Team 518: Drone Disabling Device

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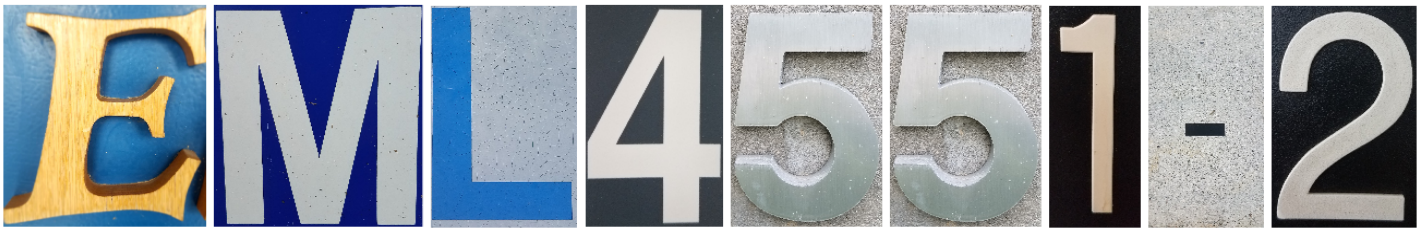
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Abstract

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1.1 Project Scope

The objective of this project is to design a device that is used to protect and secure airspace from unmanned flight vehicles. The major key goals are to detect, neutralize, and secure the unmanned flight vehicle. This project is a continuation of work from a previous team and is tasked with decreasing the form factor, adding a detection system, and improving the functionality. The primary market for this product will be government and military operatives, with the secondary market being contractors, private security, and defense companies.

The device is assumed to be primarily used in defense and security operations. It is not intended for civilian use, but to neutralize civilian unmanned aircraft (specifically drones). These aircraft can pose threats to the safety of attendees at major public events or important private gatherings. The design will be focused on increasing device portability and the addition of a detection system. Portability will allow the user to move more freely and adjust to frantic drone movements. The current device is bulky, cannon like, cannot be easily transported, and has a long assembly time. The detection system addition will give the device a slight autonomous feel while still being manually operated. Assembly and integration of the device into security tactics before an event takes place are needed to optimize the device's overall presence.

The stakeholders for this project include Tameika Hollis and Stan Zoubek of Northrop Grumman, and Shayne McConomy and Jonathan Clark of the FAMU-FSU College of Engineering.

1.2 Customer Needs

The sponsor of this project is the executive director of Northrop Grumman Mission Systems, Tameika Hollis. Due to the difficulty of schedule matching to initially meet with Tameika, more specific details and assistance was received from Stan Zoubek, who is the Chief Engineer at Northrop Grumman for E-2X Advanced Technology. The following questions were initially asked to address the needs of the Drone Disabling Device project:

1. What is the size and type of drone to be neutralized?

Recreational drones that could be carrying IEDs or have cameras.

2. How long does this device need to be operable for?

The device should be operable for the time necessary until the user powers it off.

3. What is the outcome of the neutralized drone?

We are looking to just neutralize the drone given the time constraints, but if possible, recover the drone if it is not destroyed completely.

4. Is the device expected to be autonomous?

No, due to time constraints it will most likely not be possible; but ideally that is what we would want.

5. Is there a specific range that the device must function within?

100 yards in radius, 100 feet altitude. Constraints may need to be adjusted due to not being possible to meet.

6. Does this device need to be portable?

Yes, must be able to assemble the device within 4 hours.

7. What is the purpose of Northrop Grumman sponsoring this project?

To aid-to-hire and give students an understanding of the learning process. Northrop Grumman is not looking for a proof of concept to scale.

After analyzing these questions, it was determined that the original needs of the project were to disable non-military, recreational drones; have a device operable for as long as possible; being able to at least disable the drone (recovering the disabled drone would exceed customer expectations); have a user-operated device; operate the device at the maximum range possible; design the device to be portable and quick to set up (within 4 hours); and to focus on the project development process rather than the product.

Many of these needs were addressed by last year's Drone Disabling Device project team, but our team was instructed to make the device smaller (preferably close to the size of a paintball gun) with improved functionality such as: improved drone detection, quicker target acquisition, and quicker assembly and disassembly time, and delivering a product that is sleek in design.

1.3 Functional Decomposition

The objective is to secure air space from civilian drones, and these was separated into the following functions:

- Assembling and disassembling the device
- Locating the drone
- Neutralizing and securing the drone

The sub-functions can be seen in Appendix B in the functional decomposition.

1.4 Target Summary

Target 1 quantifies the time it takes for a user to assemble and disassemble the drone disabling device, to ensure that the device can be conveniently transported and set up in various locations whenever desired. Our device is targeted to be designed to be mobile, rather than stationary, so one hour is set as a marginal value for a mobile setup. The ideal value would be five minutes or less of an assembly and disassembly time which would allow for the product to be easily transported to various locations where an unauthorized drone is speculated to be. This target will be verified by repeatedly timing the user assembly and disassembly of the device after it is constructed. Failure to meet this target cannot easily be corrected and would require a substantial re-design of the device.

Target 2 is a summarized value of all components of the device. This includes the power source, air tank, and external additions. This weight can be distributed throughout the user by implementation of a pack, rifle sling, and/or device storage off operator. Through low weight and weight distribution the devices mobility will increase, and operation of device will be more comfortable. The marginal value is 30 lbs. and the ideal value is 20 lbs. The device weight will be verified through weighing components of the device on a scale. The target is important but failure to meet the ideal value will not prove fatal to the device design.

The disabling range of the device deals with the distance that the device can successfully neutralize a drone. From the target values listed, a drone must be anywhere marginally within 30 feet and ideally within 50 feet of the operator for the jammer to successfully infiltrate the drone's receivers. If still hovering after a jamming attack a projectile will be used to fully secure the airspace. Target 3 is important as it deals with the devices range, however it is not a key objective for this project, so it is rated a three out of five of importance. This target will be verified through device testing.

The target acquisition speed is the time that it takes for the detection system to correctly identify a drone flying within the specified radius of the device. The ideal target acquisition speed for the device is 5 seconds and the marginal speed is 20 seconds, so that the user of the device can quickly begin to neutralize and capture the drone. This target is rated at 4 for importance because one of the key objectives of the project is to develop a working detection system, however if the device took up to 20 seconds to acquire a target, it would not prevent the drone from being neutralized. This target will be verified by measuring the amount of time it takes for the detection system to identify a drone when it enters the device's radius.

Target 5 is the battery life used for the device. This target refers to the battery used in the detection and jamming systems. Since both systems are computerized a laptop battery was used as an example for the marginal and ideal values. A single battery for both devices is optimal and would be preferred in the design of this device as it can be stored in an external storage on the device or operator. The use of a battery will further increase device mobility and the battery life should be long enough to see the operator through a full event if needed. This target will be verified by testing the device batteries and timing the life of the battery from a full charge to depletion.

Target 6 is the range of frequencies jammed on the targeted drone. As a marginal value target, the signal jamming component must at least jam 2.4GHz signals between the drone and its controller. A 2.4 GHz signal is the most comment band used to control a drone, but some drones are also driven by a 5 GHz signal, which is why it would be ideal for the device to be able to jam both the 2.4 GHz and 5 GHz bands. These targets will be tested by using the signal jamming device on devices known to be communicating with the frequencies and seeing if the signals are successfully jammed.

Target 7 is the reload speed of the device and refers to the time required from when the device is fired to when it can be fired again. It was chosen because the device should be able to fire repeatedly in a reasonably short period of time in case of multiple drones. In this case a short enough period would be 5 minutes with the ideal time being only 1 minute. To access whether this target was successful the time between firings will be measuring to determine the maximum fire rate of the device. Failure to achieve this target will result in the device not being able to handle multiple drones severely limiting its effectiveness.

Target 8 is the target max drone wingspan, and this refers to the wingspan of the drone that is being disabled. The wingspan of a drone is described as the point to point distance from the two furthest apart rotors. This target is chosen based on the largest commercially available drone having a 30in wingspan, but a marginal value would be a smaller drone at 20 in in wingspan. This will be tested by showing its effectiveness on the largest possible drone available to be tested and extrapolating its effectiveness on the larger drones. If the device fails, this target it will mean it is not capable of disabling drones that can be acquired by the public.

Target 9 is the max drone weight and is based on the heaviest possible drone that the net will be effective against. It is measured in pounds and the ideal weight this device will be able to secure is a 6-pound drone which is a heavy commercially available drone. This will be tested by showing its effectiveness on the largest possible drone available to be tested and extrapolating its effectiveness on the larger drones. If the device fails, this target it will mean it is not capable of disabling drones that can be acquired by the public.

The final target, target 10, is the project cost. Since the project cost is dependent on most of the previous targets it is a 5 of 5 in importance. The budget given for this project is $5000 and should not be exceeded, this is also the marginal value used. This budget allows us to see the possible devices to be designed and fabricated. The ideal value would be half, if not less, of the budget given. Remaining below budget is an important objective of this project. The verification of the project cost will be completed through proper finance organization. Saving receipts of all expenses and documenting will allow is to maintain our targeted value.

1.5 Concept Generation

The beginning stages of our concept generation was focused on creating as many potential ideas for our project as possible. Brainstorming a substantial volume of ideas was important not only for analyzing the feasibility of various combinations of components, but also for creating component combinations that were previously unthinkable. To properly organize the concepts of our project, concepts were separated into several categories of which overall system concepts could be generated. These categories were jamming, capture, projection, net design, net counter-weight, detection, size-reduction, target impact protection. The following is an overall list of potential drone disabling device ideas:

1. Neutralization

Neutralization of the target drone is the key function of the drone disabling device. The first stage of successfully neutralizing the drone begins with interfering with the signal between the hostile drone and its controller. After researching how drones react when losing signal with the controller, it was discovered that drones tend to either hover in the air until communication is re-connected or the drone will slowly descend down to Earth. Both of these situations would result in an easy capture of the drone. Most drones currently use Wi-Fi to communicate with the controller. For this reason, we have decided that our jammer will jam either the 2.4 GHz, 5GHz, or both of these frequencies; which are the most common radio-communication frequencies utilized in Wi-Fi communication. Due to federal laws implemented by the FCC, concepts in regard to jamming will not be manufactured or used in this project but may be assumed active in device functions. In addition to the wireless jamming of the drone, one design concept is embedding a Faraday Cage into a net to be launched at the hostile drone. A Faraday Cage has electromagnetic properties that causes radio waves to be substantially attenuated (reduced in power). As a result, the captured drone would be unable to receive a strong enough signal to receive control. In addition, this design would be legal under FCC standards. After analyzing other concepts, it was determined that several of these concepts are either illegal to implement on a non-military scale or would be infeasible to successfully neutralizing common recreational drones. For this reason, our best concepts out of the overall list are jamming 2.4 GHz, 5GHz, or both of these frequencies, and launching a Faraday Cage-embedded net at the hostile drone. Concepts for the neutralization system are listed below in Table 1.

Table 1. Compiled concepts for the neutralization system.

System	Concept
Neutralization	RF - 2.4 GHz
	RF - 5 GHz
	Bluetooth
	Infrared
	Cellular

	GPS
	EMP
	Faraday Cage
	Satellite
	Ultrasonic

2. <u>Capture</u>

Capturing is another essential function of the drone disabling device. These concepts were all generated in order to safely retrieve the drone without destroying it so that it can be examined once it is captured. Our best options for drone capture are using a net to cover the drone's propellers to cause it to fall, counter-drone towing to redirect the flight of the drone to the ground, and a hook to intercept the drone from the ground. The counter-drone would need to be deployed and manually steered close to the target, connected to the target via some sort of rope or hook, then guided by a user safely down to the ground. The hook would need to be connected to a rope, then shot from a rifle to connect to the drone so that it could be pulled down by a user. The final design will most likely implement the net concept because we view it as the most effective, most practical solution for drone capture. In addition to the net weighing the drone down, the spinning propellers for the drone are highly likely to get stuck in the holes of the net, stopping them from spinning, thus causing the drone to fall. Ideas for capturing the drone are listed below in Table 2.

Table 2. Compiled concepts for the capturing of the drone.

System	Concept
Capture	Net
	Hook
	Counter-Drone Towing
	Magnet
	Take Over Controls
	Silly String
	Projectile
	Sticky Substance
	Plunger

3. Size Reduction

These are the selected possibilities on how to decrease the overall size and weight of the device in order to make it easier to operate. These Size Reduction methods will also help to reduce the assembly time of the device so that it can be easily assembled in our ideal target time of 5 minutes. The final design will most likely contain multiple of these concepts in order to maximize the amount of size reduced. Incorporating a disposable compressed air system would improve upon the current design with its large compressor but this has its consequences because the device would not be able to be fired as repeatedly without the compressor, but this trade off would be worth this because of the massive decrease in size and weight as long as the pre-compressed air provides the same launch range.

Table 3. Compiled concepts for reducing the size of the device.

System	Concept
Size Reduction	Disposable Compressed Air
	Handheld Net Launcher
	Counter-Drone Net Deploying
	Lithium-Ion Battery
	Solar Powered
	Hand-Cranked Pressure Building

4. Propulsion

To launch a net or hook into the air, a force exerted behind the object is required. This force can be created by a buildup of pressure, a reaction of compounds, or even man powered. Mobility plays a major role in our decision of device propulsion. Any ideas generated that hindered this mobility were easily eliminated, i.e., catapult/hydraulic. Compressed air, combustion, spring launched, and a motor are our best options for device propulsion. Through the use of compressed air/CO_2, a buildup of pressure can be created and released in a narrow path and launch a projectile into the air. This is proved in Bernoulli's equation $P_1+(1/2)\rho v_1^2=P_2+(1/2)\rho v_2^2$ which states that following incompressible continuity, if $A_2>A_1$ then $V_2<V_1$. So, compressed air/CO_2 being funneled through a small diameter barrel like path is a feasible option in launching a net or projectile. Looking at the physics behind bullets using gunpowder, a compound with less explosive force may be an operable source of propulsion for this device. Though it is important to keep in mind, it is not intended to damage or destroy the drone. A spring with the proper specifications and compressed state could exert this non-lethal force needed. Nerf guns and spring powered pellet rifles are prime examples of this force. This is a simplistic solution to our problem and is an important concept we hope to work with. Moving the device to be fully electrical with a battery powered mechanical motor is another option that allows us to vary the force and power output through proper gear ratios. Of

these four concepts, compressed air/CO2 and spring powered are our best choices. Propulsion ideas for the device to fire into the air are listed below in Table 4.

Table 4. Compiled concepts for propelling the net into the air.

System	Concept
Propulsion	Compressed Air/CO2
	Combustion
	Electromagnetic Force
	Throwing
	Spring Launched
	Hydraulic
	Slingshot
	Catapult
	Motor
	Counter-Drone Deployed

5. Net design

With a net being our best choice of firing to capture the drone, we went further in depth with the concept and looked at possible materials to have the net made out of. Typical net materials include Nylon and Poly Dracon, and both are our top choices. Nylon netting is known to have superior strength and durability, which will withstand breaking from the drone blades. It will also outlast most roping's or nettings due to its UV and rot resistance. Poly Dracon uses plastic fibers to add strength while remaining a lightweight and cost-effective choice. It has a low stretch and high grip that will not allow the drone to escape when coming in contact with a blade. Net materials like metal, ceramic, and wool are not good choices for this project. Metal netting would be heavy and require extra work from the device to launch it into the air. It also would have high drag. Ceramic netting would be too fragile and may fracture or break from a propulsion force. Wool may be too weak and lightweight, meaning it wouldn't be easy to launch and may rip when contact happens with the drone. The best options of net material for our device are Nylon and Poly Dracon. Below in Table 5 is a list of concepts for net materials.

Table 5. Compiled concepts for the net's design.

System	Concept
	Mesh (Plastic)
	Retractable
	Rope
	Poly Dracon

Net Design	Spider Web
	Metal
	Ceramic
	Cloth
	Magnetic
	Rubber
	Semi-Conductive
	Nylon
	Wool
	Silk

6. Net Counter-Weight

Deciding on which concept of a counter-weighted net should be used is still open for debate. It is undecided on whether any of the concepts listed in Table 6 will be implemented. The net counter-weight will add a weight to the net and allow it to be launched into the air with ease. Ideas of counterweights like the four-small weight “clover” or one large weight center are the best choices of the list. Though the one large weight in the center may prove problematic when launched into the air, it may act as projectile and damage the drone.

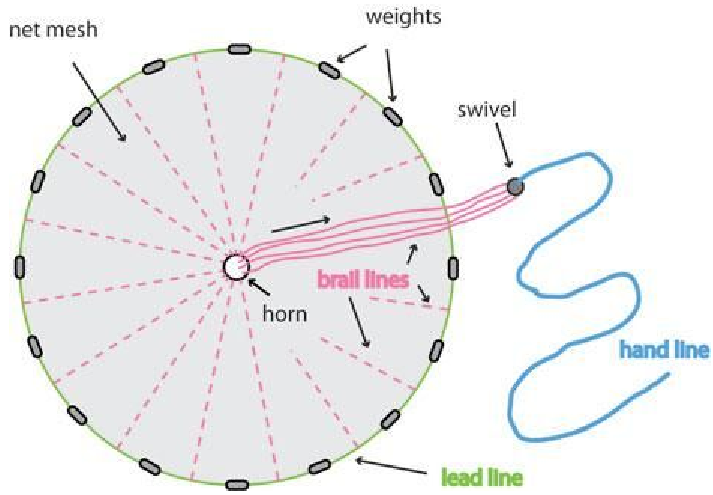


Figure 1. A diagram of a casting net commonly used for retrieving bait fish.

With four small weights, or any number of small weights, spread of the net can be improved when airborne with the edging covered in weight. Looking at a casting net for fishing, if loaded properly into the device the net will mimic and spread on launch, greatly increasing the success chance of a capture. Weights may cause hazardous to people below the drone which may call for safety checks before firing. Below in Table 6 is a list of concepts for net counterweights.

Table 6. Compiled concepts for net's counter-weight

System	Concept
	Four Small Weight "Clover" - Projection
	One Larger Weight Center - Projection

Net Counter-Weight	Evenly Weighted Net
	Magnetized Net Edges
	Faraday Cage Embedded Net (Copper Weight)

7. Detection

Another key subsystem of the project is the detection system. Our sponsors gave us the task of developing a subsystem that could automatically detect a drone in the sky and alert the device operator of the detection. This detection system is to be designed to operate and detect hostile drones passively; in other words, the detection system would function without an operator needing to actively operate the detection system. The most important considerations of generating concepts for this design are how to accurately detect a drone from long range, how to distinguish a drone from another flying object such as a bird, and the means in which the system can detect such an object. Table 7 illustrates several concepts to potentially be used for detecting a drone in the air:

Table 7. Compiled concepts for detection of the drone.

System	Concept
	3D Image

Detection	Infrared
	Sound
	Electromagnetic Signature
	Heat Signature
	Radar
	Sonar
	Eye Sight
	Laser
	Velocity Sensing
	Neural Network
	Detect Spinning Blades
	Temperature Gradient Between "Object" and Air

8. Impact Protection

Once the drone gets neutralized, and a weighted net is launched at it, it will fall to the ground. A decision was made for there to be a way to retrieve the drone without damaging it. Depending on what the device will be used for, it might be in the best interest for it not to be destroy. Table 8 below lists the different concepts of impact protection. The best options for this function would either be a net being attached to the net or to hack the drone and safely guide it to the ground. Since the preferred method to secure the drone will be by launching a net, attaching a parachute to the net. This way will allow the drone to be safely brought down to the ground for retrieval.

Table 8. Compiled concepts for Impact Protection

System	Concept
Impact Protection	Cushioned Net
	Predict Landing of Drone
	Hack Drone
	Parachute Net
	Cushioned Surface on Ground

1.5.1 Concept Designs

After brainstorming these concepts, our team diligently worked together to condense these lists into the ideas we thought were best for our disabling device. Detailed designs were created from the list of concepts above and are described below. These designs are all concepts and help visualize the overall system we expect to build and can give an expectation of how the device will function.

Concept 1.

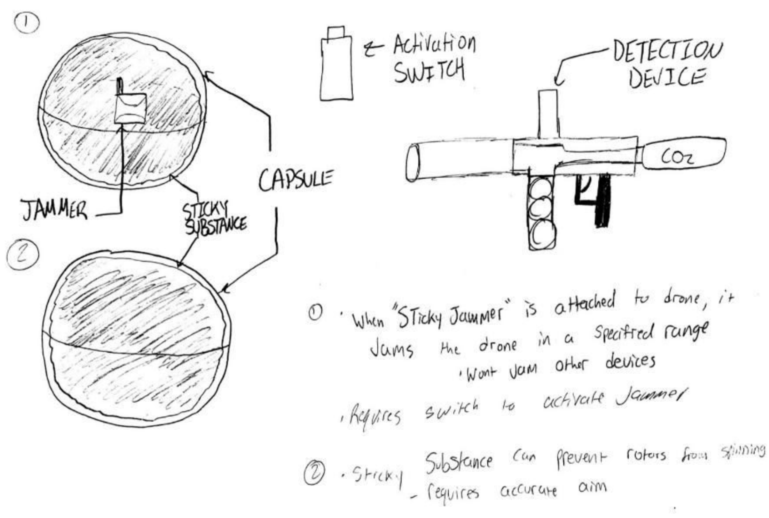


Figure 1: Concept 1 diagram and detailed view of sticky substance

Figure 1 illustrates a full-system concept of the drone disabling device. This device is essentially a paintball-styled gun that shoots capsules. The capsules can either contain a sticky substance with an integrated jammer, or just the sticky substance. The jamming capsule would actively jam the drone in the 2.4 GHz and 5 GHz frequencies, which would disrupt communications between the drone and the controller (after research, this would cause the drone to either hover in the spot where it lost communications, or it would slowly descend to the ground). The jammer would be controlled by an operator-controlled switch, which would be activated when the capsule is attached to the drone. The concept of the capsule not utilizing the jammer would simply release the sticky substance, stick to the drone, and immobilize it either by preventing the rotors of the drone from spinning or by weighing the drone down. The capsule would be propelled by force generated by a disposable CO2 cartridge, similar to how a paintball is propelled from a paintball gun.

Table 9: Concepts used in generation of concept 1

Conceptual Device #4	
System	Concept
Propulsion	Compressed Air/CO2
Neutralization	RF - 2.4 GHz
	RF - 5 GHz
Capture	Projectile
	Sticky Substance
Net Material	N/A
	N/A
Net Counterweight	N/A

Size reduction	Disposable Compressed Air
	Handheld
Impact Protection	N/A
Detection	Eye Sight

Concept 2.

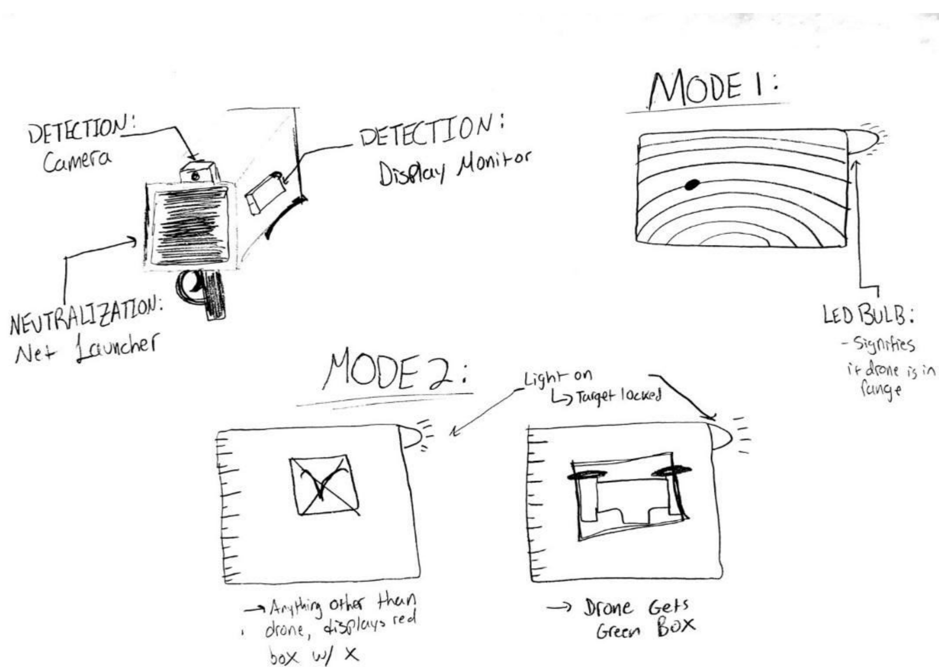


Figure 2: Concept 2 diagram and functions

This design utilizes a weighted net for the purpose of securing the drone once it is neutralized, which would be by means of 2.4 GHz and 5GHz Wi-Fi jamming. The net would be launched using compressed air in a disposable cartridge. In order to detect the target, either a camera would be attached to the launcher, or a radar function will be displayed on the monitor. Either way, an LED bulb would light up, indicating that the target is in range after it was detected. Another function of the detection device would be 3D imagery, infrared, or electromagnetic signature detection, which would tell the user whether the target is desirable or not. This concept is depicted in figure 2.

Table 10: Concepts used in generation of concept 2

Conceptual Device #4	
System	Concept
Propulsion	Compressed Air/CO2
Neutralization	RF - 2.4 GHz
	RF - 5 GHz
Capture	Net
Net Material	Nylon
	Poly Dracon
Net Counterweight	Four weights "clover"
Size reduction	Disposable Compressed Air

	Handheld Net Launcher
Impact Protection	Parachute net
Detection	3D image
	Infrared
	Radar

Concept 3.

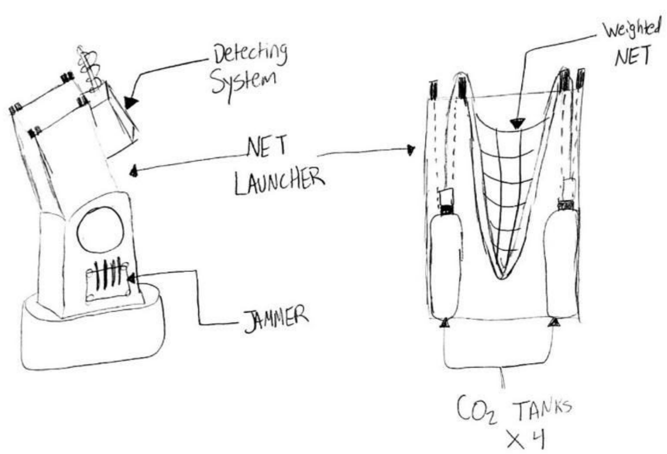


Figure 3: Concept 3 with detailed diagram.

Concept 3 is illustrated below in Figure 3. This design is another net launching device. The weighted net would be in the "clover" projection; four weights in each of the corner of the net. The weights will be guided down a track till it reaches the release of one of the four CO2 tanks. To propels the net, a button will be pressed. The net would be embedded with a faraday cage, which would actively jam any possible radio-frequency signal attempting to communicate with the drone. This concept focuses more on the function of securing the drone than any other function, but this design is open to having any combination of the detection and jamming systems listed in the tables above.

Table 11: Concepts used in generation of concept 3

Conceptual Device #4	
System	Concept
Propulsion	Compressed Air/CO2
	-
Neutralization	Faraday Cage
Capture	Net
Net Material	Nylon
	Poly Dracon

Net Counterweight	Four weights "clover"
Size reduction	Disposable Compressed Air
	-
Impact Protection	-
Detection	-

Concept 4.

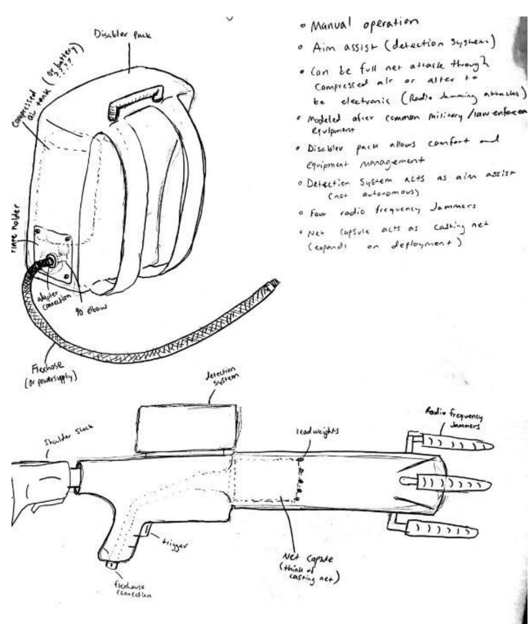


Figure 4: Concept 4 diagram and device description.

Concept 4, as shown in Figure 4, is a handheld net launcher powered by a disposable compressed air/CO_2 tank. The tank is connected to the rifle through a hose line. For concept and marketing purposes, the tank is placed inside a pack to allow extra storage for the operator. This pack can also hold a battery source to power the detection and jamming systems. The net is in a plastic capsule that breaks upon launch from the rifle. The net is modeled after a casting net with small weights on the lining of the net. This concept allows for high mobility and ease of use, being a device that is similar to military/law enforcement equipment used today. Below in table 13 are the concepts used to generate the conceptual device.

Table 11. Concepts used in generation of concept 4

Conceptual Device #4	
System	Concept
Propulsion	Compressed Air/CO2
Neutralization	RF - 2.4 GHz
	RF - 5 GHz
Capture	Net
Net Material	Nylon
	Poly Dracon
Net Counterweight	Four weights "clover"

Size reduction	Disposable Compressed Air
	Handheld Net Launcher
Impact Protection	Parachute net
Detection	-

Concept 5.

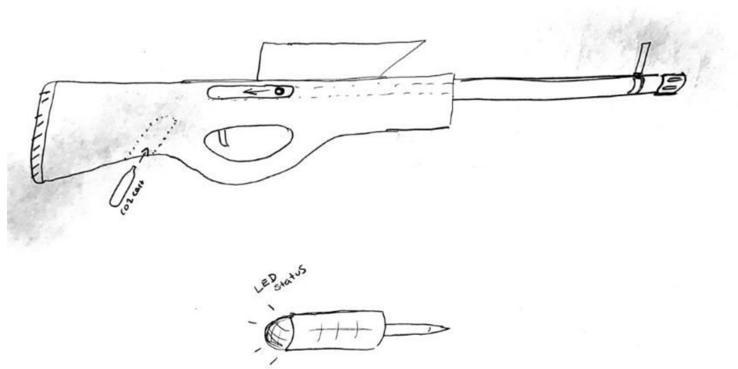


Figure 5: Concept 5, a rifle modeled after pellet rifles that uses either a spring or CO2 cartridge to launch the projectile.

Concept 5 is modeled after a classic pellet rifle. It is a single operated device using only a 16oz CO2 cartridge. This device requires the drone to be stationary in order for the operator to accurately hit the drone. When the trigger is pulled the CO2, cartridge is punctured, and the pressure generated fires the projectile used. The projectile used is a dart like projectile that lodges itself into the drone. This dart may be electronically powered and used to disable the drone's electronics and drop it from the sky. Conceptually, it may also be used as a GPS tracker to allow the operator to track and find the drone user if needed. The electronics on the dart are all remote operated. This device could be also used as a spring powered rifle. Replacing the CO2 cartridge for a high-powered spring, the user would pull the bolt as far back as possible and fully compress the spring. With the bolt open, one dart can be loaded. Once the bolt cover is closed the user can relieve the pressure with the trigger, releasing the compressed spring and propelling the dart forward. This kind of system would be extremely simplistic and require little man power. Table 14 below lists the concepts used in this device.

Table 12. Concepts used in the generation of concept 5.

Conceptual Device #5	
System	Concept
Propulsion	Compressed Air/CO2
	Spring powered
Neutralization	RF - 2.4 GHz
	RF - 5 GHz
Capture	Projectile
Net Material	-
	-

Net Counterweight	-
Size reduction	Disposable Compressed Air
	Handheld Net Launcher
Impact Protection	-
Detection	-

1.6 Concept Selection

Introduction

After the concepts have been generated, the best concept must be selected to continue the conceptual design phase. Concept selection is a key element in the design process and the process used ensures the best option is used. The concept chosen as the best option is then expanded into greater details and the process of developing the product can begin.

We incorporated three main strategies to select the best option from the concepts we generated: a House of Quality, Pugh matrices, and an Analytical Hierarchy Process. These strategies are used to help rank the importance of the different components of the device, determine the relationship between engineering characteristics and customer requirements, and compare the characteristics of the most viable concepts both amongst each other and with other options.

HOQ

The House of Quality is used to incorporate the voice of the customer into the design characteristics and targets selected. The House of Quality allows the engineering characteristics that the customer is most concerned about to be selected and used to evaluate the previously selected concepts. In this House of Quality, which is displayed in Table 1, the importance factors were generated using a pairwise comparison that showed the relative importance of the customer requirements showing that Automatic Detection system is what the customer cares most about. Next, the customer needs relation to the engineering characteristics were decided using a blank space to represent zero relation, a 1 to represent a small relation, a 3 to represent an average relation, and a 9 to represent a large or direct relation. These values were multiplied by the related importance factor and summed show which of the engineering factors are most important when the customer requirements are included. The selected engineering characteristics that were carried on from the House of Quality were target acquisition speed, battery life, disabling range, target max drone wingspan, weight of device, and frequencies jammed.

Table 1: House of Quality

		Engineering Characteristics									
Improvement Direction		↓	↓	↑	↓	↑	↑	↓	↑	↑	↓
Units		Mins	lbs	Ft	Sec	Hr	Ghz	Sec	in	lbs	$
Customer Requirements	**Importance**	Assembly/Disassembly Time	Weight of Device	Disabling Range	Target Acquisition Speed	Battery Life	Frequencies Jammed	Device Reload Speed	Target Max Drone Wingspan	Target max drone weight	Project Cost
Automatic Detection System	**6**		3		9	9			9		9
Device reach	**4**		3	9		1		3	1		1
Neutralization of Drone (undamaged)	**5**			9	9	3	9		3	3	
Device Safety	**5**		3								1
Retrieval of Drone	**2**			1					3	9	
Device Mobility	**3**		9								
Length of Operation	**2**			1		9	9				3
Ease of use	**1**	9	3					9			
Raw Score		9	75	85	99	91	63	21	79	33	69
Relative Weight %		1%	12%	14%	16%	15%	10%	3%	13%	5%	11%
Rank Order		10	5	3	1	2	7	9	4	8	6

Listed below are the concepts used in the concept generation process and carried over into the next section that is the Pugh matrix. From left to right respectively are concepts 1 through 5.

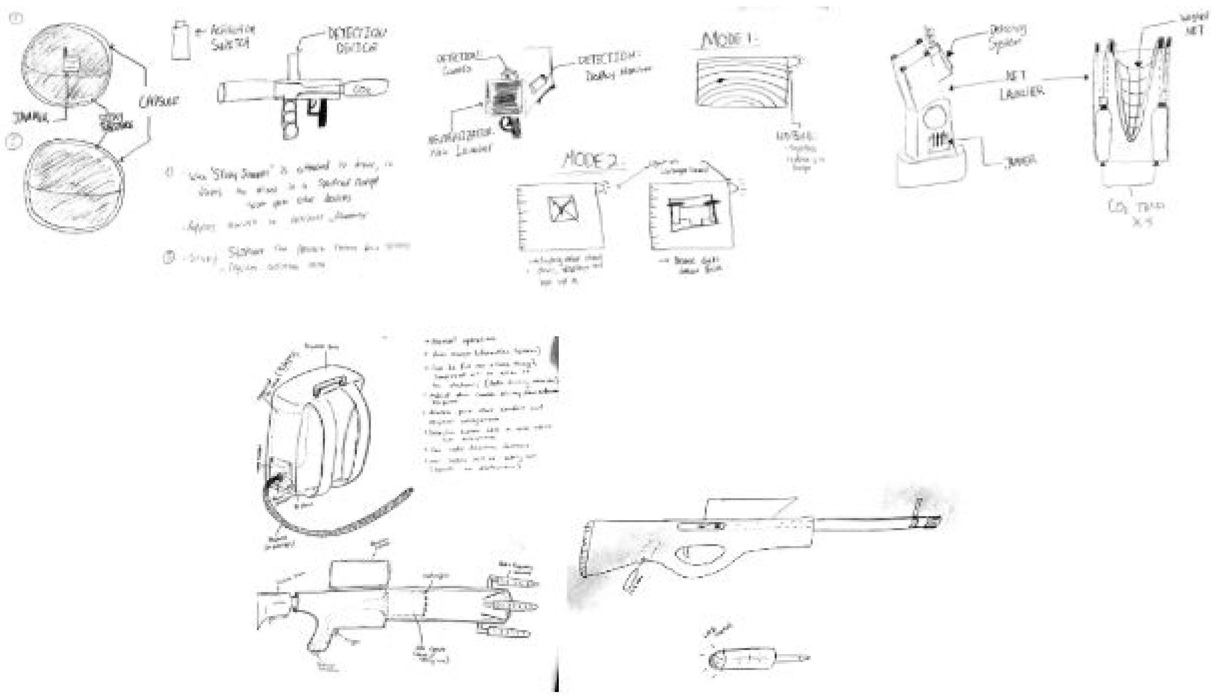


Figure 1: (a) Concept 1. (b) Concept 2. (c) Concept 3. (d) Concept 4. (e) Concept 5.

Pugh Matrix

The engineering characteristics previously selected as the most important from the House of Quality were carried over to the Pugh matrix in Table 2. The most important engineering characteristics chosen were the target acquisition speed, the battery life, the disabling range, the target max drone wingspan, the weight of the device, and the frequencies jammed. A datum was then selected to be the basis of the concepts and the DroneShield DroneGun was selected. The other concepts expected performance was compared to the datum assigning an S meaning the same, a + meaning the concept is better than the datum, or a - meaning the datum is better.

Table 2: Pugh Chart with DroneGun Datum

Selection Criteria	DroneGun	1	2	3	4	5
Target Acquisition Speed		S	-	-	S	-
Battery Life		+	+	S	+	+
Disabling Range		-	-	-	-	-
Target Max Drone Wingspan	Datum	S	S	S	S	S
Weight of Device		+	-	+	-	+
Frequencies Jammed		S	S	S	S	S
# pluses		2	1	1	1	2
# minuses		1	3	2	2	2

From the DroneShield DroneGun it was determined concept 5 was the best choice as a new datum. It had the highest number of pluses along with concept 1 and the second highest number of minuses. From the first Pugh matrix a new Pugh matrix was drafted from concept 5. The results of the Pugh matrix with concept 5 rated as the datum are listed below.

Table 3: Pugh Chart with concept 5 as datum

Selection Criteria	Concept 5	1	2	3	4
Target Acquisition Speed		S	+	-	+
Battery Life		-	-	-	+
Disabling Range		-	S	-	+
Target Max Drone Wingspan	Datum	S	S	S	S
Weight of Device		S	-	-	-
Frequencies Jammed		+	+	+	S
# pluses		1	2	1	3
# minuses		2	2	4	1

With concept 5 as the new datum it was determined with the best selected engineering characteristics that concept 2, 4, and 5, were the best choices to continue with in the selection process. Concept 4 has the highest plus score and concept 2 had the safest rating all around.

AHP

The Analytical Hierarchy Process, or AHP, is a mathematical approach to separate the best of 3 design concepts. The evaluation criteria used are the disabling range, weight of device, and battery life. This criterion is rated employing pairwise comparisons. The AHP's Rating for Pairwise Comparison is as shown in the following figure:

Rating Factor	Relative Rating of Importance of Two Selection Criteria A and B	Explanation of Rating
1	A and B have equal importance.	A and B both contribute equally to the product's overall success.
3	A is thought to be moderately more important than B.	A is slightly more important to product success than B.
5	A is thought to be strongly more important than B.	A is strongly more important to product success than B.
7	A is thought to be very much more important than B, or is demonstrated to be more important than B.	A's dominance over B has been demonstrated.
9	A is demonstrated to have much more importance than B.	There is the highest possible degree of evidence that proves A is more important to product success than B.

Figure 2: AHP's Rating for Pairwise Comparison (McConomy 2018)

Utilizing the Ranking Factors illustrated in Figure 2, the importance of each criteria can be compared to the others. If both criteria have the same level importance, a 1 is inputted, if A is a little more important than B, a 3 is inputted, and so on. If the Criteria A has precedence over Criteria B, the cell gets the ranking, while the cell on the other side of the cell with a 1 is the reciprocal value of the ranking factor. The reciprocal value allows characteristic values from the house of quality to be measured in order to convey a correlation amongst those values. In order to fill out the Normalized Criteria Comparison Matrix under each criterion you put the Norm Element, which can be calculated utilizing the equation:

Norm Elementm,n = elementm,n summ,n

The Normalized Criteria Comparison Matrix takes the Norm Elements to calculate the Criteria Weight {W} that is calculated by:

{W} = 1n*i=1nxi

where n is the number of elements of the criteria and xiis the the value of the element. These values can be seen in Normalized Criteria Comparison Matrix.

Table 4: Development of Candidate set of Criteria Weights for Drone Disabling Device

Developement of Candidate set of Criteria weights {W} for Drone Disabling Device			
Criteria Comparison Matrix [C]			
	Disabling Range	Weight of Device	Battery Life
Disabling Range	1	0.3333333333	0.2
Weight of Device	3	1	0.3333333333
Battery Life	5	3	1
Sum	9	4.333333333	1.533333333

From Table 4, the first matrix of criteria weights, the top three values of the Pugh matrix drafted were used. These values were then normalized to further increase the accuracy and precision of the concepts that had been generated in relation to the engineering characteristics.

Table 5: Normalized Criteria Comparison Matrix

Normalized Criteria Comparison Matrix [NormC]				
	Disabling Range	Weight of Device	Frequencies Jammed	Criteria Weights {W}
Disabling Range	0.1111111111	0.07692307692	0.1304347826	0.1061563235
Weight of Device	0.3333333333	0.2307692308	0.2173913043	0.2604979562
Frequencies Jammed	0.5555555556	0.6923076923	0.652173913	0.6333457203
Sum	1	1	1	1

Table 6: Consistency Check

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
0.3197	0.1061563235	3.0112
0.7901	0.2604979562	3.033
1.9456	0.6333457203	3.072
	Average	3.038733333
	CI	0.036
	CR	0.06923076923

In order to do the consistency check, the Weighted Sum Vector and the Consistency Vector needs to be determined. The Weighted Sum Vector can be equated from:

$$\{Ws\} = [C]\{W\}$$

where [C] is the values in the Normalized Criteria Comparison Matrix and {W} is the Criteria Weights, that was determined in Table 5 for the comparison between the engineering characteristics. The Consistency Vector is calculated using the equation:

$$\{Cons\} = \{Ws\}./\{W\}$$

where {Ws} is the Weighted Sum Vector determined from the equation above and {W} is the Criteria Weights. Theses equations were inputted into MATLAB to find the values for {Ws} and {Cons}. To find the consistency of the comparisons, the Comparison Consistent, CR, value needs to be found and less than 0.10. The equation to calculate CR is:

$$CR = CI*RI$$

CI is the Consistency Index and RI is the Random Index Value. The RI values depends on the number of criteria used, as according to Figure 3. For our concept selection, we use 0.52 for RI because the number of criteria is 3.

RI Values for Consistency Check

# of Criteria	RI Value
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.4
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57
15	1.58

Figure 3: Values for the Random Index

To find CI, the following equation is used:

CI=-nn-1

The variable λ is the Average Consistency, which is just the average of the Consistency Vector and n is the number of criteria. The evaluation was then further detailed into each engineering characteristic used in the AHP to confirm the reading from the normalized criteria comparison. If the CR value is less than 0.1, then it is proven that the comparisons are fairly consistent. This guarantees that there is no overlap between the characteristics and there is little influence from the designers. So once the CR value for the primary comparison matrix is less than 0.1, then the CR values for each engineering characteristic were found. The CR values are 0.069, 0.063, 0.134, and 0.037; the values for the criteria are shown in Appendix A. Three of CR values are less than 0.1, however, the comparison matrix for the Weight of Device criteria has a CR greater than .10, which represents human bias.

Table 7: Final Rating Matrix

Final Rating Matrix				
Selection Criteria	Disabling Range	Weight of Device	Battery Life	Alternative Value
Concept 2	0.607001694	0.7513804714	0.2594645115	0.3319
Concept 4	0.08965430705	0.1679461279	0.06543515311	0.3473
Concept 5	0.303343999	0.08067340067	0.6751003354	0.3076

The final step of the AHP is to do complete the Final Rating Matrix, which is the {W} values of each criteria for each concept. This produces the best concept to use. In order to accomplish that, the Alternative value for each of the final 3 concepts were found. Once again

MATLAB was utilized, taking the transpose of the Final Rating Matrix and multiplying it by {W} from Table 6. The equation used was:

Alternative Value = [Final Rating Matrix]T.*{W}

So, based on the Final Rating Matrix in Table 16, concept 4 has the highest alternative value. This means that concept 4 is the best design to pursue.

Final Decision

Based on the results of the House of Quality, Pugh Matrix, and Analytical Hierarchy Process, it was clear that concept 4 is the best concept to pursue for the Drone Disabling Device. This concept has been quantified to be the most feasible design, proving to meet the standards of customer needs to the greatest extent. Therefore, there is full confidence that this concept will be the best design to create and that the customer needs of the project will be adequately met.

Table 8: Development of Candidate set of Criteria Weights for the Criteria Disabling Range

Disabling Range			
	Concept 2	Concept 4	Concept 5
Concept 2	1	7	5
Concept 4	0.1428571429	1	0.3333333333
Concept 5	0.2	3	1
Sum	1.342857143	11	6.333333333

Table 9: Development of Candidate set of Criteria Weights for the Criteria Disabling Range

Normalized Criteria Comparison Matrix [NormC]				
	Concept 2	Concept 4	Concept 5	Criteria Weights {W}
Concept 2	0.7446808511	0.6363636364	0.7894736842	0.7235060572
Concept 4	0.1063829787	0.09090909091	0.05263157895	0.08330788286
Concept 5	0.1489361702	0.2727272727	0.1578947368	0.1931860599
Sum	1	1	1	1

Table 10: Consistency Check for the Criteria Disabling Range

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
2.2726	0.607001694	3.1411
0.2511	0.08965430705	3.0137
0.5878	0.303343999	3.0427
	Average	3.065833333
	CI	0.03291666667
	CR	0.06330128205

Table 11: Development of Candidate set of Criteria Weights for the Criteria Weight of Device

Weight of Device			
	Concept 2	Concept 4	Concept 5
Concept 2	1	5	5
Concept 4	0.2	1	3
Concept 5	0.2	0.3333333333	1
Sum	1.4	6.333333333	9

Table 12: Normalized Criteria Comparison Matrix for the Criteria Weight of Device

Normalized Criteria Comparison Matrix [NormC]				
	Concept 2	Concept 4	Concept 5	Criteria Weights {W}
Concept 2	0.7142857143	0.7894736842	0.5555555556	0.686438318
Concept 4	0.1428571429	0.1578947368	0.3333333333	0.2113617377
Concept 5	0.1428571429	0.05263157895	0.1111111111	0.1021999443
Sum	1	1	1	1

Table 13: Consistency Check for the Criteria Weight of Device

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
2.2542	0.7513804714	3.284
0.6552	0.1679461279	3.1001
0.3099	0.08067340067	3.0327
	Average	3.138933333
	CI	0.06946666667
	CR	0.1335897436

Table 14: Development of Candidate set of Criteria Weights for the Criteria Battery Life

Battery Life			
	Concept 2	Concept 4	Concept 5
Concept 2	1	3	0.3333333333
Concept 4	0.3333333333	1	0.2
Concept 5	3	5	1
Sum	4.333333333	9	1.533333333

Table 15: Normalized Criteria Comparison Matrix for the Criteria Battery Life

Normalized Criteria Comparison Matrix [NormC]				
	Concept 2	Concept 4	Concept 5	Criteria Weights {W}
Concept 2	0.2307692308	0.3333333333	0.2173913043	0.2604979562
Concept 4	0.07692307692	0.1111111111	0.1304347826	0.1061563235
Concept 5	0.6923076923	0.5555555556	0.652173913	0.6333457203
Sum	1	1	1	1

Table 16: Consistency Check for the Criteria Battery Life

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
0.7901	0.2594645115	3.033
0.3197	0.06543515311	3.0112
1.9456	0.6751003354	3.072
	Average	3.038733333
	CI	0.01936666667
	CR	0.03724358974

1.8 Spring Project Plan

In the Spring, first we will work on ordering parts for constructing our first prototype of the drone disabling device. Once the parts arrive, we will construct the drone capturing apparatus (the "gun"), and a testbench will be created to verify the functionality of this proposed design. The mechanical engineers of the team will utilize this testbench to perform small-scale testing of the net capturing method to deem this concept as a viable solution to capturing a drone out of the air. The small-scale testing will involve testing our system for safe operations at high pressures

(1000 PSI and above) and the range by which the net can be launched (with a 50 ft range). The net launcher will be fixed to a surface and fired several times to ensure consistency in our functional analysis of the device. This test will disregard the accuracy at which the net can hit the drone, and instead focus on the overall functionality of the projection system. At the same time, the electrical and computer engineers of the group will be interfacing the 3D image capturing cameras with the microprocessors. In addition, a neural network image-processing algorithm will be created to detect drones in the air (with a goal of a 50 ft range). In order to test the functionality of the automatic drone detection device, small-scale testing will involve the cameras being tested to be able to detect hovering or stationary drones and optimizing the algorithm according to the measured acquisition speed and accuracy.

Testing at this stage is important because if the equipment cannot safely sustain high pressure releases, then we either need to reduce pressure to a safe level for testing, or we need to re-analyze our generated concepts and choose a new design. In addition, we have targets set for a target acquisition speed of 30 seconds by the automatic drone detection system. To ensure a successful design, this target must be met. Otherwise, we may need to implement a new concept for drone detection into our design.

The milestones for spring semester include: semester start, VDR4, VDR5, VDR6, Engineering Design Day, VDR7, finals, and graduation. The activities that are necessary to see those milestones met are addressed in the table below. A Gantt chart was created to represent the timeline for our spring semester and can be seen in the figure below.

	Start	End	Duration		Resource names
Semester Starts	8-Jan	8-Jan	0.9	Milestone	
Small-Scale Testing	8-Jan	31-Jan	24.0	Activity	
Design Phase	8-Jan	31-Jan	24.0	Activity	
Build Prototype	31-Jan	28-Feb	29.0	Activity	
VDR 4	26-Feb	26-Feb	0.9	Milestone	
Testing & Validation	28-Feb	31-Mar	32.0	Activity	
Spring Break	12-Mar	16-Mar	5.0	Activity	
VDR 5	26-Mar	26-Mar	0.9	Milestone	
Final Documentation	31-Mar	16-Apr	17.0	Activity	
VDR 6	9-Apr	9-Apr	0.9	Milestone	
Engineering Design Day	9-Apr	9-Apr	0.9	Milestone	
Finalize Project	16-Apr	23-Apr	8.0	Activity	
VDR 7	23-Apr	23-Apr	0.9	Milestone	
Finals	30-Apr	4-May	5.0	Activity	
Graduation	4-May	4-May	0.9	Milestone	

Figure ??

In January, we will purchase the necessary materials to perform the small-scale testing. By the end of January, we intend to have completed all necessary small-scale testing and will have fixed our early design issues. Through the month of February, we will be in the developmental phase of our project, where we will work on constructing a full-scale model of our drone disabling device. This includes completing the net launcher, backpack with air tank holders, the microprocessor system, and our automatic drone detection system. In the meantime, there will be various design reviews that we will have to prepare to present our progress at that time on the final design of the device. In addition, the website for our project will be designed and updated as important milestones are hit. The website will also include all of our deliverables from the fall semester which involved the planning phase and all the research that was done. Given that the device is completely built by the end of February, we intend to begin full-scale testing of the product through the months of March and April. At the end of April our team will have designed a fully functioning device with necessary evidence that proves that our device accurately, effectively, and quickly disables drones within the specified air space of a 50-foot radius dome. In addition, the device will be showcased to be portable and easy to use. At the beginning of May, we will present our final device design and create a report explaining our design process, with all of the steps it took to create our design to the final device that was created. After the final presentation of our device, we will then focus on studying for final exams. Once this is completed, we will graduate May 4th, 2018.

Spring Project Plan Gantt Chart

PROJECT TITLE	Drone Disabling Device
TEAM MEMBERS	Taylor Stamm, Ryan Cziko, Dylan Macaulay, Quentin Lewis, Trevor Stade

TASK NUMBER	TASK TITLE	RESPONSIBLE FOR TASK	START DATE	DUE DATE	DURATION (DAYS)	PCT OF TASK COMPLETE
1	Part Ordering/Small-Scale Testing					
1.1	Order and test CO_2 tank on current device	Trevor Stade	1/7/19	1/15/19	8	0%
1.2	Test hose line for leaks and any damages for replacements	Ryan Cziko	1/14/19	1/16/19	2	0%
1.3	Interface cameras and alerting system with raspberry pi	Taylor Stamm	1/14/19	1/19/19	5	0%
1.3.1	Create initial drone detection algorithm	Quentin Lewis	1/14/19	1/19/19	5	0%
1.4	Order casting nets and size specifications finalized	Trevor Stade	1/14/19	1/28/19	14	0%
1.5	Order and begin assembly on trigger system	Trevor Stade	1/14/19	1/28/19	14	0%
1.6	Pressure chamber calculations and manufacturing	Dylan Macaulay	1/28/19	1/30/19	2	0%
1.7	Slice CAD models to be 3D printed for full-scale assembly	Dylan Macaulay	1/28/19	2/3/19	5	0%
1.8.1	Pressure equipment safety test	Ryan Cziko	1/28/19	2/3/19	5	0%
1.8.2	Net launch distance test	Ryan Cziko	1/28/19	2/3/19	5	0%
1.8.2	3D Imaging test of stationary drone	Quentin Lewis	1/28/19	2/3/19	5	0%
2	Full-Scale Development					
2.1	Test trigger assembly with low pressure utilizing air compressor from current device	Ryan Cziko	2/4/19	2/10/19	6	0%
2.2	Optimize speed and accuracy of detection algorithm	Quentin Lewis	2/4/19	2/10/19	6	0%
2.3	Assemble trigger system, air tank, hose line, and combine with 3D prints	Dylan Macaulay	2/11/19	2/15/19	4	0%
2.4	Assemble Rifle components to backpack/detection system	Dylan Macaulay	2/15/19	2/17/19	2	0%
2.5	Test pressure chamber for leaks and durability	Ryan Cziko	2/18/19	2/21/19	3	0%
2.6	Combine pressure chamber with designed trigger and CO_2 assemblies	Dylan Macaulay	2/22/19	2/24/19	2	0%
2.7	Implement casting net to device	Dylan Macaulay	2/22/19	2/24/19	2	0%
2.8	Full assembly of 3D prints for body and pack	Dylan Macaulay	2/25/19	3/3/19	8	0%
3	Full-Scale Testing					
3.1	Test and optimize net launch	Ryan Cziko	3/4/19	3/17/19	13	0%
3.3	Test and optimize detection system (stationary and moving drones)	Taylor Stamm	3/4/19	3/17/19	13	0%
3.6	Spring break	N/A	3/18/19	3/24/19	6	0%
3.6	Final system testing	Ryan Cziko	3/25/19	3/31/19	6	0%
3.7	Refine prototype	ALL	3/25/19	3/31/19	6	0%
4	Design Showcase					
4.1	Final Demonstration	ALL	4/1/19	4/7/19	6	0%
4.2	Final Poster Creation	ALL	4/8/19	4/11/19	3	0%
4.3	Final Report (Evidence Manual)	ALL	4/12/19	4/17/19	5	0%
4.4	Final Presentation	ALL	4/18/19	4/18/19	0	0%
5	Post-Engineering Design Day					
5.1	Study for Final Exams	ALL	4/19/19	5/3/19	14	0%
5.2	Graduation	ALL	5/4/19	5/4/19	0	0%

Figure ??

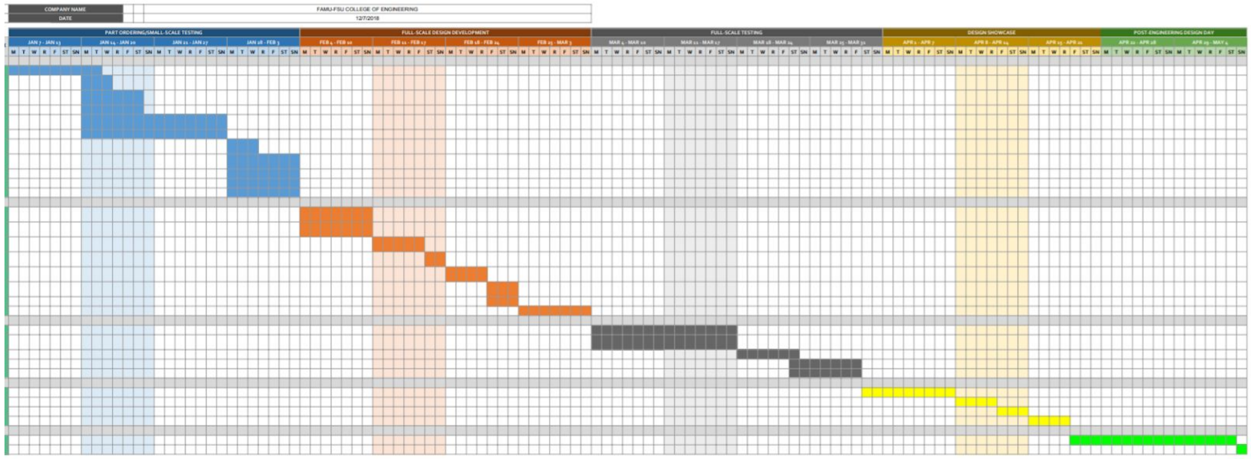

COMPANY NAME
FAMU-FSU COLLEGE OF ENGINEERING
DATE
12/7/2018
PART ORDERING/SMALL-SCALE TESTING
FULL-SCALE DESIGN DEVELOPMENT
FULL-SCALE TESTING
DESIGN SHOWCASE
POST-ENGINEERING DESIGN DAY

Figure ??

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Mission Statement

The Drone Disabling Device project team, Team 518, is committed to ensure an environment where members can work professionally and are respectful towards their peers. Within this work environment, every member is responsible for putting in 100% effort in every task that they perform. Each member of this team will contribute, with a positive attitude, towards the creation and maintenance of such an environment in order to bring out the best in all of us; as well as maintain the standards of this project.

Team Roles

Project Manager - Trevor Stade

The Project Manager is required to set meetings with sponsors and advisors. Expected to present in all presentations. Review and signs off on all assignments before submission.

Sensor Interface Engineer - Quentin Lewis

The Sensor Interface Engineer is tasked with developing the sensing system used to automatically detect and target a drone.

Design Engineer - Dylan Macaulay

The Design Engineer is tasked with the work of 3D CAD modeling. He is expected to complete extensive research on similar products in order to fully satisfy team ideas with the modeling of the device. The Design Engineer also helps to improve current products efficiency and overall performance.

Test Engineer - Ryan Cziko

The Test Engineer is required to establish a testing environment in which several scenarios are implemented different scenarios in order to test every aspect of the device and to determine any errors and change design test plans accordingly.

Systems Integration Engineer - Taylor Stamm

The Systems Integration Engineer is tasked with integrating mechanical and electrical systems together and ensuring that the electrical components are supplied with correct and safe power according to system specifications.

Though roles are assigned, each member is not confined to his said role. Advice and input are welcome, and each member is seen as an equal. Members are encouraged to take on sub-roles to increase team efficiency. Sub-roles can be webmaster, finance manager, bookkeeper, etc. Sub-roles will become apparent throughout the project.

Communication

Team members will stay in close contact with each other through text messaging and email. Any reason for being late or absent from team events or meetings should be communicated in advance (24-hour notice) to other team members so that the team has ample time to account for the absence of a member.

Dress Code

There is no required dress code for team meetings. Sponsor meetings require a business casual dress code, but this may be subject to change if deemed suitable by the group. During group presentations, a strict business formal dress code will be enforced.

Attendance Policy

Team meetings have been scheduled every Sunday from 11:00 AM to 2:00 PM. An extra meeting will be scheduled during the week if needed. Meeting times may be shortened or extended. A 24-hour notice is required if a member cannot make the scheduled meeting time. If a member is absent for a meeting and has not notified the team, they will be marked as absent for the team meeting. An attendance is taken at each meeting and is documented. If a member has frequently missed meetings without a valid excuse, then the issue will be brought to Dr. McConomy.

Team Building

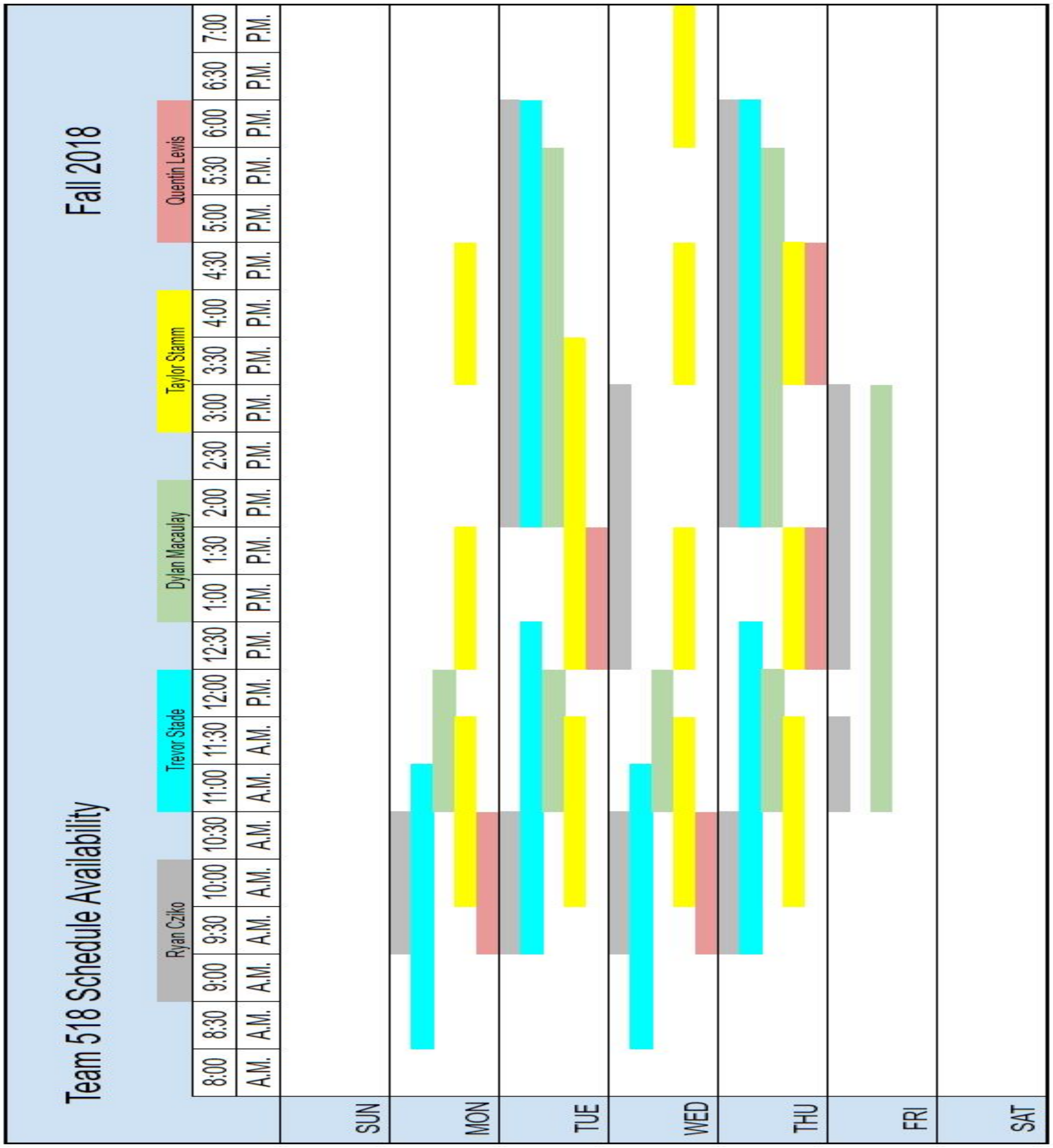
Team members are expected, but not required, to meet recreationally twice a month to promote synergy and boost morale. Such activities will be scheduled when time is available, and each member will be notified in advance via text message.

Statement of Understanding

By signing this document, each member is in agreement with said rules, roles, and the NSPE Engineering Code of Ethics.

Name (Print)	Name (Signed)	Date
Ryan Cziko	[illegible]	9/16/18
Quentin Lewis	Quentin Lewis	9/16/18
Trevor Stade	Trevor Stade	9/16/18
Taylor Stamm	[illegible]	9/16/18
Dylan Macaulay	Dylan Macaulay	9/16/18

Team Availability



*Colored Areas indicated times when the team member is unavailable

Appendix B: Functional Decomposition

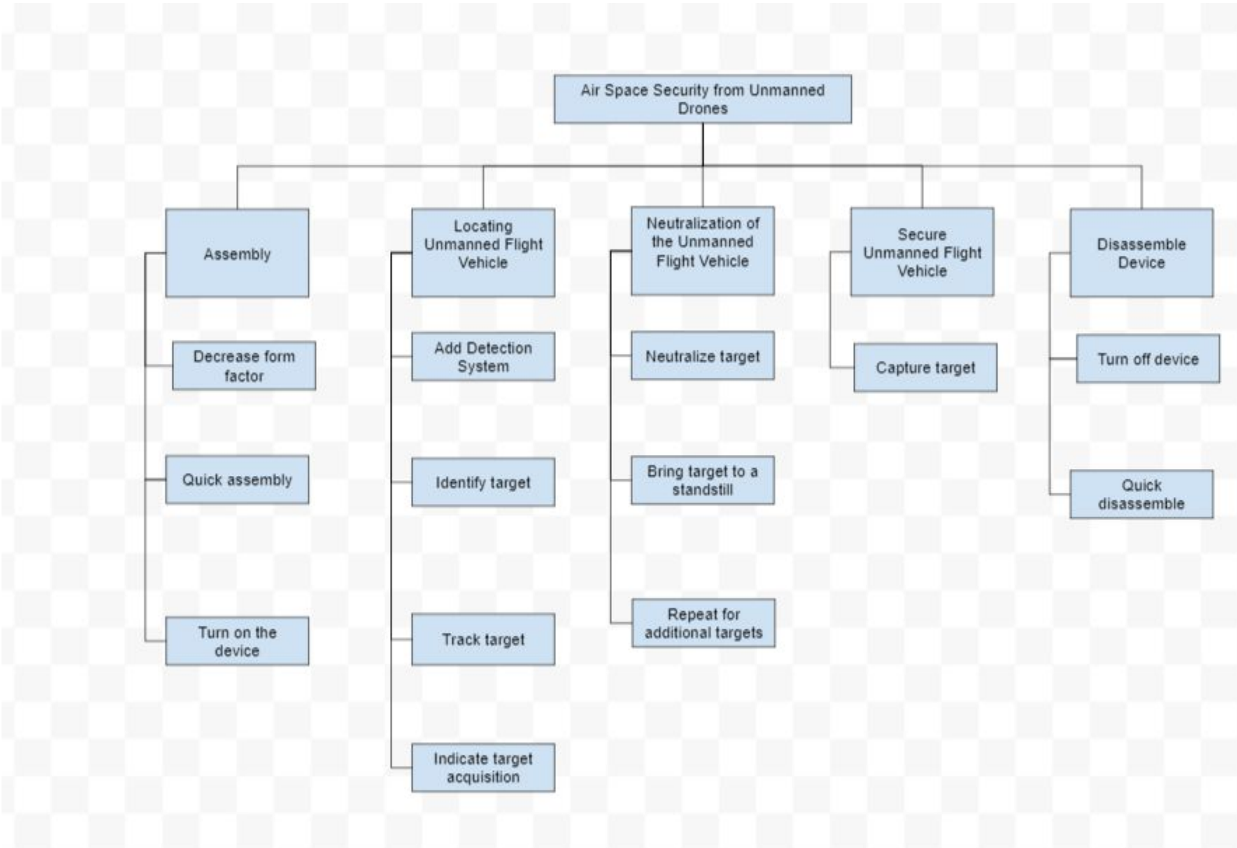


Figure B.1. –Functional Decomposition

Appendix C: Target Catalog

Target No.	Need	Metric	Importance	Units	Marginal Value	Ideal Value
1	2, 10	Assembly & Disassembly Time	5	min	60	5
2	10	Weight of Device	5	lbs.	30	10
3	4,5,10	Disabling Range	3	ft^3	30	50
4	10	Target Acquisition Speed	4	s	20	5
5	10	Battery Life	3	h	2	3
6	3,5,10	Frequencies Jammed	3	GHz	2.4	2.4 and 5
7	2,10	Device reload speed	1	min	5	2
8	10	Target max drone wingspan	3	in	25	30
9	10	Target max drone Weight	3	lbs.	4	6
10	1-9	Project Cost	5	$	5000	2500

References

Netting; An Intuitive Guide to Nets. (n.d.). Retrieved from https://www.usnetting.com/articles/2013/11/17/netting-guide.html