept.
 10. Swing Wing Plane body
 11. Pusher Style Propeller, motor and transmission Assembly
 12. Quadcopter
 13. Quadcopter body
 14. Quadcopter folding support arms, left and right
 15. Quadcopter inverted motor, transmission and propeller blades
 16. Quadcopter lid enclosure and stiffening system
 17. Can Copter concept
 18. Can Copter body and housing
 19. Can Copter dual rotating motor, transmission and propeller blades
 20. Gyroscopically stabilized camera mount
 21. Gyroscopically stabilized camera base and power system.
 22. Gyroscopic stabilized panning system
 23. Gyroscopic stabilized tilt system
 24. Compressed gas handling system
 25. Aircraft canister-ejection system, both fore and aft.
 26. Operator Changeable motor mount
 27. Environmentally Available pressure Application End Cap.
 28. Spacer System that holds the UAV above the micro controller and gas solenoid

5.4 Robert's Evaluation of Each Concept

	Design name	Within dia constraint	within length constraints	Critical to concept	cross platform interchangeable	y	n
1	Electro Optic Infrared Camera system (EolR)	y	y	y	y	4	0
2	Inner Sabot made of aluminum	y	y	n	y	3	1
3	Outer Launch Tube of Aluminum	y	y	n	y	3	1
4	High Rotational Velocity short rotor blade	y	y	n	n	2	2
5	Integrated motor hub and transmission	y	y	n	n	2	2
6	Outer Sabot Base made of Aluminum that is also the Compressed Gas Cylinder	y	y	n	y	3	1
7	Tilt Rotor Copter Body	y	y	n	n	2	2
8	Tilt Rotor housing, hub and transmission	y	y	n	n	2	2
9	Swing Wing Concept	y	y	n	n	2	2
10	Swing Wing Plane body	y	y	n	n	2	2
11	Pusher Style Propeller, motor and transmission Assembly	y	y	n	n	2	2
12	Quadcopter	y	y	y	n	3	1
13	Quadcopter body	y	y	y	n	3	1
14	Quadcopter folding support arms, left and right	y	y	y	n	3	1
15	Quadcopter inverted motor, transmission and propeller blades	y	y	y	n	3	1
16	Quadcopter lid enclosure and stiffening system	y	y	y	y	4	0
17	Can Copter concept	y	y	n	n	2	2
18	Can Copter body and housing	y	y	n	n	2	2
19	Can Copter dual rotating motor, transmission and propeller blades	y	y	n	n	2	2
20	Gyroscopically stabilized camera mount	y	y	n	y	3	1
21	Gyroscopically stabilized camera base and power system.	y	y	n	y	3	1
22	Gyroscopic stabilized panning system	y	y	n	y	3	1
23	Gyroscopic stabilized tilt system	y	y	n	y	3	1
24	Compressed gas handling system	y	y	y	y	4	0
25	Aircraft canister-ejection system, both fore and aft	y	y	y	y	4	0
26	Operator Changeable motor mount	y	y	n	n	2	2
27	Environmentally Available pressure Application End Cap.	y	y	y	y	4	0
28	Spacer System that holds the UAV above the micro controller and gas solenoid	y	y	y	y	4	0
29	Ejection Puck	y	y	y	y	4	0
30	Three-link arm operating system	y	y	n	n	2	2

Figure 1: Robert's Concept Evaluation for each design

5.5 Daynamar's List of Concepts Generated

1. Hockey Puck Vessel - This vessel is a cylindrical capsule with a suction sealed lid.
2. Conical Lid - Cylindrical capsule where the bottom is indented with the same conical shape as the lid. This is to prevent sliding when stacking.
3. "Lego" Lid - Cylindrical capsule similar to previous designs, but the lid will "click" with the bottom of another capsule to secure when stacking and storage.
4. Petal Lid - Each petal will open and serve as floating device to keep the capsule stable.
5. Buoyant Canister - The walls of the capsule can be filled with foam. To control the direction facing the surface and helping it float, without interfering with the exterior geometry.
6. Retractable Lid - The same way a sliding door behaves. The lid will be divided in 6 sections. Each section will retract and store itself under a single predetermined section.

-
7. Blimp - A helium foil balloon with a solar modulus on the top. The solar module purpose is to power the battery that keeps the balloon hovering in place and also power the camera.
 8. Ball Drone - A spherical drone with two helix in a vertical direction one on top of the other.
 9. Ball Capsule - The capsule that holds the ball drone.
 10. Cube - A cube drone with two helixes in a vertical direction one on top of the other.
 11. Cube Capsule - The capsule that holds in place the cube drone to avoid sliding on the inside.
 12. AT-AT (Starwars All Terrain Armored Transport) - Vertical to horizontal platform.
 13. Spring Vertical Projectile - Projectile impulsed by a compressed spring in the bottom.
 14. Lifesaver - a lifesaver shape inflatable pops the lid open and keeps the capsule floating.
 15. Spring-Mass - A weight at the bottom holds the drone down with a cable. The drone compresses two springs. When the capsule is deployed the weight breaks the cable and the drone is released.
 16. Capsule battery compartment - A design for the storage of payload or batteries inside the capsule.
 17. Mechanical Pencil Mechanism - Taking as an inspiration the mechanism used in a mechanical pencil. The drone can be pushed out or deployed the same way the graphite is pushed out of a pencil.
 18. Drum Capsule - The lid of the capsule can be puncture and open the payload inside it.
 19. Power Screw - A power screw mechanism can be used to lift a platform to set the drone for take-off.
 20. Pill Capsule - A cylindrical capture with it's endcaps with a half sphere geometry.
 21. Double Cone - The bottom cone would keep the batteries or mechanism water-sealed and the top cone will contain the drone.

-
22. Sphere Capsule - This geometry helps keep the top space of the capsule a float.
 23. Flute Capsule - Geometry that helps the capsule stay afloat and not flip, but the top space has a cylindrical shape for more internal space.
 24. Egg shaped Capsule - The idea was taken from the way an egg floats in salt water. The capsule can be deployed vertically and reach surface horizontally.
 25. Water Strider - Once the capsule reaches surface, the legs will open and keep it above water.
 26. Angled Projectile - The capsule reaches surfaces and the sleeve slides off. Because of the center of gravity, the internal capsule will tilt into a desired position.
 27. Compressed Air Opening mechanism - Compressed air capsules impulse a platform that lifts the lid off.
 28. Twist Drone - A quadcopter with its wings folded to one side for it to fit the 3 in diameter capsule. It's launched off the capsule and the wing will twist into position.
 29. Spring Drone - The wings are contracted in the body of the drone and once the lid opens the wings will slide out normal to each side.
 30. Sphere Papillon Drone - Sphere drone that folds into a ball. Once the lid is off the drone will open into a butterfly shape and take off.

5.6 Daynamar's Evaluation of Each Concept

The process for narrowing the designs was done by using the Pugh Chart displayed in Figure 69 of Appendix A. Per review of the designs, two were chosen. The idea for the capsule is the flute capsule, shown in Figure 2. The functionality of it being stable while floating fulfills part of the requirements set by the customer. For the design of the UAV the sphere drone, shown in Figure 3, demonstrates a design for a foldable drone. It can be folded to the limits set by the customer and once at the surface, expand into a preferred size.

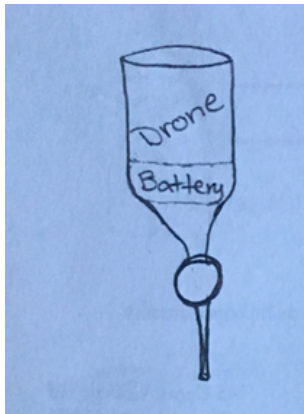


Figure 2: Flute Capsule

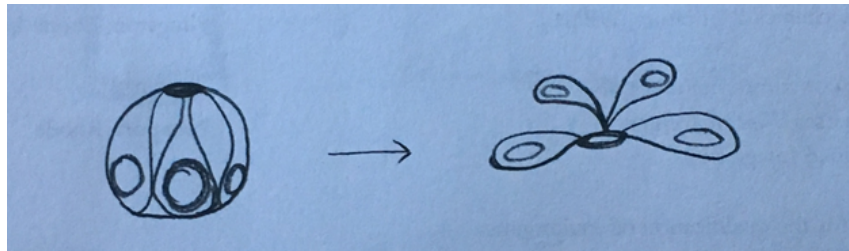


Figure 3: Sphere Drone

5.7 Hannah's List of Concepts Generated

1. Sphere with a camera in the front that flies like a helicopter with 4 blades on the top. The blades can fold in on each other to make the whole device linear to fit in a long, skinny capsule
2. X-shaped quadcopter with 2 blades on each arm and a camera on the front center of the body
3. X-shaped quadcopter with 2 blades on each arm. Each arm has a hinge in the center to allow bending when not in use for easier storage
4. Quadcopter with arms that lock straight into the body when not in use for easier storage and pop out when in use
5. Egg-shaped capsule that opens in the center, like an Easter egg, to let the UAV out after it reaches the air and becomes unsealed
6. Cylinder shaped capsule that opens at the end after being triggered by the air to become unsealed, UAV launched by spring mechanism
7. Sphere with a camera in the front. 2 layers of blades that fold up when not in use
8. Airplane inspired UAV with folding wings
9. Hover sphere, somehow flies without wings or blades, screen camera as part of body

-
10. Egg-shaped capsule with a petal-like top that allows for stability while floating when opened
 11. Cylinder shaped capsule with top consisting of 2 interlocking halves, UAV launched by spring mechanism
 12. Square pyramidal shaped capsule with a petal-like top
 13. Square prism shaped capsule with an interlocking top that blooms open
 14. Double cylinder shaped capsule, outer layer is split in half and opens to reveal the second cylinder with an open top that houses the UAV, UAV launched by spring mechanism
 15. UAV with 4 arms connected to 4 fan blades
 16. Bird shaped UAV with the eye as the camera and foldable wings
 17. UAV shaped like a hang glider with a camera in the center point
 18. Wheel shaped UAV with fan blades and a central camera
 19. Hexacopter, star shaped body with 6 arms and blades
 20. UAV with a rectangular body and 4 hollowed arms to decrease weight
 21. Spherical capsule that opens by splitting in the middle, the sides then move down into the bottom half of the sphere allowing the UAV to fly out
 22. Square box shaped capsule with a sensor on the lid
 23. Octagonal prism shaped capsule with sensor lid, UAV launched by spring mechanism
 24. Cylindrical capsule that opens from the pressure of a balloon attached to the UAV
 25. Torpedo shaped capsule with sensor lid, UAV launched by spring mechanism
 26. House shaped capsule with sensor for the top pyramid as lid
 27. Tricopter, square body with 3 arms, the side with 2 arms fold into the body to become linear
 28. Square shaped box capsule that opens flat

-
29. Cylinder capsule with conical pointed bottom that opens with sensor lid, UAV launched by spring mechanism
 30. Helicopter shaped UAV with blades on top and on side of tail

5.8 Hannah's Evaluation of Each Concept

After reviewing the designs, the most reasonable and seemingly functional combination were ideas 4 and 6 as shown below in Figures 4 and 5.

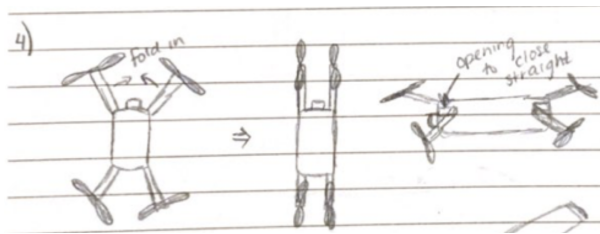


Figure 4: Folding arm quadcopter

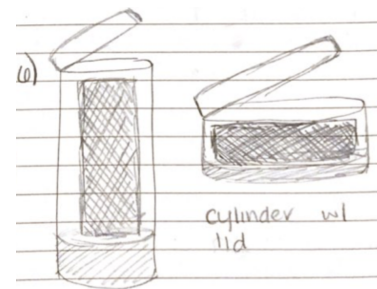


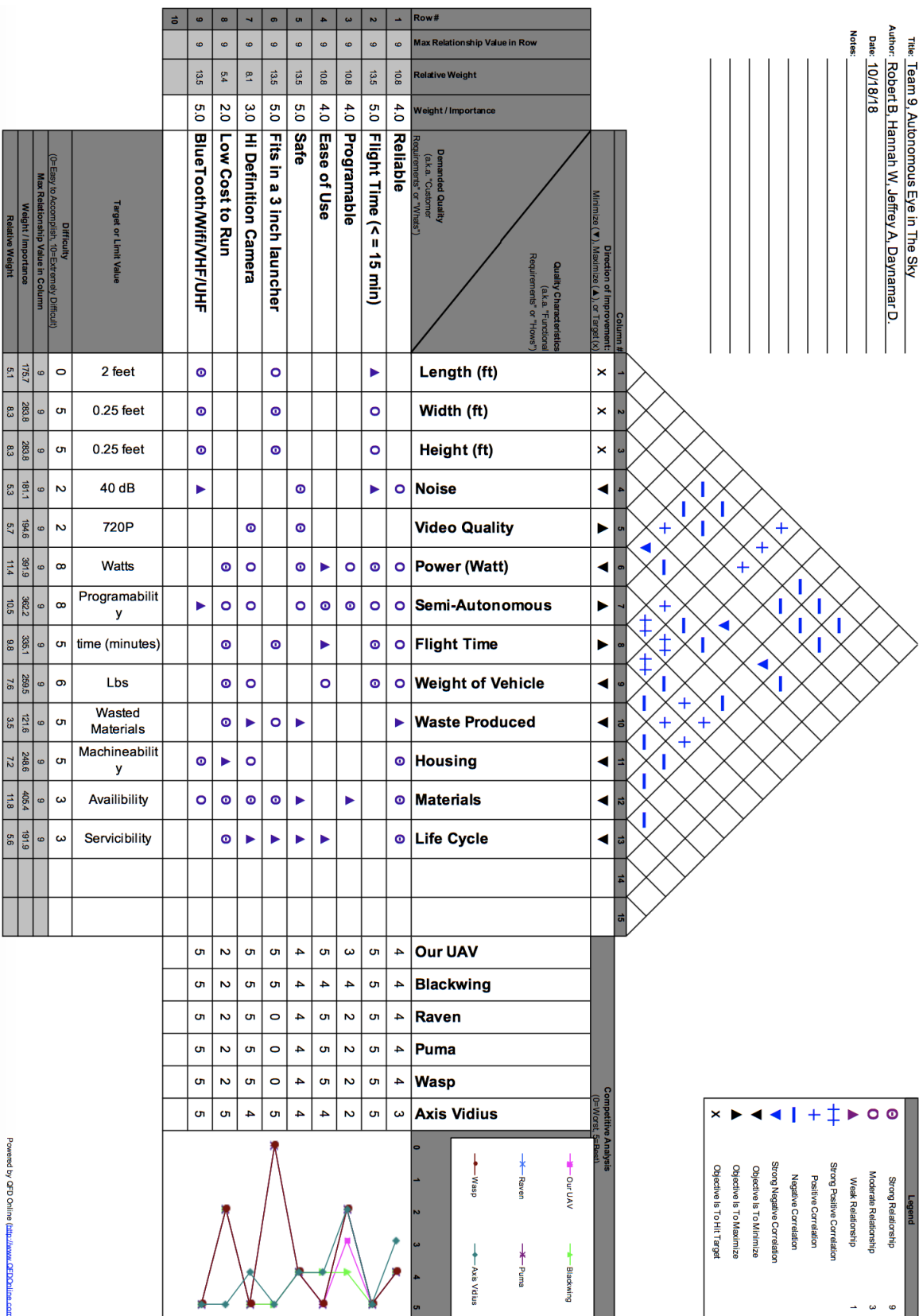
Figure 5: Cylindrical Capsule

A Pugh Chart, which can be seen in Figure 76 in Appendix A, was created to compare the rest of the ideas to numbers 4 and 6 in order to determine if there were more viable options. Ideas 9, 17, and 18 all had a high amount of pluses indicating they would be good potential options. However, the team does not have enough technical ability to successfully program and produce them.

6 QFD

The drone in this project was compared to various other similar drones currently in use or available for use by the U.S. military. When looking at the competitive analysis of the customer requirements in the QFD chart in Figure 6 below, the team's UAV is consistently equal or better than most of the other drones and UAVs in each of the customers requirements. There are a few key aspects which are of critical importance for this project, such as: fits in a 3 inch launcher, flight time, Bluetooth, reliability, and safety. In terms of reliability it can be seen that the team UAV is equal or better than all the alternatives. With regard to flight time, system safety, and Bluetooth, the team UAV is equal to all other options in

both of these categories. The criteria of fitting within a 3 inch launcher is arguably the most important aspect of this project. Of the other UAV alternatives, the Rave, Puma, and Wasp all do not meet this requirement, which would immediately disqualify them of potential use for this project. This would thus leave only the Blackwing and the Axis Vidius as potential alternatives. When analyzing the other categories, the Axis Vidius is equal or less than the team UAV in all categories, except for cost to operate. The other alternative, the Blackwing, is a fixed wing UAV which is discharged through a high acceleration, high explosive launching process, which is exactly what this project is trying to avoid and work around. Therefore, the Axis Vidius would be the only other reasonable alternative for use in this project.



7 DESIGN FOR X

The launcher and UAV were designed from the outside inward starting with the form factor constraints of: three inch outside diameter and thirty-nine inches in length. Product safety was a large driving factor in selecting minimal material thickness for both the barrel section as well as the pressure vessel section and end caps. The pressure vessel houses a charge of compressed gas and would pose a fragmentation hazard to the system-operator(s) if not properly selected. The design of the individual components had to be kept simple due to limited machining resources in-house. The 3D printed components could exceed the limits of traditional machining yet be small enough in design to fit in the printers themselves. Material costs were a set amount that were established by the vendors themselves. The size of the quadcopter was limited by the remainder of available space within the launch canister once the operating components were placed in the canister. The folding function of the arms was necessary to fit the copter inside the housing and stay within the form factor.

8 PROJECT SPECIFIC DETAILS & ANALYSIS

This system is tailored specifically to the Department of Defense (*DoD*) mission requirements and does not have a likelihood of being sold on the commercial market due to the clandestine nature of the product, export limitations, and the inability for the government to provide proprietary designs to the civilian sector as per the Defense Acquisition Workforce Improvement Act of 101-510 of 1990. This product if approved for commercial sale would be marketed under The Foreign Military Sales (FMS) program which is a form of security assistance authorized by the Arms Export Control Act (AECA), as amended [22 U.S.C. 2751, et. seq.] and a fundamental tool of U.S. foreign policy. This product if selected for sale would fall under: Section 3 of the AECA, the U.S. may sell defense articles and services to foreign countries and international organizations when the President formally finds that to do so will strengthen the security of the U.S. and promote world peace.

9 DETAILED PRODUCT DESIGN

The design of the quadcopter stemmed from the mission requirements outline by the sponsor. In order to best meet the operational capabilities an in-depth evaluation of characteristics was outlined and concepts were developed. The design that was ultimately selected

is able to accomplish all the original goals and had architecture that was consistent with industry practices.

The launch canister was built around the given form-factor constraints and mission requirements. It was determined to be the most practical delivery method and it believed to be the most reliable in operation.

The general design of the full concept can be seen in Figure 7 below. This image shows the lid of the capsule to be on the far left, with an area for the drone on the left side of the capsule. The Arduino Uno can be seen immediately to the right of the drone area near the center of the capsule. The white solenoid can also be seen adjacent to the Arduino Uno, and is attached to the air pressure chamber stored on the right side of the capsule. Surrounding the solenoid and the Arduino Uno is a separator which provides a platform for the drone without damaging the Arduino or the solenoid. The schrader valve used to pressurize the air chamber is on the far right side of the capsule.

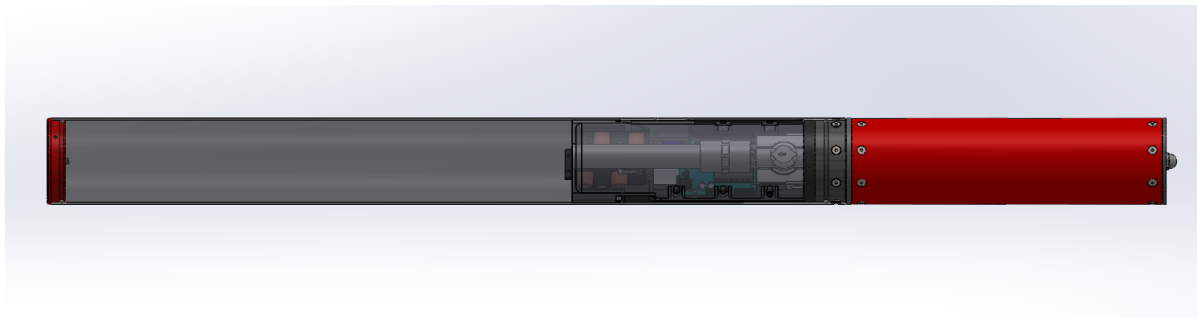


Figure 7: Model of Final UAV Capsule

The general operation of this concept design is as follows. The pressure chamber, on the right of the capsule, is pressurized using the schrader valve connected that protrudes from the far right side of the capsule. The Arduino Uno is connected to the solenoid attached to the air pressure chamber. The Arduino Uno is programmed to activate the solenoid after a specific amount of time through the use of a timer program in application form on an electronic device with Bluetooth capabilities. Once activated, the solenoid will then open and release all of the pressurized air from the air chamber. This will then fill the left half of the capsule, around the solenoid and Arduino. As the air flows from the air pressure chamber and begins to fill the left half of the capsule, the increased pressure will press on the carrier encasing the drone. This will in turn push the drone carrier into the lid of the

capsule. This will allow for the lid to be removed from the capsule and the drone to deploy. Additional images of the capsule can be found in Appendix B.

The drone design accompanying this capsule design can be seen in Figures 8 and 9.



Figure 8: Drone Final Design: Open position



Figure 9: Drone Final Design: Folded position

Figure 8 displays the drone in its flight form from the top at a slight angle to the viewer to help show some depth and details along the sides of the drone. The drone is deployed

from the capsule in the configuration seen in Figure 9. From the deployment configuration, the left and right drone support structures are split and will fly off of the drone once the drone leaves the capsule. The arms of the drone are pushed out by an extension spring. The spring will pull the arms that are located on the same side towards each other, thus forcing the arms of the drone with the motors out to their deployed configuration. The camera is positioned on the bottom of the drone in order to provide the best viewing angle for capturing images and videos. Drawings of the different views of the drone including its body and arms, the capsule, and the bill of materials may be seen in Appendix B.

A view of the entire system laid out into correct order may be seen in Figure 10 below. It is a deconstructed composition that shows exactly where each component is placed in the system.

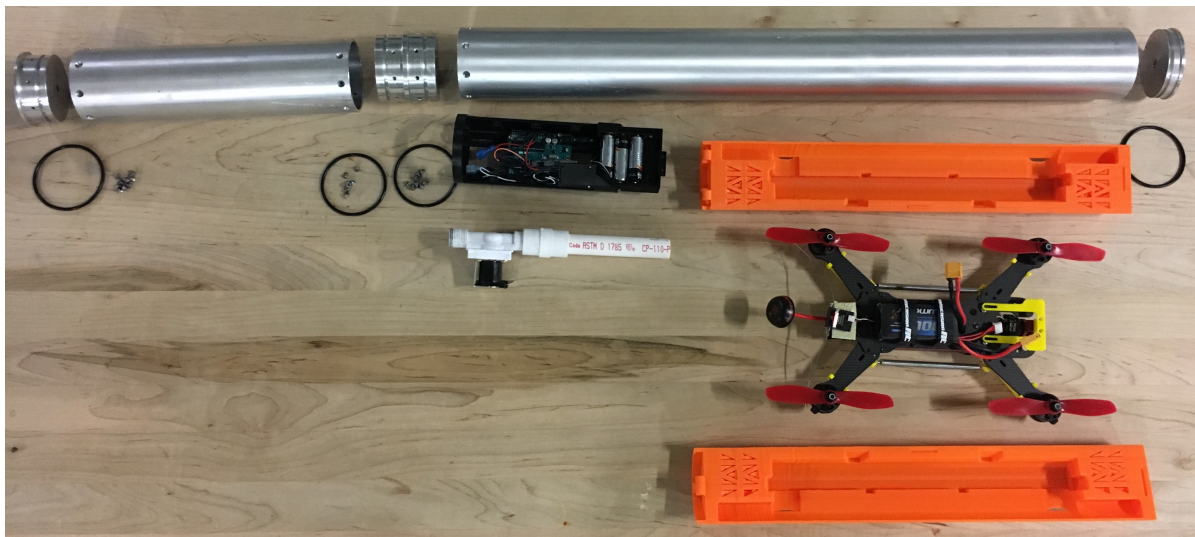


Figure 10: Complete Final Design

10 ENGINEERING ANALYSIS

In order to help determine and verify the effectiveness of the final capsule design, some engineering analysis and calculations had to be performed. The final dimensions of the capsule were 39 inches in length with a diameter of 3 inches. The engineering analysis was started off with determining what maximum pressures the capsule would have to withstand at the required depth of 200 feet below sea level. These calculations were performed for both fresh water and salt water environments, despite the fact that this design would likely be used in salt water environments. This was done simply to know what would be re-

quired if it would be used in fresh water as well. Both of these calculations were performed in the following manner for fresh and salt water, respectively:

$$P = P_o + \rho gh \quad (1)$$

where P_o is the atmospheric pressure, ρ is the density of the water, fresh or salt, g is gravity, and h is the depth at which the capsule would be situated. From these calculations it was found that the salt water environment would induce higher pressures at a depth of 200 feet below sea level, with a pressure of 0.714 MPa, when compared to the fresh water pressure of 0.698 MPa. It was therefore determined safe to design the capsule for use in salt water environments, yet use it in either salt water or fresh water.

After the pressure calculations for the capsule were performed, the Hoop stress of the cylindrical capsule design was calculated using the pressure at 200 feet for salt water. This calculation was performed as follows:

$$\sigma_h = \frac{PD}{2t} \quad (2)$$

where P is the pressure at 200 feet below sea level, which the salt water value was used, D is the diameter of the capsule, and t is the wall thickness of the hollow cylinder capsule. The Hoop stress of the capsule design was found to be 16.5 MPa.

Once these parameters were found, the buoyancy of the capsule design was determined. In order to find this, the volume of the capsule first had to be calculated:

$$V = \frac{\pi D^2 h}{4} \quad (3)$$

where D is the diameter of the capsule design and h is the height of the capsule. Subtracting the volume the weights in the pressure chamber were occupying, the total volume of the capsule was determined to be 0.00447 m^3 . Once the capsule volume was known, the buoyancy of the capsule could be calculated through the following:

$$F_B = \rho g V \quad (4)$$

The density of salt water was used in this buoyancy calculation. The resulting buoyancy force was found to be 44.96 N.

The drag force on the capsule during its ascent process was then found. In order to perform this calculation, the capsule had to be weighed when fully constructed and loaded. The weight of the unit, W , was then calculated with the measured mass and found to be 39.18 N. This weight took into account the weight of the capsule, drone, drone carrier, electronic system, and hardware which would be used. The drag force was then calculated as:

$$F_D = F_B - W \quad (5)$$

Using the calculated value of the drag force, 5.78 N, from Equation 5, Equation 6 could be rearranged to Equation 7 in order to find the velocity of the capsule during ascent:

$$F_D = \frac{C_D V^2 A \rho}{2} \quad (6)$$

$$V = \sqrt{\frac{2F_D}{C_D A \rho}} \quad (7)$$

where C_D is the coefficient of drag, V is the velocity of the capsule during ascent, and A is the area of the top circular face of the capsule. The coefficient of drag for this cylindrical capsule was found to be approximately 1.2 giving a velocity of 1.435 m/s during ascent [6].

Now that the velocity of the capsule was calculated, the total time for the capsule to surface from 200 feet below sea level had to be found. In order to do this, a few intermediate calculations first had to be performed. An assumption was made that the capsule would be deployed with an initial velocity of 0 m/s in the vertical direction since the exact details of the deployment system were withheld from the team by the sponsor due to security reasons. It is likely that any initial velocity provided during deployment would result in only a few seconds reduction of the total time to surface if any at all, therefore resulting in only a minor or negligible change in the surfacing time. The first calculation thus performed was to find the acceleration of the capsule when initially deployed. This was done

by rearranging the following equation to solve for acceleration:

$$F = ma \quad (8)$$

The force value used in this calculation was the drag force of the capsule and the weight was previously determined which provided an acceleration of 1.45 m/s^2 . With the acceleration and the final velocity during ascent of the capsule both known, the duration of this acceleration period of the capsule from deployment to its final ascent velocity could be calculated using kinematic equations:

$$t_1 = \frac{V_f - V_o}{a} \quad (9)$$

where V_o is the initial velocity of the capsule when deployed, V_f is the final velocity during the ascent period, and a is the acceleration of the capsule to its final velocity during the ascent period. The total time of this was found to be 0.98 seconds.

The distance the capsule traveled over this 0.98 s time period could then be found using an additional kinematic equation:

$$x = \frac{V_f^2 - V_o^2}{2a} \quad (10)$$

From these calculations, it can be seen that the total distance the capsule unit travels during this ascent period is approximately 0.65 m. Since the total distance of travel will be 200 feet, or 60.96 m, the remaining distance left to be traveled was determined to be 60.31 m.

Using this remaining distance and the previously determined velocity of the capsule during the ascent period, the time to surface from this period of the ascent process was determined through the use of the following kinematic equation:

$$t_2 = \frac{d}{V} \quad (11)$$

where d was taken to be 60.31 m and V was the ascent velocity. Now that this time value was known, the total time could be found by adding the duration of the initial ascent period, t_1 , with the second ascent period, t_2 . The total time for the capsule unit to surface

was then determined to be approximately 42.98 seconds. This time value is significantly reduced from the proof of concept time, which was initially calculated to be approximately 71 seconds. The total time to surface is critical for the final design because the Arduino Uno micro controller activates the solenoid, which thus releases the air pressure and launches the drone, based on a timer function. Therefore, knowing the total time to surface at this depth of 200 feet will allow the user to properly set the time to deploy the drone. If the capsule were to open too soon, then the drone would be deployed while still under water and the unit would be destroyed.

Another major concern is the launch conditions of the drone once the capsule has surfaced. The angle of the capsule, initial velocity of the drone, and the maximum height it achieves are all major factors which must be accounted for in order to properly initiate flight of the drone once launched. A greater initial velocity will provide more time for the drone to activate its motors and at the minimum obtain a hover before it falls into the water. To help find this information, the initial velocity of the drone upon exiting the capsule was needed. This analysis was done through using the following process to find theoretical launch trajectories.

The air tank pressure is known to be 100 psi, and the amount of force needed to remove the lid of the capsule is approximately 35 lb of force, which is approximately equivalent to 155 N. Knowing the mass of the drone inside the carrier system to be 0.75 kg, the acceleration of the drone inside the carrier could be determined through the following equation:

$$F = ma \quad (12)$$

The acceleration was calculated to be 206.67 m/s^2 , which is assumed to be constant while the drone and carrier travel down the capsule until exiting the tube, at which the acceleration would be gravity and acting in the opposite direction. With the acceleration calculated, the velocity at the end of the capsule, the launch velocity, could then be calculated:

$$V_f^2 = V_i^2 + 2ad \quad (13)$$

The distance is the length of travel the drone carrier would travel, which is 18 inches or 0.4572 m. With the theoretical launch velocity calculated to be 13.75 m/s, the launch height correlating to launch angle could be determined with the following equation:

$$d = \frac{V_f^2 - V_i \sin(\theta)^2}{2a} \quad (14)$$

Angular increments of 2.5 degrees were used with a range of launch angles from 0 degrees, horizontal positioning, to 90 degree, vertical positioning. The height data was then plotted against the angle of the capsule, thus creating the theoretical data. During testing, approximate heights were measured of the dummy drone when launched from a vertical position, 90 degrees. These height values were then used to calculate the launch velocity using equation 13 shown previously. Once the launch velocity was calculated, equation 14 was then used to find the launch height based on launch angle. The maximum and minimum experimental launch heights were used for this, with other intermediate heights used to help developed some other plausible data. The plot of this information can be seen below in Figure 11.

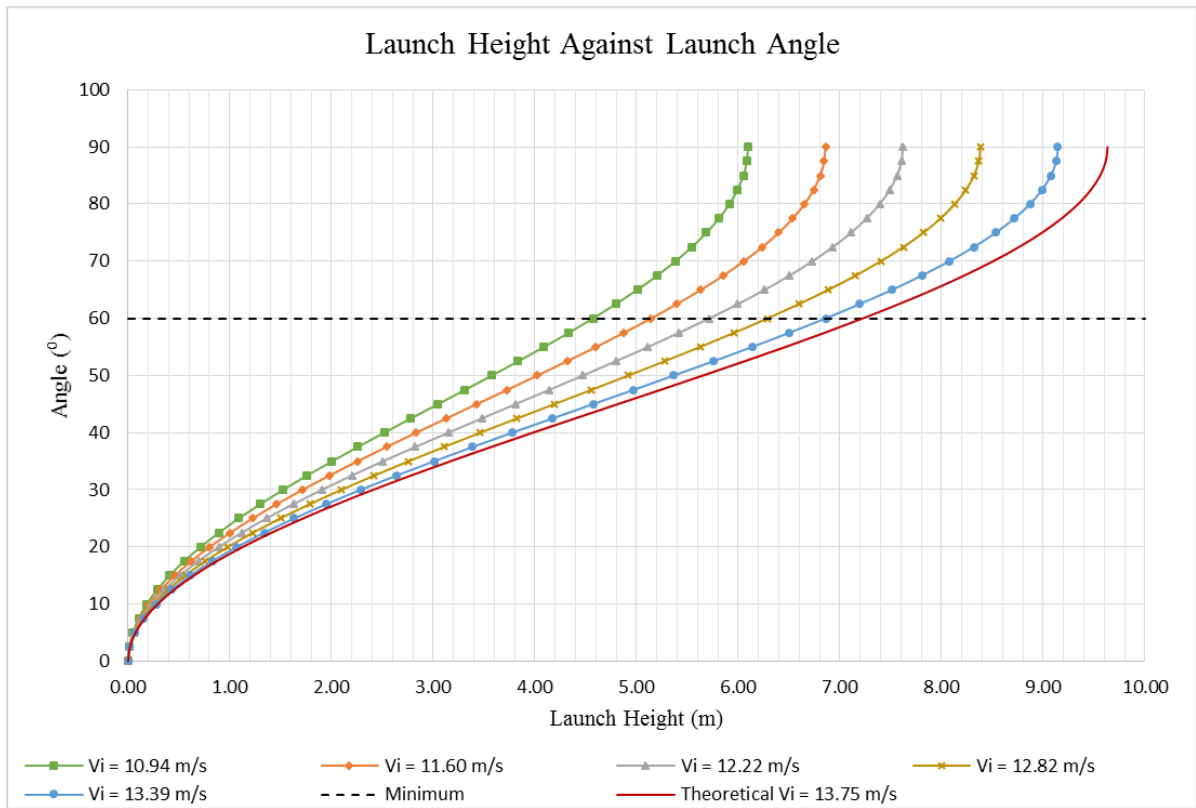


Figure 11: Launch Angle vs. Launch Height

From this graph it can be seen that the theoretical launch velocity is slightly above the

maximum testing launch velocity seen in blue, which was calculated from the maximum testing height as previously explained. The minimum testing launch velocity can be seen in green, while the orange, gray, and yellow data were intermediate data arbitrarily created to help visualize the trends and potential launch heights in between the maximum and minimum achieved heights. This was also done due to the fact that estimating the height of the dummy drone during testing is difficult and possesses inaccuracies, which is why the minimum and maximum test heights were used to develop the maximum test data and minimum test data. The theoretical data trend is likely greater than the others because the theoretical calculations assume constant acceleration within the capsule during launch, no effects due to wind or air resistance, and other factors. The horizontal black dotted line represents the approximate minimum angle reached during surfacing of the capsule. Therefore, data near or above this line can be considered as more likely to occur than below the black line during operation of the system. From this plot, it can be seen that a minimum deployment height of approximately 4.6 m can be expected, with a maximum theoretical deployment height of approximately 9.6 m. With a minimum height of 4.6 meters, this would allow the drone an approximate minimum time of 1.93 seconds to initiate a hover or vertical flight movement, which the drone needs approximately 1.0 seconds to do so.

Finally, to determine whether Aluminum 6061 T6 would be a sufficient enough material to withstand the pressure of 0.714 MPa at depth, the safety factor was calculated using the following equation:

$$SF = \frac{\sigma_y}{\sigma_c} \quad (15)$$

Based on the material's tensile yield strength of 276 MPa, it was determined that the safety factor is 17.25, and therefore is a good enough material to use in the capsule.

11 BUILD/MANUFACTURE

11.1 Capsule

The manufacturing of the launcher components was done using three types of machines: 3D printer, rotary lathe, and a milling machine. The material used to construct the capsule was aluminum 6061-T6 with stainless steel hardware, rubber O-rings, and 3D printed components printed from PLA. The electronics consisted of an Arduino Uno microcontroller,

Arduino Bluetooth shield, electronic relay, an 8 AA battery pack, and a solenoid.

The main barrel housing and pressure vessel were turned down to 3.000 in outside diameter by using the lathe in 0.001 inch increments to minimize facing-bit-chatter and thus provide a smooth surface finish. Both tubes were then cut to length using a grooving tool on the lathe, which was 27 11/16 in and 10 13/16 in, respectively. The End cap and pressure vessel base were turned on the lathe by facing the dished end with a boring-bar and then cutting the outside diameter with a facing tool and finished using a grooving blade to cut the o-ring groove. The joining fixture was turned on the lathe similarly to the end cap, barrel, and pressure vessel, however it had to allow for two different wall thicknesses and two o-ring grooves. The mill was used to place the screw holes in the joining fixture, barrel, and pressure vessel base.

The internal electronic housing was designed using the Solid Works software and built using a 3D printer. The printing process is controlled by computers and requires minimal human interfacing beyond loading print-filament and initiating the printing process. The printer has the ability to print multiple objects per print platter. If production went into a larger volume, injection molding could expedite the build process but would drive the initial prices up to cover tooling costs. A cheaper alternative could also be a casting process such as sand casting since the part does not require high tolerances, smooth surface, or a high production volume. Some smoothing might be required if the part does not slide into the main barrel easily.

The production number beyond the prototype would be based on customer needs and requirements. Testing and prototyping only required the manufacturing of one unit. Custom tooling was not required to construct the device as it was built using readily available machines, tools, and common practices. If the system went into a larger scale production it could be expedited by using a CNC lathe and mill to provide more automation in the processes and reduce manufacturing time.

Once the aluminum was machined and the 3D printed components were completed, the Arduino code was downloaded to the Arduino Uno and the electronics were assembled and placed into the electronics carrier. Once all the pieces were complete, the final assembly could begin.

11.2 Drone

The drone was manufactured from a stock Vortex 250 Pro manufactured from Immersion RC. The drone was extensively modified from its original design in order to fit the size and performance restrictions for the project. The Stock plastic arm pieces were removed and replaced with 3D printed PLA arms design on the Solid Works software system. These arms were designed to have a through bolt and pivot on the through bolt to allow for the arms of the drone to collapse. They were also designed to utilize the carbon fiber components of the drone arms, avoid interference with other electronics on the power distribution board, house the wiring for the motors for protection, and have slots to allow for air ventilation to cool the speed controllers in the motor wiring. The arms also featured anchoring points for the springs, so one spring would connect to the both left arms while a second connected to both right arms. This would pull on the arms, shifting them from a collapsed position to an open and ready for flight position. Stopper bolts were also positioned near the arm pivot bolts on the drone body. These bolts were all placed in the same position in relation to each of the four arm pivot bolts and serve as a stopper for the arms when the open. These holes were made using a mill to ensure accuracy of their positions. Therefore, the arms all open to the same position when deployed.

The overall width of the drone had to be reduced, and this was done using a sanding process for controlled removal of material to allow for a smooth finish, accurate material removal, and straight lines. The plastic side pieces were also trimmed to fit within the max width of 2.5 inches. The ends of the carbon fiber arms of the drone also had to be sanded to reduce their overall width down to within the 2.5 in maximum width. The final physical modification of the drone was the re-positioning of the antenna. The antenna was positioned to protrude from the front of the drone. Otherwise, the antenna would not fold within the required spacial confinement of the capsule. The LED light at the front of the drone was then moved to on top of the carbon fiber top plate of the drone.

A camera mount was designed to hold the camera between the arms of the drone, allowing for optimal viewing while still allowing the arms to collapse. This was designed on Solid Works and printed using PLA. The drone carrier was also designed on Solid Works and printed using PLA. The drone carrier was designed to fit around the drone and provide a snug fit so the drone would not shake or rattle while in the capsule to avoid any damage to the drone or scramble the gyro calibration.

12 TESTING

Since this project is divided in two elements, the capsule and the drone were tested individually and then together as a complete system. In the category of performance, the capsule was tested for its vertical ascent trajectory, vertical position at the surface, and recoil and payload expulsion. For the design specification compliance category of testing the capsule was subjected to a watertight test. The UAV tests have a similar breakdown of categories. For the performance of the drone it is very important for it to have a similar performance after the body modifications. Also, the FPV camera and recording were checked to assure the design specifications were met. Looking into the future of this project, the sponsor will need to qualify this under the Mil-Std and the Mil-Specs.

12.1 Capsule Tests

For the testing of the first element of this project, performance and design specification compliance had the most priority. The performance testings were all done at the Mackal-Tootell Aquatic Center in The University of Rhode Island on April 3, 2019. The design specification compliance test was done at the machine shop of Schneider Electric on April 5, 2019.

12.1.1 Performance Testings

12.1.1.1 Vertical Ascending Trajectory and Surface Position To begin with the set up for this test, one camera was attached to the body of one of the team members. The idea of using this type of camera set up was to obtain a visual of above water and underwater. On the first trial the capsule was vertically released from the 2 feet underwater and once it reached the surface it was in a complete horizontal position, as shown in Figure 12. The results of this first trial reassured the need of adding counterweights until the desired vertical position of $90^{\circ} \pm 15^{\circ}$. After several trials, that can be seen in Figures 13 and 12, the capsule passed the test after a total of 12 oz of counterweights were added to the interior of the air tank at the base. All the results can be seen in Table 3

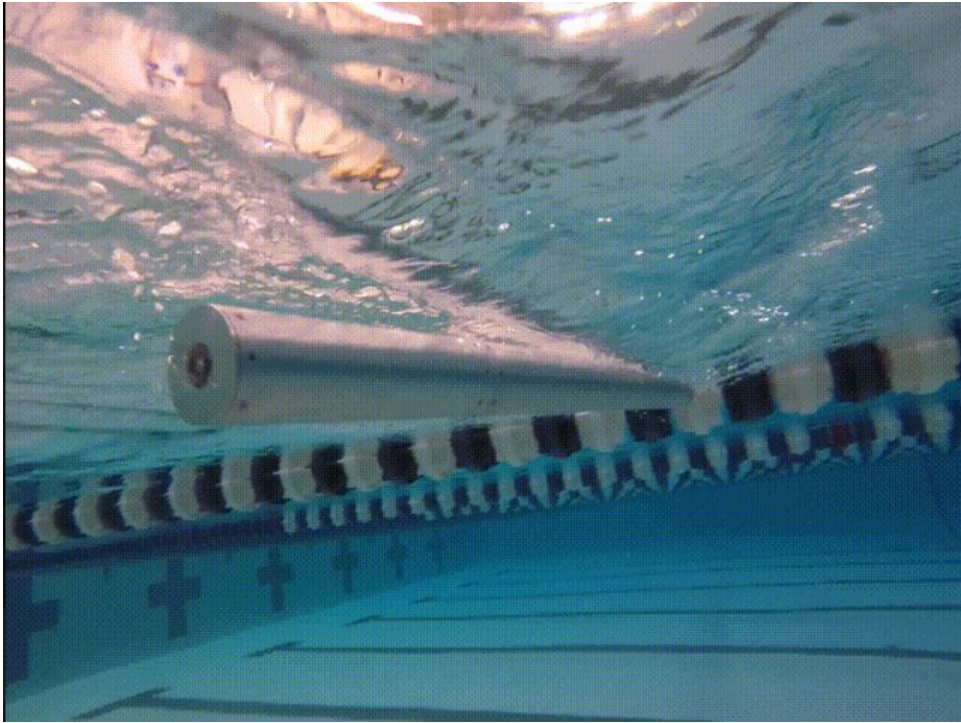


Figure 12: Trial 1



Figure 13: Trial 7



Figure 14: Trial 11

Table 3: Vertical Surface Position Test Results

Trial	Initial Depth (ft)	Pass/Fail	Counterweights (oz)
1	2	Fail	
2	2	Fail	total of 4.5 oz
3	4	Fail	total of 7 oz
4	4	Fail	total of 10 oz
5	4	Fail	total of 11.5 oz
6	2 (<i>horizontal initial position</i>)	Pass	total of 11.5 oz and cap screws
7	7.5	Pass	
8	7.5	Pass	
9	7.5	Pass	
10	14	Pass	total of 12 oz
11	14	Pass	

12.1.1.2 Recoil and Payload Expulsion This test had to be performed to verify that the drone was able to leave the capsule before it sank back to the water. The initial setup consisted of two cameras recording from water level and the capsule ready for launch with its payload in place. The chosen payload is the one shown in Figure 15 and 16 which assimilates a very similar geometry and weight to that of the final design drone, shown in Figure 8. The timer was set to 100 seconds to give enough time for positioning and clearance of the pool area. Visuals captured by the cameras can be seen in Figures 17 and 18. Also from this test, the maximum height the drone could reach at the designated pressure was estimated. The information recorded through the testing can be seen in Table 4. This testing was successful; the payload was capable of leaving the capsule and gather enough height to give the drone the necessary time to start up before the capsule submerged.

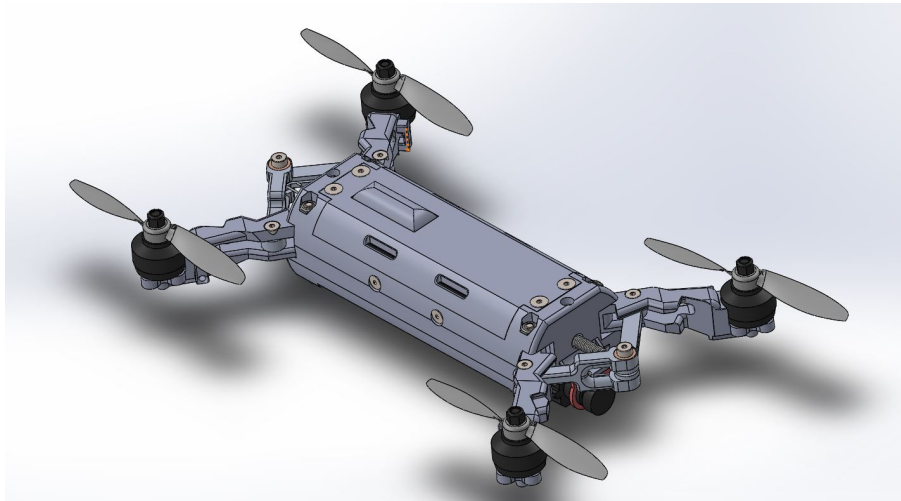


Figure 15: Dummy Load Drone

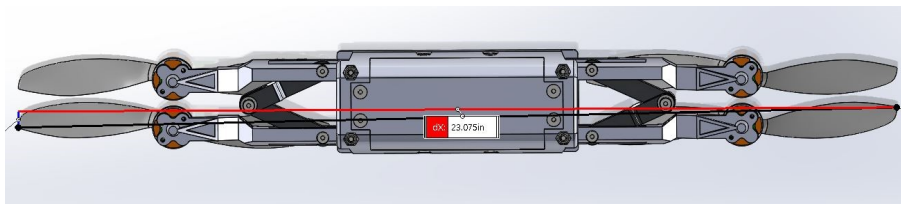


Figure 16: Dummy Load Drone Top View



Figure 17: Recoil Test Visual 1



Figure 18: Recoil Test Visual 2

Table 4: Recoil and Payload Expulsion Test Results

Trial	Depth (ft)	Air Tank Pressure (psi)	Drone Height (ft)	Drone Air time (s)	Pass/Fail
1	14	94	20	2	Pass
2	4	94	21	2	Pass

12.1.2 Design Specification Compliance

12.1.2.1 Watertight The objective of this test was to reassure that the design did not fail under the water pressure felt at 200 feet deep (100 psi). The most vulnerable areas are the seals around the end caps. Any water entering the capsule can affect the electronics and the drone itself. The procedure for this test began with a PVC pressure vessel that was designed and manufactured for this specific test. This pressure vessel was modeled to assimilate the pressure felt by the capsule at 200 ft of depth in seawater. The testing vessel consisted of a PVC tube and two end caps, shown in Figure 20. To apply air pressure to the inside of the vessel, one of the end caps was modified to have a valve in its center. Once the vessel was half filled with tap water, the capsule was positioned inside. A smaller PVC tube was positioned between the top of the capsule and the end cap of the vessel to keep the capsule submerged in the water, see Figure 19. After the end cap was secured in place, an air compressor was used to pressurize the PVC tube until it reached 100 psi. Since the estimated time to surface for the capsule is around a minute, the capsule was left in the vessel for approximately 1 minute. The results of the this test can be seen in Table 5. The test was successful and the capsule had no leakage.



Figure 19: Watertight Test setup



Figure 20: Pressurizing the Test Vessel

Table 5: Watertight Test Results

Trial	Pressure (<i>psi</i>)	Pass/Fail
1	100	Pass
2	120	Pass

12.2 UAV Tests

For the testing of the second element of this project, the category of performance also had the most priority. The performance testings were all done at the Capstone floor of Schneider Electric, during the months of April and May.

12.2.1 Performance

12.2.1.1 Redesigned Body Being able to have a drone that still performs the same as if it was on its initial body showcases that the team's redesign did not damage the performance. The objective was to evaluate the drone's performance in its new body with folding arms that open with an extension spring mechanism. All of the drone features were verified before the redesign, seen in Figure 21 for original body, and compared to the new drone body, seen in Figure 8. Table 6 shows the results of this testing. The redesigned drone passed all the parameters.



Figure 21: Original Model: Vortex 250 Pro out-of-box

Table 6: Drone Performance

Parameters	Original Model	Redesign Model
Motors	Pass	Pass
4mm Carbon Fiber arm	Pass (non-foldable)	Pass (foldable)
F3 Processor	Pass	Pass
5.8 GHz Video	Pass	Pass
Full Graphic OSD	Pass	Pass

12.3 Test Matrix

A review of all the tests can be seen in the following Figure 22.

Part	What to test?	Test parameters	Results	Planned resolutions
Capsule body	Leaks	Requires watertight seals around end caps	No detectable leaks	No change
Capsule body	Strength	Must withstand up to 100 psi	No detectable changes	No change
Capsule body	Buoyancy	Must float as vertically as possible	Somewhat horizontal in final position	Add weights to inside of air tank
Capsule body	Recoil	Must eject drone before going underwater	Submerges (water enters body) after drone is ejected then resurfaces	Coat electronics with sealant
Bluetooth shield	Connectivity	Must be able to be activated through aluminum capsule	Difficult to connect more than 6 in away from capsule	Ensure close range when activating
Air chamber	Leaks	Must hold up to 100 psi	No detectable leaks around air valve or end caps	No change
Air chamber	Accuracy	Is the same pressure reached?	100 psi not always reached	No change, 96 psi is acceptable
Air valve	Leaks	Must be completely closed until triggered to open	No detectable leaks	No change
Drone ejection	Max height of drone	Must be ejected to at least 15 feet high	Ejected to approx. 21 feet	No change
Drone Redesigned Body	Functionality	Must revert to natural state	Desired final position is reached. Performance is not affected.	No change
Receiver/transmitter	Connectivity	Must be bound	No problems	No change

Figure 22: Test Matrix

13 REDESIGN

13.1 Performed Redesign

After tests were performed on the capsule system, some design modifications were required in order to improve performance and operation of the capsule. The buoyancy test required that the capsule float in a vertical orientation, though the test resulted in the capsule floating horizontally. To fix this, weight had to be added to the base of the capsule. This was done by added lead automobile tire weights, which are used to balance tires on cars, to add weight. These weights were added to the inside lower portion of the pressure tank on the capsule. This was done in increments until a desired float orientation was achieved. A total of 24 ounces was added to the base of the capsule with these lead weights. After this redesign was implemented, the capsule consistently reached and maintained a vertical orientation no matter what its initial positioning, even when entirely inverted upside down.

Some slight modifications were made to the capsule to improve ease of assembly. When first manufactured, the edges of the pipes used for the pressure tank and capsule body were left at corners. It was found that assembly of these components with the end caps and joining piece were very difficult. This was due to binding of the components as well as the high compression percentage of the rubber O-ring. During assembly, the curvature of the O-ring would contact the flat end face of the pipe and stop the pipe from sliding over it. It was found that reducing this corner on the pipe ends by applying a fillet or chamfer to the inside of the pipe would allow the pipe to more easily slide over the O-ring, and not let the O-ring stop the pipe. Since this would be a small fillet, this would not impact performance or the water security of the system. A de-burring tool was used to slowly remove small amount of material from the inside edge at the pipe ends for both the pressure tank and the capsule tube. This was done until a much smoother assembly process was achieved. After this modification was complete, binding of the components upon assembly has been entirely removed and the components slide together more easily and no longer require excessive force or mallets to assemble.

During testing of the drone deployment with the dummy drone, necessary modifications to the drone carrier system were found. The dummy drone featured the use of pucks instead of a carrier system. To clarify the difference, the carrier consists of two pieces that wrap around the sides of the drone, while the pucks consist of three pieces that rest on

the front and back of the drone or the ends of the drone arms. During testing, the drone arms had to be positioned on the lower puck. The lower puck and drone then had to be simultaneously loaded into the capsule tube, keeping the drone pressed on the lower puck so the spring tension forcing the arms open would not shift the drone arms off the lower puck. The two halves of the upper puck then had to be positioned on the top of the drone at the ends of the other two arms. Though this practice appeared simple in theory, the physical process was found to be tedious and difficult to successfully perform in an ideal environment with multiple people to help. Since the idea is to make operation as simple and effective as possible, the carrier idea was developed for the drone. The carrier features two halves which are modeled to the geometry of the drone and wrap around the sides of the drone, as opposed to the top and bottom as the pucks did. This then fits the drone into another cylinder which is split vertically in half. The carrier features two finger holds at the top end, one on each half, thus allowing the entire unit to be removed at once if needed, which was a difficult task with the pucks since the capsule body tube had to be removed to remove the lower puck. The arms of the drone would simply force the two halves of the carrier apart and off the drone once fully deployed from the capsule, and any compressive forces during the deployment process would be experienced almost entirely by the carrier, while the pucks transferred the entire load to the drone which could cause damage to the drone or crush it.

13.2 Recommended Redesign

Though design modifications were found and made from the tests performed, there are some additional redesigns and design modification recommendations which were found.

The current drone carrier design features a pin at the base to allow for the carrier to fold open. This was initially implemented to allow for the user to hold the system easily with one hand, even with the drone in the carrier. The added complexity of the system, assembly, and dis-assembly of the carrier, along with the more restricted degrees of freedom for deploying the drone because of this pin might not be worth the benefit of having it. Therefore, it might be best if this pin were simply removed from the carrier, thus allowing a more easily deploying system away from the drone after launch.

Some additional modifications are recommended for the drone carrier. The initial design iteration was used with some tight design measurements and tolerances. This resulted in the drone having a snug fit in the carrier, and the blades not having extra room. Though

a snug fit is desired to reduce shaking and rattling of the drone, the fit is tight enough so that the drone can not jettison the carrier. Therefore, some of the spacing within the carrier modeling the drone body height must be increased slightly, by approximately 0.005 in to 0.010 in. The cutout depth for the drone blades should be increased slightly as well, by approximately 0.0010 inches.

Another recommended change is to try and find or manufacture a slightly longer cable for the drone camera. The provided cable is very short and restricts the potential locations and positions of the camera. A longer camera cable would thus allow for other alternative positions for placing the camera on the drone, as well as various camera angles to change the viewing angle of the camera which is currently very restricted. The cable could be one or two inches longer from the current cable length, and any excess cable can easily be tied and managed.

An additional design change recommendation is to reduce the size of the electronics carrier and improve access to the screw mounting locations on the carrier. The carrier currently features four screw locations, though two of which are positioned where the harsh angle of the screwdriver will not allow for the screw to properly thread into the holes. Additionally, if the height of the electronics carrier can be reduced, the drone can be shifted further down into the capsule and thus shift the center of gravity and the center of buoyancy further down, improving the floating characteristics of the capsule. The configuration of the electronics in the electronics carrier would likely have to be modified in order to reduce the carrier height.

14 PROJECT PLANNING

This project was broken into three main sections with milestones and action items in each section. The first main group of milestones was the Definition Phase. This section contributed 18.1% of the project work-in-place (WIP). The section was the lightest WIP contributor to the overall project but held the most milestones and sub-tasks. The definition phase is closed-out as complete.

The second section of the project was the Execution Phase that contributed 52.9% of the overall WIP and stands at 96% completed. The Execution section is the heaviest WIP contributor and yields the highest consumption of capitol to the overall stretch goal of 100% WIP.

The third section of the project is the Acceptance Phase. This phase contributed 29% of the overall WIP. This section had the greatest amount of deviation from the original Plan of Action and Milestone's (POAM) of the overall project. The current Gantt Chart illustrating each section, their tasks, and percent completed can be seen in Figure 23

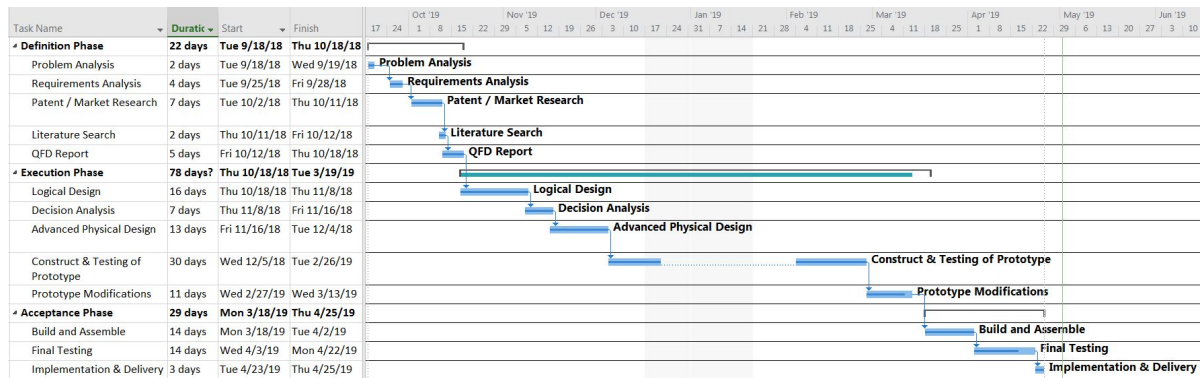


Figure 23: Project Gantt Chart

The project is currently at 95% completion, as seen in Figure 24 which put the project 5% behind the projected schedule. There was a 10% Float built into the schedule for any non-projected time-overrun(s). Due to unexpected design changes, the final delivery date was not met.

TUE 9/18/18 - THU 4/25/19

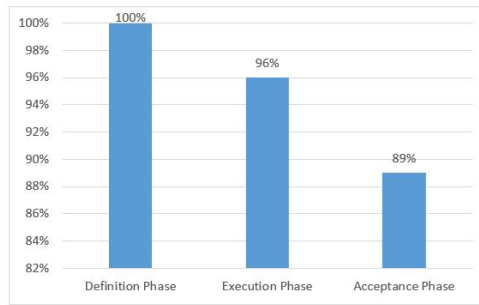
% COMPLETE

95%

MILESTONES DUE

Milestones that are coming soon.

Name	Finish
------	--------



LATE TASKS

Tasks that are past due.

Name	Start	Finish	Duration	% Complete	Resource Names
Prototype Modifications	Wed 2/27/19	Wed 3/13/19	11 days	75%	Daynamar Delgado, Hannah Waters, Jeffrey Arnold, Robert Bones
Final Testing	Wed 4/3/19	Mon 4/22/19	14 days	75%	Daynamar Delgado, Hannah Waters, Jeffrey Arnold, Robert Bones

Figure 24: Project Completion Percentage Report

Additional Figures 84 through 86 of Appendix C illustrate the remaining critical tasks, work remaining, and the breakdown of work.

15 FINANCIAL ANALYSIS

Analysis of the financial aspects of the current project design can be analyzed as follows. The approximate current number of hours invested into this project by the team members totals to about 1112 hours. Of this total, about 27 hours were spent at the machine shops at Kirk and Schneider electric. With a cost of \$40 per hour at each of these, the total cost of machining is \$1080. The hourly rate for the machining techs is \$35 per hour with a total of 9 hours spent working with the techs, totaling a cost of \$315. The team members also consulted with various faculty and staff at the University of Rhode Island for approximately 4 hours. The consulting fee for this is \$100 per hour, resulting in a total cost of \$400. An extensive amount of 3D modeling using the Solid Works software package was done. Considering the cost of using computers with this software \$5 an hour, the team members performed about 305 hours of 3D modeling. This results in a total cost of \$1525 for using these systems. The models created were then printed, and the total time printing these various objects is approximately 124 hours at a rate of \$4 an hour. The total cost of 3D printing for this project is therefore \$496. The meetings and consulting with the group

sponsor was also factored into the total team cost. The sponsor rate is \$60 per hour with an estimated total amount of time being 20 hours. The total cost for consulting with the sponsor is therefore \$1200. Finally, the total amount of time invested by the team members through performing testing, working on calculations, progress reports, working on ideas and changes, and other ancillary work totals to approximately 776 hours. The total rate for an undergraduate student is \$20 an hour which means the total cost for the time invested by the team members is \$15,520. The net total cost for this project excluding materials is therefore \$20,536 based on the estimated hours committed and by whom for this project, as well as the costs for each individuals time.

The materials for this project can be split into two categories: the drone and the capsule. The total material cost to create the final capsule design is \$364.02. This does not include the 3D printed PLA electronics carrier. This component is estimated to cost about \$8.00 in material. This would therefore make the total cost for the capsule \$372.02. The cost for the drone and the materials required for its operation is \$796.07. This also excludes any 3D printed components cost. Considering the 3D printed components used on the drone are PLA, the approximate cost for the components used for the drone is \$23.30, which would bring the total drone cost to \$819.37. These costs only include the cost of materials. The bill of materials documenting the list of materials and costs needed to create a single complete unit can be seen in Figure 83. The total time machining was estimated previously, however, the time approximate time spent manufacturing the capsule is about 20 hours and the drone about 7 hours out of the total 27 hours. With machining costs of \$40, the machining cost for the capsule is therefore \$800 while the drone is \$280. This would mean the approximate total cost to manufacture the capsule is \$1,172.02 and the drone is \$1,099.37. The total cost of one unit would therefore be approximately \$2,271.39 including the material and manufacturing costs of both the drone and capsule. The final cost of completing this project, including materials used to create the drone and the capsule as well as hours inputted by team members and other individuals, totals to \$21,696.09.

If this system were to be sold, based on the purpose of the project, it would be strictly sold to the U.S. Navy or the navy of other allied countries, thus restricting the market. It is assumed units would be sold only to the U.S. Navy, which consists of approximately 70 submarines, and the units would be used at a rate of 2 units per submarine per week, totaling and estimated 6,720 units used each year. If each unit is manufactured in the same manner as the one created by the team, the cost for a single unit would be \$2,271.39. In order to obtain a 50% profit per unit, a single unit would have to be sold at a rate of \$3,407.09, pro-

viding \$1,135.70 in profit for a single unit sold. With the estimated usage of 6,720 units a year, a cost of \$22.90 million would be incurred by the U.S. Navy for these units. This would result in a total profit of \$7.63 million each year.

Mass production or production of large quantities could help reduce overall manufacturing costs. Processes such as sand casting of some components could reduce the costs of making some components. Sandcasting is a viable option for parts such as the electronics carrier or the drone carrier. This is because these components don't require a smooth surface finish and tight tolerances for proper system function. Unfortunately, other aspects and components require high precision machining and manufacturing which reduces other more cost effective choices. Assuming production of large quantities of units reduces the overall cost to manufacture by 15%, the cost of manufacturing would be reduced by \$340.71 to \$1930.68. Maintaining the sales price of \$3,407.09 would therefore lead to increased profits from \$7.63 million to \$9.92 million, or an additional \$2.29 million per year.

Future revisions and derivations of this project could include more enhanced technology and equipment. Improvements in the hardware and electronics of this system could help to improve the overall performance and effectiveness of the system, but it would also likely greatly increase the cost of manufacturing these, and therefore increase the sales price per unit. It is difficult to say what a new model would cost if improved technology was implemented, mostly because of the range of available equipment. Cameras alone could range from a few hundred to thousands of dollars or tens of thousands based on the video quality, capabilities, size, etc. Any improvements made would be based on the demand for the current unit created by this capstone team.

16 OPERATION

Overall, the operation of the capsule and UAV system is fairly simple once the main components (pressure tank, coupling, solenoid/PVC, and electronic carrier) are assembled. Assembly for the entire system is described in the assembly and operation manual in Appendix D, but in practice, the bottom portion should already be assembled. Therefore, operation begins with the operation section of the manual.

To begin operation, use Molykote to generously lubricate 2 o-rings and their respective grooves on the coupling and the end cap then place the o-rings in the grooves. Then, insert the last of the 8 AA batteries into the battery pack. The other 7 should already be in the

pack, but if they are not there then insert all 8. Screw the cover to the battery pack in place. Then, screw the capsule barrel to the coupling piece. Connect the 1300 mAh lipo battery to the drone and the 3300 mAh battery to the monitor. Turn on the controller. The transmitter and receiver should be bound, but if they are not, follow binding instructions. Ensure the monitor is displaying FPV (first person view) images from the drone. Once the connection is established, load the drone into the drone carrier and slide into the capsule barrel. Next, place the end cap on the barrel end. Use an air compressor to pressurize the pressure chamber up to 100 psi. Use the app on a device with Bluetooth capability to connect to the Arduino UNO and set the timer to the desired amount of seconds. Release the capsule system into the water. After the desired amount of seconds, the timer should trigger the release mechanism and the UAV should be expelled. Quickly use the controller to begin to fly the drone as needed. Press the button in the upper right corner of the monitor to begin recording the video feed. Finally, land the drone after use or stop flying to let it sink.

As stated earlier, an assembly and operation manual was created for users to follow. A safety guide was not created because the system is completely safe to use under normal circumstances. If a user follows instructions and common sense and does not point the end of the capsule at anyone or anything or does not get any of the electronics wet, then there is no safety hazard. A repair manual was also not created because if a part is physically damaged, there is no easy fix. All the capsule pieces and 3D printed parts are machined and printed exactly to size so if there is a dent, chip, or broken piece that impacts the function then the part would need to be completely replaced. If there is an issue with the electronics, a troubleshooting section was put into the assembly and operation manual. If none of those options work, then the pieces should be completely replaced as well.

17 MAINTENANCE

To maintain the capsule and UAV, very little needs to be done. The body of the aluminum capsule has a long shelf life as does the body of the drone and all the 3-D printed parts. To ensure the electronics are working properly, a shelf life of up to one year is recommended. The Lumenier batteries should be stored separately, as in unplugged from their respective devices. They should also be charged before each use to ensure there will be enough juice to power the drone and monitor. The AA batteries in the electronics carrier are allowed to be in the battery pack except for one to make sure they do not drain. If the user wishes, he/she may store all AA batteries out of the battery pack while the system is in storage. It

is also important for the pressure chamber to be unpressurized while in storage in case something were to happen.

Before releasing the capsule into the water, the user may test the functionality of the capsule and drone individually to ensure they will behave properly once in use. To test the capsule, the user may pressurize the pressure chamber a minimal amount to see if the Bluetooth connects and that the rest of the parts will work as intended. To test the drone, the user may plug in the batteries to the drone and monitor and proceed with a short test flight. If anything does not work according to plan, the user can check the troubleshooting guide at the end of the assembly and operations manual to see if they can fix the problem. If not, something will have to be replaced. In practice, if the user is in a submarine he/she most likely will have other systems to use in place of the one he/she tested. If simple tests on the second one pass, the user can swap out the systems and figure out the problems at a later time.

This product is meant to be used only once before it is discarded. Tethers to the capsule are unnecessary because there is no desire for recovery after the system has been deployed. Therefore, the capsule pieces, drone carrier, and drone will all fall into the ocean or another body of water after they have been used. Unfortunately, the pieces will just become littered waste as they are not 100% biodegradable.

18 ADDITIONAL CONSIDERATIONS

This project has little to no direct economic impact as it would not be available for commercial use. The system is designed to be used by members of the navy only. Since the system would be owned and operated by the US government, the societal and political impact could be large. For example, if the US was at war and the navy used the system for surveillance to enhance war strategy or to determine what an enemy was doing, then that would be a great benefit. As stated earlier, the product is to be used by naval personnel only for specific naval assignments and projects. Ethically, the capsule should not be used as a toy; random objects shall not be inserted into the body to be shot out for fun. Also, the UAV is not meant to be used for spying on civilians or any other personal reason. There are no known health risks associated with this product. Ergonomics were not taken into consideration when designing the system. There are many small pieces such as screws involved in the assembly, so it may not be suitable for those with dexterity and motor control problems. There are no specific safety rules one should follow when using the product. As

with all electronics, one should be careful not to get them wet to avoid product damage and possible electrocution or shortages. It is part of the project idea that the product was to be a one time use only system and it was known that the end result would be the pieces in the ocean. Therefore, the team tried to make the design as environmentally friendly as possible. The plastic used in the 3-D printed pieces is polylactic acid (PLA) which is corn based making it non toxic and biodegradable. However, all of the aluminum, carbon fiber, and electronic pieces will go to waste. The system is not sustainable, especially due to the use of Molykote. Unfortunately, Molykote is toxic to aquatic organisms and should be disposed of as hazardous waste [7].

19 CONCLUSIONS

Figures 7 and 8 show each part of the current final design, and Figure 10 shows how both parts fit together. All the design specifications mentioned in Table 2 have been accomplished. Every planned testing was repeated until the the results were positive and consistent. The engineering analysis has given the team the confidence that this innovative design will work. The buoyant force acts in a positive direction assuring that the capsule will float to the surface. Previously it was concluded that by maintaining the capsule in a vertical position, less pressure and velocity will be needed to expel the UAV in flight, allowing it to have a longer period of flight time. After testing it was found that the capsule was capable of shooting its payload to a height of 21 feet with a flight time of 2 seconds, with 94 psi in the air tank. To determine if the stresses in the capsule caused by the water pressure is allowable, the safety factor was calculated to be 17.25.

Per this result it is safe to say that the material selected is a strong candidate because of the high safety factor obtained. The calculations were verified by the watertight test, where no failure was experienced by the capsule even at 120 psi. At the end of this semester the team knows that there is still room for improvement, as shown in the Redesign Section. A more compact, efficient, and autonomous design could help set future design specifications and create an even more competitive product.

20 REFERENCES

REFERENCES

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- [7] 2013, "Safety Data Sheet", Dow Corning, Vol. 3.3, pp. 1-2.

21 APPENDIX A - CONCEPT DESIGNS

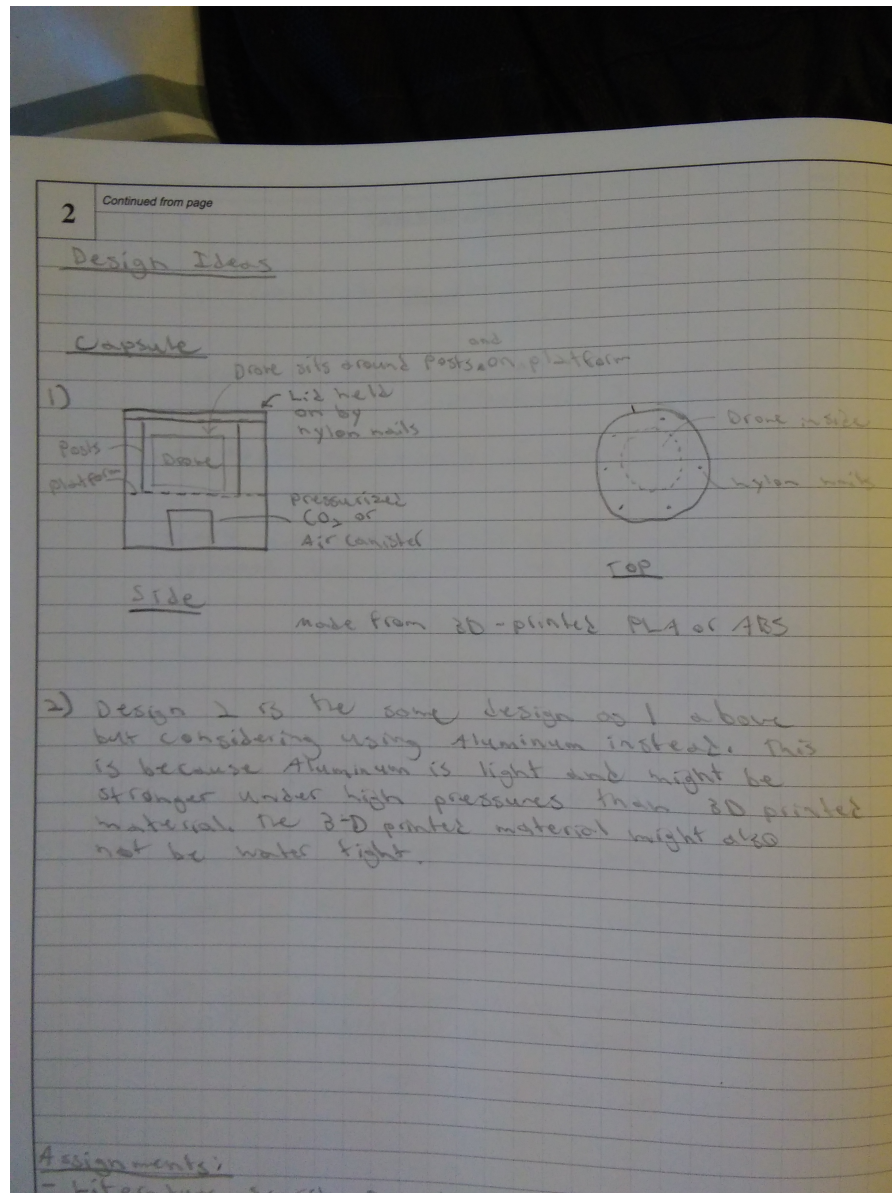


Figure 25: Jeffrey's Concept 1-2

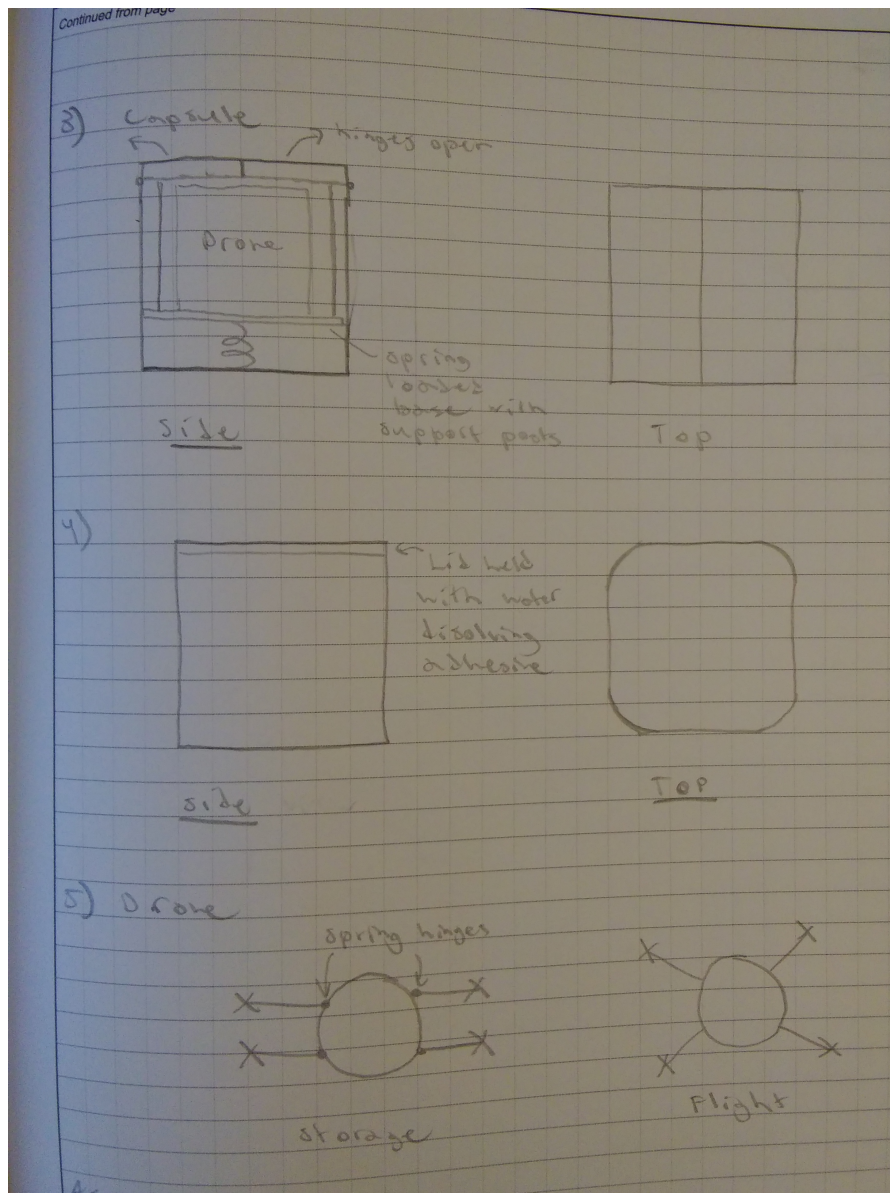


Figure 26: Jeffrey's Concept 3-5

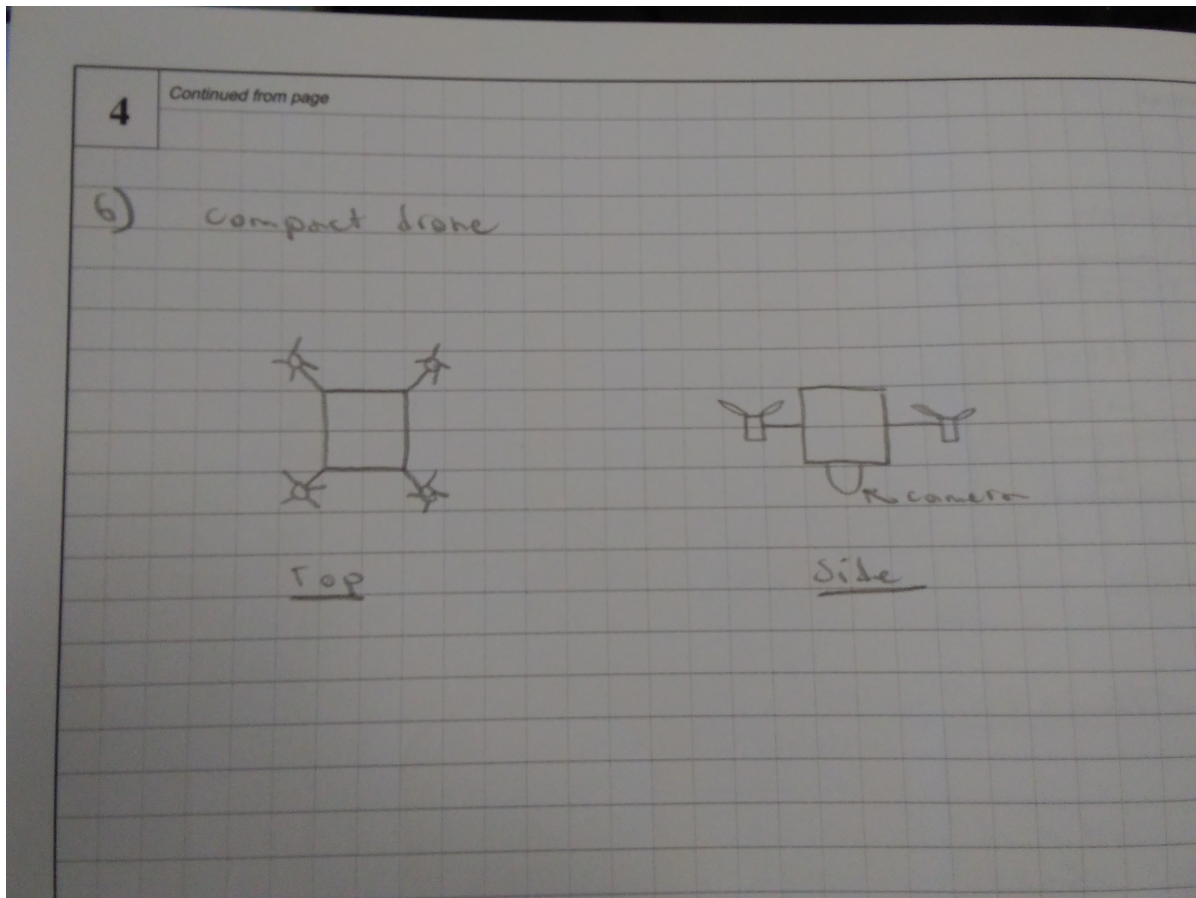


Figure 27: Jeffrey's Concept 6

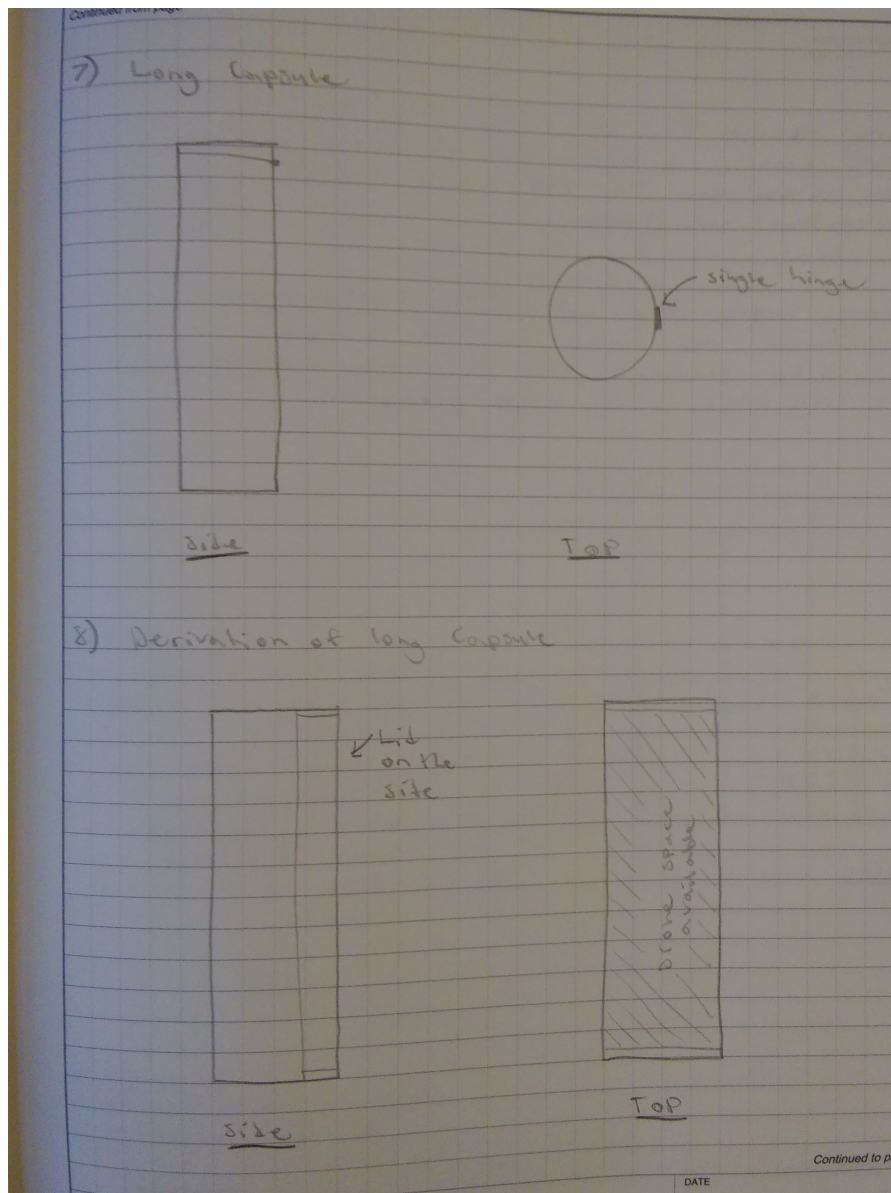


Figure 28: Jeffrey's Concept 7-8

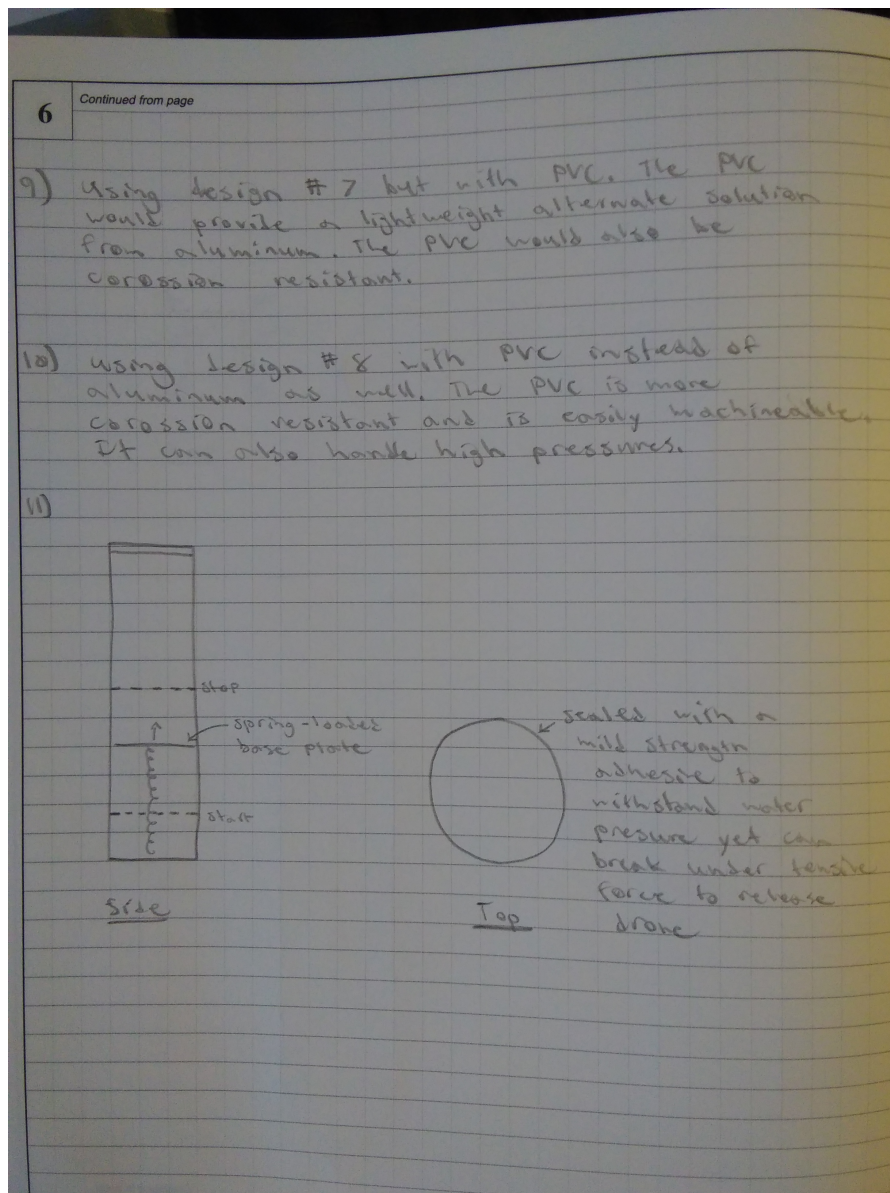


Figure 29: Jeffrey's Concept 9-11

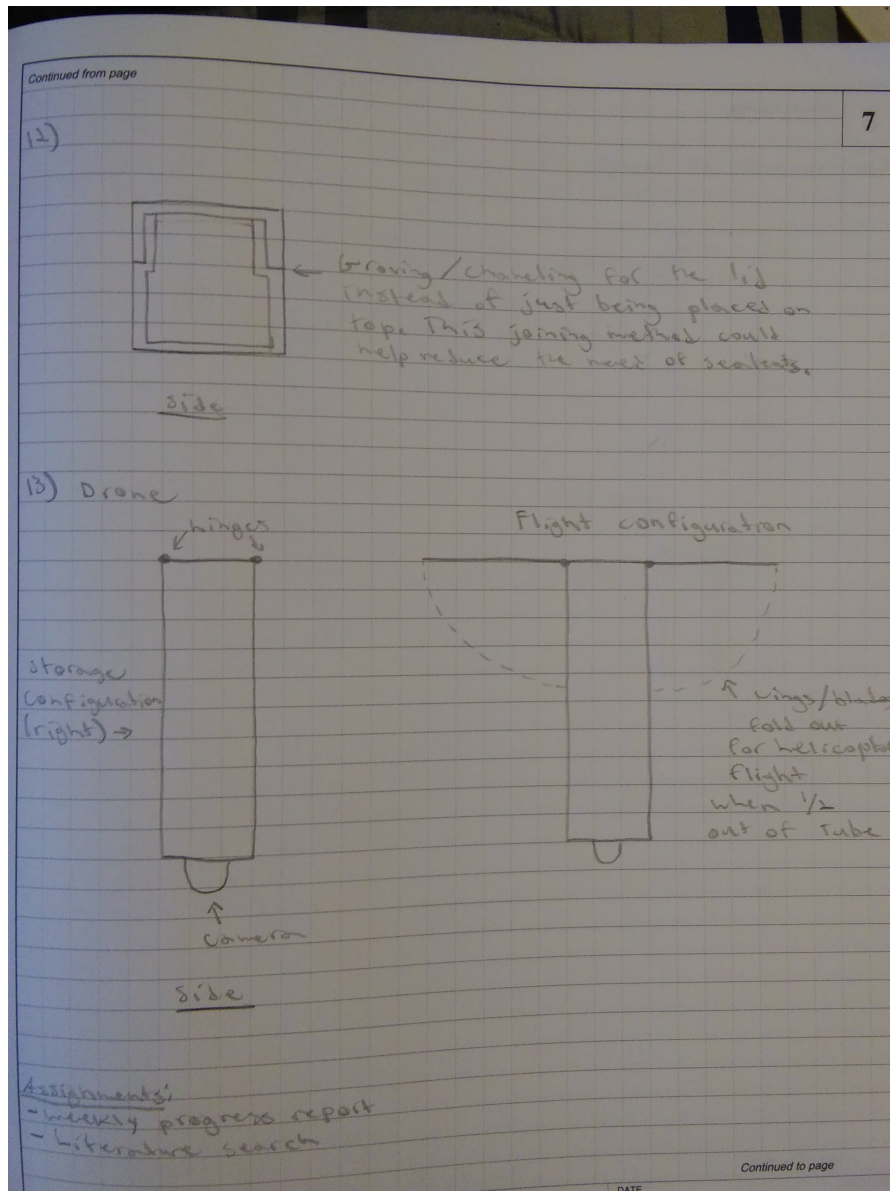


Figure 30: Jeffrey's Concept 12-13

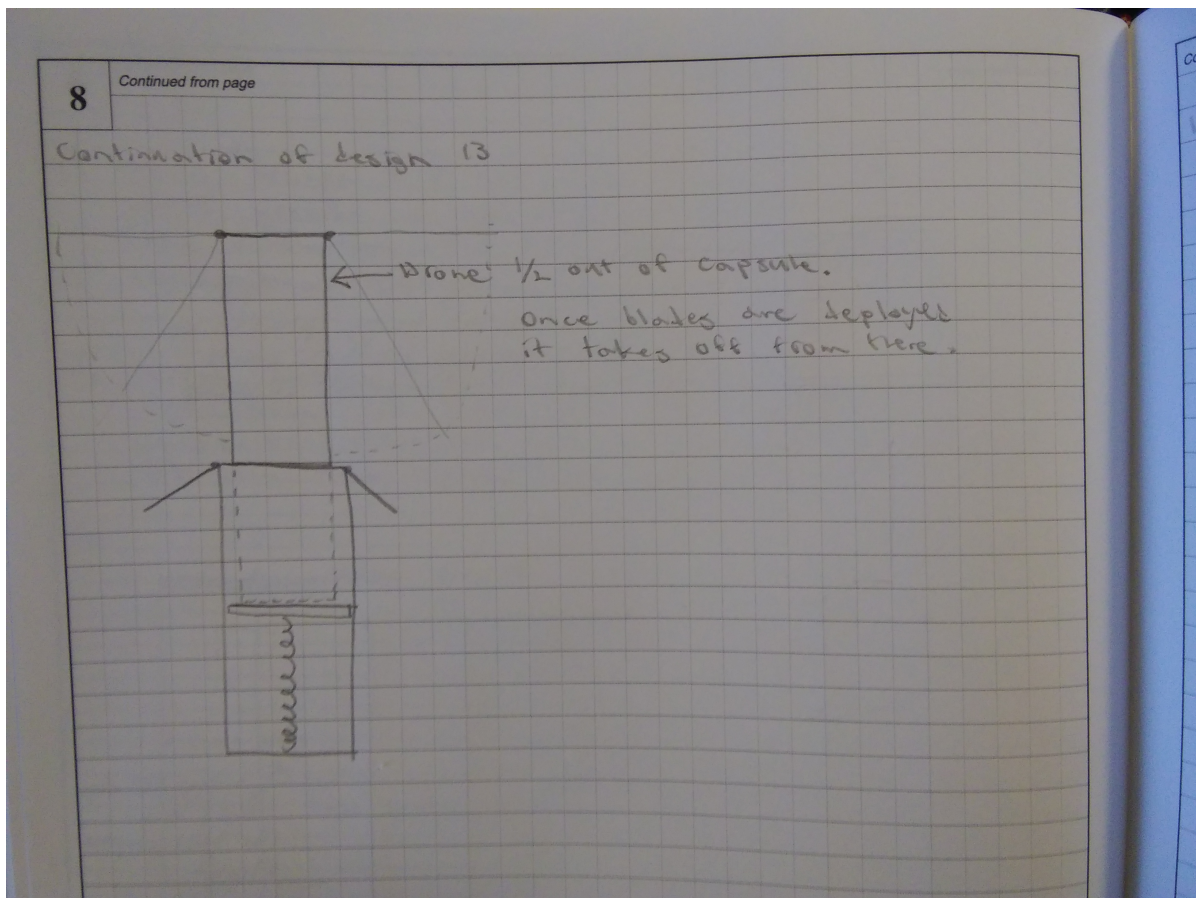


Figure 31: Jeffrey's Concept 13 Continued

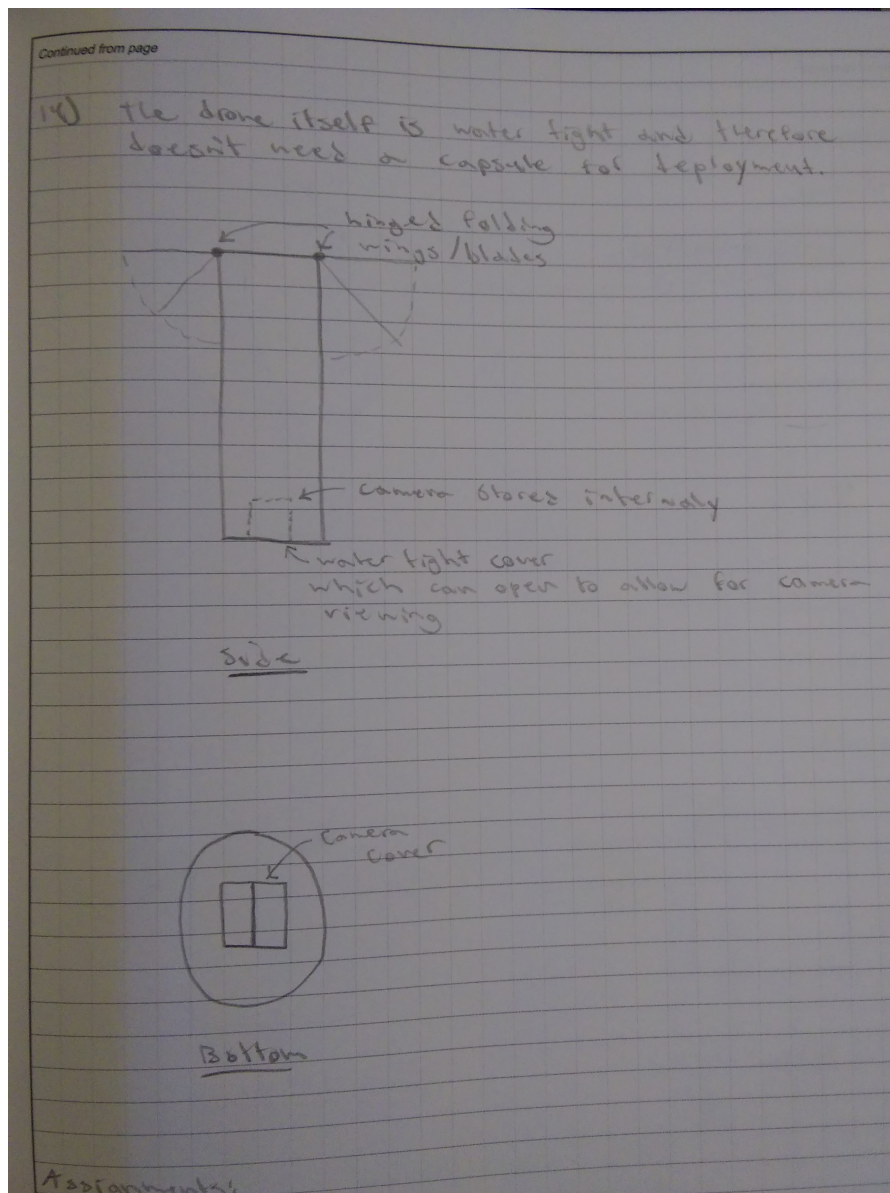


Figure 32: Jeffrey's Concept 14

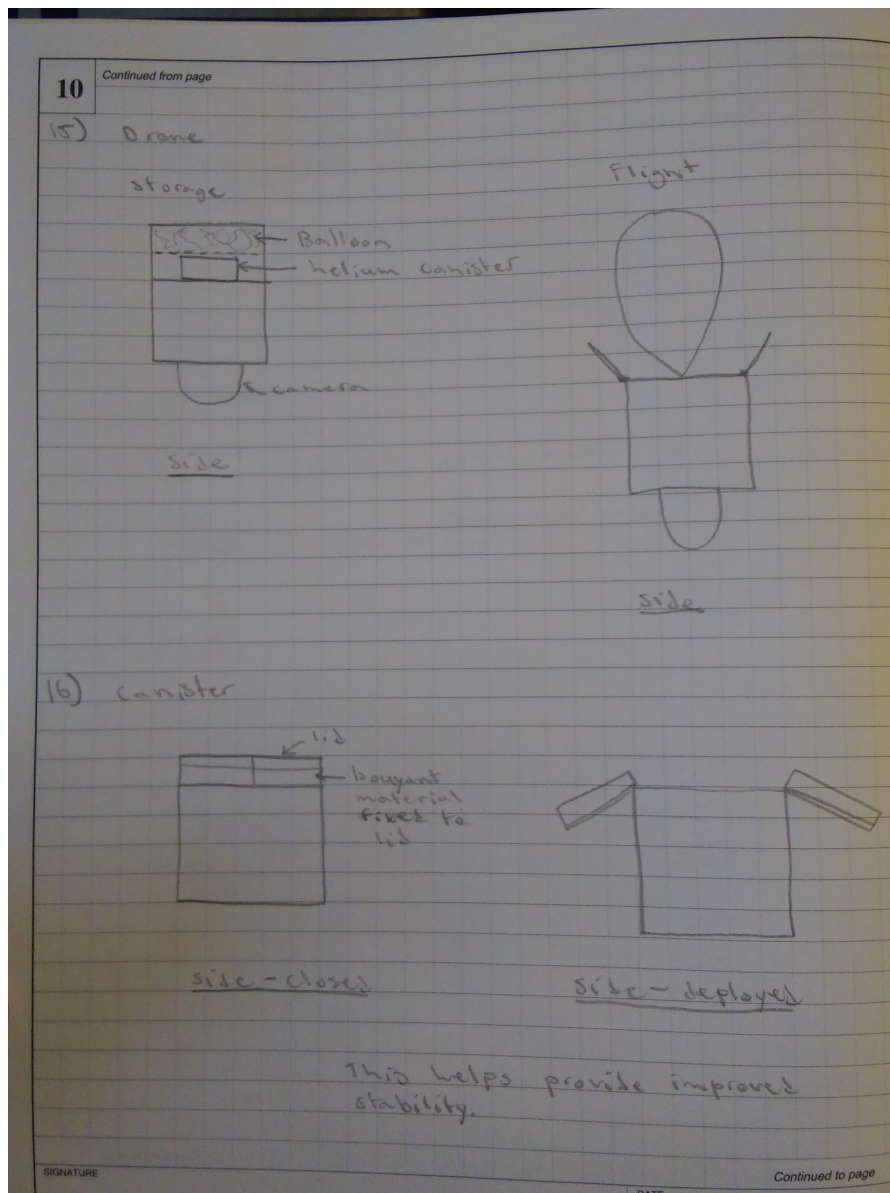


Figure 33: Jeffrey's Concept 15-16

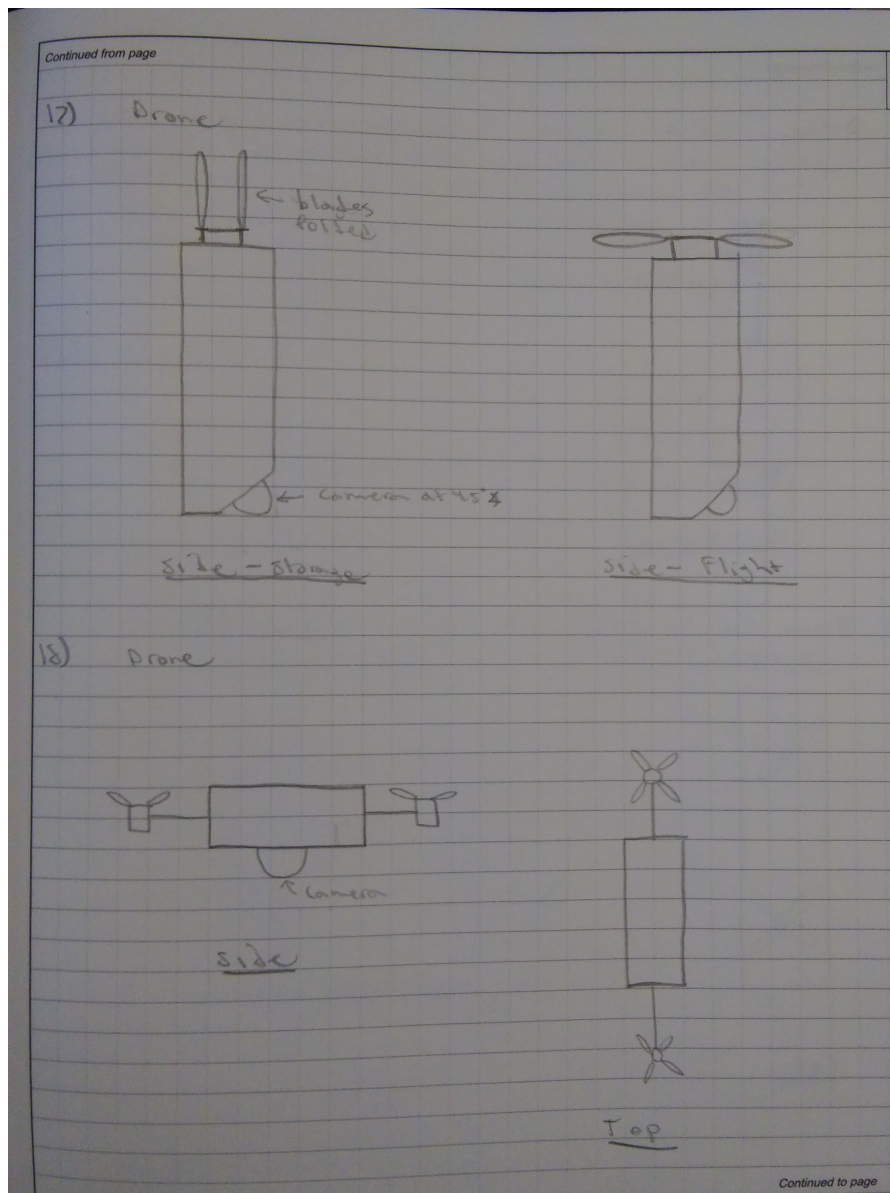


Figure 34: Jeffrey's Concept 17-18

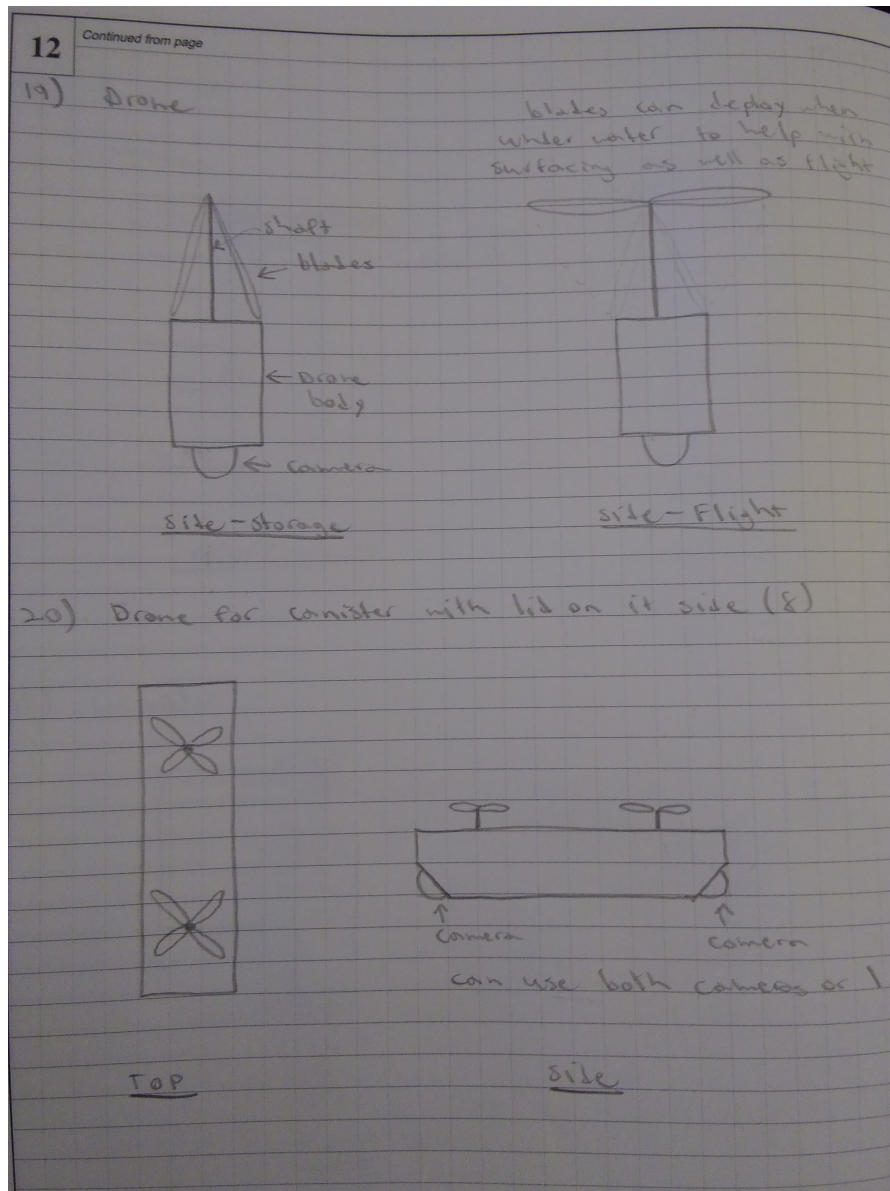


Figure 35: Jeffrey's Concept 19-20

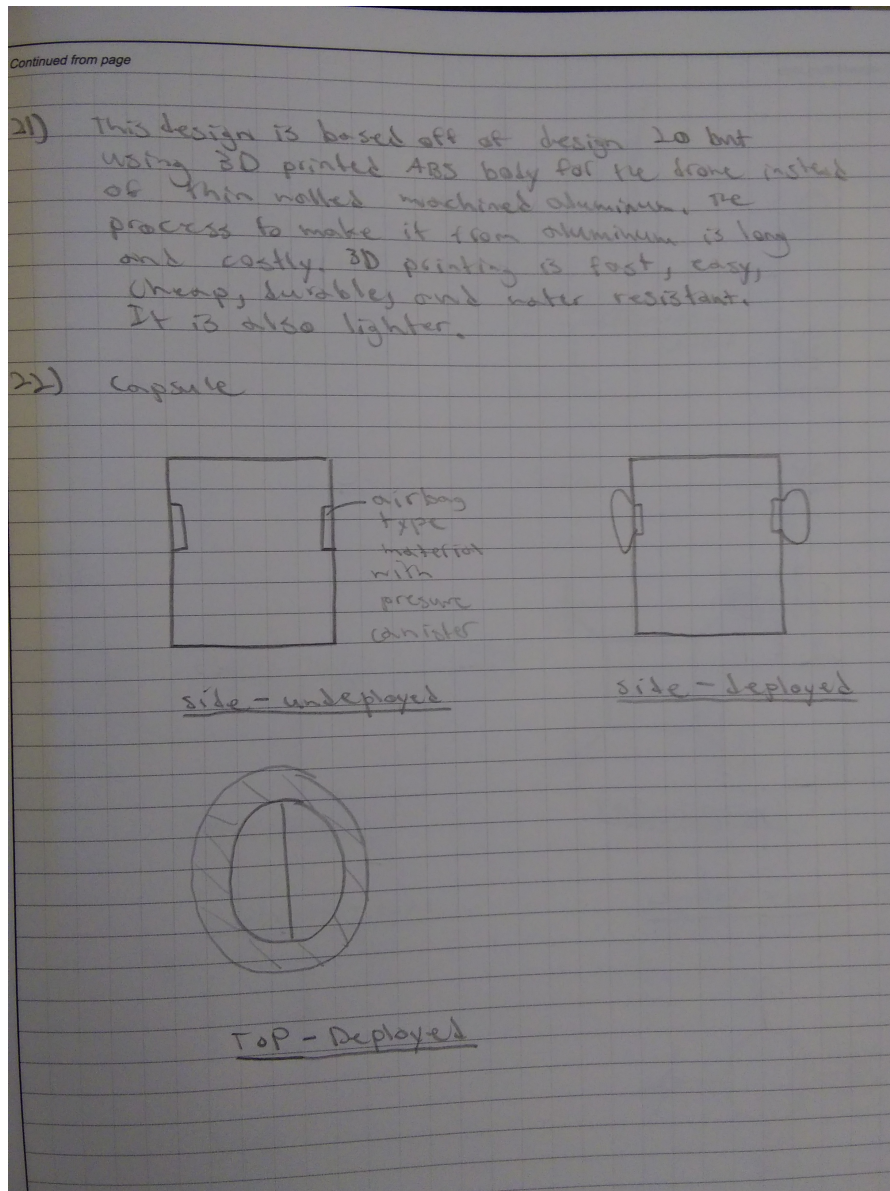


Figure 36: Jeffrey's Concept 21-22

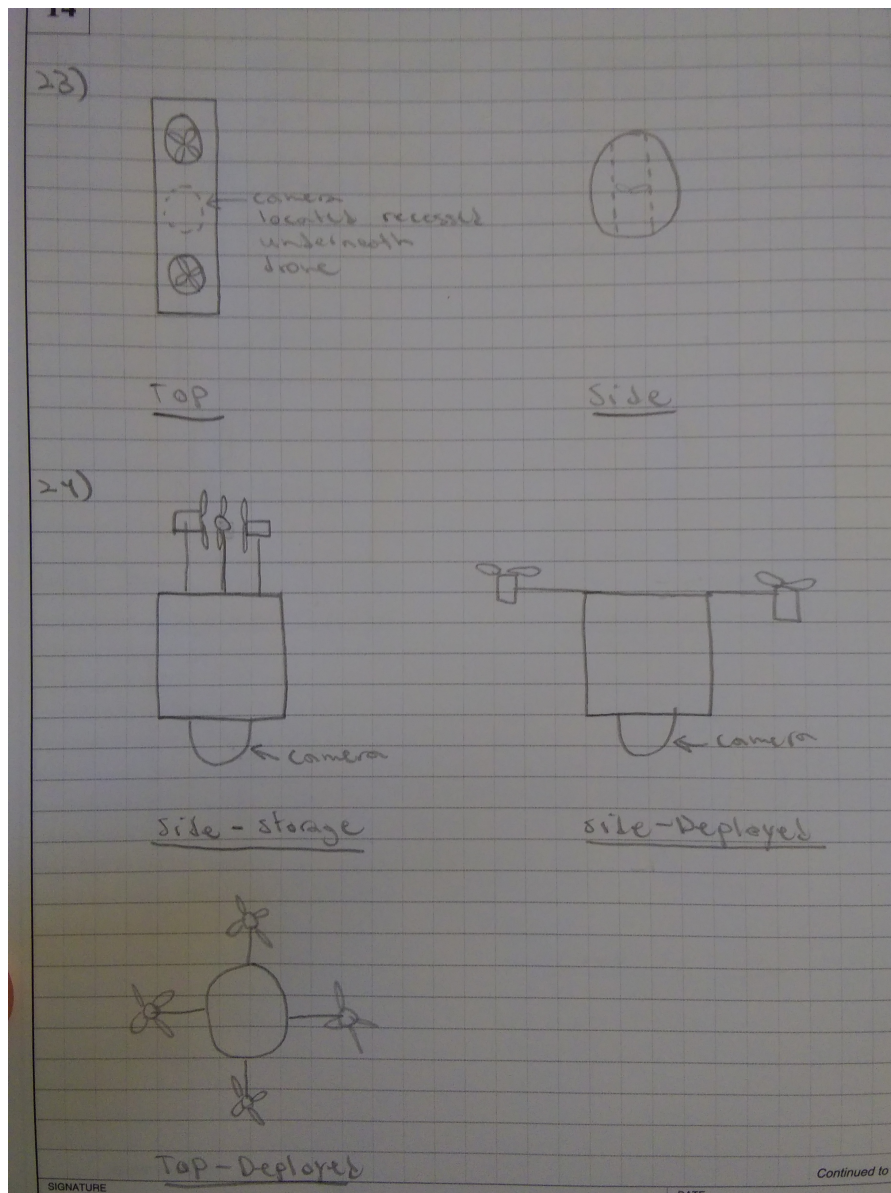


Figure 37: Jeffrey's Concept 23-24

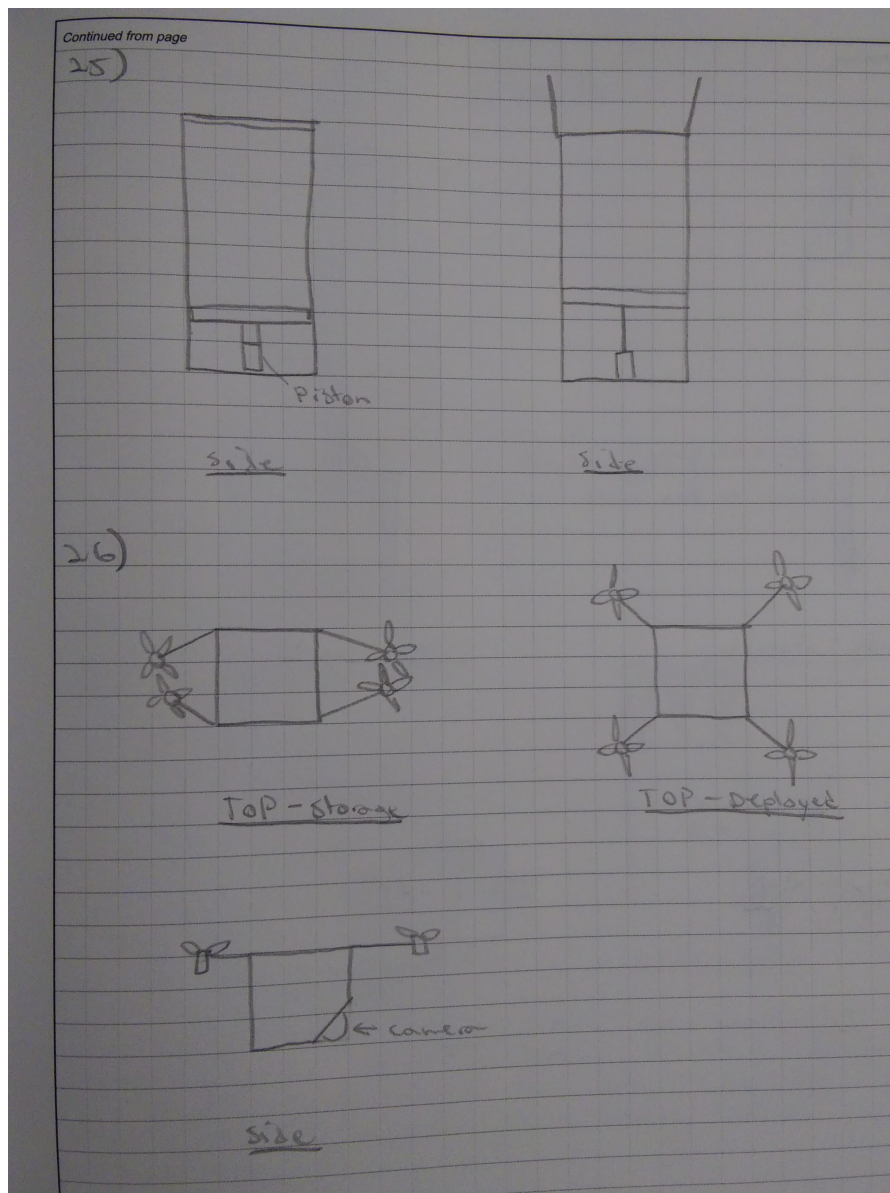


Figure 38: Jeffrey's Concept 25-26

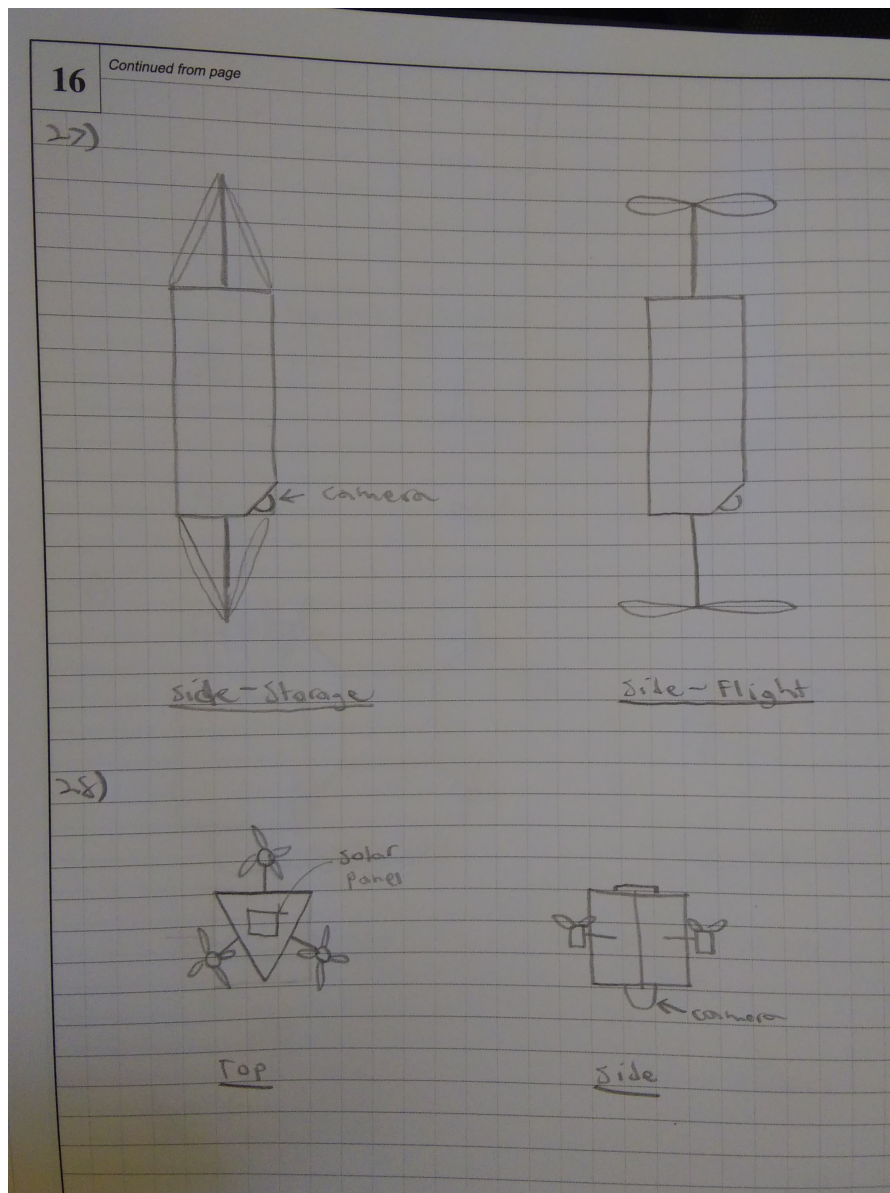


Figure 39: Jeffrey's Concept 27-28

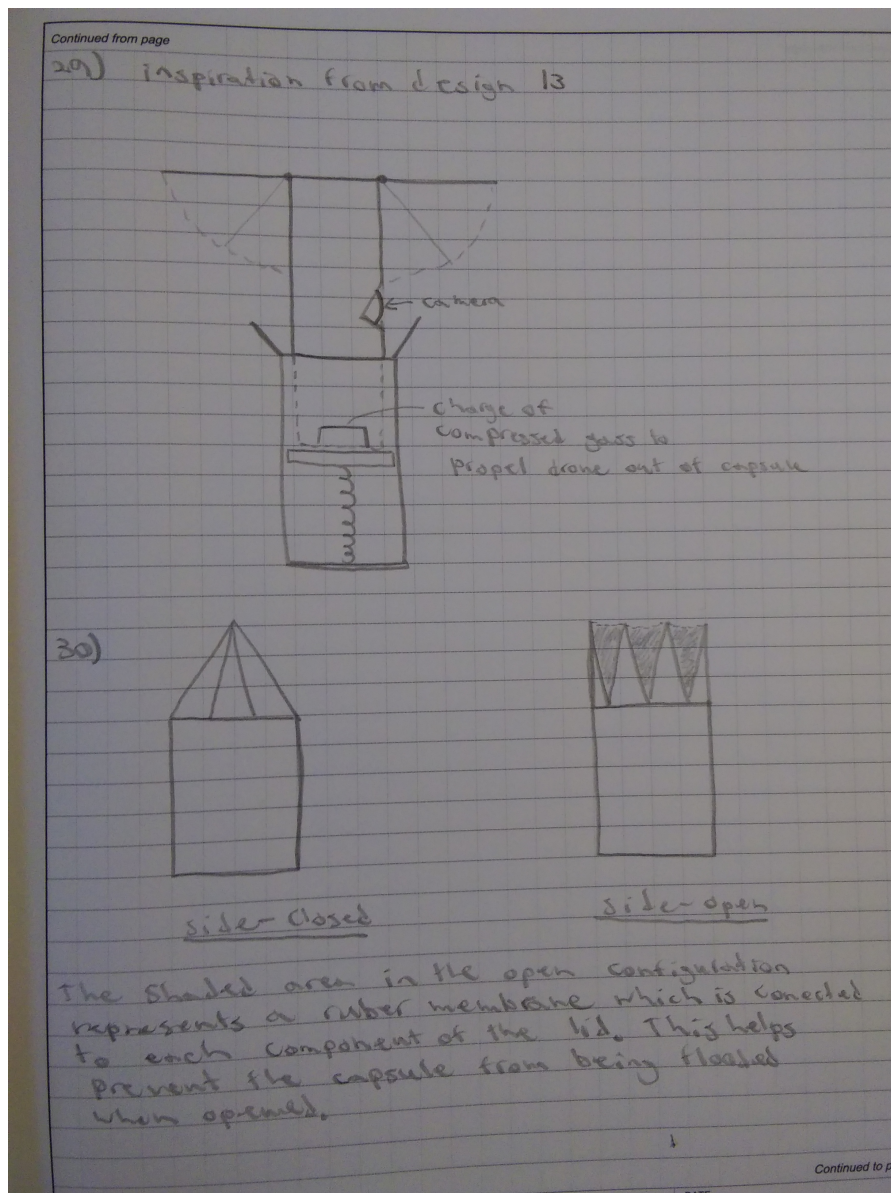


Figure 40: Jeffrey's Concept 29-30

Engineering Criteria	Reference Concept	Concepts																													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Waterproof	14	S	S	S	-	-	-	+	S	+	S	S	+	-	S	-	S	-	-	-	S	-	S	+	S	S	-	S	S	-	-
Low Weight	14	+	+	+	+	+	+	+	+	+	+	+	+	S	S	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Strength	14	S	S	S	-	-	-	S	S	S	S	S	+	S	S	-	S	S	-	-	S	-	S	S	S	S	-	S	S	-	-
Ease of Deployment	14	+	+	-	+	-	+	S	+	S	+	S	+	S	S	-	+	-	+	-	-	+	S	+	+	-	+	-	-	+	-
Ease of Preparation	14	-	-	-	-	S	+	S	+	S	+	-	-	S	S	-	+	-	-	S	-	+	S	+	+	-	-	-	-	-	S
Camera View	14	NA	NA	NA	NA	S	S	NA	NA	NA	NA	NA	NA	S	S	S	NA	NA	S	S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	S
Reliable	14	S	S	-	-	S	S	S	S	S	S	-	-	S	S	-	S	-	-	S	-	-	S	S	S	-	-	S	-	-	S
Probability of drone deploying properly	14	-	-	-	-	-	-	-	-	-	-	+	-	S	S	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Probability of Capsule deploying properly	14	-	-	-	-	NA	NA	-	+	-	+	+	S	S	S	NA	S	-	NA	-	-	+	-	+	-	-	-	-	-	-	NA
# of Plususes		2	2	1	2	1	3	2	4	2	4	3	4	0		1	3	1	2	1	1	2	4	2	4	1	2	2	1	2	1
# of Minuses		3	3	5	6	4	3	2	1	2	1	2	3	1		6	0	6	6	4	5	6	1	2	1	5	6	3	5	6	4

Figure 41: Jeffrey's Pugh Chart

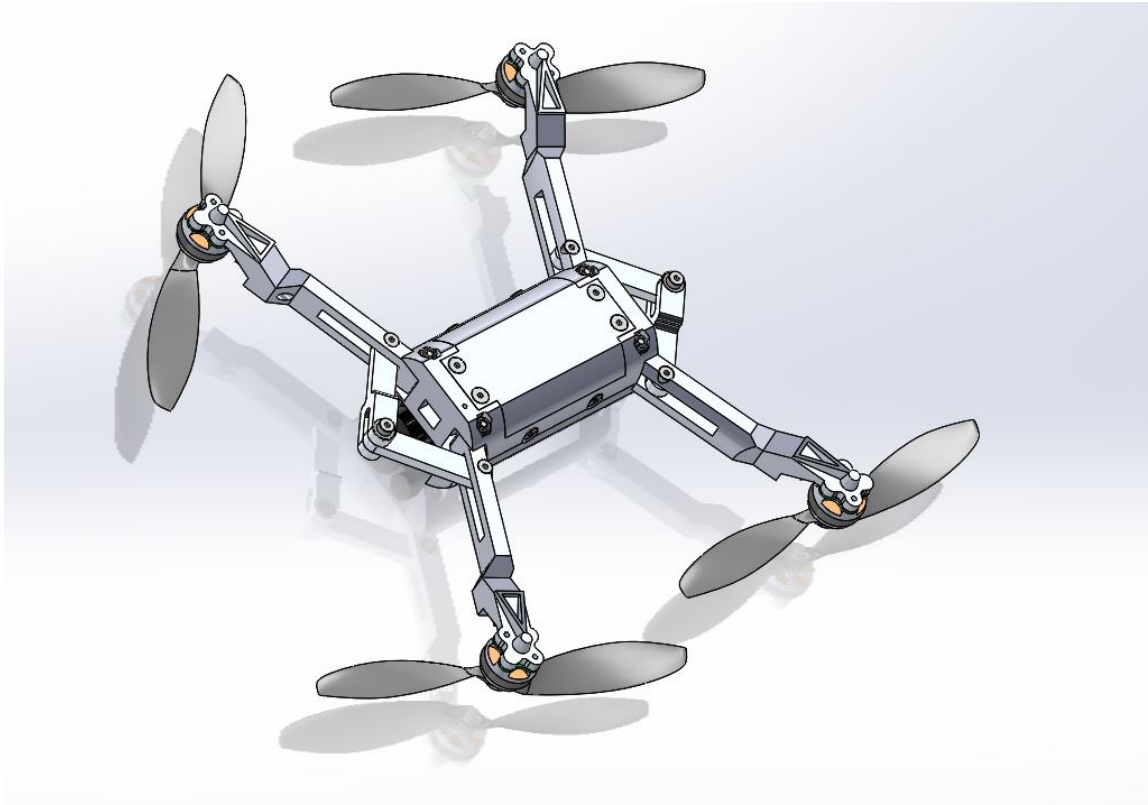


Figure 42: Robert's Quadcopter

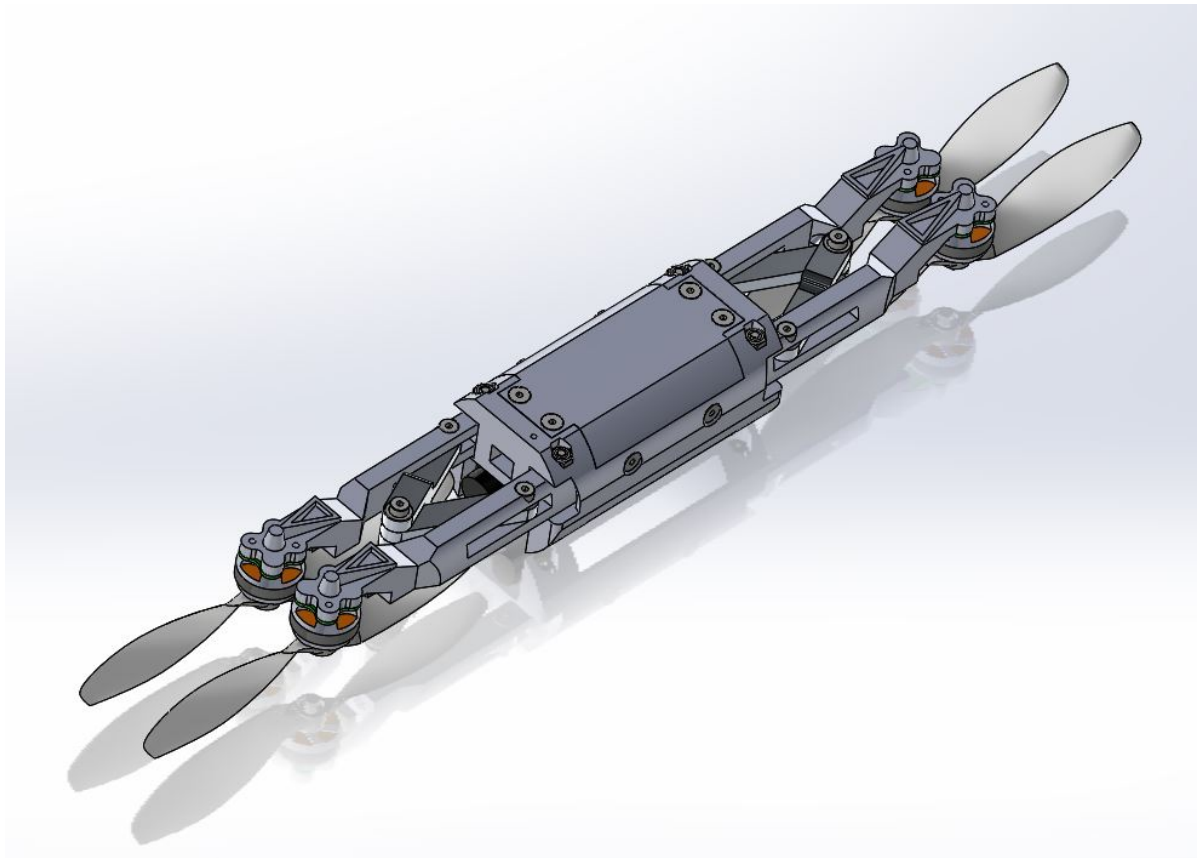


Figure 43: Robert's Collapsed Quadcopter

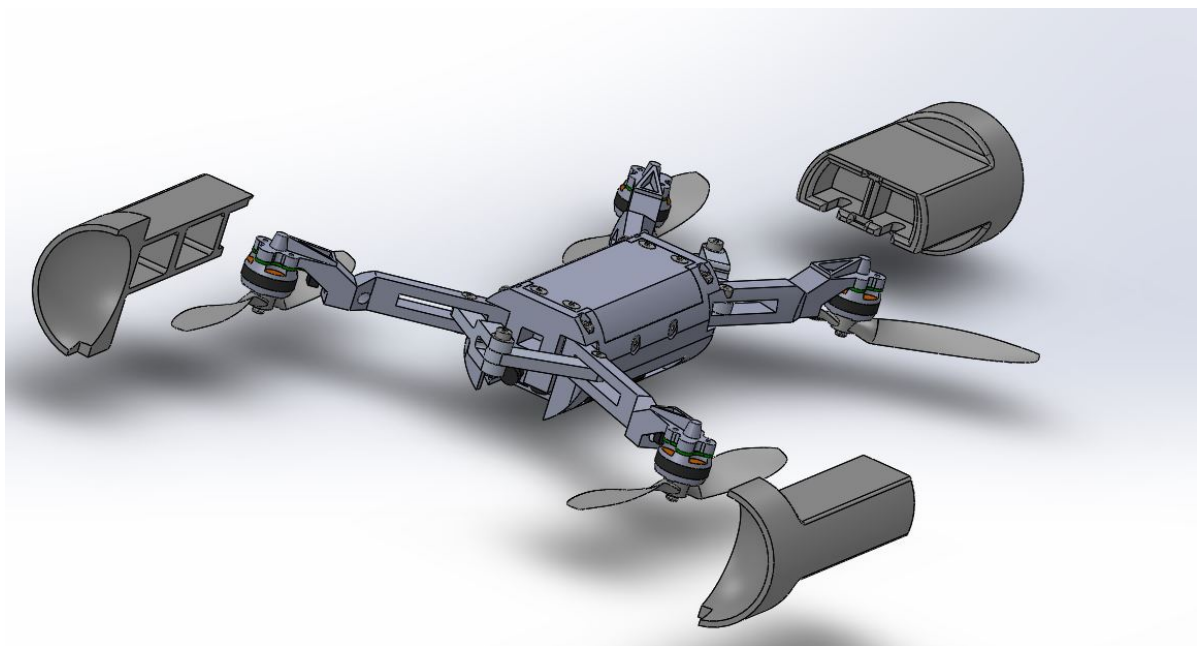


Figure 44: Robert's Quadcopter exiting the launch tube

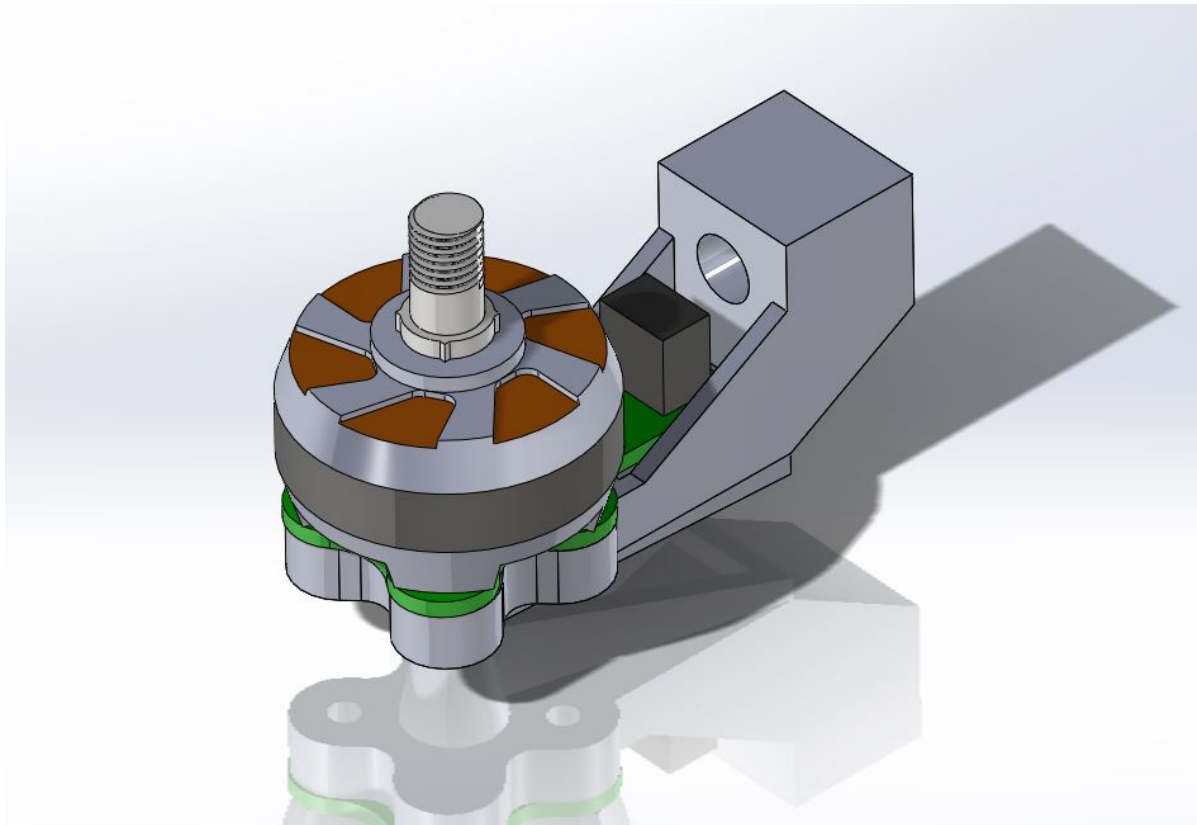


Figure 45: Robert's rapidly Changeable Motor Mount

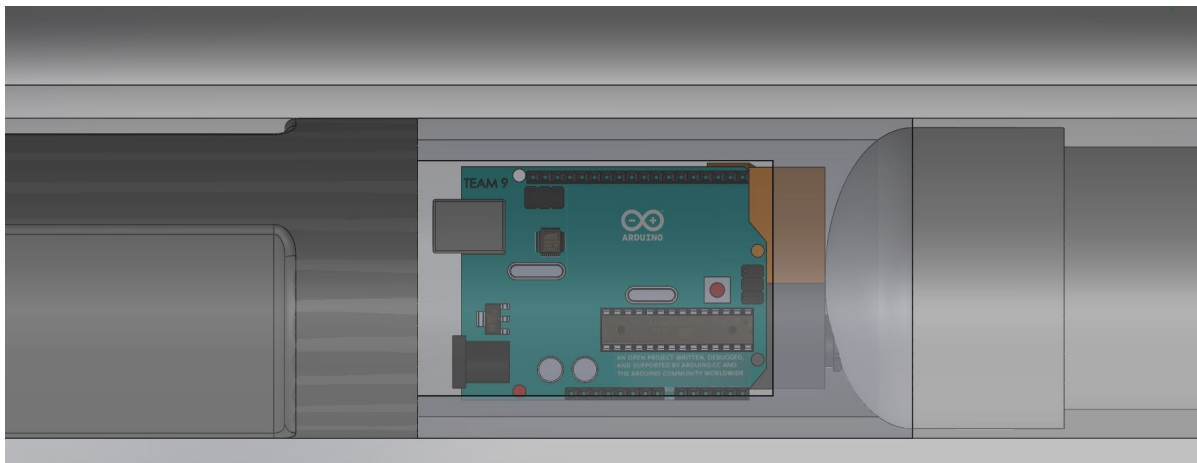


Figure 46: Robert's Arduino Placement

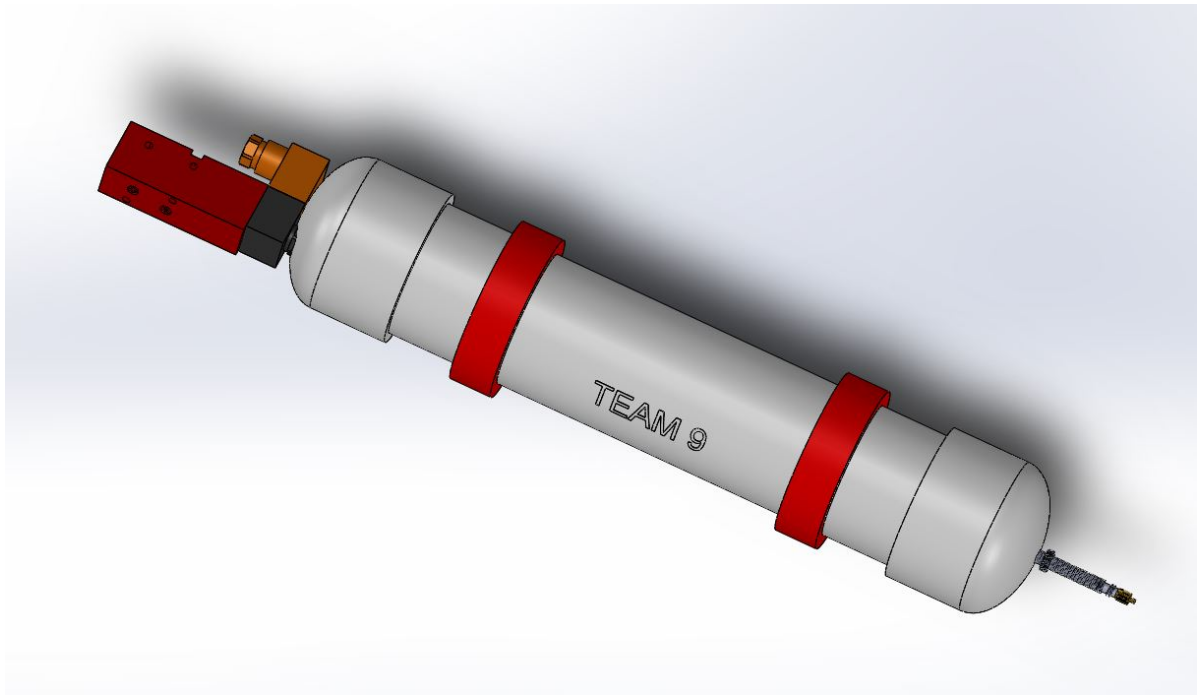


Figure 47: Robert's Compressed Gas System

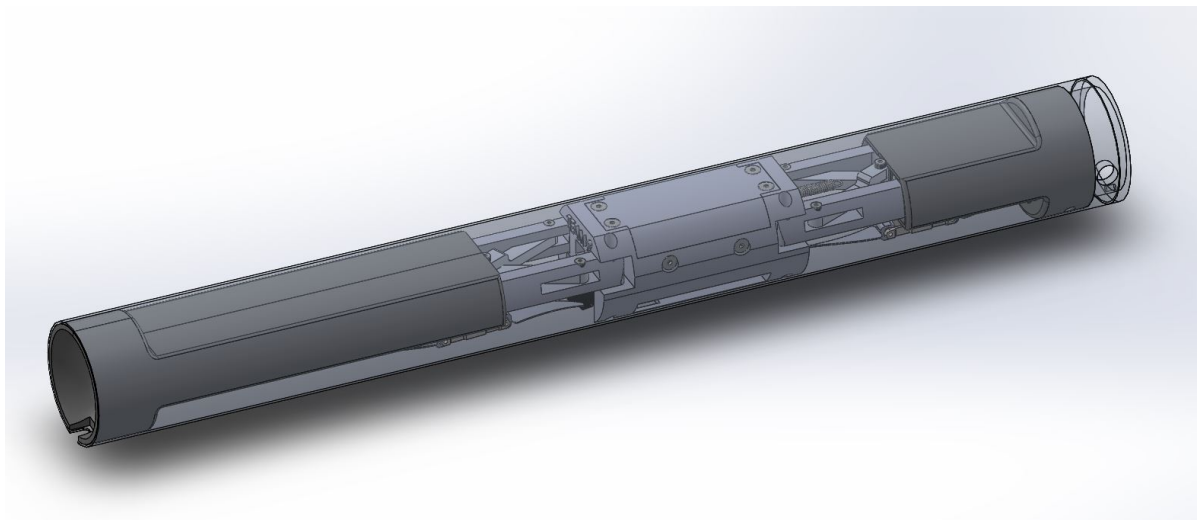


Figure 48: Robert's Complete Sabot System

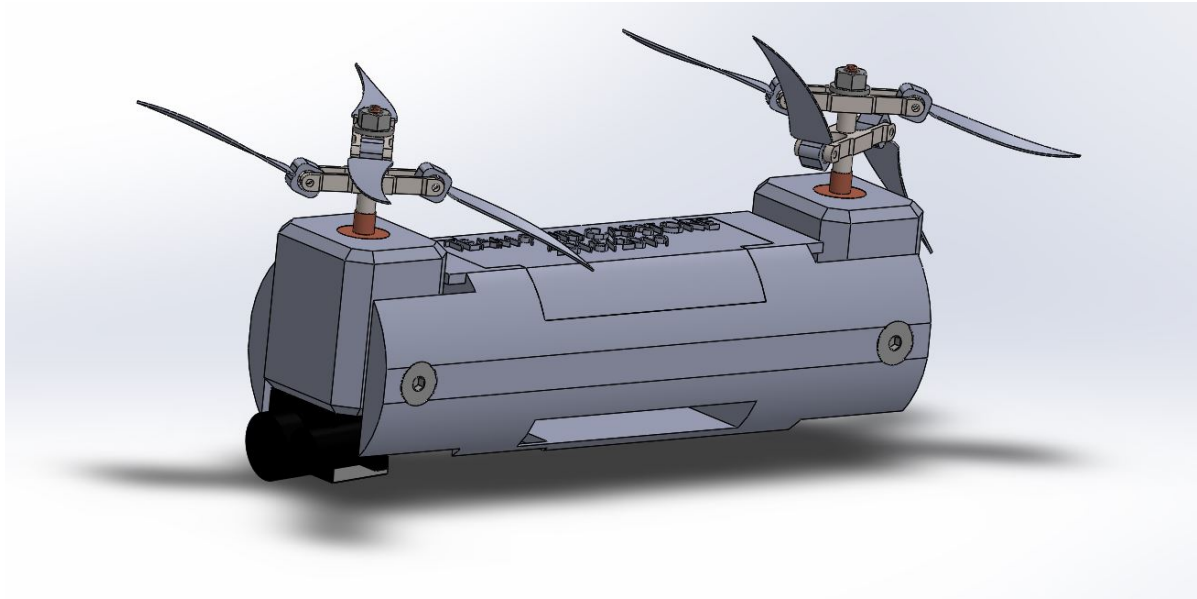


Figure 49: Robert's Dual Tilting Rotor Copter

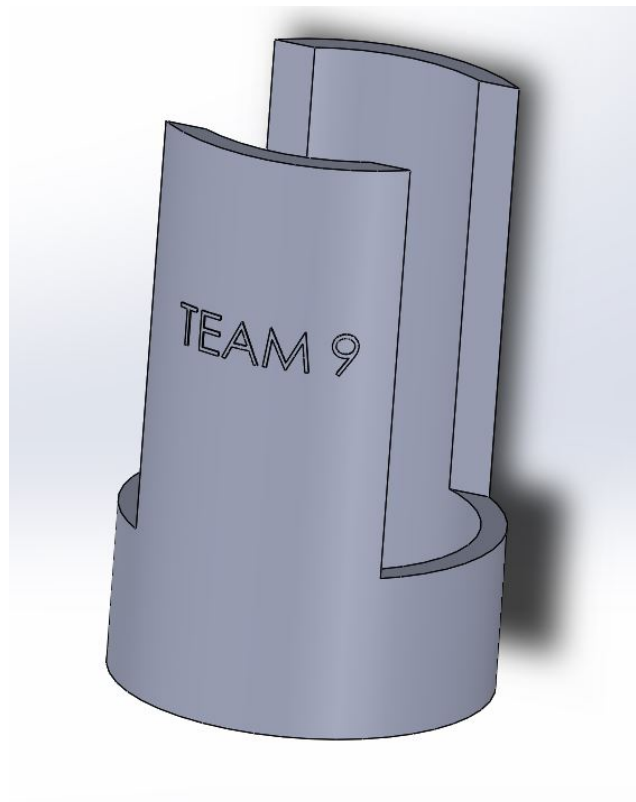


Figure 50: Robert's UAV and control system Stand Off Device

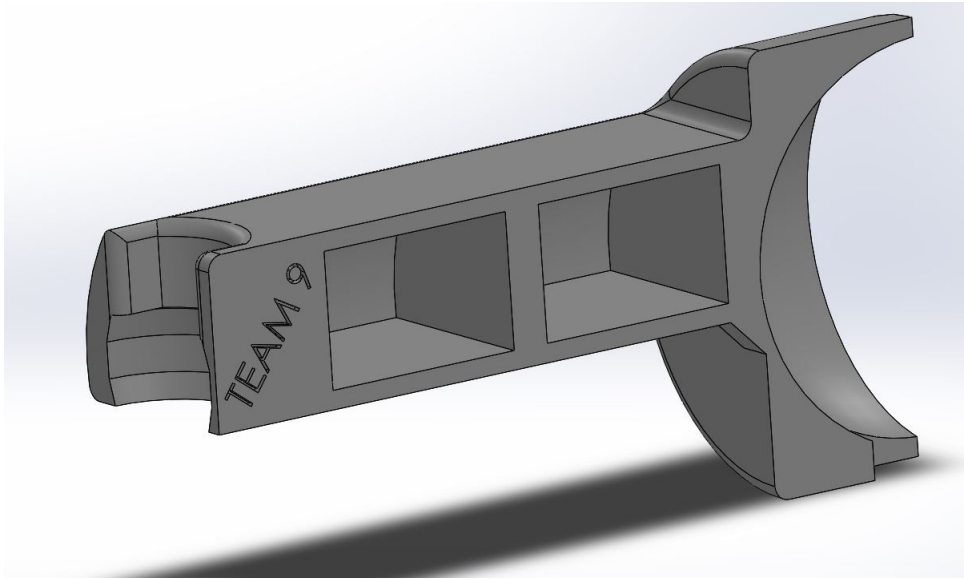


Figure 51: Robert's UAV retention device that removes the end cap during launch



Figure 52: Robert's Dual-Rotor, counter rotating Copter with Gyro Cam

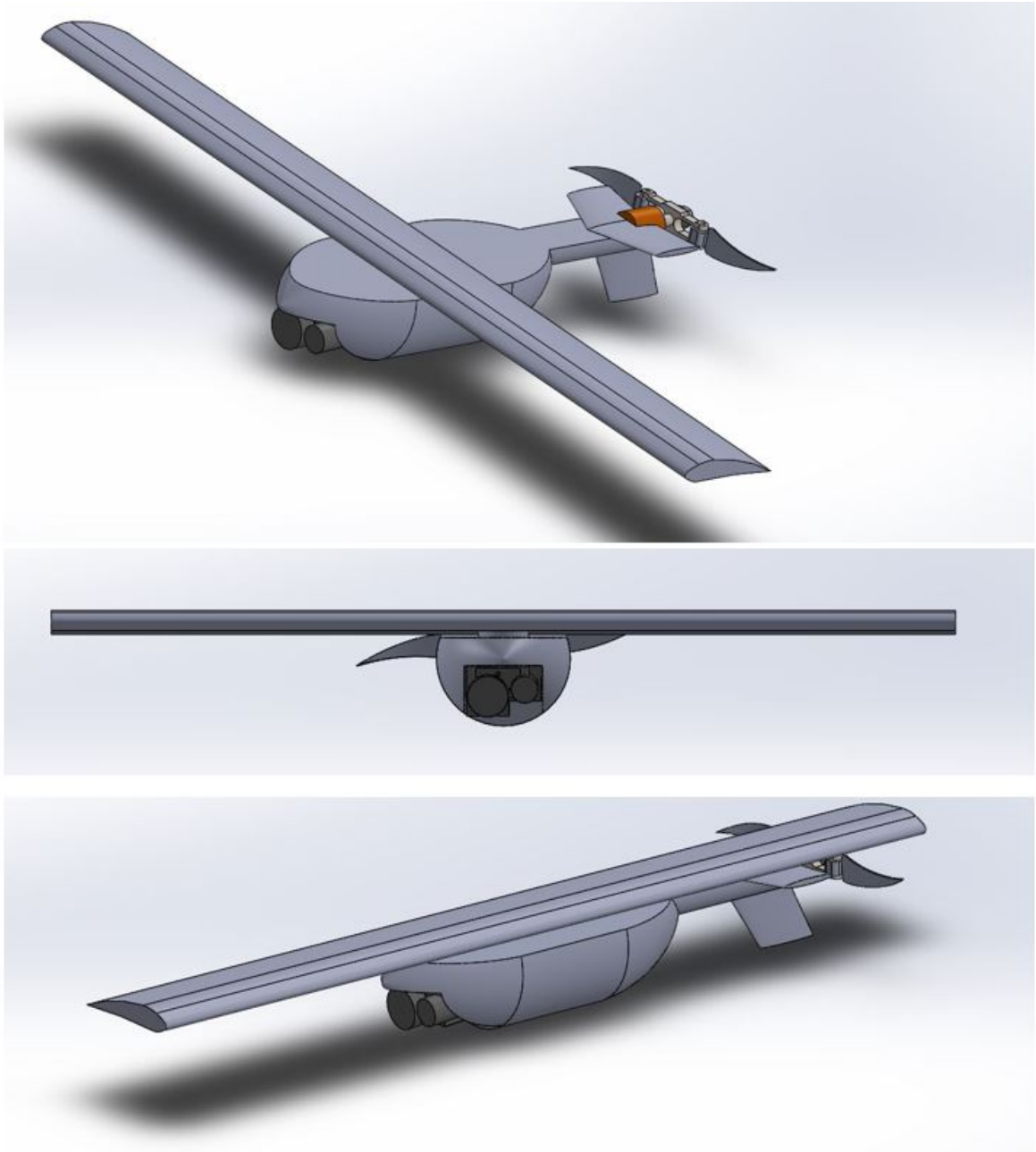


Figure 53: Robert's Rotating Swing Wing

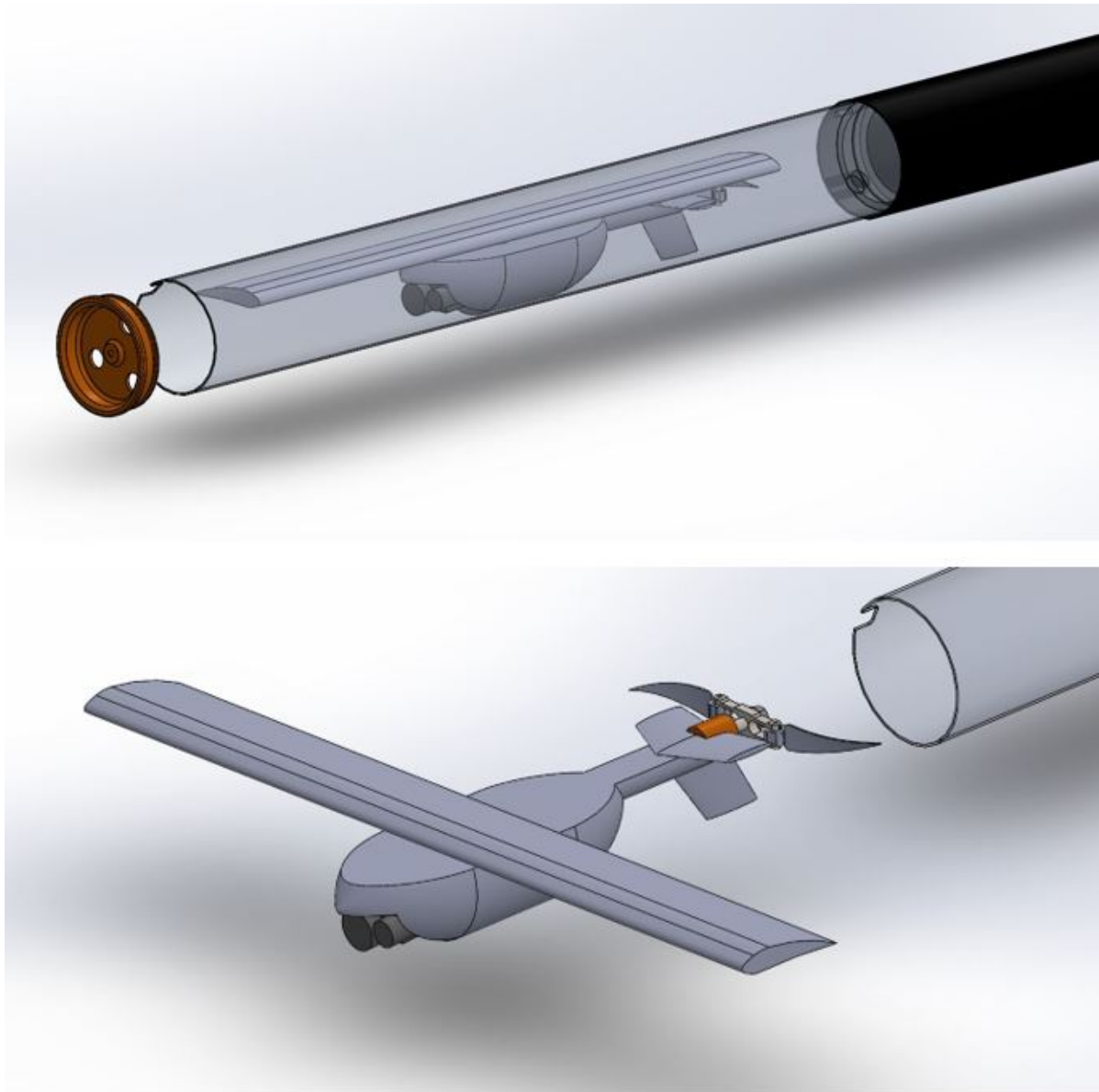


Figure 54: Robert's Swing Wing Plane exiting the launcher

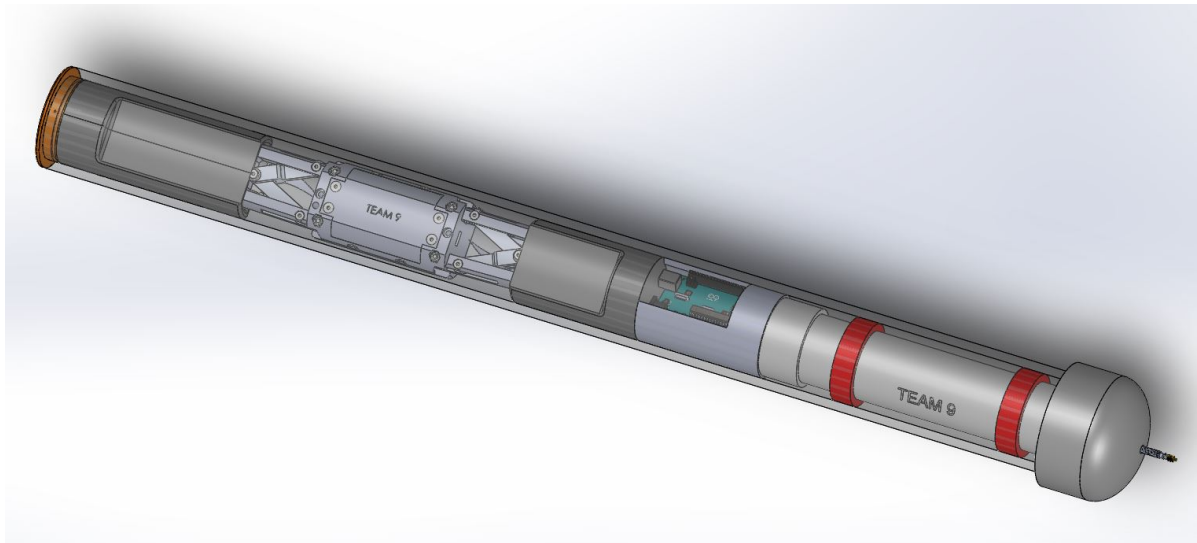


Figure 55: Robert's PVC Drone Cannon

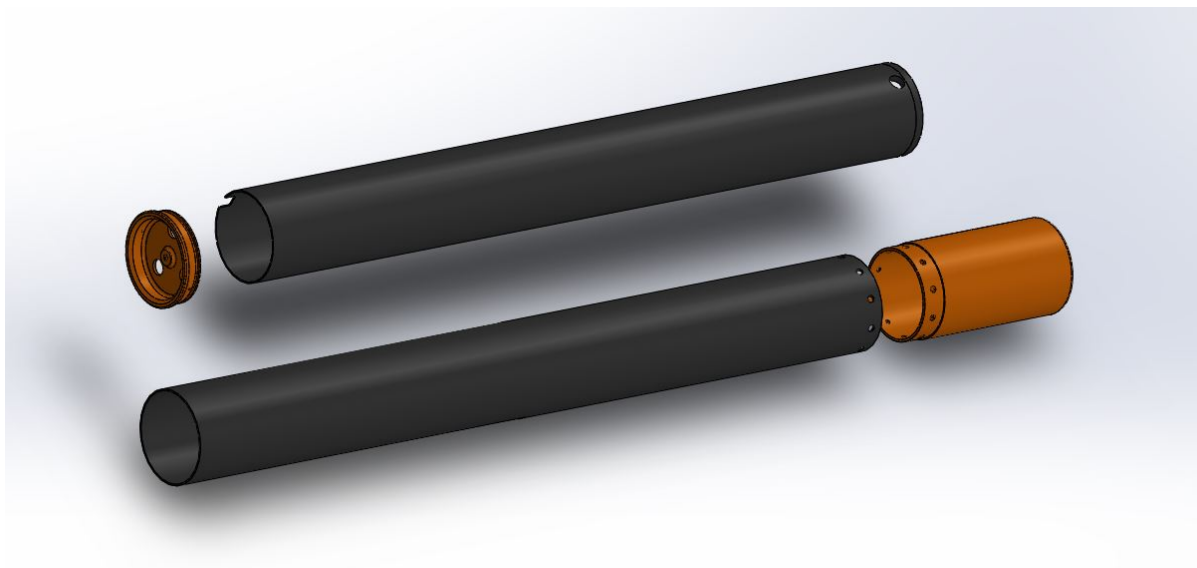


Figure 56: Robert's Launch Canister System

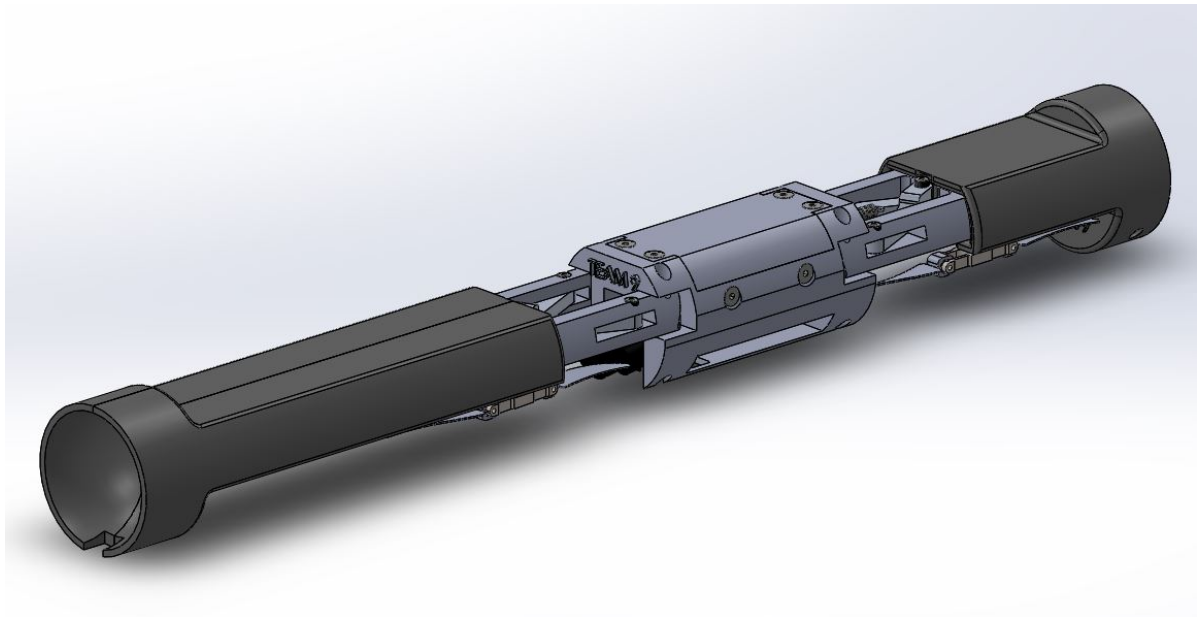


Figure 57: Robert's Inner Launcher Retention System

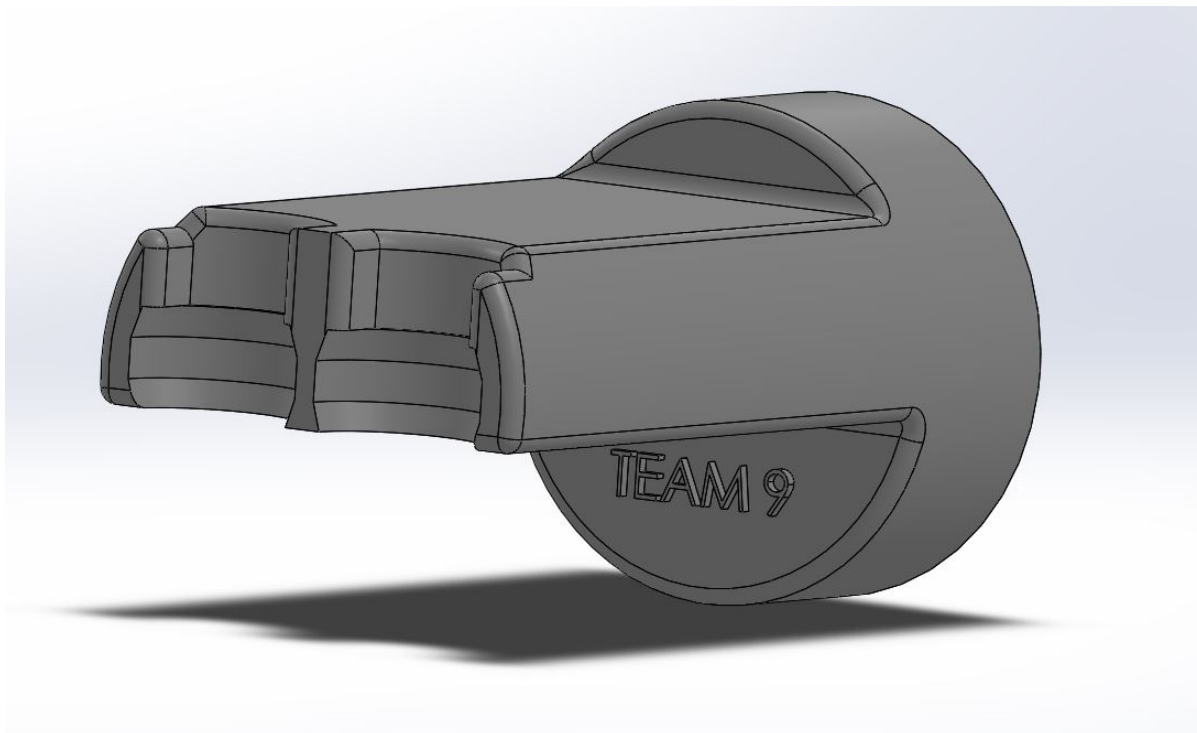


Figure 58: Robert's Inner Launcher Ejection System

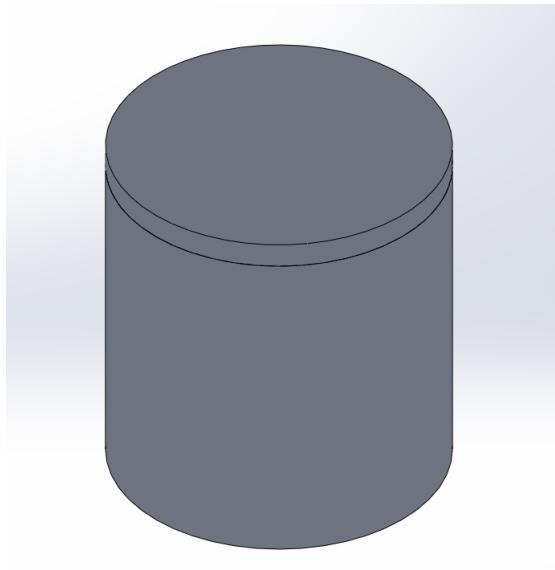


Figure 59: Daynamar's Concept: Hockey Puck

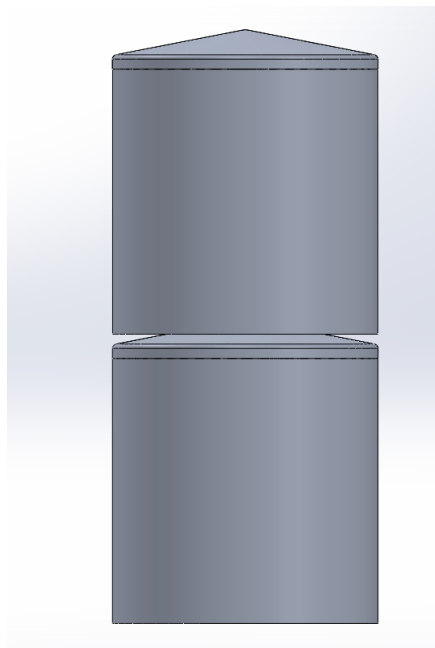


Figure 60: Daynamar's Concept: Conical Lid

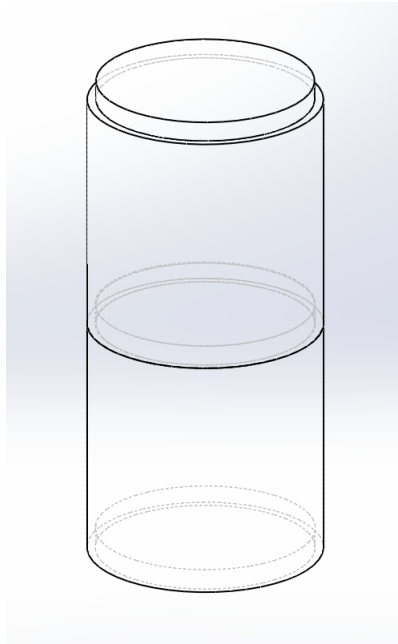


Figure 61: Daynamar's Concept: "Lego" Capsule

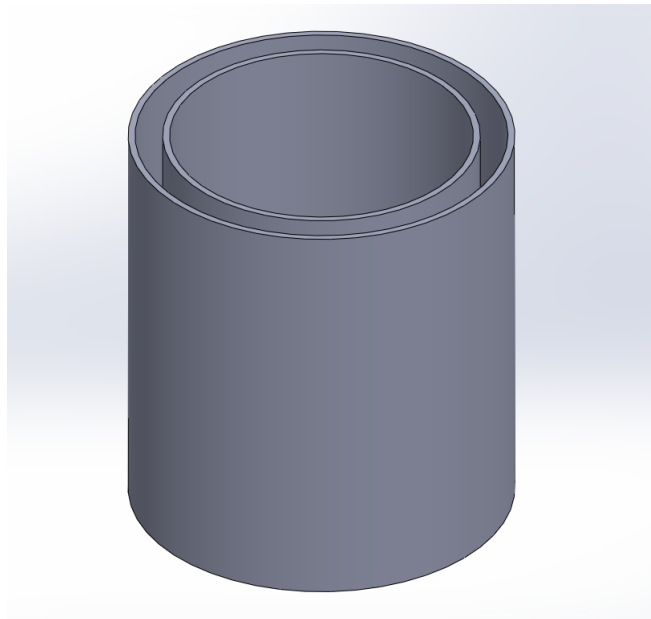


Figure 62: Daynamar's Concept: Buoyant Canister

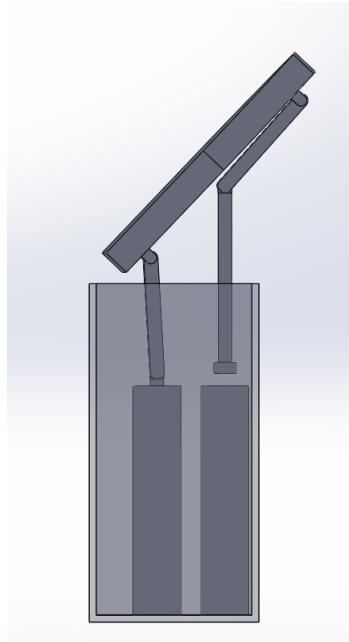


Figure 63: Daynamar's Concept: Starwars All Terrain Armored Transport

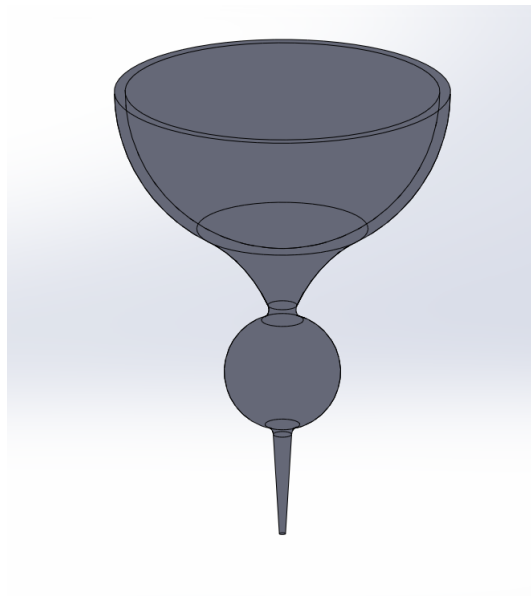


Figure 64: Daynamar's Concept: Sphere Capsule

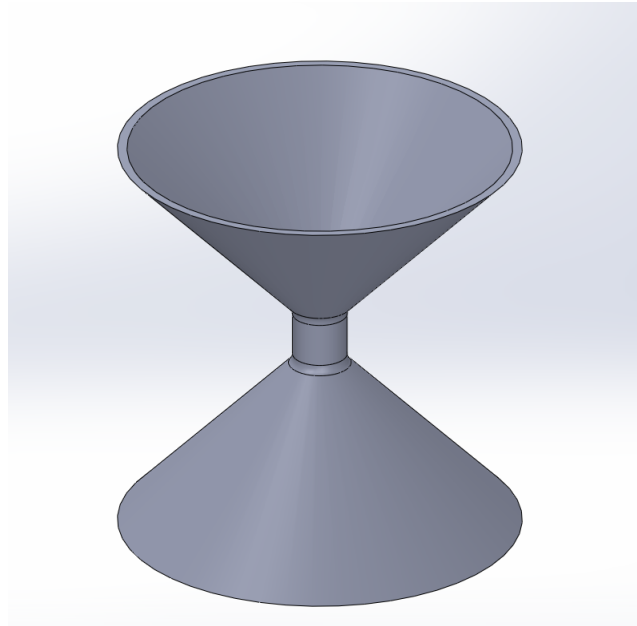


Figure 65: Daynamar's Concept: Double Cone

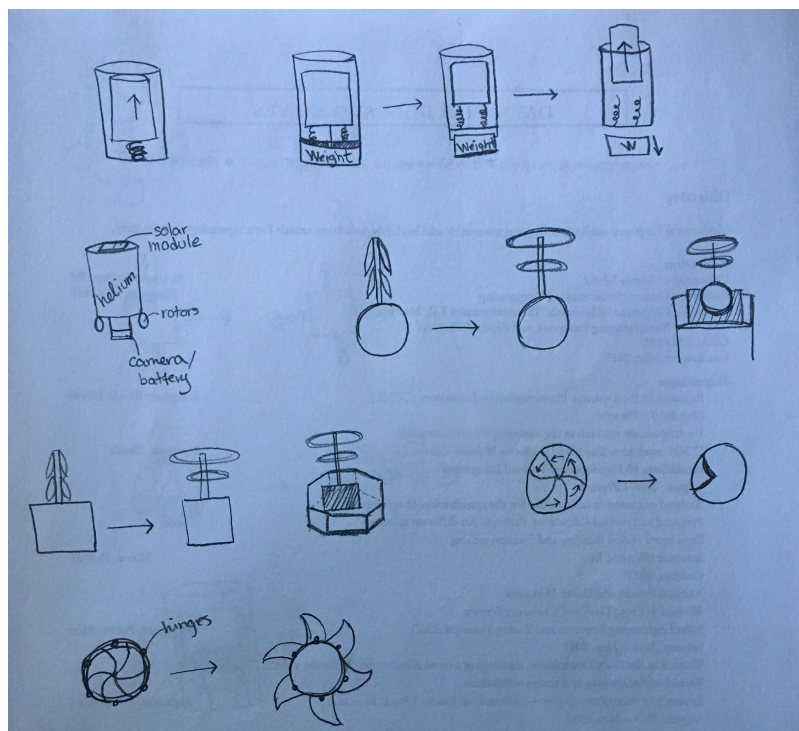


Figure 66: Daynamar's Concepts page 1

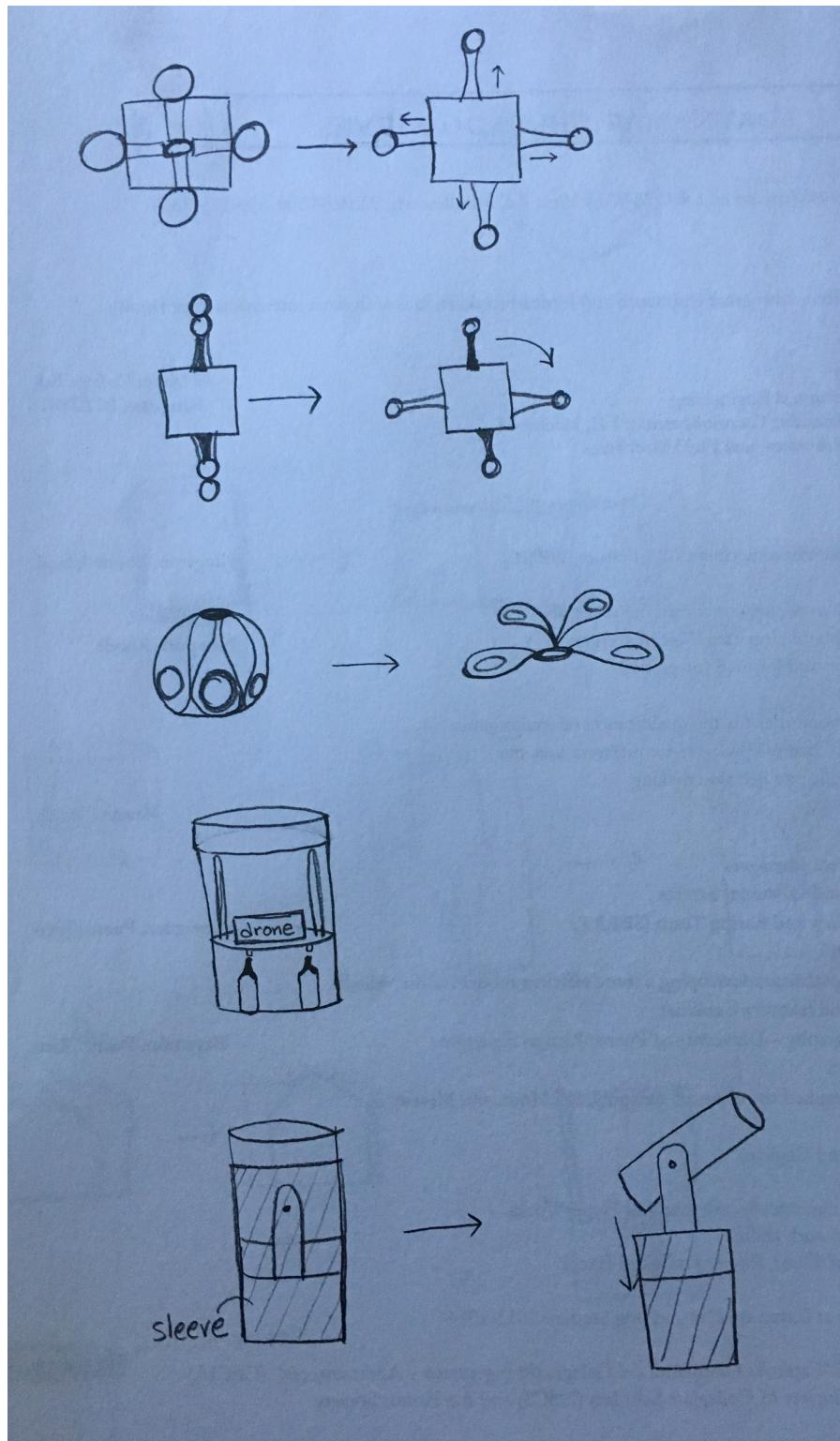


Figure 67: Daynamar's Concepts page 2

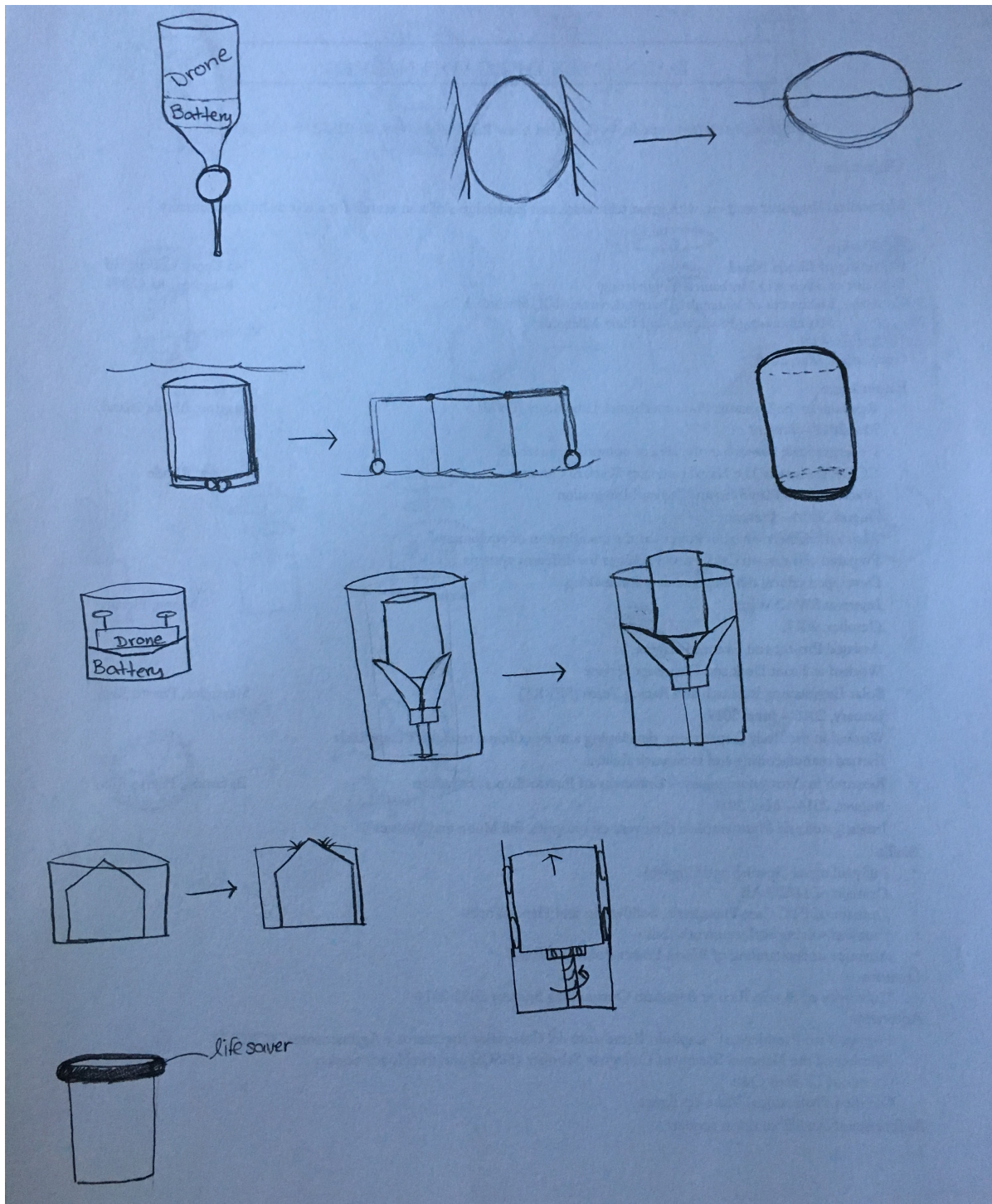


Figure 68: Daynamar's Concepts page 3

		Concepts																														
Engineering Criteria	Reference Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Noise	23,30	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
Video or Photo Quality	23,30	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
Power (Watt) – Battery or Solar power	23,30	S	S	S	+	+	+	+	S	S	S	-	+	S	+	+	S	S	-	S	S	S	S	S	S	-	-	S	S	S	S	
Semi-Autonomous – Remote Control	23,30	S	S	S	+	S	+	S	S	S	S	S	S	+	+	S	+	S	+	S	S	S	S	S	S	+	-	+	S	S	S	
Waste Produced	23,30	S	S	S	S	S	S	S	S	S	S	-	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
Housing and Storage – Storing temperature and humidity	23,30	+	+	+	S	+	+	+	S	S	S	S	S	S	S	S	S	S	+	-	+	+	S	S	-	S	+	+	S	S	S	
Materials – lightweight (1060 – T6)	23,30	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
Life Cycle – 1 year shelf-life	23,30	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
# of Plusses		1	1	1	2	2	3	2	0	0	0	0	0	1	1	2	1	1	1	2	0	1	0	0	0	1	1	2	0	0	0	0
# of Minuses		0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	1	0	0	0	1	1	2	0	0	0	0	

Figure 69: Daynamar's Pugh Chart

Design Ideas

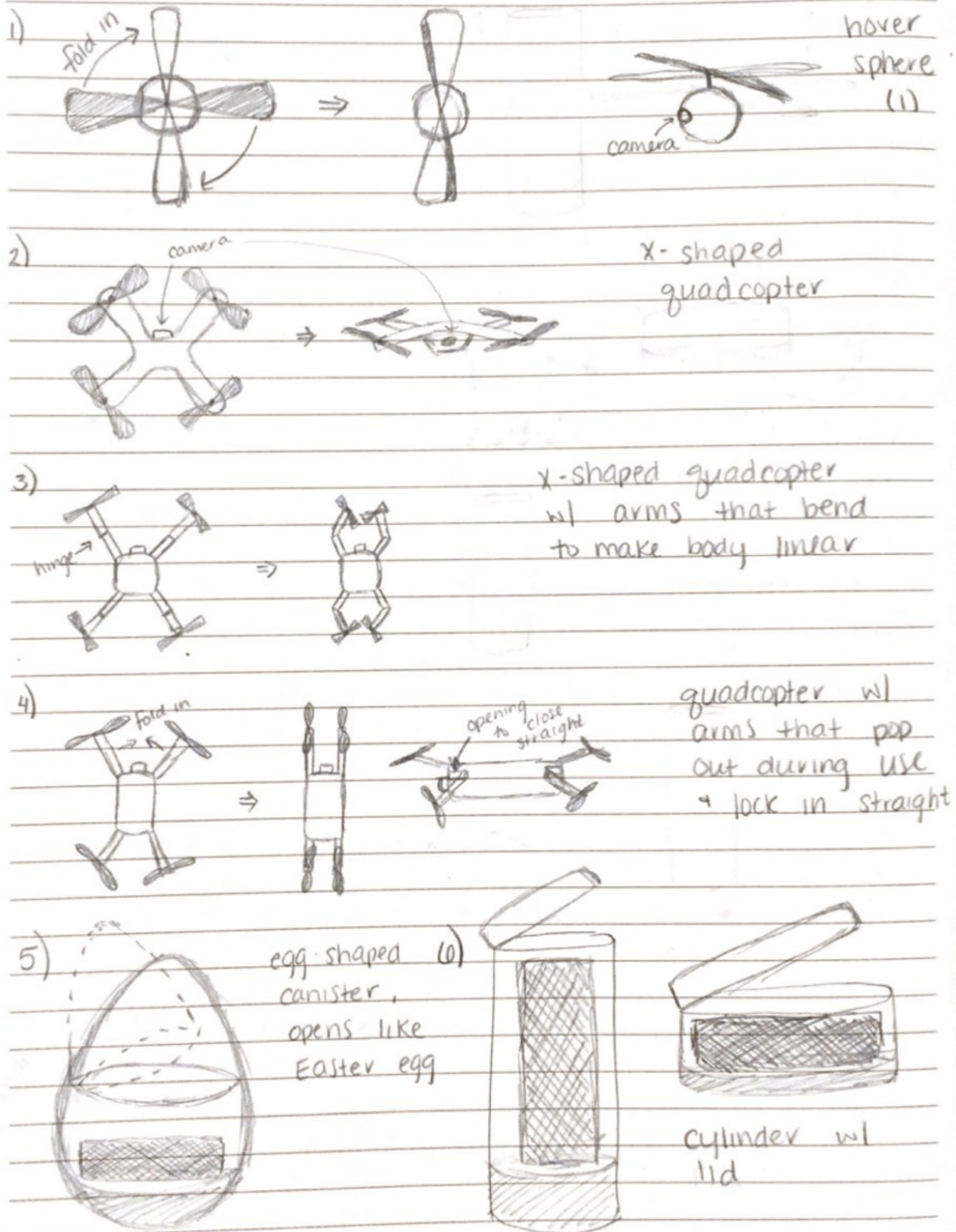


Figure 70: Hannah's Concept Designs 1-6

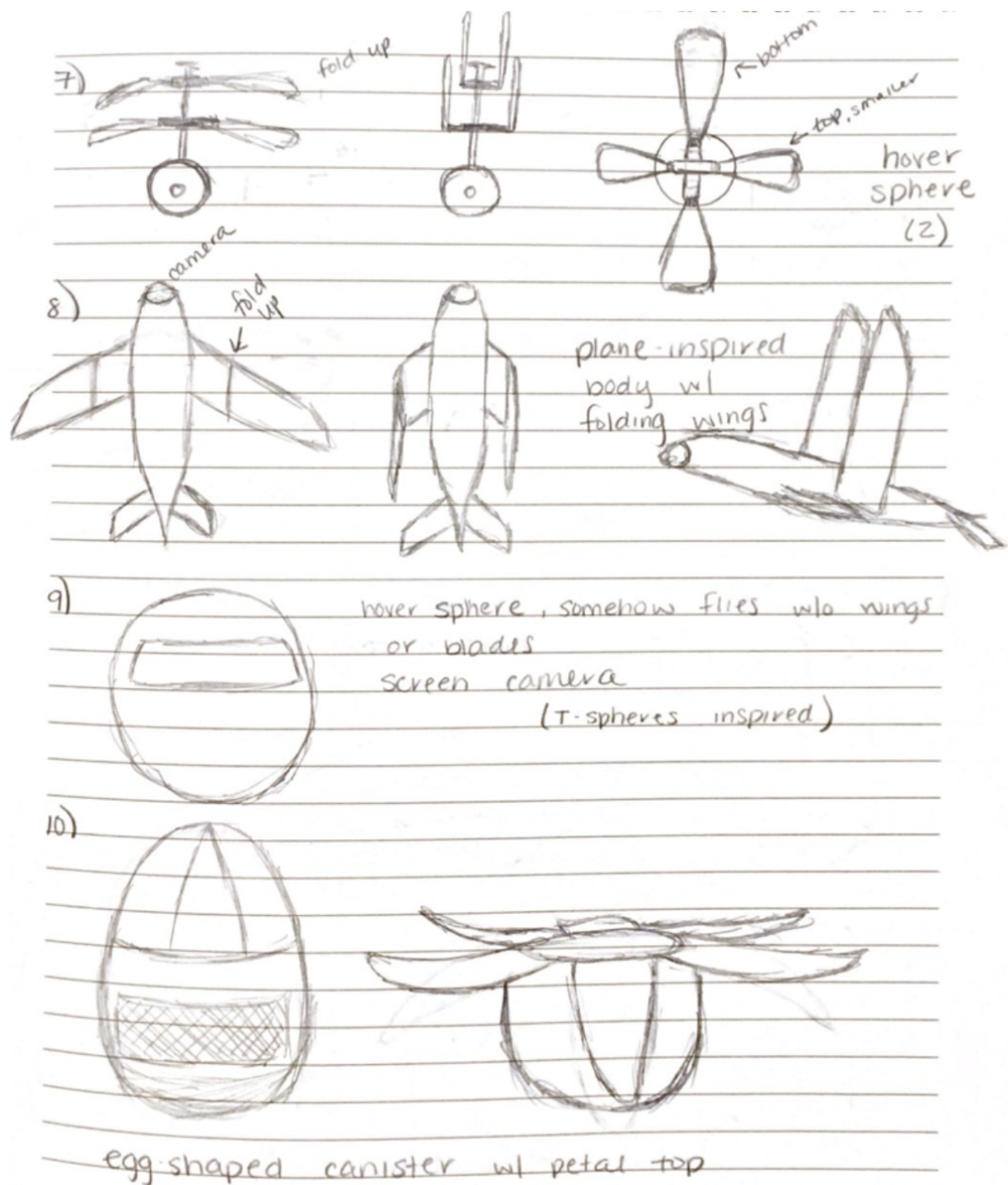


Figure 71: Hannah's Concept Designs 7-10

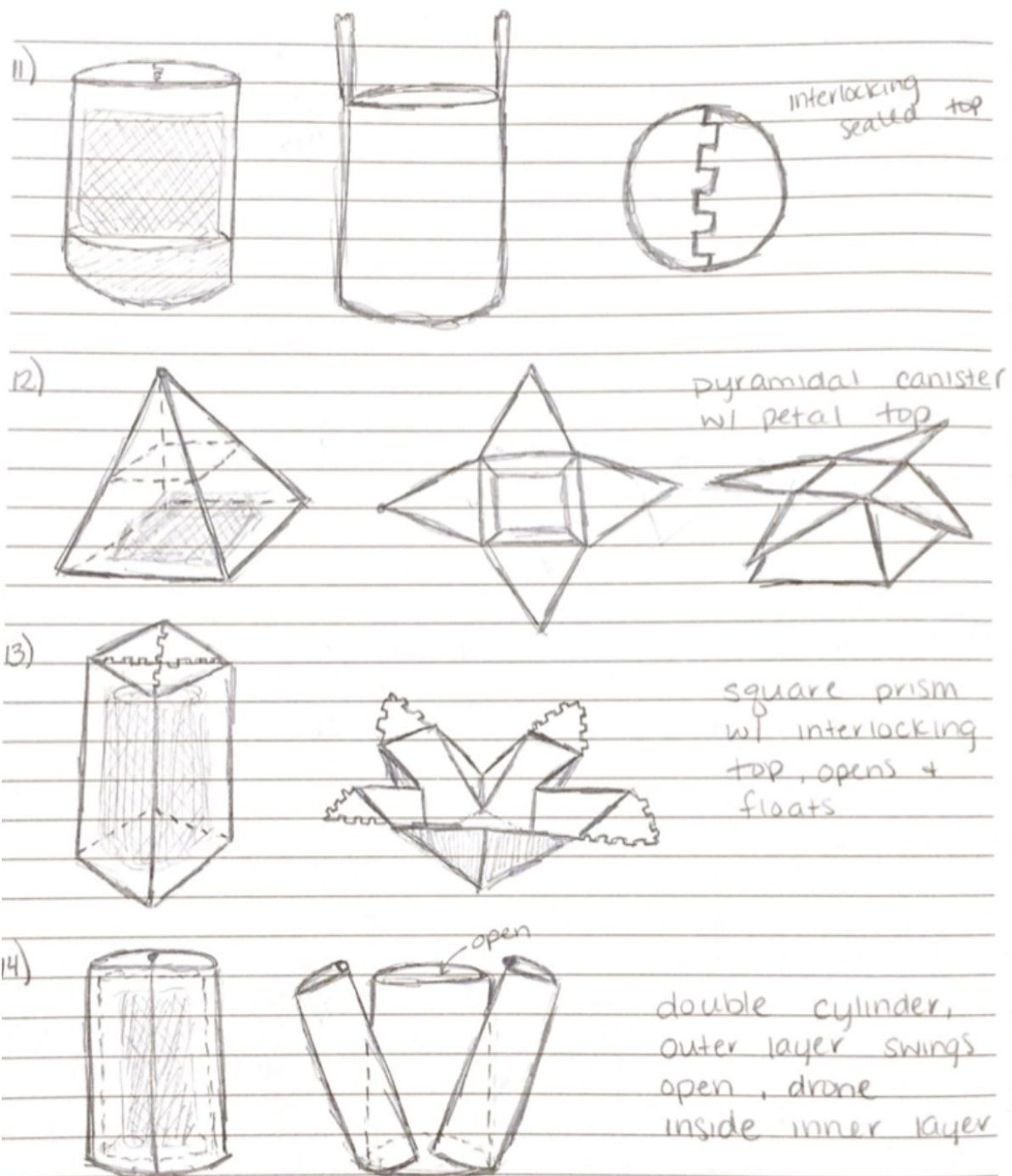


Figure 72: Hannah's Concept Designs 11-14

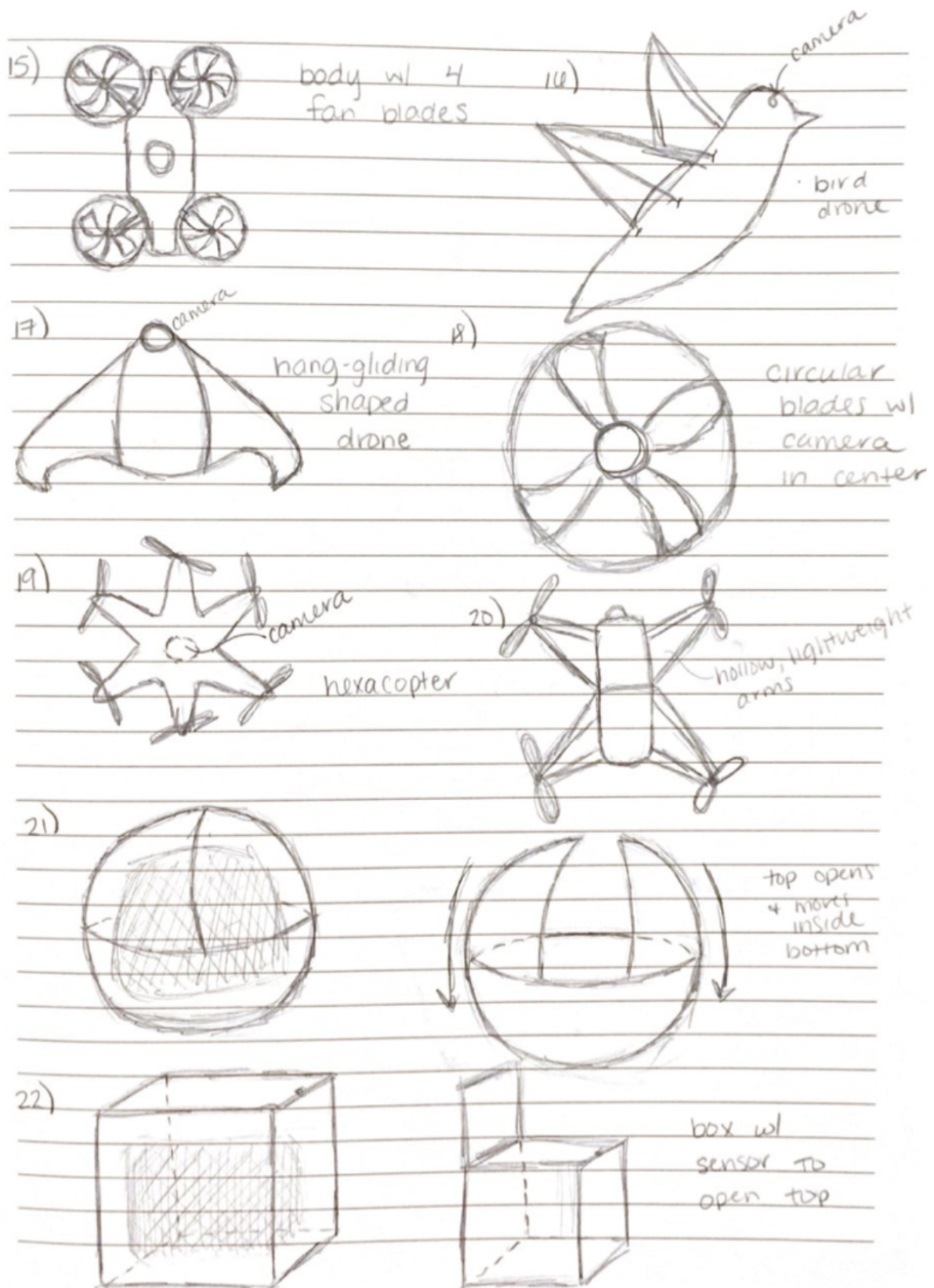


Figure 73: Hannah's Concept Designs 15-22

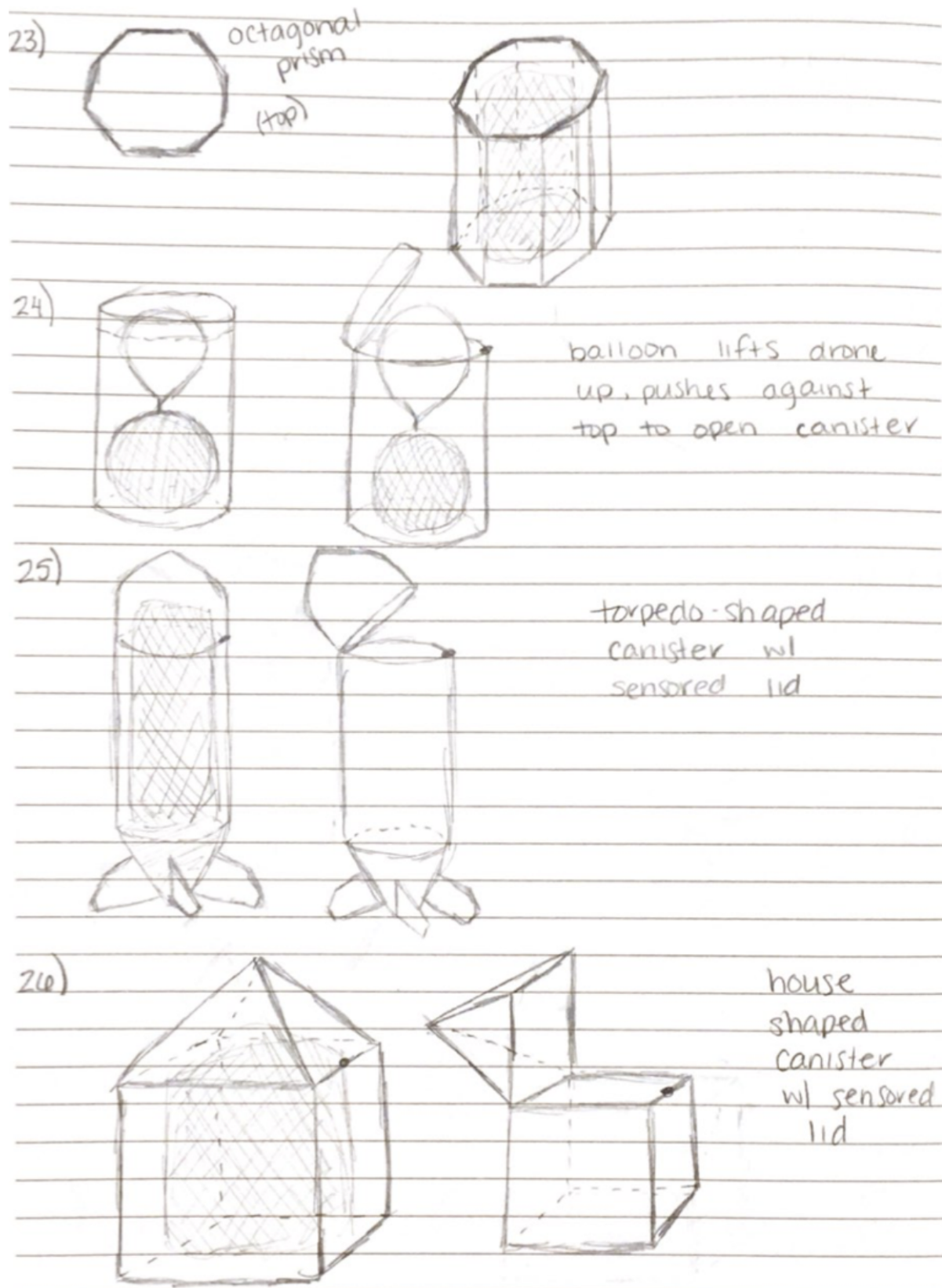


Figure 74: Hannah's Concept Designs 23-26

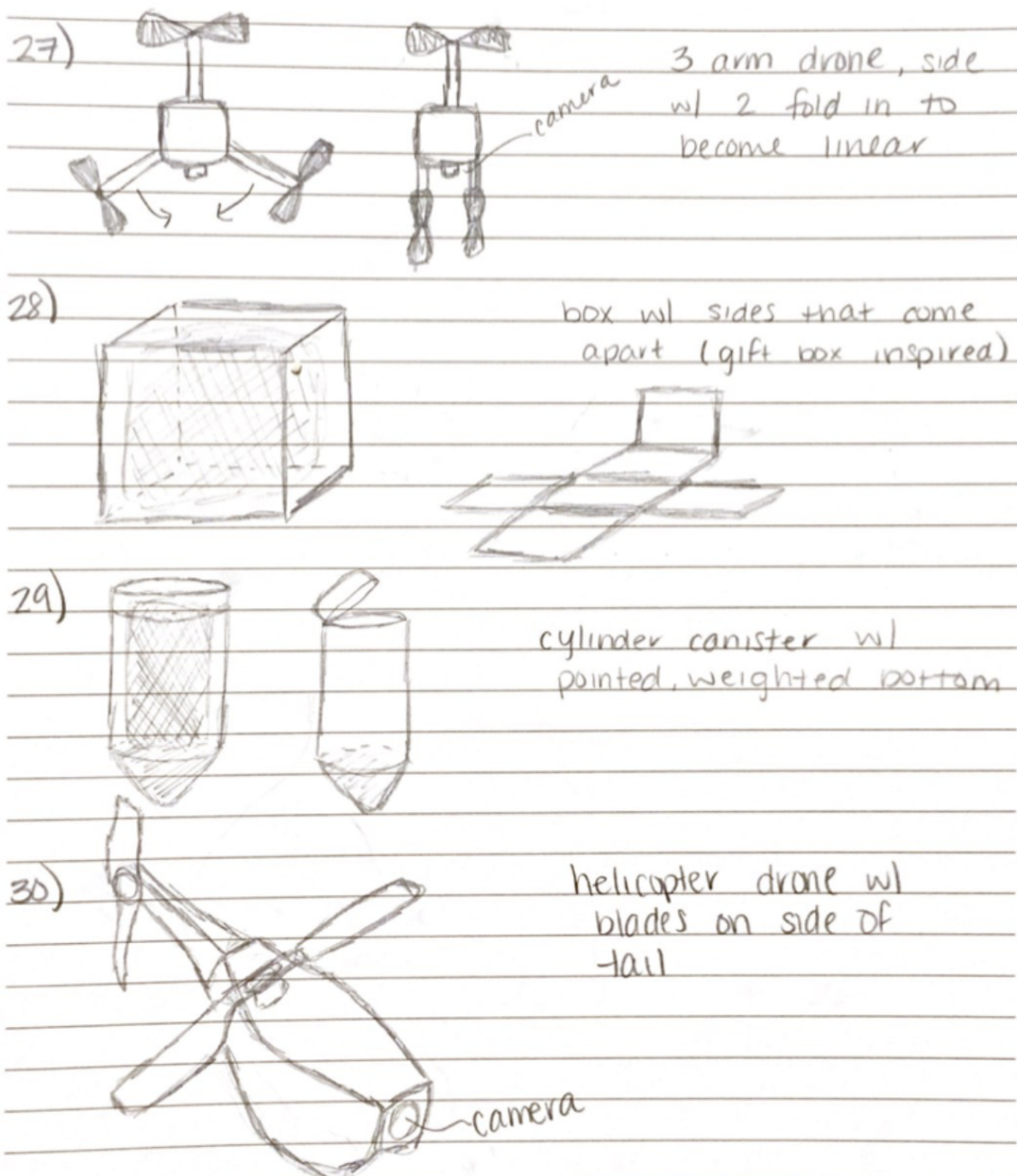


Figure 75: Hannah's Concept Designs 27-30

Engineering Criteria	Reference Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Weight	4, 6	+	+	S		+		+	-	+	-	S	+	-		+	+	+	+	+	+	+	S	S	-	+	+	+	S	+	
Width	4, 6	S	S	S		S		S	-	S	S	S	S	S	S	S	-	S	+	S	S	S	S	S	S	S	S	S	S	S	S
Length	4, 6	+	+	S		+		+	+	+	+	S	+	S	S	+	+	+	+	+	+	+	S	S	S	+	S	+	S	+	
Storage Volume	4, 6	S	+	S		+		S	-	+	+	S	+	S	S	+	+	+	+	+	+	+	S	S	S	-	-	S	+	+	
Weather Resistance	4, 6	S	S	S		S		S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Waterproof	4, 6	S	S	S		S		S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Battery Life	4, 6	+	S	S				+	+	+						S	+	+	+	-								+			+
Probability of capsule not opening	4, 6					S					S	-	S	-	S								S	S	-	S				S	
Probability of UAV jamming in capsule	4, 6	+	+	S		+		+	-	+	+	S	+	S	S	+	+	+	+	+	+	+	S	+	+	S	+	S	+	S	S
# of Fuses		4	4	0		4		4	1	5	3	0	4	0	0	4	5	5	6	4	4	4	4	0	1	0	3	2	4	0	4
# of Minuses		0	0	0		1		0	4	0	1	1	0	2	1	0	1	0	0	1	0	1	0	0	1	2	1	0	1	1	0

Figure 76: Hannah’s Pugh Chart

22 APPENDIX B - UAV AND CAPSULE DRAWINGS

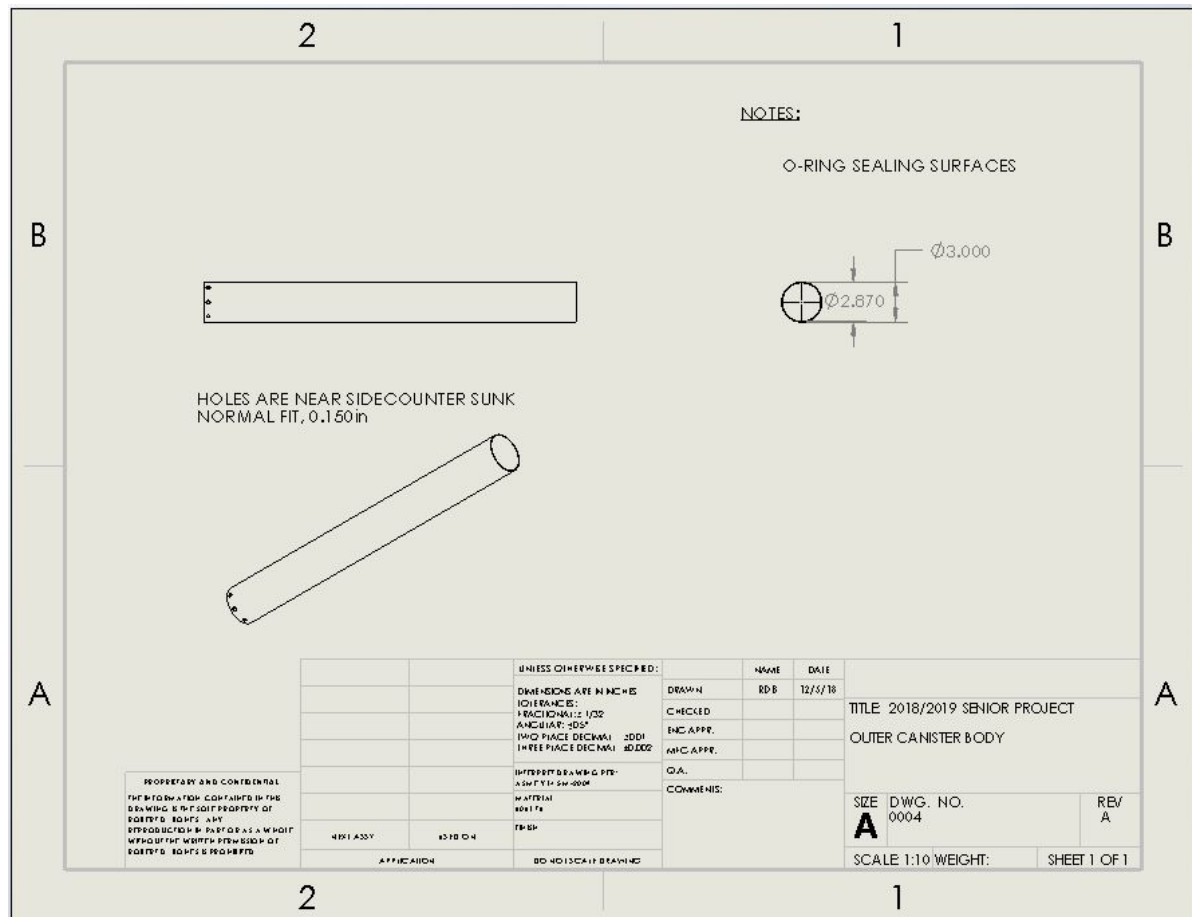


Figure 77: Drone Housing

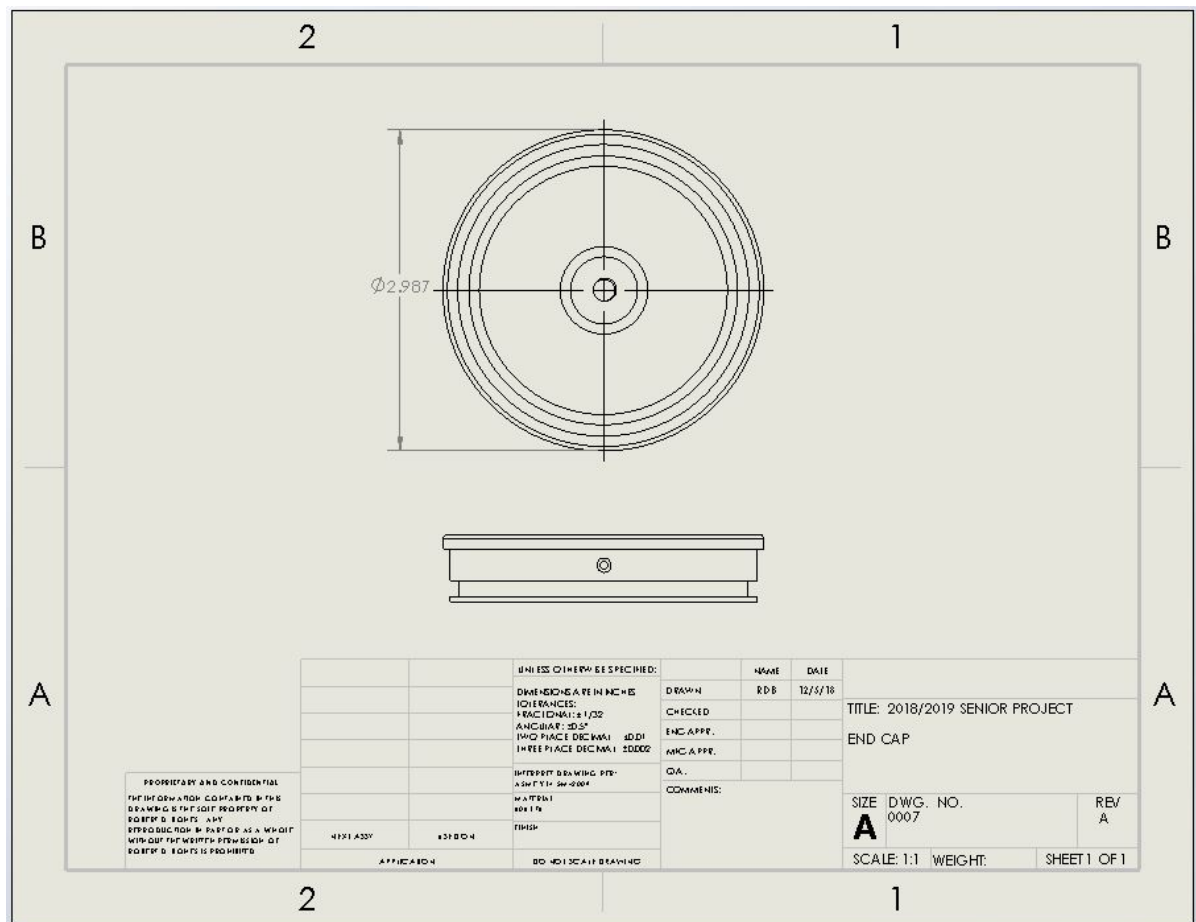


Figure 78: Barrel End Cap

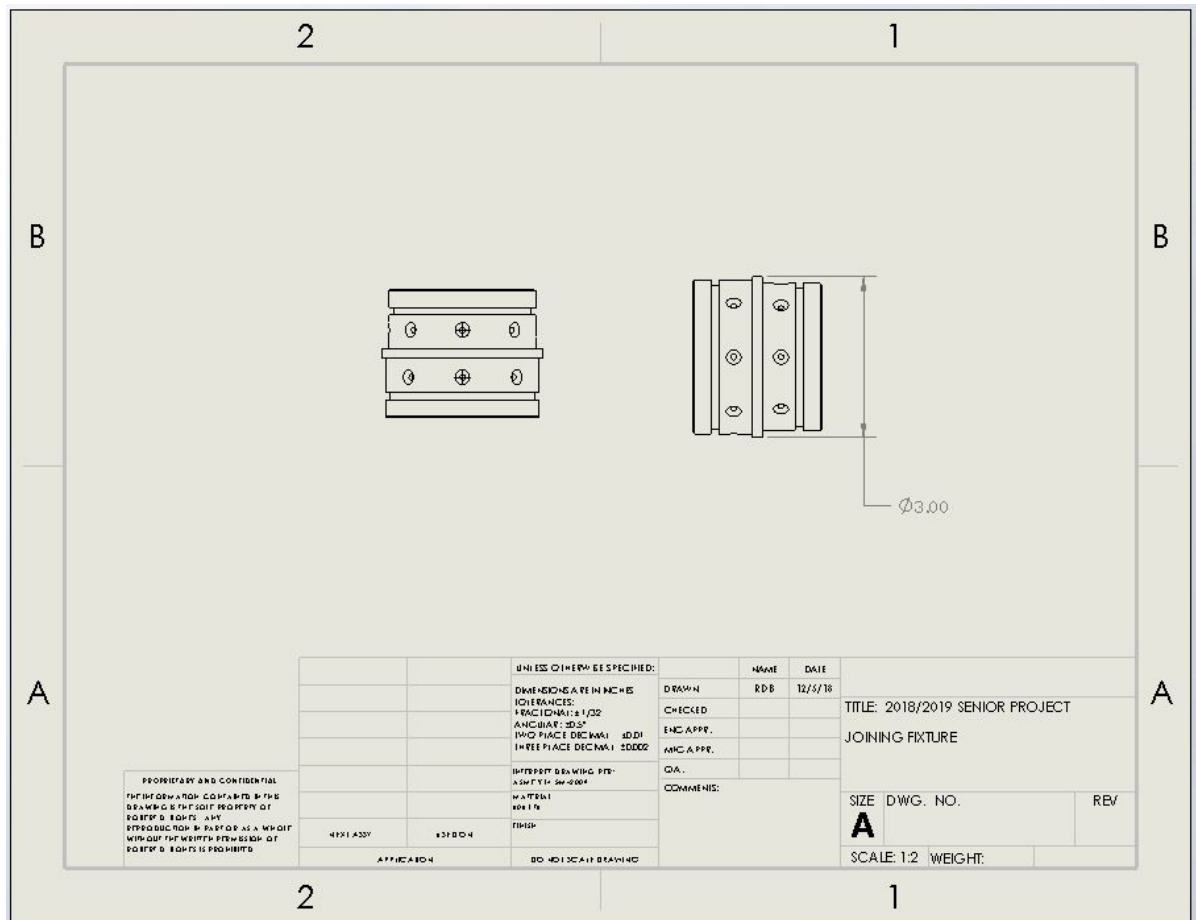


Figure 79: Joining Fixture

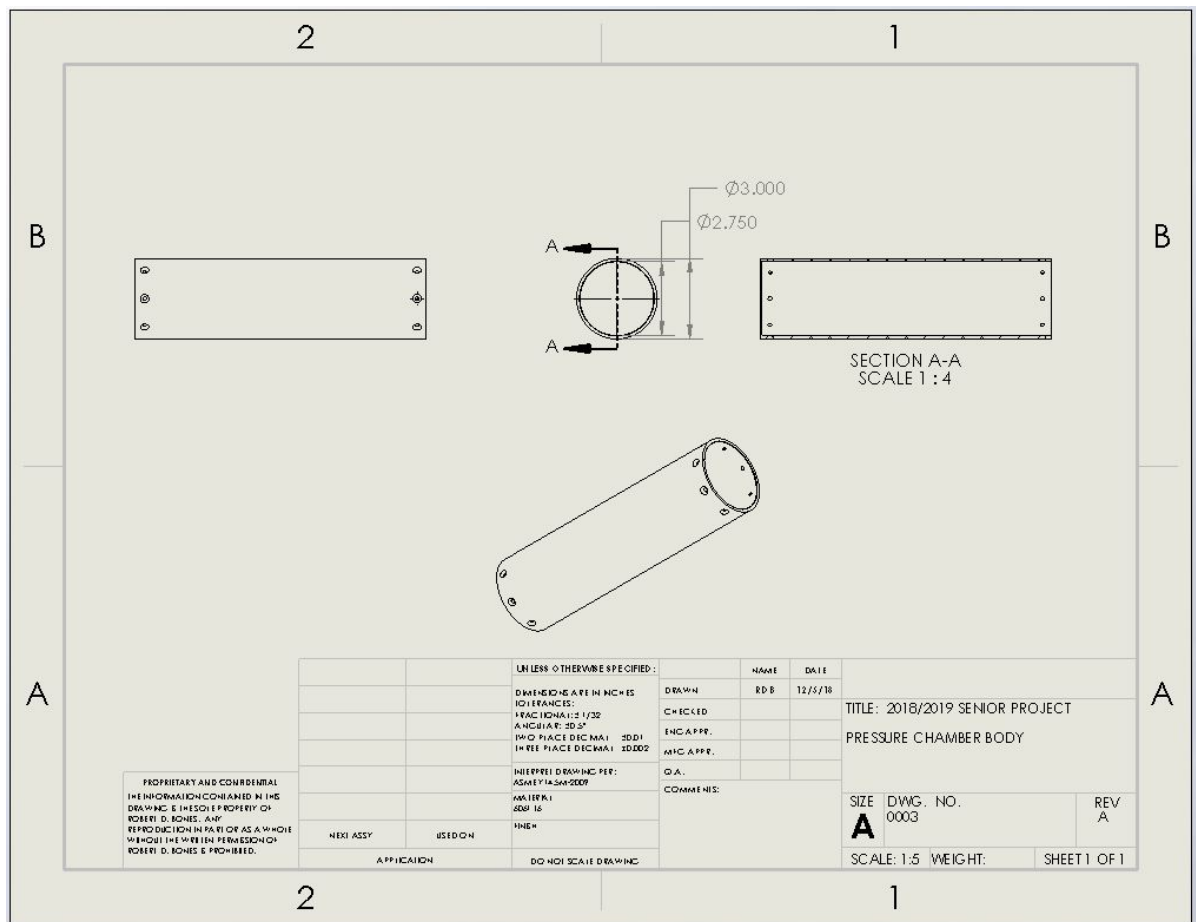


Figure 80: Pressure Vessel

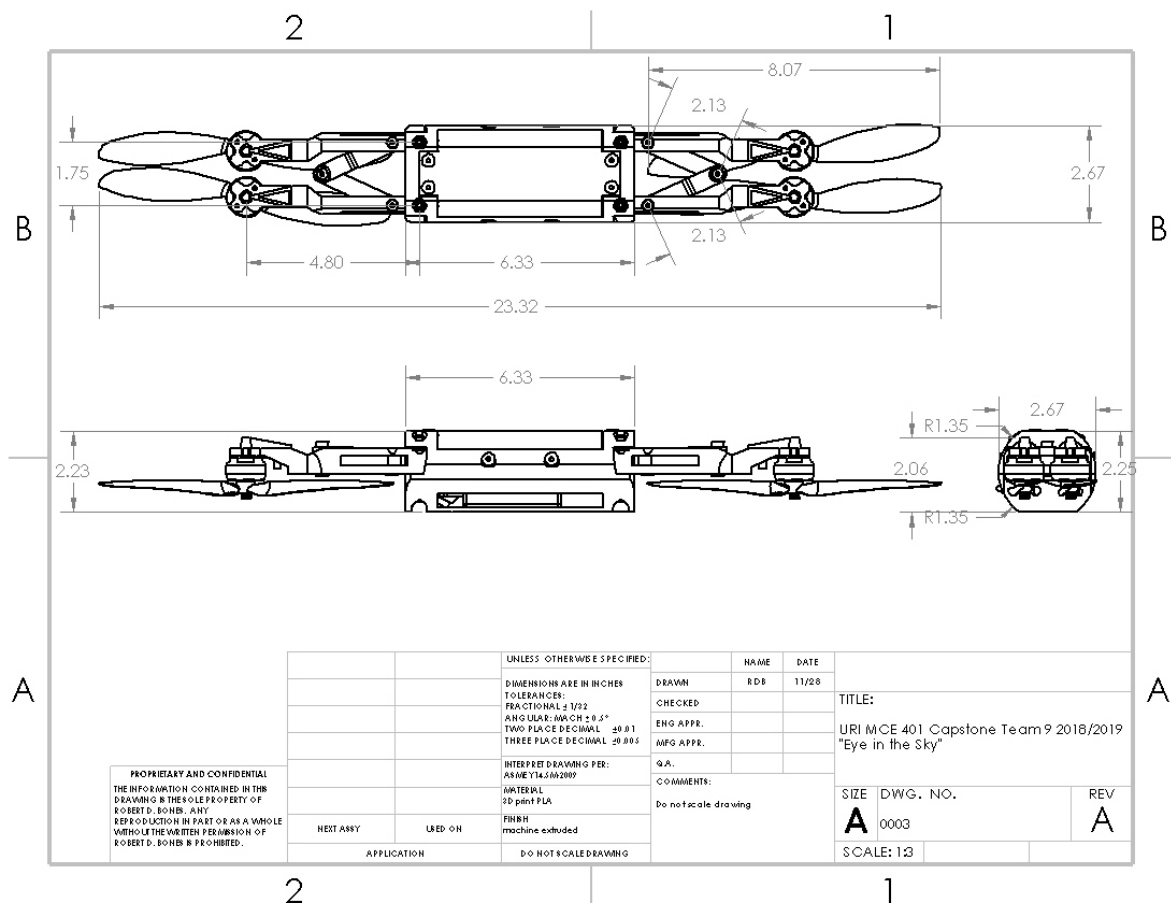


Figure 82: Dummy Drone

Quantity	Part Number	Description	Unit \$	Subtotal
1	arduino uno rev3	arduino control board	\$22.00	\$22.00
1	teflon tape	teflon tape	\$3.11	\$3.11
1	OSOYOO bluetooth shield	HM-10 master slave module for xbee arduino uno r3 mega 2650	\$9.99	\$9.99
1	21715	extruded aluminum bare round 6061 t6511, random lengths (10-	\$47.55	\$47.55
1	7054	drawn aluminum re tube 6061 t6,	\$133.12	\$133.12
1	4470	extruded aluminum bare tube	\$44.75	\$44.75
1	arduino relay	tolako 5v relay module for arduino	\$5.50	\$5.50
1	V25PAT5G825	Vortex 250 PRO	\$356.25	\$356.25
1	FXT FX508	FXT FX508 Monitor	\$99.99	\$99.99
1	solenoid	12V plastic water solenoid valve	\$10.32	\$10.32
1	battery pack	12 V AA battery pack	\$8.99	\$8.99
1	molykote	molykote oring/valve lubricant	\$5.98	\$5.98
1	battery charger	Keenstone lipo battery charger	\$49.99	\$49.99
1	9557K233	o-ring, 1/8 fractional width, dash	\$10.32	\$10.32
1	8063K33	air fill valve with 1/8 NPT Inlet and 3/8" long outlet	\$5.77	\$5.77
1	9557K234	o-ring, 1/8 fractional width, dash	\$11.26	\$11.26
1	battery	Lumenier 3300 mAh 3s 35c lipo	\$29.00	\$29.00
1	receiver	Spektrum DSMX 8-Channel	\$149.99	\$149.99
1	90825A953	Sealing Pan Head Screws	\$8.39	\$8.39
1	battery	Lumenier 1300 mAh 3s 60c lipo	\$29.69	\$29.69
1	receiver	Spektrum DSMX Quad race serial	\$24.95	\$24.95
1	programming cable	Spektrum transmitter/receiver programming cable: USB interface	\$22.18	\$22.18
1	molykote	molykote valve lubricant and	\$15.59	\$15.59
1	93625A100	18-8 stainless steel nylon-insert	\$5.31	\$5.31
1	92855A335	18-8 stainless steel low-profile socket head screws	\$8.40	\$8.40
1	9654K207	steel extension spring	\$4.33	\$4.33
1	BLH9202	ImmersionRC Cable Set: Vortex	\$15.99	\$15.99
1	conformal coating	ACL staticide 8690 acrylic conformal coating, aerosol, 12 oz	\$21.38	\$21.38
Items highlighted in gray are for the capsule			TOTAL	\$1,160.09

Figure 83: Bill of Materials for a Single Unit

23 APPENDIX C - PROJECT CHARTS

LATE TASKS

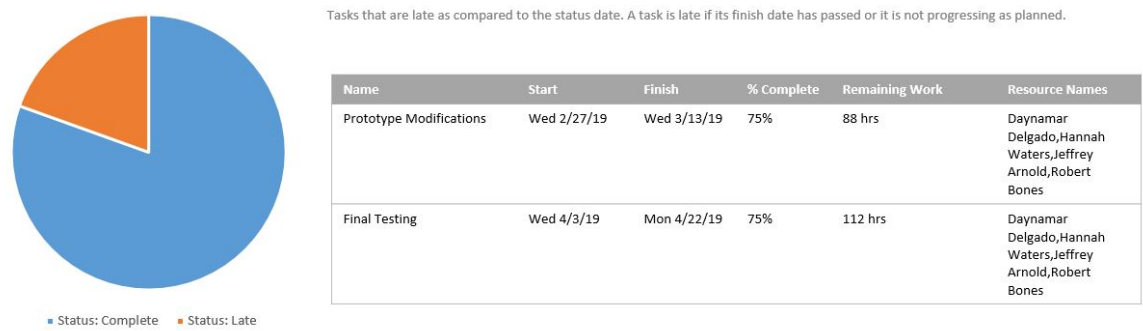


Figure 84: Remaining Critical Tasks

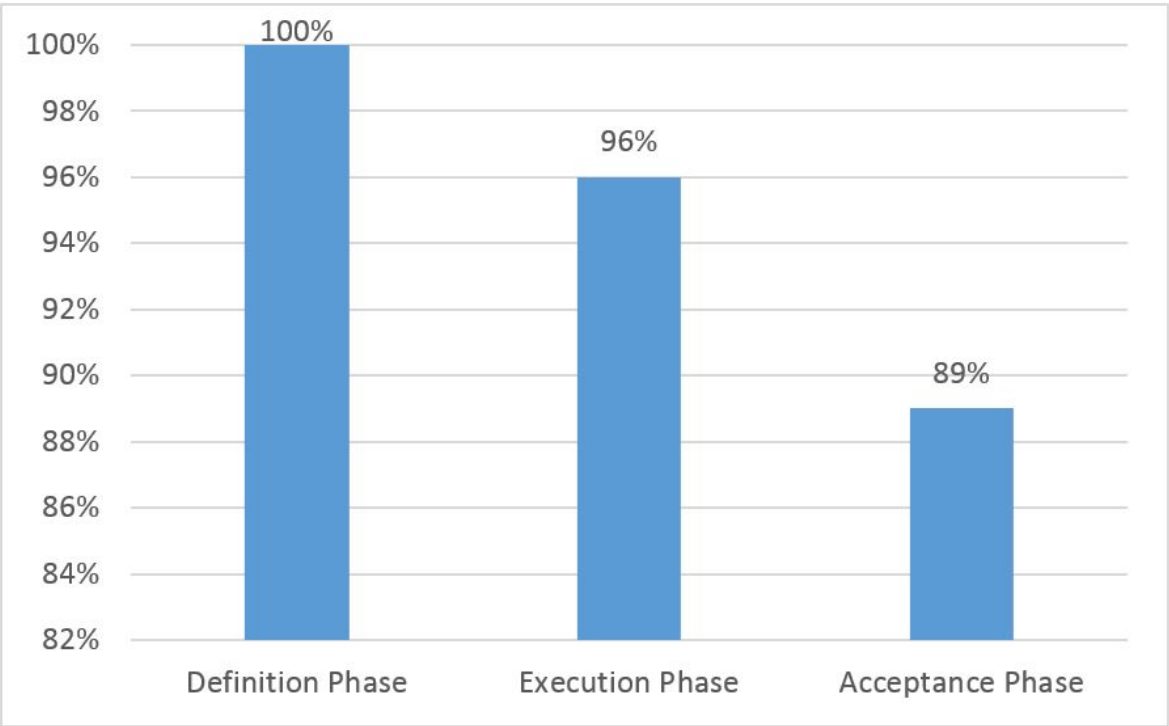


Figure 85: Work Completed

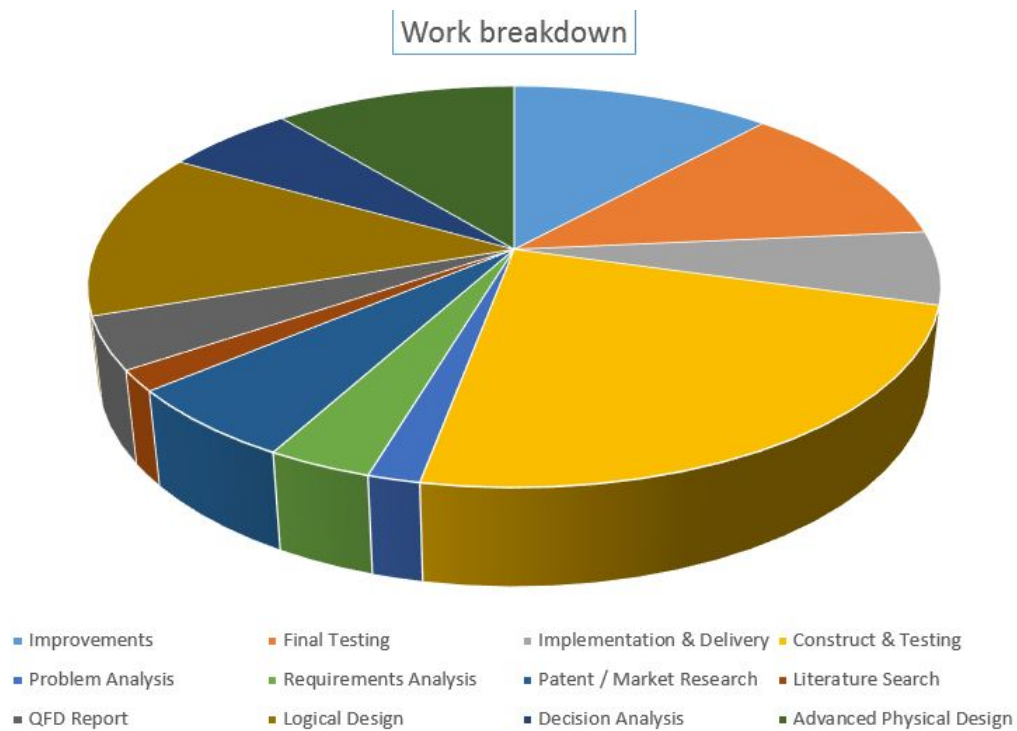


Figure 86: Work breakdown

24 APPENDIX D - ASSEMBLY AND OPERATIONS MANUAL

24.1 Item List



Figure 87: Capsule Items

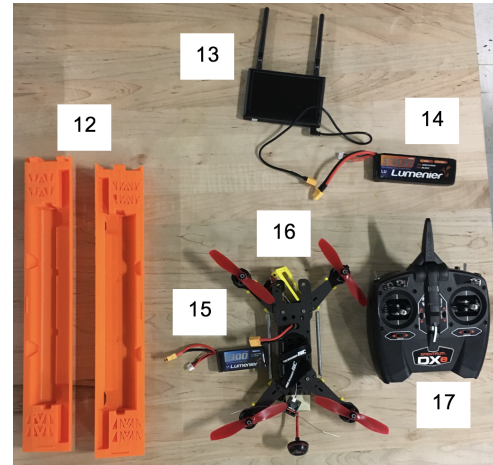


Figure 88: Drone Items

- | | |
|--|---|
| 1. Electronics carrier (plus 13 screws not pictured) | 10. 24 screws |
| 2. Molykote | 11. Capsule barrel |
| 3. Phillip's head screwdriver | 12. Drone carrier |
| 4. Pressure chamber | 13. Monitor |
| 5. Solenoid and PVC | 14. Monitor Battery (Lumenier 3300 mAh) |
| 6. Coupling | 15. Drone Battery (Lumenier 1300 mAh) |
| 7. Pressure chamber end cap | 16. Drone |
| 8. 4 o-rings | 17. Controller |
| 9. End cap | 18. Air compressor (not pictured) |
| | 19. Allen key size M4 (not pictured) |

24.2 Initial Assembly Instructions

For pressure chamber, coupling, solenoid/PVC, and electronics carrier

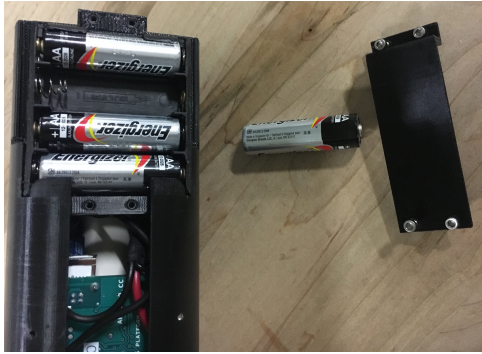
1. Make sure all materials pictured above are present
2. Lubricate 3 o-rings and grooves with Molykote
3. Place o-rings in respective grooves (1 in pressure chamber end cap and 2 in coupling)
4. Lubricate pressure chamber end cap
5. Insert pressure chamber end cap to weighted end of pressure chamber and screw into place (will use 8 of the 24 screws)
6. Lubricate and screw coupling to other end of pressure chamber (will use 8 of the 24 screws)
7. Twist solenoid and PVC into largest hole in coupling
8. Slide electronics carrier over PVC valve and use 4 screws to hold in place (set of 4 needing Phillip's head)

24.3 Operation Instructions (including rest of assembly)

1. Make sure all materials pictured above are present
2. Lubricate remaining o-ring and end cap with Molykote



-
3. Place o-ring in groove
 4. Insert 8th AA battery into electronics carrier battery pack, cover, and screw in place (set of 4 needing Allen key)



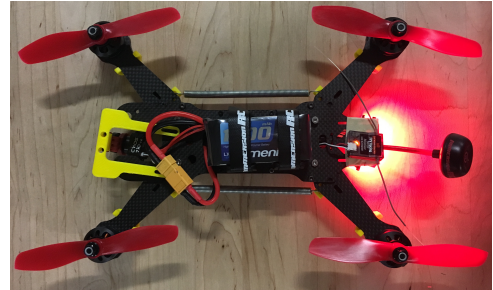
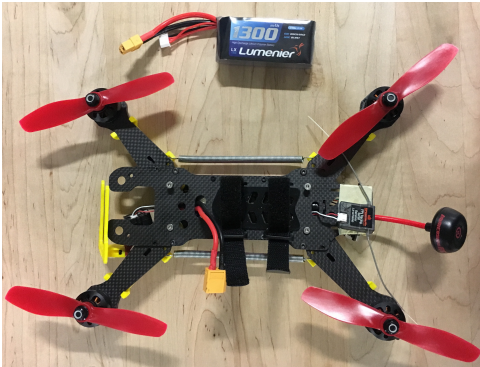
5. Place other side of electronics carrier on and screw into place (will use remaining 5 of the 9 screws)



6. Lubricate coupling, slide capsule barrel on to coupling, and screw into place (will use remaining 8 screws of the 24)



7. Connect battery to drone



8. Connect battery to monitor

9. Turn on controller by sliding middle switch up (if the transmitter and receiver are not bound, follow binding instructions)

10. Ensure monitor is displaying FPV images

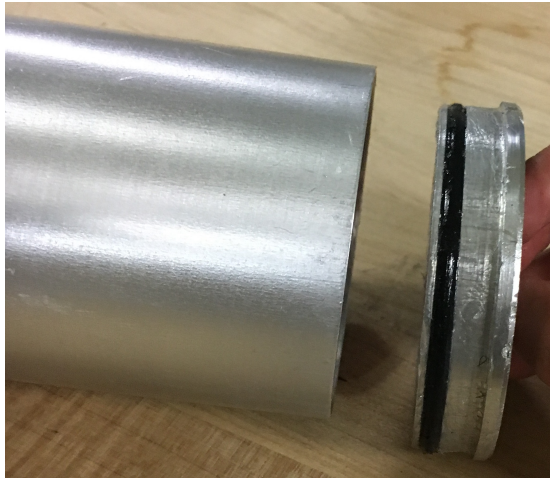
11. Load drone into carrier



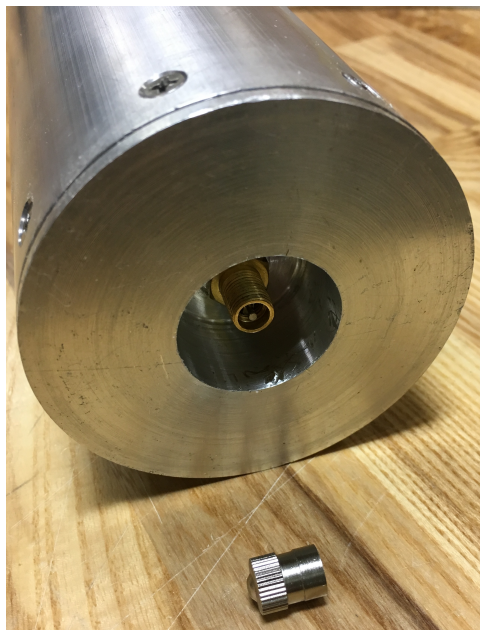
12. Slide drone and carrier into capsule barrel



13. Lubricate the end cap and place on end of capsule barrel



14. Remove the cap to the pressure valve



15. Use air compressor to pressurize the pressure tank to 100 psi



16. Put cap to pressure valve back on



17. Use app to connect device to Arduino UNO via Bluetooth and set timer to desired number of seconds

Settings

Connection Settings

Not Connected

Find Devices

6CC4CED2-5231-AC95-6530-250...

65881380-3CD2-6C41-24A8-CC5...

66889FF5-F0E5-9744-51B3-837E...

8A0B4105-5902-666D-8F16-E5C4...

FA549009-D0D8-9203-B87C-24E...

1C31F9E3-EF64-1A35-E691-3D06...

Command

Edit

Text

Send

zero delay, instant launch

twenty second launch delay

one hundred second launch delay

two hundred second launch delay

- Release capsule into water
- After seconds, drone should be expelled
- Use controller to fly drone
- Press button on upper right corner of monitor to record video

24.4 Binding Instructions

- Turn on the drone by plugging in the battery
- Hold bind button on controller (upper left button on top side)
- While holding bind button, turn on controller (slide middle switch up)
- Continue holding bind button until orange blinking light on receiver stays solid (not blinking anymore)

24.5 Troubleshooting Guide

Problem	Possible Solutions
App says communication with Bluetooth failed	<ul style="list-style-type: none">• Move device closer to Arduino, hold device no farther than 6 inches away• Remove end cap and check if green LED is on (green means it is connected, red is not connected)• Disconnect device from Bluetooth and try to reconnect
Air pressure is not remaining constant (loss of air pressure)	The gasket, fill valve, and/or solenoid could have a leak. Check to see if there is a leak by placing the pressure tank into a tub of water with soap. If bubbles form, there is a leak in one or more of these areas. If there is a leak, replace parts.
Valve does not release air	<ul style="list-style-type: none">• Check for leaks using the method mentioned above• Bluetooth connection may have failed, check connectivity using methods above• Arduino could be damaged, may need replacing• Solenoid valve could be damaged, may need replacing
Drone and controller are not binding	<ul style="list-style-type: none">• Unplug battery from drone and turn off controller• Make sure the controller is turned off before holding the bind button• Follow binding instructions again• Make sure not to let go of the bind button until the light stops blinking

Monitor is not showing feed from camera	<ul style="list-style-type: none">• Make sure the cover is not on the camera lens• Switch the channels on the monitor by toggling the button on the back of the monitor• Make sure camera did not become unplugged
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