

# Design of the Life-ring Drone Delivery System for Rip Current Rescue

Andrew S. Hardy, Mohammed T. Rajeh, Lahari K. Venuthurupalli, Gang X. Xiang

**Abstract**— Over 40% of the US population will visit the beach each year. Over 30,000 of them will need to be rescued by a lifeguard, dozens will not be saved in time. Rip currents account for approximately 80% of those rescues and deaths. Lifeguards are the primary rescuers, they are supported by lifeguarding organizations who train and certify the lifeguards. Municipalities typically own and operate beaches, are concerned with the well-being of beachgoers, and employ and/or regulate lifeguards and lifeguarding organizations. There is a need for a system that can integrate with the current lifeguarding setup, which can reach and assist a victim in under 90 seconds in order to increase the victim's survival time. This will be done by a drone system that will receive call out of drowning victims, fly out to the victim, and release a flotation device to support the victim until the lifeguard can reach them for rescue. Various flotation devices have been analyzed based on lifeguard opinion. Ring buoy is the best choice. A comprehensive simulation has been built and from that have determined that a battery with \_\_\_ mAh, a \_\_\_ designed drone platform and a motor that is \_\_\_ big (eh?) will provide for the best response time and increase the victim's survival time to enable a lifeguard to reach them before the victim drowns.

## I. INTRODUCTION

Drones are an emerging technology as such there is a lot of research on potential applications. With the amount of weight a drone can carry and with the speed a drone can travel, they seem ideal for emergency and first responder work. The authors of this paper are interested in determining the best way, or if there is indeed one at all, of applying drones to the rescue of drowning victims in hopes of saving lives. As such the authors will focus on the design of a whole rescue system centered around the drone, what type of flotation device would be best will be determined based on

(I'm not sure what the deal is with this)

Manuscript received December 9, 2015. This work was supported in part by the Center for Air Transportation Systems Research at George Mason University and ExpertDrones (uh?)

A. S. Hardy is a student in the Systems Engineering and Operations Research department of George Mason University's Volgenau School of Engineering, Nguyen Engineering Building, 4400 University Dr., Fairfax, VA 22030 USA (e-mail: ahardy9@masonlive.gmu.edu).

M. T. Rajeh is a student in the Systems Engineering and Operations Research department of George Mason University's Volgenau School of Engineering, Nguyen Engineering Building, 4400 University Dr., Fairfax, VA 22030 USA (e-mail: mrajeh@masonlive.gmu.edu).

L. K. Venuthurupalli is a student in the Systems Engineering and Operations Research department of George Mason University's Volgenau School of Engineering, Nguyen Engineering Building, 4400 University Dr., Fairfax, VA 22030 USA (e-mail: lvenuthu@masonlive.gmu.edu)

G. X. Xiang is a student in the Systems Engineering and Operations Research department of George Mason University's Volgenau School of Engineering, Nguyen Engineering Building, 4400 University Dr., Fairfax, VA 22030 USA (email: gxiang@masonlive.gmu.edu)

lifeguard preferences, a simulation will be created for use in determining how much battery, what general drone configuration, and how much motor is needed to create an acceptable rescue system. A cost and utility analysis will be performed to ensure the system will be functional useful in the real world. The authors will also deliver a recommended integration of the drone system into the lifeguarding and rescue process.

## II. CONTEXT ANALYSIS

### A. Beach Analysis

In the United States, approximately 42% of the adult population visits the beach every year [1]. Beach goers visit the beach for activities such as swimming, surfing, scuba, and to just walk around the beach. While on beaches, they pay for beach services and give revenue to the owners. There are approximately 6,200 beaches in the United States [2]. In addition, those beaches are a profitable business for the U.S.; they generate more than \$320 billion annual revenue [3]. The costs to manage and maintain a beach in the United States are less than 4% of \$2.65 billion annual park service budgets. For example, beach patrol in Ocean City, Maryland operates on a budget \$2.3 million [4]. On any sizable beach, there are lifeguards that make sure beach goers are safe.

### B. Beach Rescues

There are different incidents that lifeguards respond to every year. Each incident can lead to successful rescues, or in the worst case, fatalities. For the first type beach rescues, we have considered statistical data from the USLA between 2003 and 2013 [5]. That data includes rip currents rescues and total rescues. For fatalities, we have considered statistical data from the USLA between 2003 and 2014 [5]. That data include surf zone fatalities total, rip current

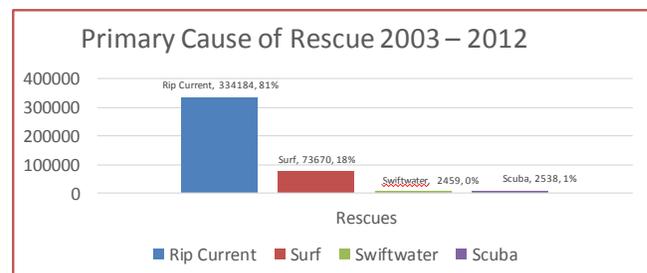


Fig 1. Rip currents are the primary cause of rescues for the years 2003-2012

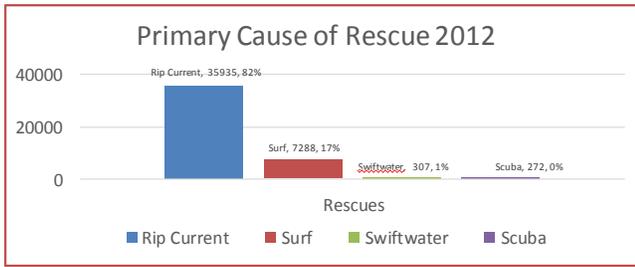


Fig 2. Rip currents are the primary cause of rescue for the year 2012. Causing 82% of all rescues

drowning deaths and total drowning deaths. For rip current drowning deaths and total drowning deaths, we have considered the situation when there was a lifeguard and when there was not a lifeguard.

Please note, some beach agencies only report totals for fatalities and rescues, but not the specific causes of rescues. For example, just because a graph says there are only two rip current rescues that year, does not mean there were only two rip current rescues that year for all agencies. It means only two rescues from agencies that do report that subcategory. We show these graphs to reveal the general trends and minimum numbers regarding rescues and fatalities.

Figure 1 and Figure 2 are the most important graphs on beach rescues [6]. Figure 1 shows that rip currents are the primary cause of rescue in the United States in the last decade since rip currents accounted for nearly 330,000 or nearly 80%, of rescues. The rescues from surf, swiftwater, and scuba were 18%, 0%, and 1% respectively. Compared to surf, swiftwater, and scuba rescues, rip currents are the primary cause of rescue. Figure 2 is a sample from 2012 to emphasize that rip currents are the primary cause of rescue

Figure 3 shows the amount of rip current rescues from 2003 to 2013, according to the USLA [5]. When looking at the trend line, rip current rescues are increasing over the years by a rate of about 900 people per year. Figure 4 shows the total rescues for all causes between 2003 and 2013. The total includes rip currents with swift, surf and scuba rescues. By looking at the trend line, total rescues are increasing over the years by an increasing rate of about 1160 people per year. When comparing rip current rescues with the total rescues, rip current rescues are almost half of the total

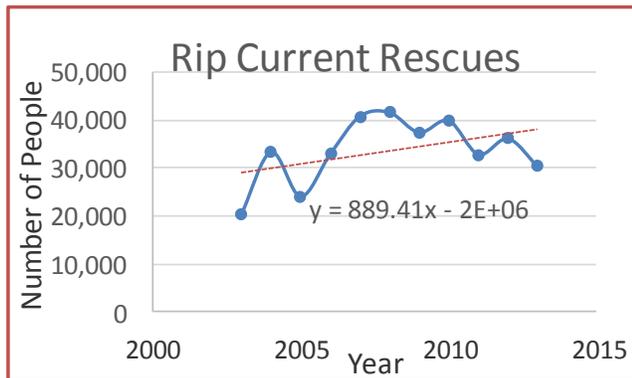


Fig 3. Shows the rip current rescues for the USA. From 2003-2012.

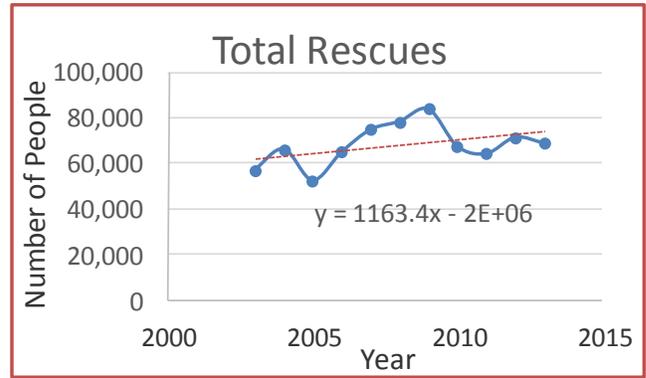


Figure 4. Total rescues for the USA for the years 2003-2012

rescues. For example, in 2011 the rescues from rip currents were 32,867 while the total rescues were 63,909 people rescued. Remember that some agencies report totals and not rescues with specific causes, so the 32,867 is an estimate of the minimum number of rip current rescues that year

### C. Beach Fatalities

Figure 5 shows the fatalities in 2014 in the United States according to the National Oceanic and Atmospheric Administration (NOAA) [7]. Rip current drowning accounts for 79% of all beach fatalities. On the other hand, drowning from high surf accounts for 7%, sneaker wave drowning accounts for 3%, other drowning accounts for 6% and unknown drowning account for 5%. Rip current drowning accounts for the majority of beach fatalities. In addition, according to NOAA, the 10-year average of annual rip current fatalities is 51 people per year [8]. However, the

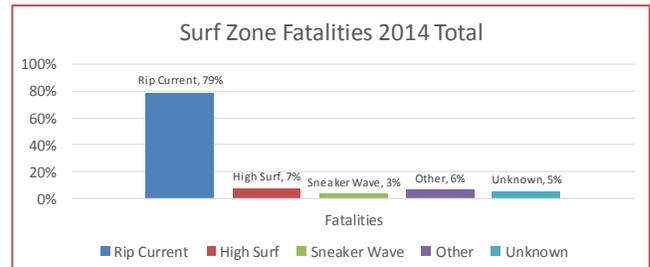


Fig 5 Rip currents account for 79% of all fatalities in the surf zone in 2014 for the USA

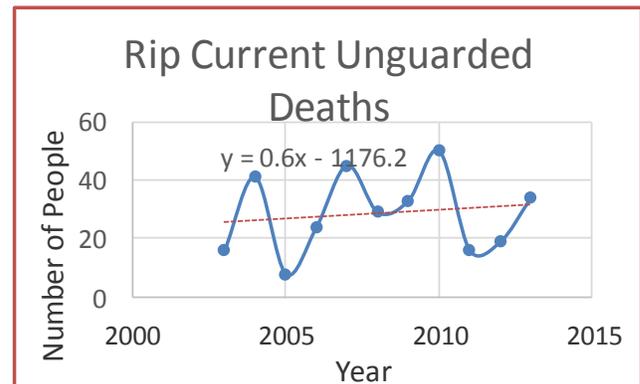


Fig 6. Rip currents deaths at unguarded beaches for the years 2003-2013

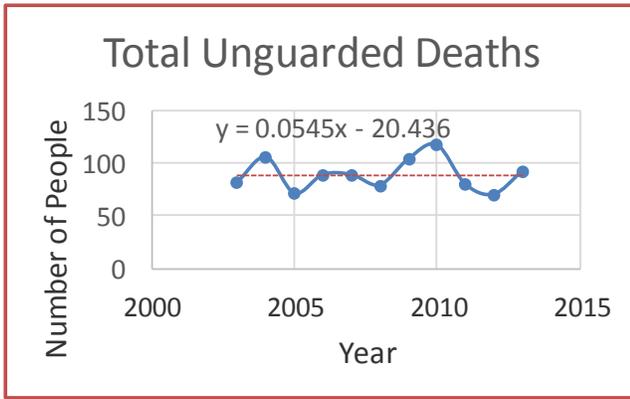


Fig 7. Total unguarded deaths across the US

United States Life Saving Association (USLA) believes rip current fatalities exceed 100 people every year [9].

Figure 6 and Figure 7 show unguarded (no lifeguards present) deaths between 2003 and 2013, and unguarded drowning deaths from rip currents from 2003 to 2013 [5]. Drowning deaths from rip currents is slightly increasing at a rate of 0.6 per year. In Figure 7, you can see the total unguarded drowning deaths from 2003 to 2013. The total includes rip currents with swift, surf and scuba. The total drowning deaths is mostly stable

Figure 9 and Figure 8 show guarded drowning deaths according to the USLA from 2003 to 2013 [5]. Guarded

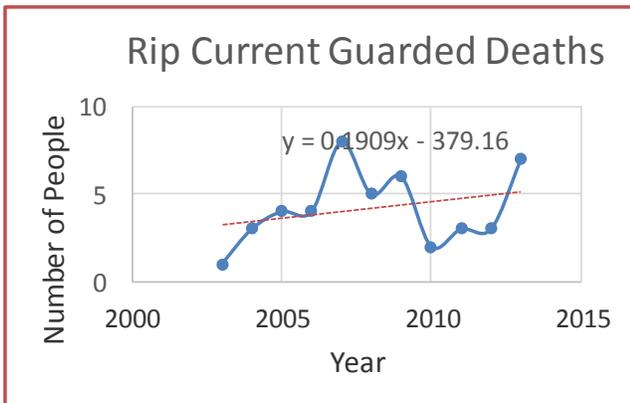


Fig 8. Guarded rip current fatalities 2003-2013

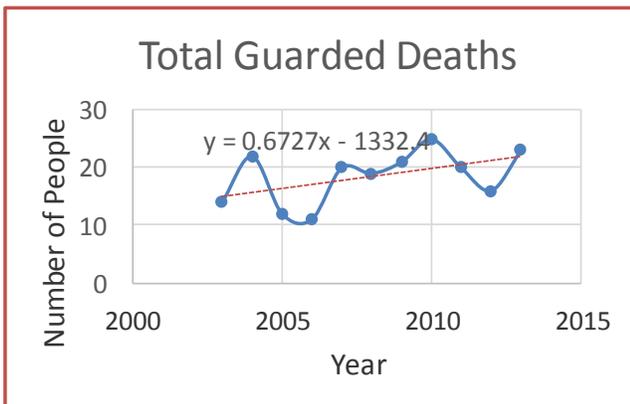


Fig 9. Total guarded fatalities 2003-2013



Fig 10. Image of a large rip current near a jetty

(lifeguard present) drowning deaths from rip currents are increasing at a rate of 0.19 per year. The total deaths includes fatalities caused by rip currents, swiftwater, surf and scuba. Total drowning deaths is increasing by a rate of 0.67 per year.

#### D. Rip Currents)

Shown by the statistics from section 1.2, beach goers who swim in the waters have to be careful of rip currents, as they are very dangerous and they drag people away from shore. Agencies like the USLA and NOAA are actively spreading knowledge about the dangers of rip currents [10]. Rip currents are strong powerful currents of water that flow away from shore. They form when waves break near the shoreline, meaning it can occur at nearly every beach. Beaches usually have multiple rip currents spread across the shoreline.

When waves break near the shoreline, they generate feeder currents that move along shore [11]. Once this feeder current is deflected offshore, it forms the rip current. This rip current has a neck and a head area. The neck is the area where the rip current's speed and strength is highest. Most drowning deaths happen in the neck area of the rip current. The head of the rip current is the area where the rip current's speed and strength starts to weaken.

Shown in Figure 10, rip currents can also form around jetties. Additionally, when waves travel through sandbars, the water level increases and this is also form rip currents. As the water level increases, the pressure increases and this

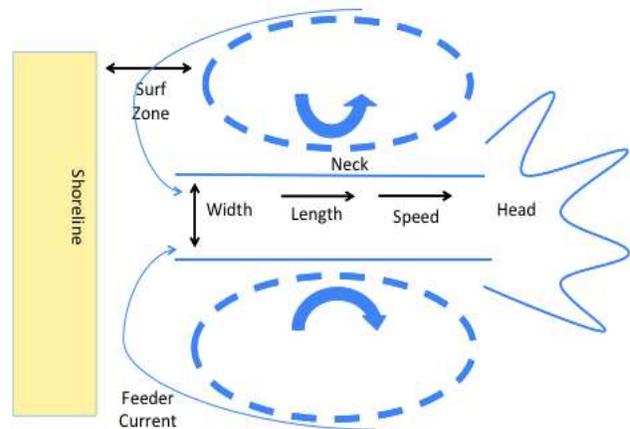


Fig 11. Rip current circulation diagram

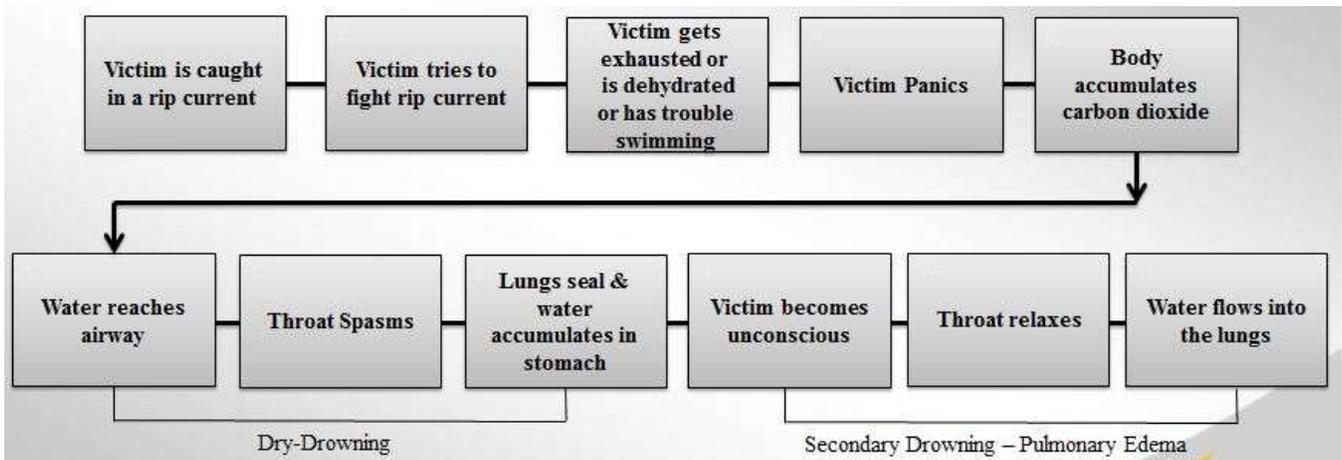


Fig 12. Drowning Process

would form faster and stronger rip currents. Some rip currents last for many days or months, while others some last hours or days.

The width of the neck ranges between ten and two hundred feet. The neck length ranges approximately from one hundred to one thousand feet away from shore. The speed of the rip current ranges from one to eight feet per second. When the rip current's speed is below four feet per second, it is not considered to be dangerous for strong swimmers, but it is dangerous for the weak swimmers [9]. However, if the speed exceeds four feet per second, this is considered to be dangerous for all the swimmers.

If swimmers caught in a rip current, it is dangerous for them if they try to fight it by swimming against the rip current. The best method is to swim parallel to the shoreline to get out of the neck first, then swim back to shore.

### E. Drowning Process

Drowning is a very common and deadly experience. After the victim is caught in a rip current, their first reaction is to fight it. The victim tries swimming against the current however they should float with the current, or swim parallel to the shore.

The main reason for a victim to drown is either because they are exhausted, dehydrated, or they do not know how to swim. Hence, they start to panic. The body accumulates carbon dioxide which leads to dry-drowning. Dry-drowning is when the water reaches the airway, and the lungs start to seal and the water starts to accumulate in the stomach. This eventually leads to secondary drowning where the victim becomes unconscious and the water flows into the lungs. In less than a minute the victim will be dead. This is shown in figure 12.

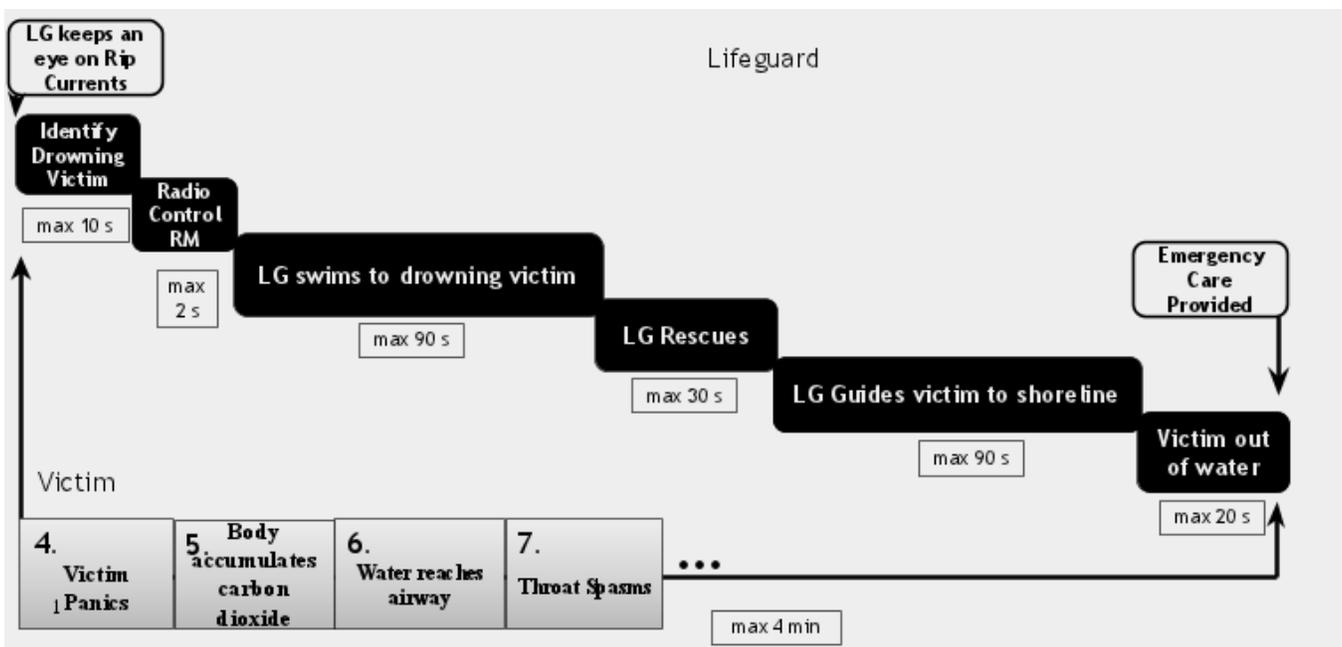


Fig 13. Lifeguard Rescue Process

### F. Lifeguard Rescue Process

A lifeguard chair is placed every couple meters or miles, depending on how big the beach is. The beach is separated into multiple zones with one lifeguard chair in the top most center of each zone. If a drowning victim is spotted in the zone, the lifeguard will radio the control room, whistle at the adjacent lifeguards to cover their zone and point in the direction of the victim [13]. The lifeguard then will start running towards the shoreline with either their right hand up in the air, which means assistance is needed, or pointing and tapping on top of their head, which means assistance is NOT needed. The lifeguard usually detects the drowning victim when they first start to panic. The lifeguard swims to the victim, rescues them, guides them back to the shoreline, and then drags them out of the water. Medical care is provided as needed afterwards. This entire lifeguard rescue process takes a max of 4 minutes [14]. This process is shown in the function block diagram depicted in figure 13.

### G. Performance Gap

There is a gap between victim survival time and lifeguard rescue time. Shown as the green line above, lifeguards can reach a victim in a maximum of 93 seconds [14]. Victims that can survive more than 93 seconds are on the right side of that green line. They are safe because they can survive long enough for lifeguards to come and rescue them. The victims that cannot survive for more than 93 seconds are in the red shaded area. They are the ones in risk of drowning. The time of 60 seconds marks the estimated survival time for a weak swimmer that attempts to fight against the rip current.

## III. STAKEHOLDER ANALYSIS

There are five main stakeholders: 1) lifeguarding associations, 2) lifeguards, 3) beach goers, 4) manufacturers, and 5) municipalities.

Lifeguarding associations are professional lifesaving associations that train dedicated beach lifeguards and open water rescuers. These associations certify lifeguards and make sure they are up to date with all four requirements: 1) Yearly licensing, 2) Four hours of in-service training, 3) Monthly training meetings and, 4) Red ball test. If the individual meets all these requirements each year they will be certified as a lifeguard.

Lifeguards are strong swimmers who supervise the safety and rescue of swimmers, surfers, and other water sports participants. Three certified lifeguards were interviewed to

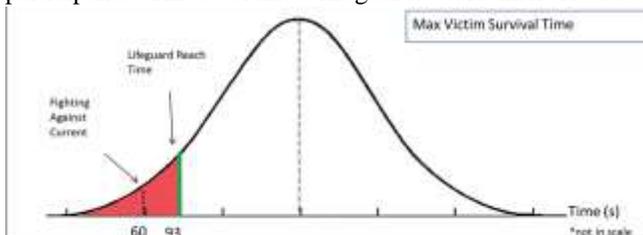


Figure 3. Gap between survival time and rescue time

help with research on rip currents, rescue process, and liability issues.

Beach goers are people who go to the beach and use its services. They want the least restrictions. Instructions given by lifeguards are of no concern. However, they want the lifeguards to be 100% effective at their jobs. In other words, the beach goers want the lifeguards to be always alert, well-trained, and to save everyone in time.

Manufacturers are companies that produce equipment for the lifeguards. Some major companies include Swimoutlet and Marine Rescue Products. A lifeguarding association can also manufacture rescue products. For an example, the Jeff Ellis & Associates, an international lifeguard training company, builds their own products such as a rescue board, a lifeguard buoy, a ring buoy and life jackets.

Municipality is broken down into owner and operator. The owner can be the county, city, or state government that owns the beach property. The operator documents the lifeguards current status of certification and requirements met. They are the ones who pay the lifeguarding associations, certified agencies (like Jeff Ellis), and lifeguards. Both the owner and operator are usually the same. However there are some operator businesses that concentrate on the documentation and financial aspect of lifeguarding that owners may hire.”

### A. Liability Issues

Between these five stakeholders there are liability issues. The body of water, in this case a beach, is broken down into municipalities which can be looked at as the owner and operator. The operator keeps the lifeguard certification history, updates are all documented and monitors the financial status. The lifeguard associations are certified lifeguard agencies. These associations train lifeguards who are hired by the owner to supervise the safety of the beach goers.

Lifeguards and certification agencies are always liable if a drowning victim sues a lifeguard for any injuries during the rescue process. However, if the lifeguards use only the designated, branded equipment the agencies provide, and the agencies have proof and correctly document the lifeguard's training and license, there is a very low chance of a successful lawsuit. Most cases would be settled out of court [13].

### B. Stakeholder Tensions

The below diagram in Figure 15 is a summary of all the interactions, liabilities, and tensions among the relevant stakeholders. There are tensions between all the stakeholders such as the lifeguards not doing their jobs correctly and not following what the agencies have taught them, or the municipalities not having proper documentations stored or the beach goers not obeying the rules and regulations. The lifeguards protect the beach goers in case of any emergency. If the beach goers are injured during the rescue process they can sue the lifeguards. However, at the end of the day, the beach owner is always responsible for any lawsuits against

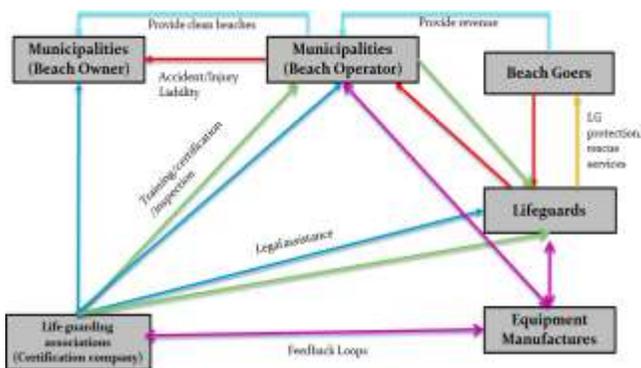


Fig 15. Stakeholder tension diagram

the lifeguards. The beach owner is protected under the catastrophic umbrella insurance which is an extra layer of liability protection over and above the beach property in case the owner is sued because of an accident. If the owners lose the lawsuit, the taxpayers pay that umbrella insurance.

The beach goers provide the revenue for the operator who then provides clean and safe beaches for the owner. The Life guarding associations train and certify professional lifeguards who are hired by the operator. These associations also provide legal assistance for the owner, operator, and lifeguards. Also, the associations, operator, and lifeguards provide feedback of the equipment the manufactures produce. The associations are looking for the most reliable and effective equipment whereas the operator is looking for something that is affordable.

### C. Win-Win

Assume there exists a solution that would decrease the amount of rip current fatalities. Since there is less fatalities, beaches with the system would be considered safer, thus more beach goers would come, which is a win for municipalities and for beach goers. The system could be equipped with any reasonably weighted flotation device, so it is unlikely any lifeguarding agencies need to buy equipment from a different manufacturer. Thus, manufacturers should not be affected by the system. Currently, there is no stakeholder that is again a new system. All stakeholders will receive some benefits if the system is successful.

## IV. PROBLEM AND NEED

### A. Problem Statement

On average, rip currents are the cause of 81% of annual beach rescues, 79% of annual beach fatalities, and they cause a minimum of 51 deaths per year (USLA 2015)(NOAA 2014)(NOAA 2015). Lifeguards are very good at their job and can reach a victim caught in a rip current in a max of 93 seconds (Butch 2015). However some victims cannot survive this long, as some have survival times as low as 60 seconds.

### B. Need Statement

There is a need for a system that can reach and assist a

victim in under 60 seconds in order to increase the victim's survival time. If a victim receives a flotation device in time, they can survive long enough for the lifeguard to pull them back to shore.

### C. Proposed Design Solution

We will design a system that will increase the victim survive time during the rip current rescue process. This will be done by delivering a flotation device to the victim while they are in the water. Once a victim has the flotation device, they will be able to survive long enough for the lifeguard to rescue them. The delivery will be done by the use of an unmanned aerial drone.

## V. REQUIREMENTS

\*We are current revising our requirements to be more organized and relevant to our components.

### A. Mission Requirement

MR.1 - The LDDS system shall reduce the average annual number of rip current deaths by a minimum of X%.

### B. Functional Requirements

F.1 The system shall hover at a minimum altitude of 3m above the ground.

F.1.1 The system shall hover at an altitude of 3m with a minimum payload of 2.268kg.

F.2 The system shall be operable within X m of the home point.

F.3 The system shall reach a victim within X seconds.

F.3.1 The system shall increase the victim survival time by an average of X seconds, if the system does reach the victim.

F.4 The system shall be able to restock its payload within X seconds.

F.5 The system shall be able to deploy its payload within X seconds.

F.6 The system shall do the entire rescue process at a maximum time of X seconds.

F.7 The system shall be able to hover within a horizontal distance of 0.5m from the target.

### C. Design Requirements

DR.1 The system shall attach the lifesaving device to the drone through a tether.

DR.1.1 The system may have a disconnect method to cut or release the tether in order to deliver the lifesaving device.

DR.1.2 The system shall have a tether release system that weighs under X kg.

DR.1.3 The system shall be able to release the tether within X seconds of the request to release.

DR.2 The system shall have a camera system pointing downward.

DR.3 The system shall have a camera system pointing

forward.

#### D. Usability Requirements

##### Usability

U.1 The system shall be usable by a person that has less than 12 hours of training.

##### Availability

A.1 The system shall be available to at least any beach on U.S territory

A.1.1 The system shall comply with all federal drone regulations (see Appendix A)

A.2 The system shall be available for rescues over 95% of the time.

A.3 The system shall be usable in X rescues a day when balanced charged.

A.4 The system shall have a minimum lifetime of 5 years

##### Reliability

RE.1 The system will have MTBF of X months

RE.2 The system shall have a tether system error MTBF of 7 days

##### Resistibility

RS.1 The system shall resist sand conditions of an average beach.

RS.2 The system shall resist humidity conditions of an average beach.

RS.3 The system shall resist temperature conditions of an average beach

## VI. CONCEPT OF OPERATIONS

\*We are currently revising our concept of operations to

meet questions from the faculty presentation.

#### A. Function Flow Block Diagram

The lifeguard process and the drone system are independent, meaning the lifeguard rescue process is outside of our system boundary. If the lifeguard for some reason is not able to reach the victim the drone will still continue and drop the ring buoy. If the drone is not able to drop the ring buoy, the lifeguard will still reach the victim. The drone process will start and simultaneously take place in the 90 seconds the lifeguard has to swim to the drowning victim. The controller receives what zone the victim is and finds the exact coordinates the victim is. The controller will then command the drone to lift off. After the drone leaves the home point to the given coordinates, there is a decision mark if the drone reaches the victim on time. If the drone reached the victim in time, it will continue the process of dropping the ring buoy near the drowning victim and releasing the tether when the victim grabs it, and then the drone returns to its home point. This will modify the victim's survival time. However, if the drone does not reach the victim on time, the drone will directly go back to its home point.

#### B. Operational Scenario

Precondition:

Lifeguard has identified a drowning victim. Lifeguard is prepared for rescue process. Lifeguard informs the controller about the section number or victim's general direction. Victim is located somewhere on the rip current

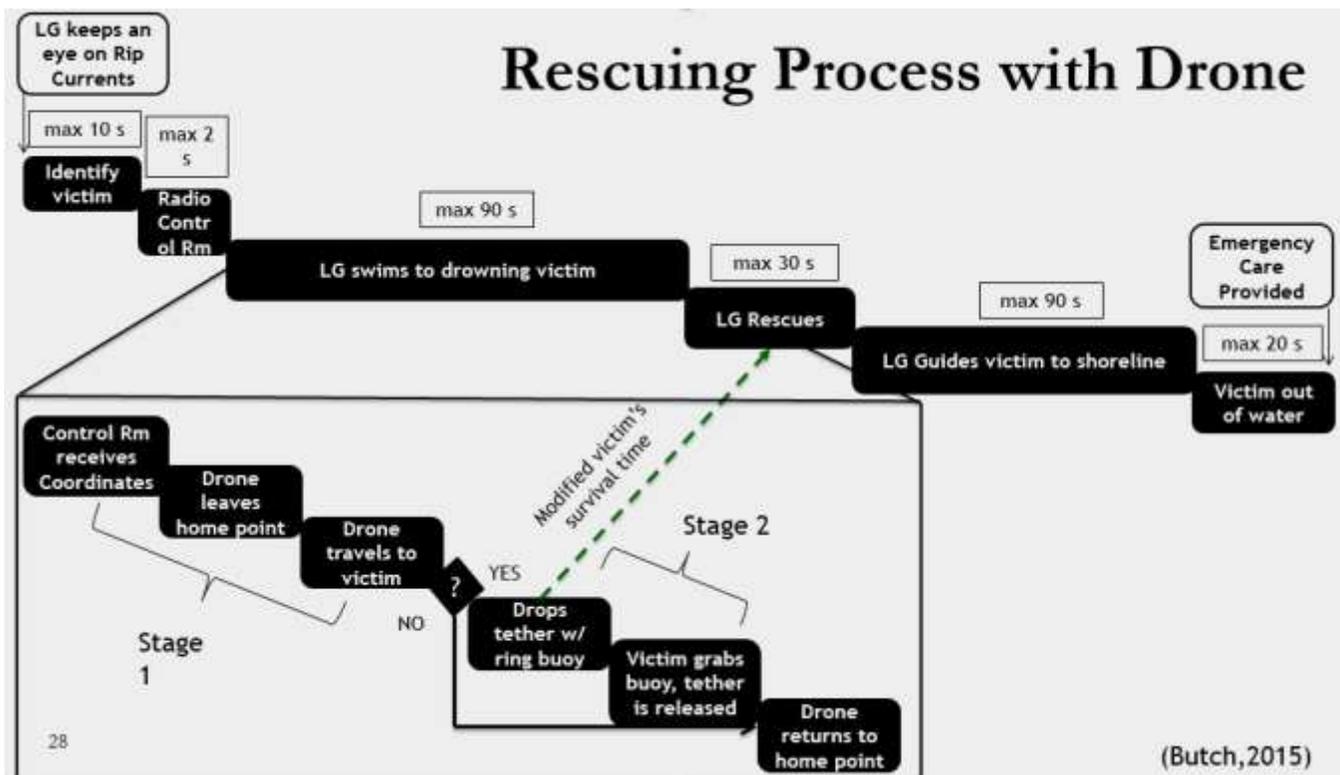


Fig 16. Rescue process with LDDS system

and is attempting an escape method. Drone is ready to deploy. Flotation device is stocked on drone.

Primary:

Stage 1

1. Controller is informed by lifeguard of general area of the victim
2. Controller takes off drone and confirms victim location by eyesight if near tower
3. The system takes off to a height of X meters.
4. The system accelerates to X m/s towards the section given.
5. Controller confirms specific location relative to drone in that section through camera or eyesight
6. The system maintains X m/s towards the victim's location.
7. Once the system is within X m of the victim's location, system shall decelerate to victim's speed and position. At the same time, the system will reduce height until the flotation device is just above the water (confirmed by controller).

Stage 2

8. The system drops the flotation device when it is 5m away from the victim and positions it by the victim.
9. Once the victim is about to grab the flotation device, system detaches the tether.
10. The system maintains a X m hover over victim until lifeguard has reached the victim.
  - a. Controller uses camera to visually determine victim state (active or passive)

Return

11. Once lifeguard has reached the victim, or drone has been determined to be of no further use, or drone has reached critical battery charge, system will be flown back to the home point.
12. System lands on home point.

Post-Condition:

Lifeguard is enacting the rest of rescue process starting with rescuing the victim. Drone has landed back at the home point and awaits restocking of ring buoy. Victim is being helped by the lifeguard.

## VII. ALTERNATIVES

We have three sets of alternatives we are looking to evaluate to ensure that the LDDS drone system will be the most effective.

### A. Drone Design Alternatives

For the design of the LDDS drone system we must consider how big a battery the system actually has to carry, the larger the battery the more flight time the drone will have. However, with the increase in size comes an increase in weight. We wish to ensure that the drone can devote the majority of its carrying capacity to the flotation device and related components so the lightest battery possible while still ensuring we have enough flight time necessary to perform

the mission is required.

The size of the motors increases the lift the drone can generate, however larger motors would require the drone to be both larger and heavier to take the resultant increased forces. We need motors that are big enough to provide the necessary carrying capacity for the done while not turning it into a helicopter.

Another way to increase the drone carrying capacity is to increase the number of motors that are on the drone, so we wish to find the minimum number of motors and the optimum configuration of motors while not turning the drone into a motor pile.

### B. Drone location alternatives

There are three considered locations that it could be station for use in the updated rescue process. First is in a central control room. This would allow the drone to be sheltered from the elements and be near its charging station. However, the drone would be forced to travel a farther distance to reach any drowning persons. Second is to station the drone near the lifeguard towers. This would reduce the travel time to drowning persons, but it exposes the drone to the elements and removes it from maintenance and charging areas. Third is to have the drone stationed out in the ocean. This is only being considered as a method of ensuring compliance with potential FAA regulations.

### C. Flotation Device Alternatives

Alternatives for the flotation device are being considered. We will compare the four most popular and reasonable flotation devices in order to conclude the best alternative for the drone to carry and deliver to the drowning victim. The quantitative factors being compared are weight, dimensions, buoyancy, and cost [21]. The most reasonable one is the ring buoy as it is cost effective and the victim has a better chance of grasping it, and it has been recommended by our stakeholders. The effectiveness and usability are the ratings from a professional lifeguard which is purely opinion based. The best alternative is found by performing an AHP analysis. The weights for each factor is found however calculations to find the best alternative by using these weights is still in process (TBA).

## VIII. METHOD OF ANALYSIS

### A. Simulation Goal

The goal of our simulations is to verify that the LDDS system meets the mission requirement of reducing fatalities. The LDDS system works best with a lifeguard, however 75% of all fatalities are in unguarded areas. Thus, we will perform simulations to check the LDDS system's performance for both unguarded and guarded rescues.

To make sure the simulation is close to reality, we will have design of experiments on verifying the properties of the drone.

## B. Equations

In order to analysis the feasibilty of the system, we shall use a MATLAB simulation to test a drone's ability to fly to a moving target, which represents the victim in a rip current. In order to do that, we first detail the equations and notations we will use. We used Andrew's work and last year's NSPDAV team works for our equations [16] [17].

Drones, or Unmanned Aerial Vehicles, have an even number of motors (four, six, or eight). Half the motors spin counterclockwise and the other half spin clockwise. By having motors that spin in different ways, the drone can controll rotation about its axes. For example, this figure shows the top view of the drone. Clockwise rotation is stronger, thus the drone body must be rotating counterclockwise.

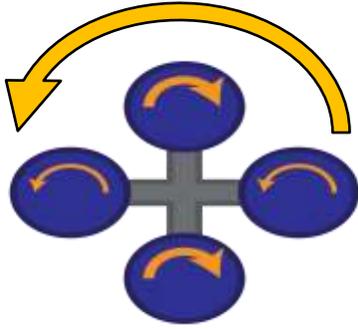


Fig. 17: diagram for a counterclockwise rotation

There is also two frames of reference we need to consider. The drone has its own reference, or point-of-view. While the controller, standing still on a beach, has his own reference; his own left, forward, and up. We define the drone's point-of-view as the body-frame, and the controller or beach's point-of-view as the inertia-frame.

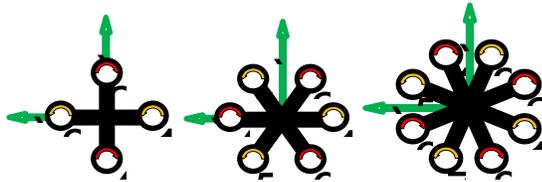


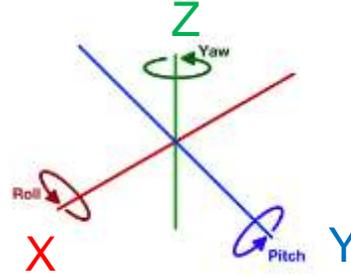
Fig. 18: motor numbers and rotations for different platforms

We first define the motor numbers, and spins in Figure 18. The simulation will focus on hex copters and octocopters. We define odd-numbered motors to be spinning clockwise and even-numbered motors to be counterclockwise. Although this might seem contrary to the figure, these notations are for viewing the drone from the bottom-up. Thus, clockwise means, from the bottom view, it is rotating clockwise. We define the axis of the body-frame drone as the following: the front side as the positive X-axis, the left side as the positive Y-axis, and the top side as the positive Z-axis (the Z axis is point out of the screen in).

We will define the position of the drone in X-Y-Z coordinates. The orientation of the drone will be in the Euler

angles of  $\varphi$ - $\theta$ - $\psi$ , or roll-pitch-yaw.

There is three axis of rotations. They can rotate around their X-axis (roll), the Y-axis (pitch), and the Z-axis (yaw) as shown below.



<http://theboredengineers.com/2012/05/the-quadcopter-basics/>

Fig 19 Axes of rotation

In order to transform body-frame forces into inertia-frame forces, we will use transformational matrices. For example, force-inertia = Rotational-matrix\*force-body. There are respective transforms for  $\varphi$ - $\theta$ - $\psi$  (roll-pitch-yaw). We only need the product of the three rotational matrices in order to a full transform using the three values of  $\varphi$ - $\theta$ - $\psi$ .

$$R_{\psi} = \begin{bmatrix} \cos \psi & \sin \psi & 0 \\ -\sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$R_{\theta} = \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix} \quad (2)$$

$$R_{\phi} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \quad (3)$$

$$R = R_{\psi} R_{\theta} R_{\phi} = \begin{bmatrix} \cos \theta \cos \psi & \sin \psi \cos \phi + \sin \phi \sin \theta \cos \psi & \sin \phi \sin \psi - \cos \phi \sin \theta \cos \psi \\ -\cos \theta \sin \psi & \cos \phi \cos \psi - \sin \phi \sin \theta \sin \psi & \sin \phi \sin \psi + \cos \phi \sin \theta \cos \psi \\ \sin \theta & -\sin \phi \cos \theta & \cos \phi \cos \theta \end{bmatrix} \quad (4)$$

Additionally there is a transform matrix to convert derivatives of Euler angles to inertia-frame angular velocities. Shown below:

$$\begin{bmatrix} \omega_X \\ \omega_Y \\ \omega_Z \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\sin \theta \\ 0 & \cos \phi & \sin \phi \cos \theta \\ 0 & -\sin \phi & \cos \phi \cos \theta \end{bmatrix} \begin{bmatrix} \dot{\varphi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} \quad (5)$$

## C. Power and Thrust

We first assume that the propeller motor torque is proportional to the current difference.

$$\tau = K_t (I - I_0) \quad (6)$$

Where  $\tau$  is motor torque,  $I$  is the current,  $I_0$  is the no-load current when the motor is not spinning, and  $K_t$  as the proportionality constant. We assume  $I_0$  is negligible. We also assume that the voltage difference is the sum of the voltage drop across internal resistance and a term that involves the angular velocity of the propellers. Because the faster the propeller spins, the more voltage it uses

$$V = IR_m + K_v \omega \quad (7)$$

Where  $V$  is voltage,  $I$  is the current,  $R_m$  is the internal resistance,  $K_v$  is the proportionality constant, and  $\omega$  is the angular velocity of the motor's propeller. For the simulation, we assume  $R_m$  is negligible. Also note that motor manufacturers list  $K_v$  publicly, but that is the inverse of the  $K_v$  we are using. Their equation for  $K_v$  is  $K_v * V = \omega$ , while we have  $V = K_v * \omega$ . We simply need to do  $1/K_v$  of the manufacturer's value to get our version of  $K_v$ .

From the two equations before (6) (7), we gain terms for current and voltage, thus we can find power.

We now assume that motor torque is proportional to the motor's thrust

Where  $\tau$  is the motor torque,  $K_\tau$  is a proportionality constant,  $T$  is thrust,  $P$  is power generated,  $K_v$  and  $K_t$  are proportionality constants, and  $\omega$  is motor propeller angular velocity. The table below summarizes all the proportionality constants we have shown

Variable 1	Relation	Variable 2	Proportionality Coefficient	Equation
$\tau$	$\propto$	$I$	$K_t$	$\tau = K_t * I$
$\tau$	$\propto$	$T$	$K_\tau$	$\tau = K_\tau * T$
$V$	$\propto$	$\omega$	$K_v$	$V = K_v * \omega$

Table 1: Proportionality Constants

Each motor has a propeller. Each propeller spins, pushing air downwards. The air in turn push upwards. This is the general idea of how motors provide an upward force. The thrust equation we use is listed below:

Where  $T$  is thrust,  $D$  is diameter of the propeller,  $\rho$  is the air density, and  $P$  is power. Notice that we have a power term (10), thus we can use our earlier power equation to substitute into the thrust equation (11). The new thrust equation is listed below.

Where  $K_v$ ,  $K_\tau$ , and  $K_t$  are proportionality constants, and  $\omega$  is propeller angular velocity. In the body frame, the drone only provides thrust upwards. Moving is possible when the

drone is tilted, but to the drone it always provide thrust force in the positive Z-axis. Also each motor follows the thrust equation, and so the motor's thrusts can be added together. The follow shows that idea.

Where  $\omega_i$  is the  $i$ th motor.

#### D. Life vest Model

For the flotation device, we will model the force of gravity and the vector sum of the drag force on the device, the force of gravity is of course  $F = mg$ , while the force of drag is from the equation of drag (14).

#### E. Main Force Model

With the force of drag(14), force of thrust (13), force of gravity, force due to the tether rope, and force due to the life vest, this will lead up to the equation of

Where  $m$  is the mass of the drone system,  $a$  is the acceleration, and  $F$  is the various forces acting on the drone. Expanding on this equation, we have:

Where  $x,y,z$  is the coordinate position of the drone,  $g$  is the gravitational constant (9.81 m/s/s),  $R$  is the rotational matrix(4),  $TB$  is the thrust in body-frame,  $FD$  is the force of drag, and  $Flifevest$  is the force due to the life vest or flotation device. Here is a summation of our forces in a free body diagram, shown below.

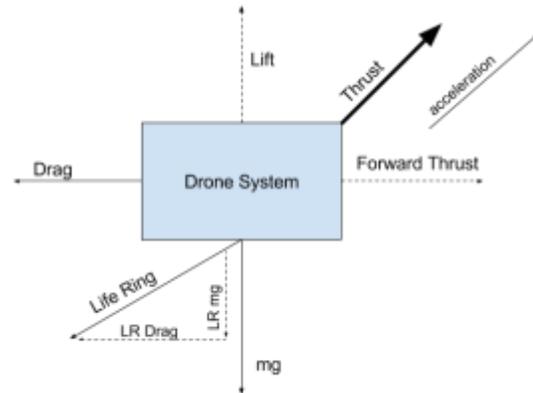


Fig. 20: Free body diagram, side view of drone system

#### F. Rotational Dynamics Model

The torque on the body of the drone is from the motors. Each motor has spinning propellers that push air horizontally, but the air also pushes back. This creates a force at a distance away from the center of the drone, which is the definition of torque. The torque is given by

$$\tau_D = r \times F_D \quad (19)$$

Where  $r$  is the distance between the motor and the drone's center of mass. We already know the force of drag from above. We also know that velocity = radius \* angular velocity, thus we can derive a torque equation based on angular velocity. However we also note that torque = moment of inertia \* angular acceleration. However, it is a small enough value that we can later consider negligible in equation (21).

$$\tau_D = \frac{1}{2} r \rho C_D A(r)^2 (\omega)^2 \quad (20)$$

$$b = \frac{1}{2} r \rho C_D A(r)^2 \quad (21)$$

$$\tau_Z = b\omega^2 + I_Z \dot{\omega} \quad (22)$$

Where  $\tau_Z$  is the torque around the body Z-axis,  $I_Z$  is the moment of inertia about the body Z-axis. Now that we know torques are related to the angular velocity squared, we can find the torques about the X-Y-Z axes.

For roll, the torque is given as torque = force \* distance. The distance is the distance from the motor to the center of mass. We assume the drone is symmetrical, thus the distance is the same for all motors. When rolling, drones usually increase the thrust of one motor while decreasing the other motor in the pair in order to maintain the same body thrust while also creating a torque from that difference of thrust. Thus, the torque from one motor minus the torque from the opposite motor creates the body's rolling torque.

For pitch, it is the same as roll, however it involves the other pair of motors on the drone.

For yaw, we add up all the motor's torques (21). Since two motors spin counterclockwise and two spin clockwise, two of the terms must be negative. We denote the even numbered motors contributing to clockwise spin, thus the terms involving even numbered motors are negative.

Where  $L$  is the distance from a motor to the center of mass. This equation is for a quadcopter, however similar equations exist for the hexacopter and octocopter. These equations are based on Figure.

We will be using Euler's equation for torque in order to get the angular acceleration of the system.

Where  $\tau$  is the body's torque,  $I$  is the moment of inertia, and  $w$  is the angular velocity of the drone. This equation does not directly give us roll, pitch, or yaw, thus we need to

expand on it. Since we assume the drone is symmetric, the moment of inertia about the X-Y-Z axes are independent of each other, shown below in that equation. If we modify the equation to solve for angular acceleration, we get the other equation below.

Where  $\tau_\phi$ ,  $\tau_\theta$ , and  $\tau_\psi$  are the torques in their respective rotations (22),  $I_{xx}$ ,  $I_{yy}$ ,  $I_{zz}$  is the moment of inertia about their respective axes, and  $\omega_x$ ,  $\omega_y$ ,  $\omega_z$  are the angular velocities about their respective axes. Once we have the angular accelerations, we can use the transformation matrix to get the Euler angle derivatives (5). Integrate those to get the Euler angles. To find moment of inertia for the X, Y, and Z axes we will use the general equation for moment of inertia around the center of mass,

Where  $m_i$  is the mass of component  $i$ ,  $r_i$  is the distance from the center of mass for component  $i$ , and  $r_c$  is the distance between the edge of the object and the center of mass.

## IX. 7.3 SIMULATION

The three processes we will simulate are: 1. Rip Current and Victim Process 2. Drone dynamics and control 3. Lifeguard Rescue Process

### A. Rip Current and Victim Process

Fig. 21: simulation diagram of rip current effects on victim state

This simulation will calculate the position of the victim over time. There is three methods of escape methods (float, swim parallel to shore, swim toward shore). The white block is the integration block, showing that position is the integral of velocity.

Each method would be represented as a velocity. For example, swimming toward the shore can be represented as a 2 m/s velocity in the negative x-axis direction. The rip

current velocity will be randomly chosen between its minimum and maximum possible velocity. The distribution of chosen methods was developed after talking with a lifeguard stakeholder [14]. The distributions are shown below:

victVelo is the victim's velocity which is decomposed into horizontal and vertical swimming speed. A and B are the ranges for the human swimming speed. We will develop this further over Winter break. A is negative and B is negative, thus a victim is always represented as possibly swimming toward shore or swimming toward the guard tower.

Rip current properties include rip current width, length, position on the shore, and current velocity. The width, length, and current velocity ranges are shown in the Context #. Position on shore will be a uniform distribution between 0m and 750m.

Using the rip current properties This process's output is the victim's position, which will later act as the waypoint input for the drone and for the lifeguard.

### B. Lifeguard Rescue Process

Fig. 22: lifeguard model

This process calculates the lifeguard position over time. The lifeguard simulation will be inputted the victim position as a waypoint. The victim position will be randomly modified to be at a position at a later time due to the delay of lifeguards identifying victims. The time to identify can be a distribution, but the maximum is 10 seconds [14]. It will also input the rip current properties because lifeguards jump into the rip current to get to the victim quickly. Using the victim as the target and the rip current as a boost, the lifeguard will attempt to reach the victim before they drown. The lifeguard velocity is also a range, the minimum swimming speed to be a lifeguard is publicly available and we can estimate the max velocity using the fact that 90 seconds is the max time to reach. Once the lifeguard has reached the victim, we will add a delay time to simulate the time needed for the lifeguard to help the victim and grab hold of them.

The rescue process after the lifeguard reaches the victim is outside the scope of the drone system. It is up to the lifeguard from here on out to help the victim, thus we will not simulate the rescue process beyond this point.

### C. Drone Dynamics and Control

In order to test the drone's abilities to fly and accelerate when carrying a life ring, we must simulate the electrical and mechanical properties of the drone under flight. The simulation will follow the following diagrams.

Fig. 23: dynamcis and control model

Fig. 24: rotational dynamics model

Fig. 25: thrust/throttle/translational model

The controller will be simulated as GPS flight. This means that the drone autonomously hovers when there is no input, there is a maximum velocity and tilt, and that it maintains altitude while in horizontal movement.

The way the first model works is that the target's position is used as a waypoint. Using the drone's current state and the victim's position, the controller outputs voltages to the motors. The motors provide some thrust and torque on the drone, which is used to calculate errors in the PID controls.

The controller is programmed to use Euler angle errors to adjust the voltage, but how do we convert errors in velocity and position to errors in angles? The velocity error could be any value in the interval  $[-\infty, \infty]$ , and the wanted angle can be any value that is within the tilt limits set by the drone's controller. Thus there needs to be a relation between the velocity domain and wanted angle range. The simplest relation is:

Fig. 26: control relation between velocity and wanted angle

Where  $a$  is the tilt angle limit in radians, and  $b$  is a coefficient. The higher the value of  $b$  is, the more we want to tilt to get the right velocity.

The waypoint is the position of the victim. Using its position and various errors calculated, we can control the drone to be the same position and velocity as the waypoint. Once it reaches that waypoint and stays at it for a set period of time, we record the time.

### D. Post MATLAB & Simulink Analysis

Fig. 27: main simulation model

The above model shows how we will derive successful rescues with and without the drone. Calculate Victim Position is referred in. Calculate Lifeguard Position is referred in. Calculate Drone Position is referred in. At the end, using the lifeguard and drones position over time, we can calculate the survival of the victim. The green block will evaluate whether the victim survived until the drone reached them, whether the lifeguard reached the victim in time, whether the drone dropped the ring buoy in time, and then record the time it took for the lifeguard and drone to reach the victim. Depending on the drone simulation and if it deployed the life ring on time at the right position, the victim survival time will be modified.

After the simulation of the processes is over, we generate a random victim survival time. Repeat for several trials to generate survival rate for with-drone and without-drone processes, along with average time to reach victim, average successful rescue, and average drone velocity.

### E. Simulation Requirements

The simulation requirements are currently being redone to be better organized.

#### Functional Requirements

SR.1 The system shall be able to fly towards a waypoint and maintain position within 0.5m of the waypoint.

SR.2 The system shall have one run simulated under 1 minute.

SR.3 The system shall simulate wind and weight interactions with the drone.

SR.4 The system shall model drone rotational and translational dynamics.

SR.5 The system shall model the lifeguard-victim rescue process until the lifeguard reaches the victim.

SR.5.1 The system shall model the three victim escape methods (swim parallel to neck, swim against the neck, and float)

SR.5.2 The system shall model riptides of length 100/200/300/400/500 meters.

SR.5.3 The system shall model the lifeguard speed on land and on water as an average velocity of X m/s and Y m/s respectively.

#### Input Requirements

IR.1 The system shall inputted a victim swimming method. It will pick between floating, swimming parallel against the shore, and swimming parallel to shore.

IR.1.1 The system shall model the swimming methods as velocities. The choice will be based on a discrete random distribution.

IR.1.2 The system shall be inputted a random victim survival time based on the swimming method chosen.

IR.2 The system shall be inputted a random rip current speed. The speed will be chosen by a random X distribution with mean X and variance X.

#### Output Requirements

OR.1 The system shall output the victim position over time.

OR.2 The system shall output the lifeguard position over time.

OR.3 The system shall output the drone position over time.

OR.4 The system shall output 1 or 0 depending if the lifeguard rescue time is under victim survival time.

OR.4.1 The system shall detect if the drone reached the victim before the lifeguard and increase victim survival time by X seconds

#### F. Simulation Design of Experiments

In order to gather meaning results from the simulation, we need to run it through experiments. Each experiment gives outputs that flow into the next experiments.

##### 7.5.1 1st DoE: Victims distance from shore before dying

Using the victim escape method, escape velocity, and survival time distributions we have, we will general a distribution for distance travelled by the victim while they are surviving. The distributions will be generated using ARENA.

Input		Output	
Rip Speeds	Current	Rand. Victim Properties	Distance Travelled Distribution
1m/s		50reps	
2m/s		50reps	
3m/s		50reps	

4m/s	50reps	
5m/s	50reps	
6m/s	50reps	
7m/s	50reps	
8m/s	50reps	
Rand. Uniform(1,8)	50reps	

Whether we use a specific distribution for the selected rip current velocity, or use a randomized one for all velocities, will be decided in the next semester.

#### 2nd DoE: Best Path, Best Location, Minimum Velocity Needed

This experiment is to find the necessary minimum velocity, best location to set up a drone, and the best path a drone should take

The DoE does expand to another octocopter platform, and the velocities of 14,8, and 16m/s, and 6 m/s. Using the distribution of victims in each of the 20 reps, we can determine the best location and best path. The minimum velocity will be set if more than 90% are saved in under 60 seconds. This percentage might change as the team deliberates more over Winter break.

Since the flight speed and flight path might have some issues and have no clear winner, we will need a utility test to determine the best speed and path. This function will be completed over the Winter break.

#### 3rd DoE: Drone Design Space Model

We now need to find the power needed for the drone's weight. There is a circle of feedback where the more weight we add, the more thrust we need, more thrust means more power, more power means bigger battery, and bigger battery means more weight. Thus, we need to know what power we need and what battery alternatives we can use in this drone system. The following DoE is for that purpose:

By varying the weight and flight maneuver, we will find the power needed to do that maneuver. We can then plot our design space in a line graph between Total weight vs. Power needed. There will be three functions to plot for the three maneuvers. For constant velocity flight, we will use the minimum velocity needed found in DoE 2.

#### 4rd DoE: Guarded and Unguarded Rescue

Finally, we evaluate all the alternatives to possible improvements to rip current rescue.

The alternatives considered include:

1. Lifeguard
2. Lifeguard with LDDS
3. Lifeguard with ATV
4. Lifeguard with ATV with LDDS
5. Lifeguard with Boat
6. Lifeguard with Boat with LDDS

We will then determine which alternative gives the most utility, using the utility function below:

$S_G$  = percent guarded lives saved (%)

$S_{UG}$  = percent unguarded lives saved (%)

$T_R$  = mean time to reach victim (sec)

$E$  = mean battery energy usage per rescue (kWh/Rescue)

Once the experiment is done after Winter break, we will finish these utility functions.

### G. Cost Model

To calculate the net present cost of a drone system, we will consider the costs within a two year lifecycle. We will assume inflation is equal to the 2015 inflation rate and is constant over the two years. We will convert annual costs to a present value costs. Here is the model of how we will calculate costs:

Fig. 28: hierarchical cost model

Evaluation of non-drone alternatives will only include two factors: (1) Acquisition Cost, (2) Annual Upkeep cost (boat or ATV maintenance, if any).

### H. Utility Function

To evaluate the best alternative to completing the mission requirement, we will use the utility function and the experiment done in section 7.4.4, as well as the cost model from section 7.6.

Below is a table of the weights and values for all the alternatives. Using 7.5.4 DoE#4 results, we will create a graph on utility vs. cost and determine the best result is.

SG SUGTR) E

Weights:	Utility:
Alternatives	
Lifeguard	
Lifeguard with LDDS	
Lifeguard with ATV	
Lifeguard with ATV with LDDS	
Lifeguard with Boat	
Lifeguard with Boat with LDDS	

Graph here:

## X. CONCLUSION

We have done no experiments, thus there is no recommendations as of yet. We will refine this over the Winter break.

## APPENDIX

Should we appendix the code and stuff for the conference paper?

## ACKNOWLEDGMENT

The authors wish to acknowledge that the authors are the best and everyone else is indeed the rest.

## REFERENCES

- [1] "LEARN: Beach Basics," EPA, [Online]. Available: <http://www2.epa.gov/baches/learn-beach-basics>.
- [2] "National list of Beaches," EPA, [Online]. Available: [http://ofmpub.epa.gov/apex/beamcon2/f?p=117:12:6598228724511::NO::P12\\_YEARS:Current](http://ofmpub.epa.gov/apex/beamcon2/f?p=117:12:6598228724511::NO::P12_YEARS:Current).
- [3] "New Student shows beaches area key driver of U.S. economy," American Shore and Beach Preservation Association, [Online]. Available: [http://www.asbpa.org/news/Beach\\_News/080814Houston.pdf](http://www.asbpa.org/news/Beach_News/080814Houston.pdf).
- [4] "Town of Ocean City Adopted budget," Ocean City Maryland, [Online]. Available: [http://oceancitymd.gov/City\\_Manager/BudgetBook.pdf](http://oceancitymd.gov/City_Manager/BudgetBook.pdf).
- [5] USLA, "Statistics," USLA, [Online]. Available: <http://arc.usla.org/Statistics/public.asp>. [Accessed 18 October 2015].
- [6] USLA, "Primary Cause of Rescue at Surf Beaches," USLA, [Online]. Available: <http://arc.usla.org/Statistics/Primary-Cause-Analysis.pdf>. [Accessed 12 October 2015].
- [7] National Oceanic and Atmospheric Administration, "U.S Surf Zone Fatalities 2015," National Oceanic and Atmospheric Administration, [Online]. Available: <http://www.ripcurrents.noaa.gov/fatalities.shtml>. [Accessed 18 October 2015].
- [8] National Oceanic and Atmospheric Administration, "List of Severe Weather Fatalities," National Oceanic and Atmospheric Administration, [Online]. Available: [http://www.nws.noaa.gov/om/hazstats/resources/weather\\_fatalities.pdf](http://www.nws.noaa.gov/om/hazstats/resources/weather_fatalities.pdf). [Accessed 15 September 2015].
- [9] "About Rip Currents," USLA, [Online]. Available: <http://www.usla.org/?page=RIPCURRENTS>.
- [10] "Rip Currents," NOAA, [Online]. Available: [http://www.ripcurrents.noaa.gov/resources/Final%20Talking%20Points%20and%20Fact%20Sheet\\_041707.pdf](http://www.ripcurrents.noaa.gov/resources/Final%20Talking%20Points%20and%20Fact%20Sheet_041707.pdf).
- [11] "Rip Current Sciences," NOAA, [Online]. Available: <http://www.ripcurrents.noaa.gov/science.shtml>.
- [12] "Rip Current Facts," Florida Diaster, [Online]. Available: <http://floridadisaster.org/EMTOOLS/Severe/documents/Rip%20Current%20Brochure.pdf>.
- [13] D. Underwood, Interviewee, *Lifeguarding Litigation and Insurance*. [Interview]. 2015.
- [14] B. Arbin III, Interviewee, *Lifeguarding Information*. [Interview]. 2015.
- [15] Jimbuoy, "Marine Product List," Jimbuoy, [Online]. Available: <http://www.jimbuoy.com/index.htm>. [Accessed 18 October 2015].
- [16] A. Gibiansky, "Quadcopter Dynamics and Simulation," Andrew.gibiansky.com, 23 November 2012. [Online]. Available: <http://andrew.gibiansky.com/blog/physics/quadcopter->

dynamics/. [Accessed 18 October 2015].

currents/. [Accessed 18 October 2015].

- [17] "Decision Support Tool for Designing Niche Small Package Delivery Aerial Vehicles," GMU SEOR, 30 April 2015. [Online]. Available: [http://catsr.ite.gmu.edu/SYST490/490\\_2014\\_SPDAV/USMA\\_DST\\_NSPEAV\\_DRAFT\\_031315.pdf](http://catsr.ite.gmu.edu/SYST490/490_2014_SPDAV/USMA_DST_NSPEAV_DRAFT_031315.pdf).
- [18] lancet.mit.edu, "Understanding D.C. Motor Characteristics," MIT, [Online]. Available: <http://lancet.mit.edu/motors/motors3.html>. [Accessed 4 October 2015].
- [19] Me.umn.edu, "Understanding DC Motors," [Online]. Available: <http://www.me.umn.edu/courses/me2011/arduino/technotes/dcmotors/motor-tutorial/>. [Accessed 04 October 2015].
- [20] Micromo, "DC Motor Calculations," Micromo, [Online]. Available: <http://www.micromo.com/technical-library/dc-motor-tutorials/motor-calculations>. [Accessed 24 September 2015].
- [21] indeed, "Systems Engineer Entry Salary," indeed, [Online]. Available: <http://www.indeed.com/salary?q1=Systems+Engineer+Entry&11=Fairfax>. [Accessed 18 October 2015].
- [22] salary.com, "Salary Wizard," salary.com, [Online]. Available: <http://swz.salary.com/SalaryWizard/Systems-Engineer-I-Salary-Details-22030-Fairfax-VA.aspx>. [Accessed 18 October 2015].
- [23] DJI, "Inspire 1 - Specs," DJI, [Online]. Available: <http://www.dji.com/product/inspire-1/spec>. [Accessed 24 September 2015].
- [24] DJI, "Phantom 3 Professional & Advanced - Specs," DJI, [Online]. Available: <http://www.dji.com/product/phantom-3/spec>. [Accessed 24 September 2015].
- [25] DJI, "Spreading Wings S1000+ - Specs," DJI, [Online]. Available: <http://www.dji.com/product/spreading-wings-s1000-plus/spec>. [Accessed 24 September 2015].
- [26] DJI, "Spreading Wings S900 - Specs," [Online]. Available: <http://www.dji.com/product/spreading-wings-s900/spec>. [Accessed 24 September 2015].
- [27] 3DRobotics, "X8+," 3DRobotics, [Online]. Available: <http://store.3drobotics.com/products/x8-plus>. [Accessed 24 September 2015].
- [28] Expert Drones, "All Drones," [Online]. Available: <http://www.expertdrones.com/alldrone/>. [Accessed 24 September 2015].
- [29] S. Litovich, Interviewee, *Drowning Information and Drone Considerations*. [Interview]. 18 September 2015.
- [30] NOAA's SciJinks, "How to Escape Rip Currents," [Online]. Available: <http://scijinks.jpl.nasa.gov/rip->