Soaring to Spec: Designing a Concept Aircraft for Cargo Deployment

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ABSTRACT

Aerial firefighting has proven itself to be a valuable procedure in containing the wildfires that consume millions of acres of land every year. Unfortunately, aircrafts must descend drastically to deliver the water and fire retardant they carry, thus exposing themselves to dangerous thermal winds, smoke, and debris.

In order to make aerial firefighting safer, a prototype cargo plane was developed to test the feasibility of using water bombs for spot treatment. Using such bombs would allow aircrafts to fly at higher altitudes and avoid the dangers associated with proximity to fire. The prototype was designed with an original airfoil with a high coefficient of lift. The fuselage of the plane was based off of an inverted Kline Fogelman design for extra lift and easy cargo storage. The water bombs used were 3D printed cylinders that were released by a mechanical arm.

The model was made of extruded polystyrene. All cylinders burst upon contact with the ground, showing that such bombs can be used to fight actual wildfires.

1. INTRODUCTION

Forest fires are an old and ongoing issue. In 2012, there were 67,774 fires that consumed 9,326,238 acres of land in the US alone.[1] The most damaging fire that year cost $353 million, as estimated by the Rocky Mountain Insurance Information Association.[2] Despite the benefits of natural wildfires, most fires are still destructive in nature. The issue at hand is the containment of wildfires to prevent extensive damage of property, resources, businesses, and life.

Wildfires are battled by conventional ground techniques and aerial firefighting techniques. For containment purposes, aerial firefighting is the superior method. Aerial firefighting consists of dumping water, gel, foam, or specially treated fire retardant onto the flames below. Planes need to fly dangerously close to the fire to ensure even a loosely accurate delivery of payload,[3] and the thermal winds and other dangers associated with proximity to forest fires can easily influence moments on aircrafts and endanger crew members.

The goal of this project was to improve the safety of aerial firefighting, thus reducing risk for the pilots and aircraft involved. This paper specifically addresses the feasibility of using water bombs in fighting wildfires. To explore this, a small scale aircraft was designed that could deploy cylindrical water bombs one by one. Calculations relating to balancing flight forces and moments were performed, and a system was designed to partially deploy cargo, which would allow a pilot to target the wildfires in crucial areas.

2. AERIAL FIREFIGHTING AND AERODYNAMIC CONCEPTS

2.1. Aerial Firefighting

Aerial firefighting vehicles come in three types: land-based airtankers, helitacks, and scoopers.[4] These three models differ by their method of loading retardant or water. While airtankers fill up at airport tanker bases, helitacks use buckets or tanks to carry water. Scoopers, on the other hand, gather their water supply from natural water sources.

A common misconception about aerial firefighting is that it is the sole method of fighting wildfires.[4] In fact, conventional firefighting squads put out most of the fire. Airplanes, in addition to attempting to contain the fires, use spot treatment to cool down the area for the safety of the ground squads.

The three main types of attack employed by aerial firefighting are indirect attack, parallel attack, and direct attack.[4] Indirect attacks target wildfires by deploying retardant away from the actual fire, which is extinguished before it reaches the point of deployment.[4] For this type of fighting, airtankers are the most ideal. Similar to an indirect attack, parallel attacks do not deploy retardant directly onto the fire.[4] However, they do deploy the retardant at a smaller distance from the fire's edge. This acts as a "control line", meaning it makes the path of the fire smoother and sets a boundary for where the fire will die out. In a direct attack, aircrafts deploy retardant directly onto "hot spots" or larger fires.[4] For this type of fighting, scoopers are the best type of aircraft.

These techniques, while effective to an extent, are by no means ideal. For example, to deliver the retardant, planes must dive towards the fire, risking damage from heat, debris, smoke, and thermal winds.[3,5] Maneuvering in these conditions is time-consuming and inefficient, and in situations where time is of the essence, these issues are even more pressing. Low altitudes force firefighting aircraft to only fly during the day because flying low over populated areas is too dangerous at night.[6] If planes try to fly at high altitudes, the water diffuses by the time it reaches the ground, thus becoming nullified.

Recently, to combat the problem of flying too close to fire, Boeing has tested the effectiveness of biodegradable water bombs.[3] After being deployed from the plane, each bomb holds its shape during its drop and bursts upon contact with the fire. Just one aircraft full of these bombs would perform work equal to that of 100 helicopter deployments. Furthermore, the bombs can be dropped from 1,000 to 2,000 ft. above the ground, high enough to avoid thermal winds.

Another effort on Boeing's part to make aerial firefighting safer is its Precision Container Aerial Delivery System (PCADS).[7] This system deploys retardant in containers and allows pilots to fly at a high, level attitude, thereby eliminating the dangerous dive-bombing efforts of current planes.

2.2. Design Principles and Aerodynamics

In order to build a plane, the basic principles of aerodynamics and how they affect aircraft design need to be understood.

2.2.1. Forces

Four forces govern flight: weight, thrust, lift, and drag (Figure 1).

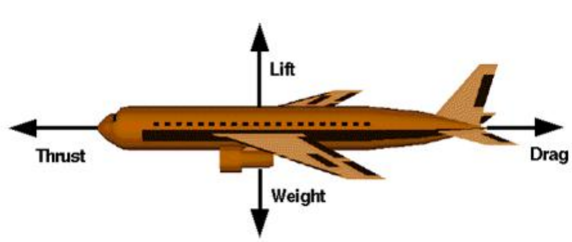

Figure 1. Four Governing Forces[8]

Weight is the force caused by Earth's gravitational field on the plane and its cargo. Thrust is typically generated by a rotating propeller, which is powered by either an engine or a motor.

Drag and lift are the two components of aerodynamic force.[9] When an object moves through a fluid like air, the pressure of the fluid creates a force on the object that acts on the plane at its center of pressure. This is called the aerodynamic force.

Lift is defined as the component of this force perpendicular to the object's motion, while drag is defined as the component of this force parallel to the object's motion.[9] Both lift and drag are determined by the shape and speed of the aircraft and the density, temperature, and composition of the fluid.[10,11]

Drag can be thought of as air resistance and is calculated by Equation 1. C_d is a constant called the coefficient of drag that is determined by the shape of the object in flight, ρ is density, A is planform area or the area of the top view of the wing, and v is velocity.

$$D = C_d \rho A v^2/2 \quad \text{Equation 1}^{10}$$

Lift is the force that makes flight possible. The wings of an aircraft contribute the most lift, while additional and less substantial lift is generated by the rest of the plane.[12] A solid object generates lift when it turns the moving flow of a gas. In doing so, the object diverts the flow in one direction and, according to Newton's law of equal and opposite reactions, generates lift in the opposite direction.[13]

Lift is generated because the air around a plane can have different velocities and therefore, according to Bernoulli's Principle, different pressures.[14] The total lift can be obtained by integrating the pressure difference multiplied by the fuselage area.

Because the airflow must be turned, motion is essential for lift to exist. In addition to turning the air flow, the solid body must be in contact with the fluid for lift to occur. Lift is calculated by Equation 2. C_L is a constant called the coefficient of lift that is determined by the shape of the object in flight, ρ is density, A is planform area, and v is velocity.

$$L = C_L \rho A v^2/2 \quad \text{Equation 2}^{11}$$

Weight is the fixed variable of flight dynamics. In designing an airplane, one must consider how all the other forces interact with weight. Lift opposes weight and allows the aircraft to become airborne. Lift is exponentially related to thrust, but higher thrust also creates higher drag, which reduces the effective lift. The lift limits how much weight the aircraft can carry. Thus, it is clear that weight, lift, thrust, and drag are affected by each other and numerous other variables that need to be considered in design. A stable aircraft requires balance of all these forces.

2.2.2. Reynolds Number

Another factor that affects the aerodynamic force acting on an object is the Reynolds Number of the air. The Reynolds Number is a measure of the viscosity of the air and is calculated by taking a ratio of the air's inertial forces and viscous forces. The equation for calculating a Reynolds number is given by Equation 3; v is the velocity of the object, L is a length scale, and ν is the kinematic viscosity coefficient. The higher the Reynolds Number, the smaller the importance of the fluid's viscous forces. The lower the Reynolds Number, the bigger the importance of the fluid's viscous forces. In addition, lift and drag vary by operating Reynolds Number. It is imperative to consider this when designing the wings.

$$Re = vL/\nu \quad \text{Equation 3}^{15}$$

2.2.3. Wings

Figure 2 shows a diagram of a standard wing.

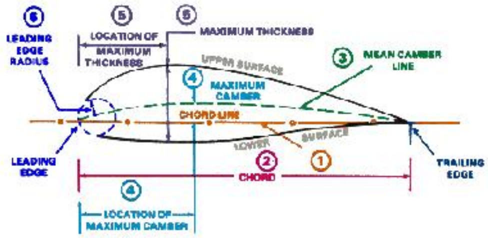

Figure 2. Standard Wing[16]

The cross-section of a wing is called the airfoil, while the chord is the tip to tip distance. Airfoil selection is a crucial process that has more of an impact than any other factor on a plane's ability to fly. Because a significant majority of an airplane's lift is generated by the wing's airfoil, the lift generated by the wing must be large enough to lift the entire body of the plane. However, changing the shape of the airfoil to increase lift can also increase drag, and if the airfoil produces too much drag, it will negate the plane's thrust. Another consideration when choosing an airfoil is the operating Reynolds Number because some airfoils are not designed to fly at certain Reynolds Numbers.

2.2.4. Control Surfaces

Most aircrafts have control surfaces, which are adjustable surfaces that allow the pilot to rotate the plane around its axes. The three most common types of control surfaces are ailerons, elevators, and rudders (Figure 3).

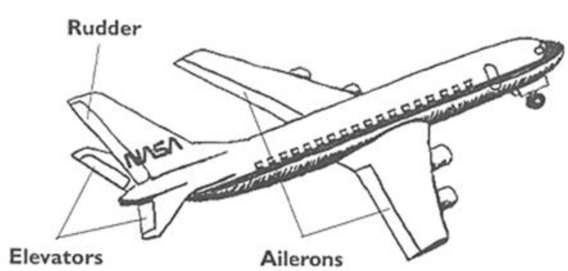

Figure 3. Control Surfaces[17]

Ailerons work in pairs and are located on the back of the wings.[18] Moving the ailerons creates a change in shape of the wing, which will cause the aircraft to roll either right or left, allowing the plane to turn.[19] When the left aileron is up and the right one down, the lift generated by the left wing decreases, while the lift generated by the left wing increases, causing the plane to roll left.[18] When the right aileron is up and the left one down, right wing lift decreases and left wing lift increases, causing the plane to roll right. The challenge in designing ailerons is being able to control the sensitivity of the roll.

The elevators are attached to the back of the horizontal stabilizer, one of two parts of the plane's tail, and work together to pitch the plane up or down.[20] When the elevators are pointed down, more lift is generated in the back of the plane, causing the back of the plane to rise and the nose to drop. Conversely, when the elevators are pointed up, less lift is generated in the back of the plane, causing the back of the plane to drop and the nose to climb. Similar to designing ailerons, designing elevators requires balancing pitch moments for a stable controlled flight.

The rudder is attached to the vertical stabilizer, the second part of the plane's tail, and can change whether the nose is pointed left or right.[21] When the rudder points left, more lift is created on the tail in the right direction, causing the nose to bank left. When the rudder points right, more lift is created on the tail in the left direction, causing the nose to bank right. Many forces, such as propeller wash, wing tip vortices, and engine exhaust, induce moments on the aircraft, causing it to roll or yaw. The rudder ensures that the nose of the airplane is pointed in the right direction. These parameters must be considered in rudder design.

3. DESIGN OF SCALED MODEL

The plane described in this paper was designed to be able to lift its own weight in cargo, specifically plastic water bombs that could hold fire retardant or water.

3.1. Airfoil Design

The first step in picking an airfoil was finding a minimum required coefficient of lift. Since the function of the plane is to deploy retardant and water, its wings need to be able to carry a significant weight. To find the minimum coefficient of lift, Equation 4, a modified version of the standard lift equation, was used.

$$C_L=2L/(\rho v^2 A)) \qquad \text{Equation 4}$$

C_L is the coefficient of lift, L is the lift generated by the wing, ρ is the density of the air, and A is the planform area.[22] Since the predicted weight of the plane was 7 lbs., the cargo would also weigh 7 lbs., and so the generated lift would need to equal 14 lbs. To find the speed of the plane, the online service eCalc was used. eCalc uses details about certain plane components to calculate useful flight information.

Some of the necessary details were as follows. The motor is a Cheetah A4120-7, the battery cell is a five cell LiPo battery, and the propeller is a two blade 16” x 8” APC Electric E propeller with a gear ratio of 1:1. The local elevation used was 52 ft., the air temperature was 85 °F, and the air pressure was 29.91 in. Hg. The temperature and air pressure were those recorded on the day of calculation. eCalc predicted a top speed of 55 mph, and assuming the speed drops almost in half for the sake of simplicity, the coasting speed of the aircraft was predicted to be 30 mph (44 ft./s).

According to the DeNysschen air density calculator, the density of the air in Piscataway is 0.0727 lbm/ft^3.[23] The humidity and temperature used were those of a typical day during this project. The lift coefficient equation requires units of slugs, so the density of air used was 0.00226 slugs/ft^3. The planform area of the wings was originally 660 in^2 or 4.583 ft.^{2}, obtained by a 66” wingspan and 10” chord. However, the coefficient of lift required by these dimensions was 1.40, and taking into account a partial efficiency of 0.8, the required C_L would be 1.75.

When looking at C_L, one must also look at Reynolds Number. Kinematic viscosity is necessary to calculate the Reynolds Number, and using a table from Engineering Toolbox, the kinematic viscosity for these purposes is 2.234 x 10^{-4} ft.^{2}/s.[24] Using a Reynolds Number calculator with a velocity of 30 mph, a chord width of 10”, and a kinematic viscosity of 2.234 x 10^{-4} ft.^{2}/s, the Reynolds Number is 164,087.[25] More generally, the Reynolds Number is on the order of 100,000.

A C_L of 1.75 is a fairly high value for a Reynolds Number on the order of 100,000. To remedy this, the wingspan was increased to 72”, and the chord was increased to 11”, giving a new planform area of 792 in^2 or 5.5 ft.^{2} and a required C_L of 1.16. Taking into account partial efficiency, the chosen airfoil was picked to have a C_L = 1.16696/0.8 = 1.45, a much more feasible C_L.

The step after calculating the minimum coefficient of lift was to search for an appropriate airfoil. It needed to generate as much lift as possible without creating too much drag in order to carry the relatively massive weight of the cargo. Furthermore, it needed to be feasible to create in a workshop setting.

The UIUC database was the primary source of airfoil information for this project.[26] Airfoil Tools was used to analyze C_L v. C_d plots of ten airfoils at Reynolds Numbers on the order of 100,000. Of those ten, three were eliminated (CH10-Smoothed, GOE 523, and FX 76-MP-160) because their C_L v. C_d plots in the specific Reynolds Number range was jagged. See Figure 4 for details.

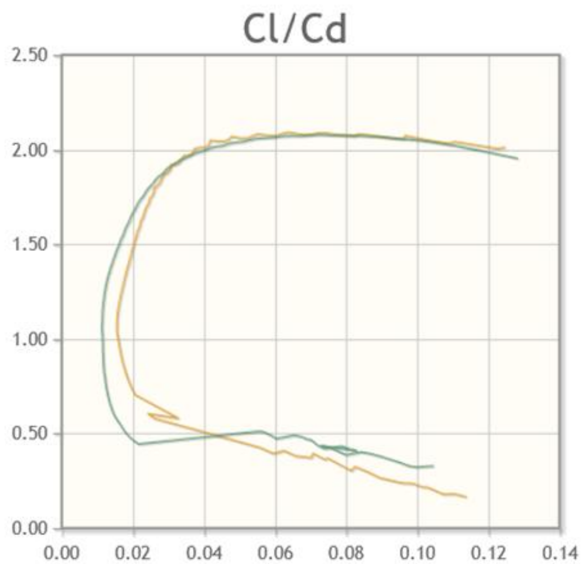

Figure 4. Example of Jagged Graph[27]

C_L v. C_d graphs are often used to determine the predicted performance of airfoils at different Reynolds Numbers. Cusps in such graphs indicate an unsteady and volatile pitch level throughout the flight, which is dangerous for a small aircraft.

Another six airfoils (Clark YM-15, Clark Z, FX 63-137 13%, MH 113 14.62%, Eppler 395, Wortman FX 60-126) were eliminated because their C_L was either too low or too close to the minimum required value. The last airfoil, the S1223, was eliminated because it has a characteristically sharp and sudden trailing edge that makes the manufacturing process difficult and its durability questionable. Finally, finding no success in the databases, the Java applet JavaFoil™ was used to experiment with different designs. After experimenting with iterations of the NACA 4-digit style airfoil, Joukowsky airfoils, and Horten Brothers airfoils, the best airfoil turned out to be a modified NACA 4-digit style airfoil with 18% thickness and 10% camber (Figure 5).

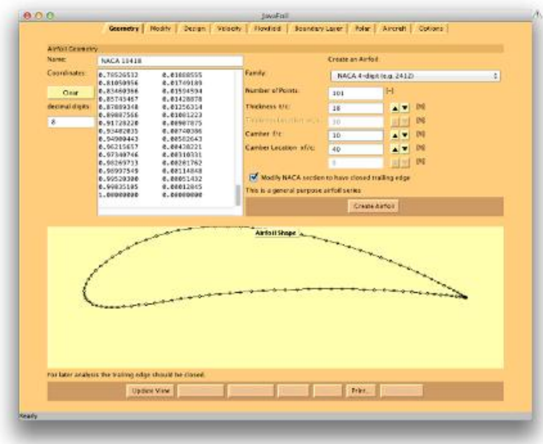

Figure 5. Final Airfoil Design

JavaFoil™ and XFLR 5 both returned results of a $C_L > 1.64$ at an attacking angle of 3º (±.003), in addition to promising C_L/C_d ratios and smooth C_L v. C_d plots. This high coefficient of lift would allow the plane to fly higher, avoiding dangerous thermal winds, and carry the cargo more easily.

3.2. Fuselage Design

Obtaining extra lift is specifically useful for cargo planes, and one way to do this is to use a fuselage that generates lift. An airfoil-shaped fuselage, while certainly capable of producing extra lift, compromises the space available for cargo storage. An inverted Kline Fogelman-like design (Figure 6), on the other hand, also provides more lift than a typical cylindrical fuselage and is advantageous in several ways for cargo deployment. Its flat bottom lends itself to simple cargo storage, and its stepped underside allows for an open back from which cargo can be dropped.

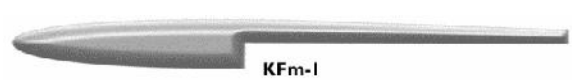

Figure 6. Inverted Kline Fogelman Design[28]

The design for the fuselage was heavily influenced, though not dictated, by an inverted Kline Fogelman model. In addition, the fuselage was designed with flat sides for proper aerodynamic flow as well as ease of construction.

Based on general rules of thumb from the guidance of an experienced mentor, the fuselage length was determined to be around 48” or 70% of the wingspan.

3.3. Tail Dimensions

The tail consists of the horizontal stabilizer, the vertical stabilizer, the elevator, and the rudder. The final dimensions for these pieces came from generally accepted conventions.[29]

The horizontal stabilizer’s area is usually 20 to 25% of wing area. In this case, since the wing area is 792 in^2, the horizontal stabilizer’s area should be 158.4 to 198 in^2. The area was chosen to be around 158 in^2. Additionally, the traditional aspect ratio for a horizontal stabilizer is from 4.5 to 5. Letting x be the chord, the leading to trailing edge distance, of the horizontal stabilizer and y be the span, a system of equations can be set up. This system is given by Equations 5 and 6. Solving this system gives approximate values of x = 6” and y = 26”, giving an area of 156 in^2. The horizontal stabilizer span should also be about 33% of the wingspan, and 26” is close to 24”, which is 33% of 72”. The elevator area should be 20 to 25% of the horizontal stabilizer’s area, meaning 31.2 to 39 in^2. Because the span of the horizontal stabilizer is 26”, the chord of the elevator is 1.5”.

$$xy = 158 \qquad \text{Equation 5}$$
$$y/x = 4.5 \qquad \text{Equation 6}$$

The vertical stabilizer’s area is usually 7 to 12% of wing area. In this case, since the wing area is 792 in^2, the vertical stabilizer’s area should be 55.44 to 95.04 in^2. The area was chosen to be around 71.28 in^2, which is approximately 9% of the wing area. The traditional shape of a vertical stabilizer is roughly a trapezoid with two right angles, a shape that can be made by making a cut from the midpoint of the top side to the midpoint of the left side of a rectangle and attaching the resulting triangle to the bottom left corner of the rectangle (Figure 7).

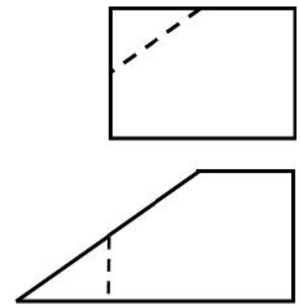

Figure 7. Vertical Stabilizer

Thus, the dimensions of the vertical stabilizer can be treated as the dimensions of a rectangle. The accepted aspect ratio for a horizontal stabilizer is from 1 to 1.25. Letting x be the horizontal distance and y be the vertical distance, a system of equations can be set up, given by Equations 7 and 8. Solving this system gives approximate values of x = 7.6” and y = 9.5”, giving a total area of 72.2 in^2. This means that the vertical stabilizer is a right angled trapezoid with a top side of 3.8”, a bottom length of 11.4”, and a height of 9.5”. The rudder’s horizontal length should be 30 to 50% of the vertical stabilizer’s horizontal length; this length was chosen to be 2.75”, which is around 36% of the vertical stabilizer’s horizontal length.

$$xy = 71.28 \qquad \text{Equation 7}$$
$$y/x = 1.25 \qquad \text{Equation 8}$$

Tail volume coefficient calculations were used to check the general reliability of these dimensions. The horizontal stabilizer volume coefficient is calculated by Equation 9. S_{hs} is the area of the horizontal stabilizer; TMA is the tail moment arm, meaning the distance from the center of gravity to the tail’s aerodynamic center; S_w is the area of the wing; and C_w is the chord of the wing. The areas and chord length are inherent parts of the plane’s design. By convention, the TMA is 2 to 3 times the length of the wing's chord, so for these calculations, it was assumed to be 2.5 times the chord length, which is 27.5". For the purposes of this plane, the V_{hs} should be in the 0.35 to 0.5 range, and [(156 in^2)(27.5 in)]/[(792 in^2)(11 in)] = 0.492, which is right in the target range.

$V_{hs} = S_{hs}*TMA/(S_w*C_w)$ Equation 9

The vertical stabilizer volume coefficient is calculated by Equation 10. S_{vs} is the area of the vertical stabilizer; TMA is the tail moment arm; S_w is the area of the wing; and b_w is the wingspan. For the purposes of this plane, the V_{vs} should be in the 0.02 to 0.035 range, and [(72.2 in^2)(27.5 in)]/[(792 in^2)(72 in)] = 0.0348, which is right in the target range.

$V_{vs} = S_{vs}*TMA/(S_w*b_w)$ Equation 10

3.4. Propeller and Motor Specs

The propeller used for this plane is a 16" x 8"APC Electric E propeller with two blades and a 1:1 gear ratio. The motor is a Cheetah A4120-7 with a 530 KV. The battery cell is a LiPo battery with a cell capacity of 3700 mAh and a weight of 3.6 oz.

The motor was chosen because it fits this project's budget. Its maximum current is 55A, and accordingly, the Electronic Speed Controller was chosen to be a Phoenix Edge Lite 100 that has a maximum amperage of 100A.

Six servos were needed for this project: two for the aileron, one for the rudder, one for the elevator, one for the cargo, and one for the front wheel. Each needs approximately 0.5 amps. The Battery Eliminator Circuit, which ensures that the battery doesn't overload the engine thus needed at least 3 amperes. Fortunately, the Phoenix Edge Lite 100 has a built in BEC that can take up to 5 amps.

Thrust testing was done with the same battery but a slightly different sized propeller, and 10.8 lbs. of thrust were generated, which is enough to lift the plane off the ground. A 16" x 8" propeller was chosen because it would have a necessary 1" ground clearance.

3.5. Water Bomb Design

In place of simply dumping water and retardant on fires, this plane was designed to use cylindrical water bombs to target "hot spots" in direct attacks. This allows the plane to fly at higher altitudes because the packaging ensures that the retardant will not diffuse in the air. Moreover, this higher altitude would allow firefighting to occur at night, and planes could fly level while deploying cargo rather than dive.

The water bombs for this plane were cylinders made of polylactic acid (PLA) by a Makerbot Replicator 2 in the Mabel Smith Douglas Library. The cylinders have 4" diameters, 6" heights, and caps that fit snugly (Figure 8, Figure 9). These dimensions are just smaller than the plane's exit port. PLA was chosen because it is biodegradable.

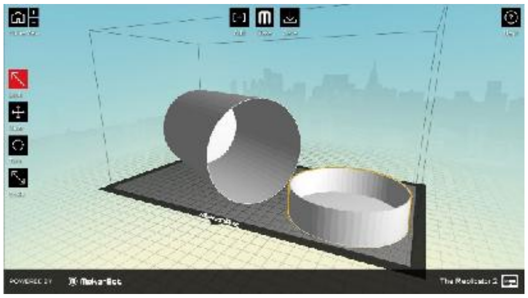

Figure 8. Water Bomb Design

Figure 9. Water Bombs

3.6. Cargo Deployment System

The cargo deployment system for this plane is a ramp coupled with a mechanical arm (Figure 10).

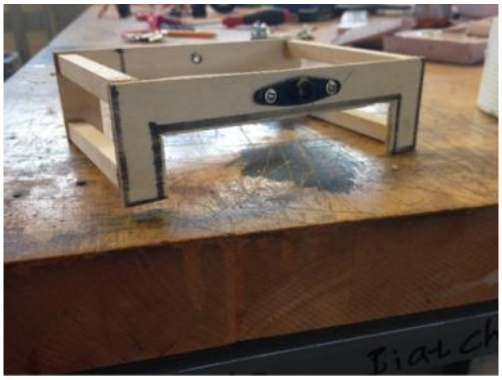

Figure 10. Mechanical Arm

The release process is demonstrated by Figure 11. In the first stage, all three cylindrical bombs rest on the ramp during flight. While in this position, the lower part of the arm prevents the bomb closest to door from rolling out. In the second stage, the lower part of the arm moves up, the bomb closest to the door rolls out, and the other part of the arm prevents the second bomb from falling out. In the third stage, the arm then shifts back to its original position, and the bombs roll down the ramp to fill the gap. In the fourth stage, the cylinders have rolled down the ramp, and the second and third bomb can be deployed the same way as the first.

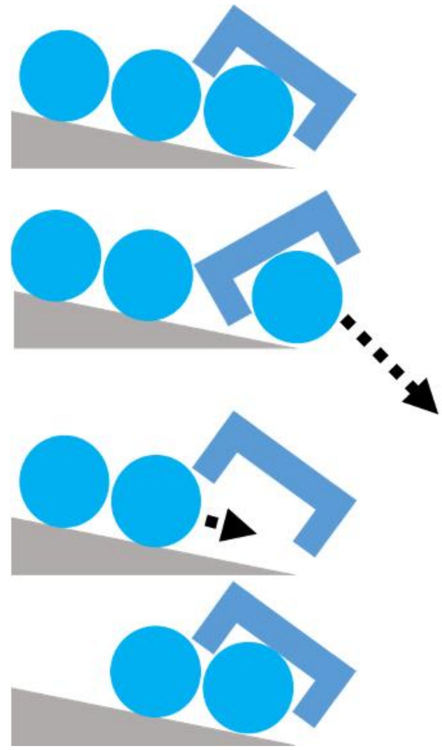

Figure 11. Deployment System

3.7. Landing Gear

For the front wheel of the landing gear, a fixture was constructed out of plywood and spruce (Figure 12).

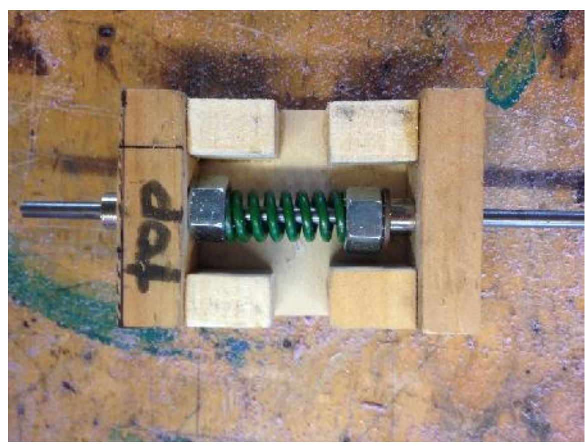

Figure 12. Landing Gear

It consists of a backing that is mounted on a rectangular support that separates the nose and cargo bay. Two square pieces are perpendicular to the top and bottom of the rectangular support, and the rod to which the wheel is attached runs through the center of the squares. A 1” spring with collars at both ends rests between the two square pieces without touching the rod. The purpose of the spring is to absorb shock when the plane hits the ground. This spring, which has a 0.6” travel, can absorb 48 lbs., which is three times the weight of the plane and cargo.

The back landing gear is shown by Figure 13. The legs are made of aluminum.

Figure 13. Back Landing Gear

4. CONSTRUCTION OF PROTOTYPE

All foam used in the plane construction was extruded polystyrene. Both sides of the plane consist of one uninterrupted piece of 3/4” foam. Both pieces of foam were made using the same paper template and hot wire cutter and then sanded down to equal size. The bottom and top of the back of the plane were similarly created and attached to the sides with an epoxy. The top and bottom of the front of the plane were made with separate 2” pieces of foam, attached with the epoxy, and then sanded down to match the profile created by the sides. All edges were beveled slightly. For support, a beam was added between the tops of the sides, and a rectangle was placed between the walls. This second structure additionally separates the cargo bay from the nose, where the electronics are stored. The wing and top of the front of the plane were attached last in order to place the electronics in more easily. Figure 14 shows the fuselage resting upside down.

Figure 14. Fuselage

To create the wing, six 11” x 24” x 2” pieces were cut by a hot wire cutter, and three final pieces were created by using spray glue to attach two pieces together. These three pieces had total dimensions of 11” x 24” x 4”. Then, with two laser cut wood templates (Figure 15), the hot wire cutter was used to cut the final airfoil design.

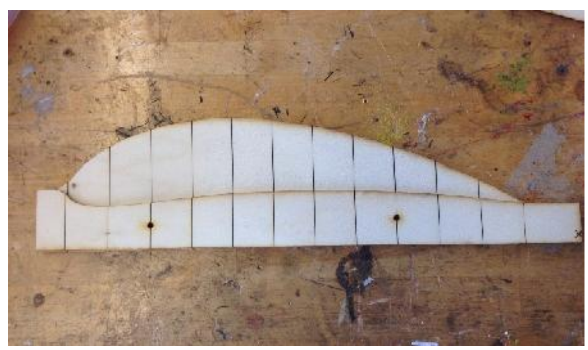

Figure 15. Airfoil Template

To create a polyhedral shape for the wings, the edges of the three pieces were sanded at an angle of 4 degrees to create a total angle of 8 degrees. Carbon fiber rods were placed inside the wings to prevent bending and buckling. To prevent vortices, wing tips were fashioned out of balsa wood. For extra strength, fiberglass cloth was glued onto the foam and painted with polycrylic, which is a liquid plastic that cures and makes the cloth stronger. The ailerons were cut out of the same foam as the wing. The saddle for the wing was also created with foam pieces. The final wing is shown in Figure 16.

Figure 16. Wing

The vertical and horizontal stabilizers were cut with a razor blade from 3/4” foam and sanded and beveled down to the design dimensions. They were also coated with fiberglass cloth and polycrylic. The rudder and elevators were made out of the same foam as the tail. All of the parts were attached with an epoxy, and the final product can be seen in Figure 17 and Figure 18.

Figure 17. Completed Plane Front View

Figure 18. Completed Plane Side View

The battery was placed in the nose of the plane, with the rectangular support separating it from the cargo area. This was done to protect the battery if the water bombs leaked.

Six servos were used; two were attached to the bottom of the wings, one to the rudder, one to the elevator, one to the mechanical arm, and one to steer the landing gear. These servos were connected to an RC receiver and controlled by a remote (Figure 19).

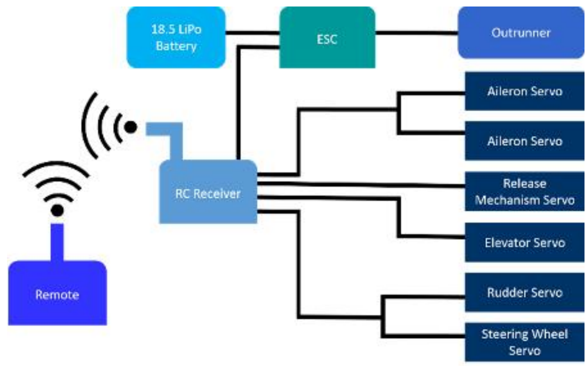

Figure 19. Electronics

5. RESULTS

Ground deployment testing was successful. The mechanical arm was able to release one bomb at a time.

Then, taxiing was attempted, and though the plane could travel in a straight line for a few seconds, it eventually tipped forward onto its nose. This was because the front landing gear was too short and not centered. As a result, the nose was angled downwards, and a moment was created that caused the plane to turn more in one direction than the other. This made takeoff impossible. To address this issue, the single front wheel was replaced by a setup similar to that of the back wheels, shown by Figure 13.

The first test flight lasted 11 seconds and took off in 15 ft. During takeoff, the plane veered slightly to the left, flew at around 30 ft. above the ground, and flipped over upon landing. The flight itself was fairly steady. However, there was a roll imbalance, which caused the plane to bank in one direction more than the other. This was likely because of a weight difference between the right and left sides of the wings. Roll sensitivity was also not calibrated properly, making mid-flight corrections difficult.

The second test flight lasted approximately 30 seconds. Again, straight flight was relatively stable, but turning was difficult.

Due to limited time and flight issues, midair deployment tests were not conducted. Two water bombs were thrown into the air and burst upon contact with the ground. Based on observations from the first two flights, the plane would have been able to take off with the intended cargo.

The biggest limitations of this prototype is its scale. Making this plane life-sized could add complexity, making more advanced and precise moment calculations necessary.

6. CONCLUSIONS AND FUTURE WORK

The prototype plane was successful in midair flight. Limitations in time prevented midair cargo deployment testing. However, ground testing of the deployment system was successful, and the bombs did burst upon contact with the ground, proving the feasibility of the design.

The implementation of water bombs in aerial firefighting would make the entire process safer by allowing planes to fly at higher altitudes, which has a number of benefits. The most important of these benefits is avoiding dangerous thermal winds, smoke, and debris that are present at low altitudes; flying level rather than diving towards the fire; and being able to fight fires at night.

Because the test flights indicated that the airplane would have been able to carry 100% of its weight, adopting this new style of wildfire fighting would not compromise current industry standards. Thus, this plane shows promise for being used in real life situations.

Immediate future work includes midair deployment testing and corrections for the roll imbalance. Other future work includes scaling up and making sure that the plane functions similarly on a larger scale. In doing this, the biggest challenge would be determining the moments, which would become more significant with increasing size and weight. Another aspect would be creating environmentally friendly bombs. Although PLA is technically biodegradable, it is certainly not the best option for the containers. Research could therefore be conducted to synthesize water bombs that create almost zero impact on the environment and ecosystems. Another area of study would be to test GPS target systems to deploy the water bombs and using efficiency testing to find the optimal plane design.

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