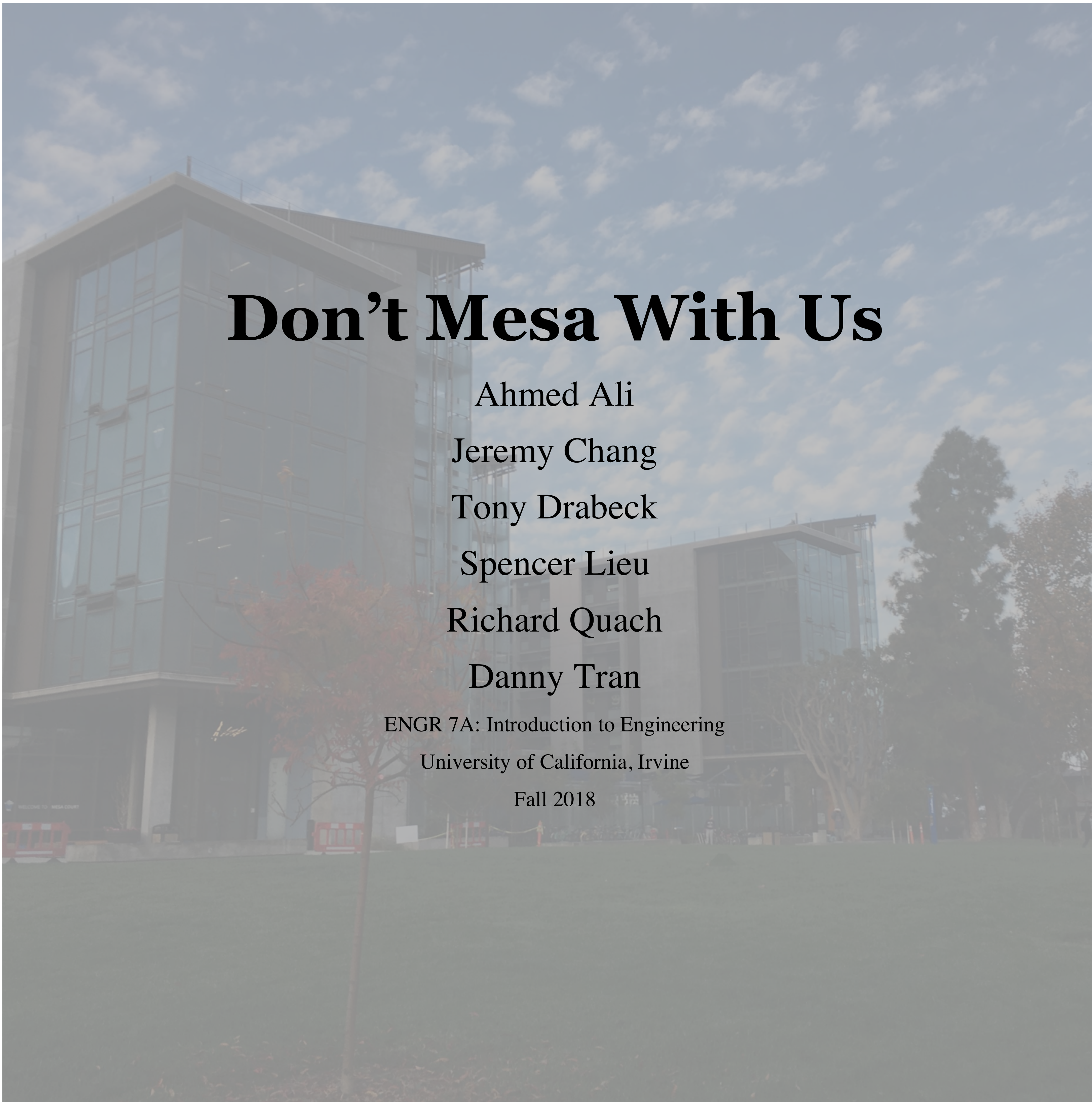


Don’t Mesa With Us

Ahmed Ali

Jeremy Chang

Tony Drabeck

Spencer Lieu

Richard Quach

Danny Tran

ENGR 7A: Introduction to Engineering

University of California, Irvine

Fall 2018

Table of Contents

Executive Summary

In summary, the quadcopter project is designed to introduce us to fundamental engineering design processes (Brainstorm, Design, Fabrication, Testing) through hands-on application, development, and manufacturing of a functioning quadcopter. The project focuses on building teamwork, problem-solving skills, and project management skills. In addition to establishing these skills throughout the quarter, our team's objective was to build and design a quadcopter from scratch that meets the criteria presented to us by our instructors.

Problem Definition

Introduction

Our goal is to manufacture and fly a quadcopter that will have a minimum flight time of 5 minutes. In this class, we are engaging in the engineering process in order to learn technical and interpersonal skills such as teamwork and communication.

Technical Review / Background

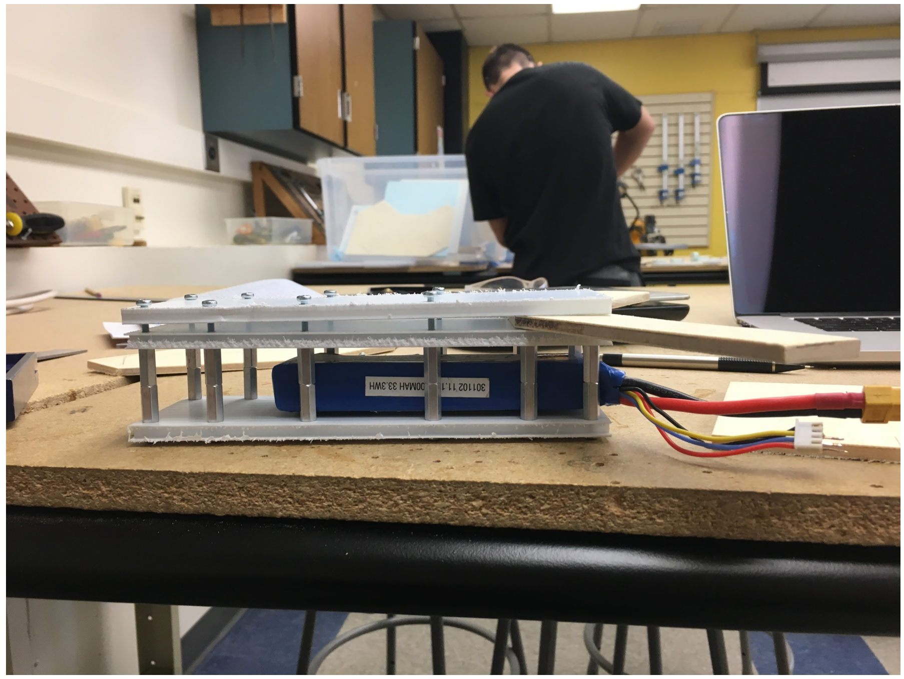
The history of the quadcopter traces back to VTOLs, or vertical take-off and landing vehicles, in order to bring forth a solution to effective vertical flight. One of the earliest recorded quadcopters was the Breguet-Richet Gyroplane - constructed in 1907 with counter-rotation of the propellers for vertical flight. The rest of the twentieth-century followed with additional quadcopter prototypes: Oehmichen in 1920, de Bothezat in 1923, and then eventually the Ehang 18. Currently multirotor VTOLs are used for surveillance, search and rescue, and commonly photography or video.

Design Requirements

The raw materials used for the quadcopter must be fabricated in labs or outside with permission. They are purchased through the PO form; the budget must remain under $400. The diagonal motor-to-motor distance must be smaller than 14 inches. The propeller guards must cover at least a quarter of the circumferential distance extending at least half an inch from the tip of the propeller.

Design Description

Summary of Design

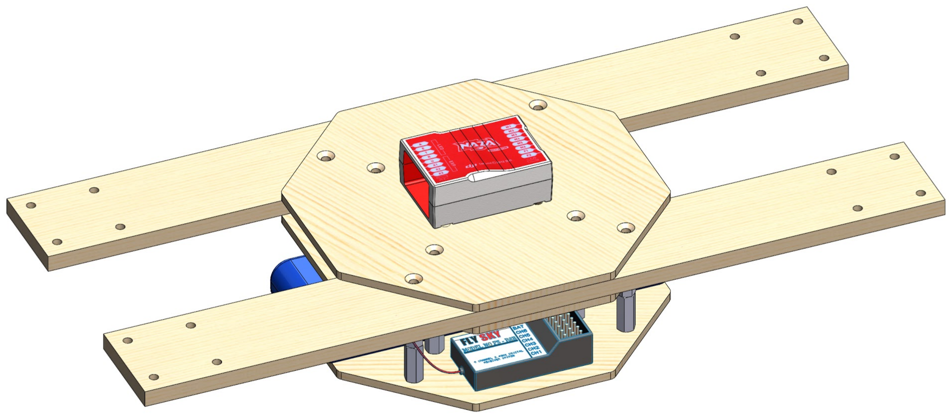


Our team decided to design our quadcopter such that its chassis will be constructed using three layers of rectangular-cut plastic chloroplast material. We chose to use plastic chloroplast for the main chassis because we believed that it provided a very structurally sound chassis while at the same time being very lightweight. We designed our angled arms to give enough space between the motors for the implementation of our eight-inch propellers. These arms are to be made from Italian Poplar wood to have a balance between high manufacturability and light weight. We will house the arms of the quadcopter between the first and second layer of the quadcopter, and the space between the second and third layer of the quadcopter will house the battery.

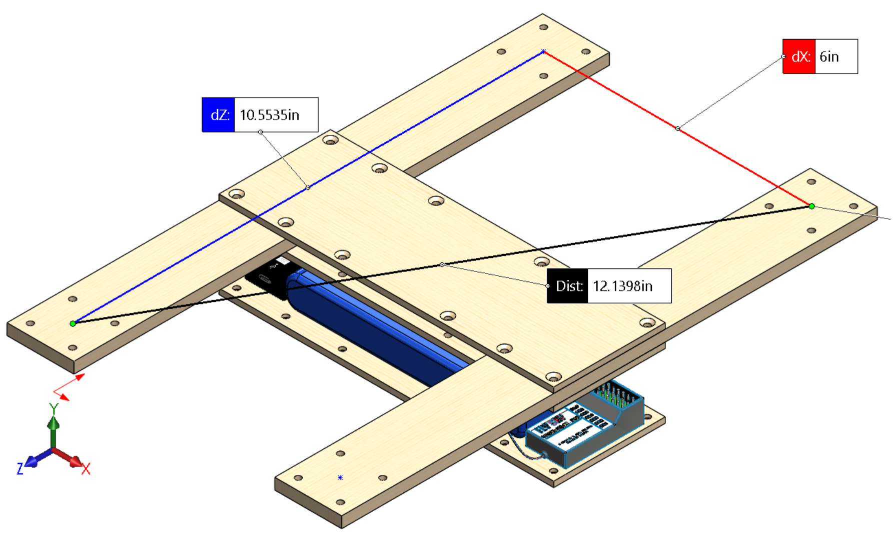
The motors will be attached to the ends of the arms, with the Electronic Speed Controllers attached to the arms with the wiring for the ESC's zip tied around the arms. The NAZA flight controller will be placed centered on top of the first layer of the quadcopter, with the voltage regulator tucked away with the battery. The landing gear is made from plastic polycarbonate that we bent to our desired shape using a heat strip, and we padded the bottoms of our landing gear using foam in order to soften the landings for our quadcopters.

Design Details

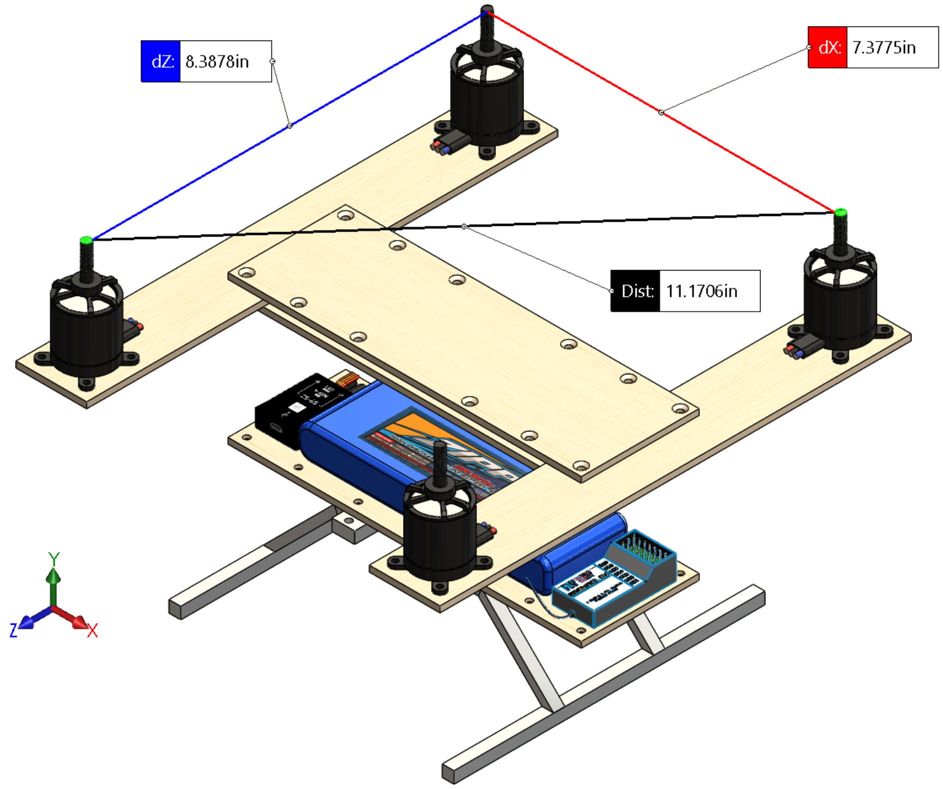
Pictured here is our first design prototype. We liked the idea of sticking with the octagon chassis because it was already manufactured and modeled from the homework. We added an extra plate middle in order to wedge the two arms together and increase strength. However, this did not allow us to use our two continuous arms which would allow for more rigidity. The propellers would not have enough clearance. We had to make the decision of either sticking with the octagon and changing the arms or keeping the arms and changing the octagon.



As you can see, we ended up switching to a rectangular design. This would increase the motor to motor distance and allow us to keep our long arms. This still did not leave enough clearance for the 8-inch propellers however. It only gave us 6 inches in the X axes when we needed at least 8 to accommodate these propellers. We would have to decide as a team if we wanted to change the design or change our propeller choice.

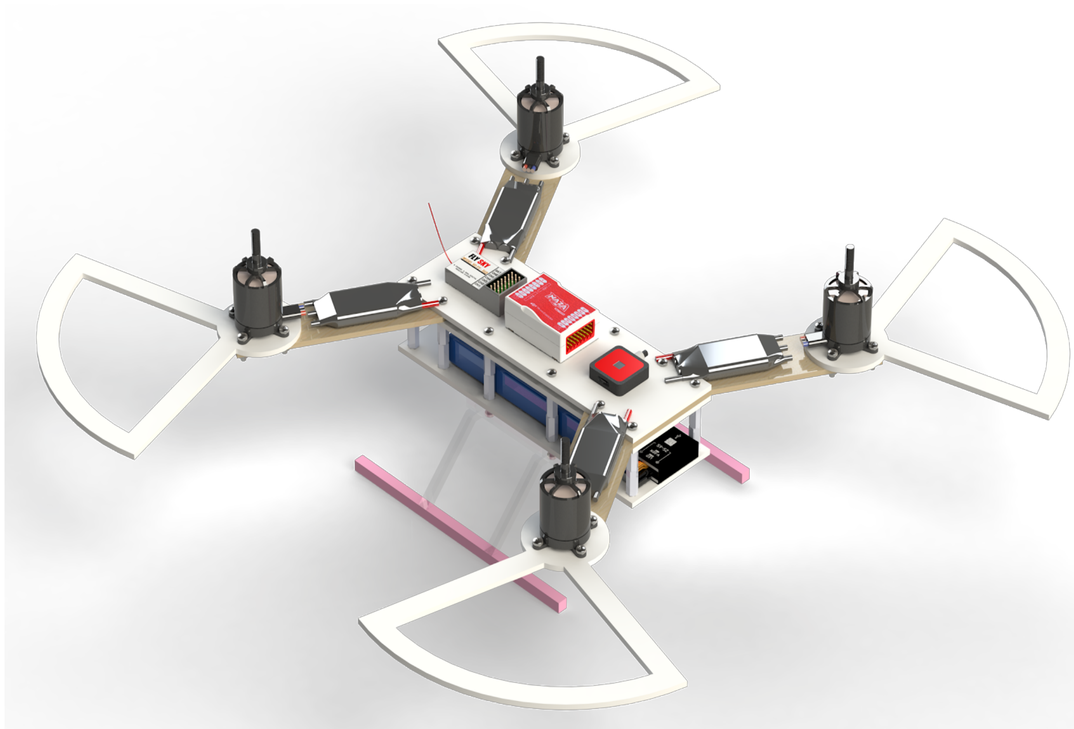


One of the solutions to this motor to motor distance problem we came up with was moving the arms out in the X direction, so they are hanging out of the chassis. This was a quickly and easy fix that would not require any redesigns of parts. After implementing this solution in the assembly, you can see that the motor to motor distance in the X direction is still not sufficient at 7.4 inches. You can also see the first prototype of the landing gear in this assembly picture.

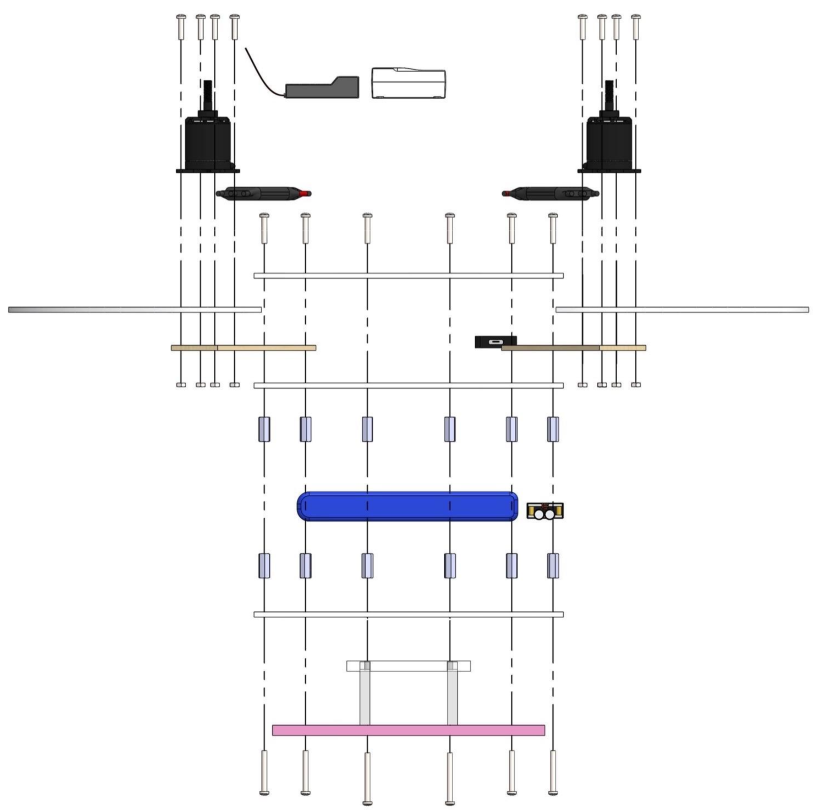


We ended up creating a bent arm design which would allow for full clearance of our 8-inch propellers. Ultimately, we went through all this design change because we wanted the extra thrust the 8-inch propellers offered in combination with the 1400KV motors. You can also see we were still unsure about materials at this point, however our design was complete. We rotated the landing gear to be more aligned with the front and back of our quad, which were the short ends of the rectangle. You can also see the propeller guards which were designed early on but recently added to the assembly.

This is our final SolidWorks render with accurate materials. You can see most of the wood was replaced with Chloroplast. We simplified the propeller guards by taking off the fillets. This was due to not being able to manufacture fillets with chloroplast. You can also see the bent polycarbonate and foam on the landing gear.

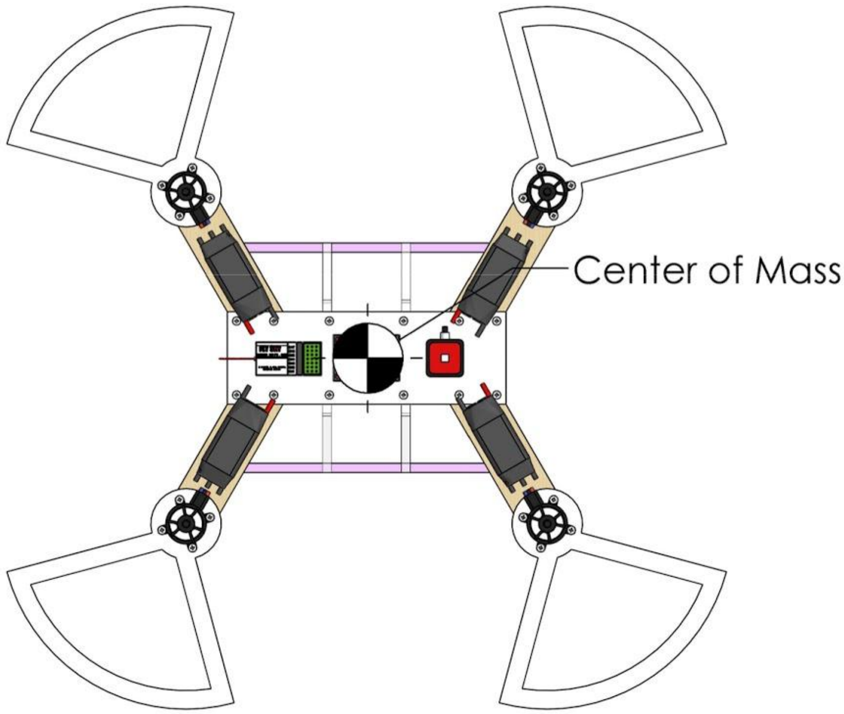


You can see how using this three plate, sandwich design allowed for the same screws to go all the way through the quadcopter. The screws started at the top plate and connected all the way down to the landing gear. This allowed for more simplicity and strength throughout. The motors and propeller guards were also attached to the arms using the same screws. This efficient design proved to be successful as the quad was very sturdy and did not show any signs of breaking throughout our rigorous tests. Wedging the arms between the middle and top plates also proved to be very strong. We changed our design many times to accommodate two arms instead of four smaller ones as we believed it was a more effective design.

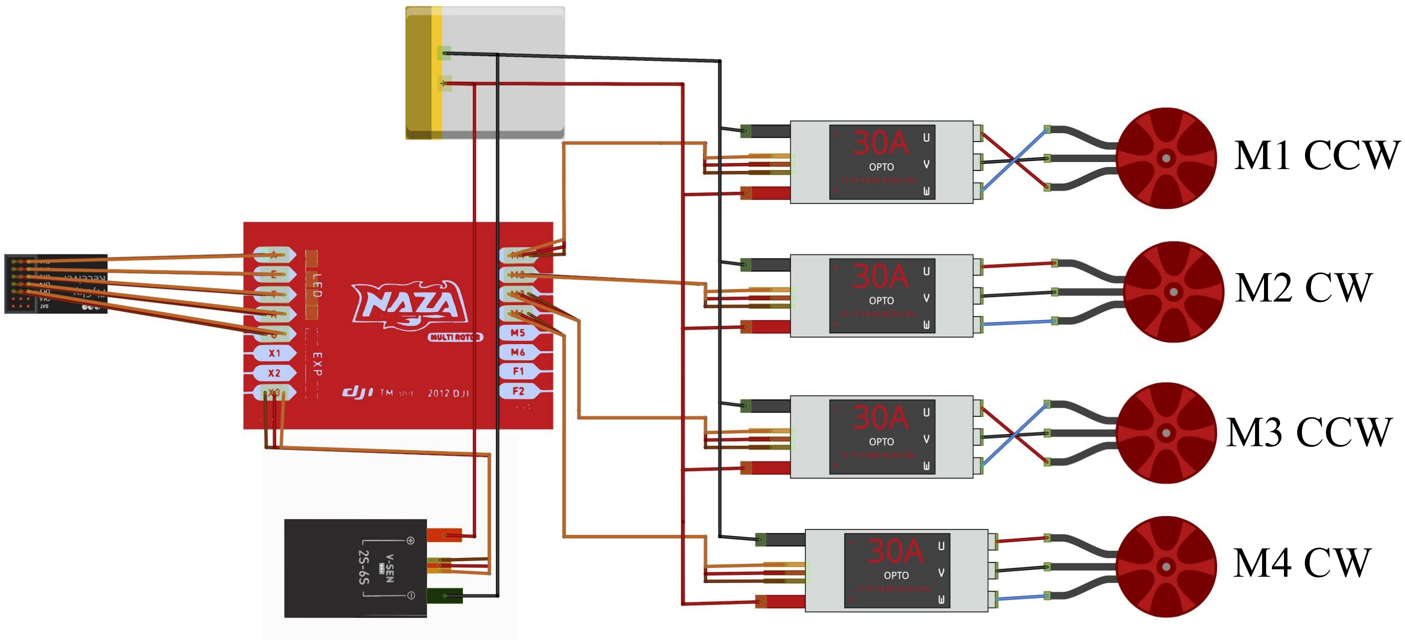


Center of Mass

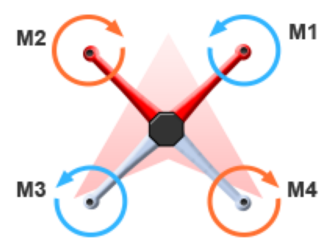
When putting together the assembly, we imported all of the electronic parts from GrabCAD.com in order to get extremely accurate volume dimensions for our center of mass calculation. We also weighed all of these parts in the lab. We wanted to have our center of mass exactly in the center of the quad in order to give the pilot a very neutral and balanced aircraft. Otherwise, the pilot would constantly be correcting the quadcopter. It is also important for the NAZA to be placed at the center of mass in order for its sensors to orient themselves correctly. We were able to move parts around inside and on top of the chassis in SolidWorks in order to get the center of mass in the center of the quad. It was very helpful having accurate parts so we would know exactly how things would come together in real life.



Wiring Diagram



The circuit diagram pictured above is almost completely representative of the wiring of electronics on our quadcopter chassis. One item to note is that on our original build of our quadcopter, we inverted the NAZA flight controller such that the front of the NAZA was facing the rear of our quadcopter, and the rear of our NAZA was at the front. This mistake caused our quadcopter to crash and snap its arms twice, but fortunately the error was recognized and fixed before the third test flight. It is important to note that the wires of the counter-clockwise motors are flipped in order to flip the polarity from the ESC and make them spin in the opposite direction.



Quad-rotor X

Action Item Report

Task Assignment

When we first started the design of the quadcopter, we split the designing process into several parts in order to speed the process up. Danny was in charge of designing the propeller guards, Jeremy designed the landing gear, chassis was designed by Tony, Spencer, and Richard, and the arms were designed by Ahmed. We then sent our designed parts to one person (Jeremy) to assemble the quadcopter in SolidWorks. We made this decision since it would be easier having only one person assemble the quadcopter in SolidWorks.

After the designing process, we manufactured the parts that we were tasked with designing. We ended up collaborating as a whole since assembling some parts required more time to manufacture than others. For example, after the chassis was finished, we split up to help with the landing gear, the propeller guards, and the arms. When it came to assemble the quadcopter, we had to place the arms between the chassis, assemble the motors, and connect the motors and propeller guards to the arms to which Spencer, Danny, Richard, and Ahmed came into open labs to do.

For soldering the bullet connectors, we split our group into two halves so that Richard and Tony could demonstrate how to properly solder. Tony and Richard then worked on connecting the electronics (the motors, the ESCs, the NAZA, etc.) Spencer and Tony then calibrated the ESC's and the NAZA, a problem came up with the NAZA, so Richard and Jeremy came into open labs to rectify the problem. When one of our arms broke during our test flight, Ahmed, Tony, and Spencer came to open labs to manufacture new arms and Richard worked to reconfigure the incorrect NAZA setup that caused the quadcopter to flip over.

Gantt Chart

Don't Mesa With Us
Thurs. 10-11:50am

Planned | Actual | Due Date

	Week 1					Week 2					Week 3					Week 4					Week 5				
	1/10	2/10	3/10	4/10	5/10	8/10	9/10	10/10	11/10	12/10	15/10	16/10	17/10	18/10	19/10	22/10	23/10	24/10	25/10	26/10	29/10	30/10	31/10	1/11	2/11
	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F

Activity	Planned Start	Planned End	Actual Start	Actual End
Team Formation				
Team Name & Captain Chosen	9/10	11/10	9/10	11/10
Quadcopter Design	8/10	2/11	8/10	2/11
Determine Quad Layout	15/10	19/10	15/10	19/10
Select Motor/Propeller Config.	25/10	1/11	25/10	1/11
Purchase Order Form	22/10	4/11	6/11	8/11
SolidWorks Part Designs	29/10	2/11	27/10	6/11
SolidWorks Assembly	1/11	2/11	1/11	2/11
SolidWorks Detailed Drawings	2/11	2/11	2/11	2/11
Structure Fabrication	8/11	16/11	8/11	15/11
Frame Arms	8/11	16/11	8/11	15/11
Frame Center	8/11	16/11	8/11	15/11
Propeller Guards	8/11	16/11	8/11	15/11
Landing Gear	8/11	16/11	8/11	15/11
Motor Mounting Holes	8/11	16/11	9/11	15/11
Structure Assembly	15/11	16/11	15/11	15/11
Electrical Fabrication	19-11	30/11	27/11	29/11
Solder Bullet Connectors	29/11	30/11	29/11	29/11
Heat Shrink Bullet Connectors	29/11	30/11	29/11	29/11
Mount & Connect Electronics	29/11	30/11	29/11	29/11
Electrical Calibration	29/11	7/12	29/11	6/12
ESC Throttle Calibration	29/11	7/12	29/11	6/12
NAZA Flight Calibration	29/11	7/12	29/11	6/12
Motor Response Tilt Test	29/11	30/11	4/12	6/12
FINAL COMPETITION	6/12	7/12	6/12	7/12
Action Item Reports	17/10	6/12	23/10	29/11
Preliminary Presentation	6/11	7/11	6/11	7/11
Final Presentation	27/11	11/12	27/11	11/12

Don't Mesa With Us
Thurs. 10-11:50am

Planned | Actual | Due Date

	Week 6					Week 7					Week 8					Week 9					Week 10					Finals Week				
	5/11	6/11	7/11	8/11	9/11	12/11	13/11	14/11	15/11	16/11	19/11	20/11	21/11	22/11	23/11	26/11	27/11	28/11	29/11	30/11	3/12	4/12	5/12	6/12	7/12	10/12	11/12	12/12	13/12	14/12
	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F

Activity	Planned Start	Planned End	Actual Start	Actual End	
Team Formation					
Team Name & Captain Chosen	9/10	11/10	9/10	11/10	
Quadcopter Design	8/10	2/11	8/10	2/11	
Determine Quad Layout	15/10	19/10	15/10	19/10	
Select Motor/Propeller Config.	25/10	1/11	25/10	1/11	
Purchase Order Form	22/10	4/11	6/11	8/11	
SolidWorks Part Designs	29/10	2/11	27/10	6/11	
SolidWorks Assembly	1/11	2/11	1/11	2/11	
SolidWorks Detailed Drawings	2/11	2/11	2/11	2/11	
Structure Fabrication	8/11	16/11	8/11	15/11	
Frame Arms	8/11	16/11	8/11	15/11	
Frame Center	8/11	16/11	8/11	15/11	
Propeller Guards	8/11	16/11	8/11	15/11	
Landing Gear	8/11	16/11	8/11	15/11	
Motor Mounting Holes	8/11	16/11	9/11	15/11	
Structure Assembly	15/11	16/11	15/11	15/11	
Electrical Fabrication	19-11	30/11	27/11	29/11	
Solder Bullet Connectors	29/11	30/11	29/11	29/11	
Heat Shrink Bullet Connectors	29/11	30/11	29/11	29/11	
Mount & Connect Electronics	29/11	30/11	29/11	29/11	
Electrical Calibration	29/11	7/12	29/11	6/12	
ESC Throttle Calibration	29/11	7/12	29/11	6/12	
NAZA Flight Calibration	29/11	7/12	29/11	6/12	
Motor Response Tilt Test	29/11	30/11	4/12	6/12	
FINAL COMPETITION	6/12	7/12	6/12	7/12	
Action Item Reports	17/10	6/12	23/10	29/11	
Preliminary Presentation	6/11	7/11	6/11	7/11	During Each Lab
Final Presentation	27/11	11/12	27/11	11/12	To Be Scheduled

Evaluation

Calculations

Thrust/Weight Ratio

To calculate our thrust, we multiplied the number of blades (2) to the propeller chord (0.019) and divided that by pi times propeller radius (0.102) to find the s value (0.119). Then, we multiplied pi to radius squared to get the disk area (0.032). To find the angular speed of the propellers, we multiplied kV and V to get Ω (1451.416 rad/sec). We plugged these values into the thrust equation to get a thrust (805.057 N). We divided this value by the weight of the quadcopter (1068.8 g) to get the thrust/weight ratio, which is 0.753.

$$s = \frac{Nc}{\pi R}$$
$$s = \frac{2(0.01905)}{\pi(0.1016)}$$
$$s = 0.119$$

$$A = \pi r^2$$
$$A = \pi(0.1016)^2$$
$$A = 0.032$$

$$\Omega = kV \cdot V$$
$$\Omega = 1400 \cdot 9.9$$

$$\Omega = 13860\ \frac{rev}{min}$$
$$= 1451.416\ \frac{rad}{sec}$$

$$T = 2\left(\frac{sa}{16}\left[\sqrt{1 + \frac{64}{3sa}\theta} - 1\right]\right)^2 \rho(\Omega(4))^2 A$$

$$T = 2\left(\frac{(0.119)(5.7)}{16}\left[\sqrt{1 + \frac{64}{3(0.119)(5.7)}(1.571)} - 1\right]\right)^2 (1.1839)((1451.416)(0.1016))^2 0.032$$

$$T = 805.057$$

$$Thrust/Weight = 805.057/1068.8 = 0.753$$

Predicted Flight Time

To estimate the hover time, we take the ampere-hour of the batteries (3000mAh), divide that by the product of the current draw (19.4) and number of motors (4), and multiply this by 60 to get the flight time in minutes. This gave a flight time of about 2.27 minutes at full throttle.

$$\frac{amphere{-}hour}{curreent\ draw \cdot number\ of\ motors} = \frac{3}{19.8 \cdot 4} = 2.27$$

Test Plan

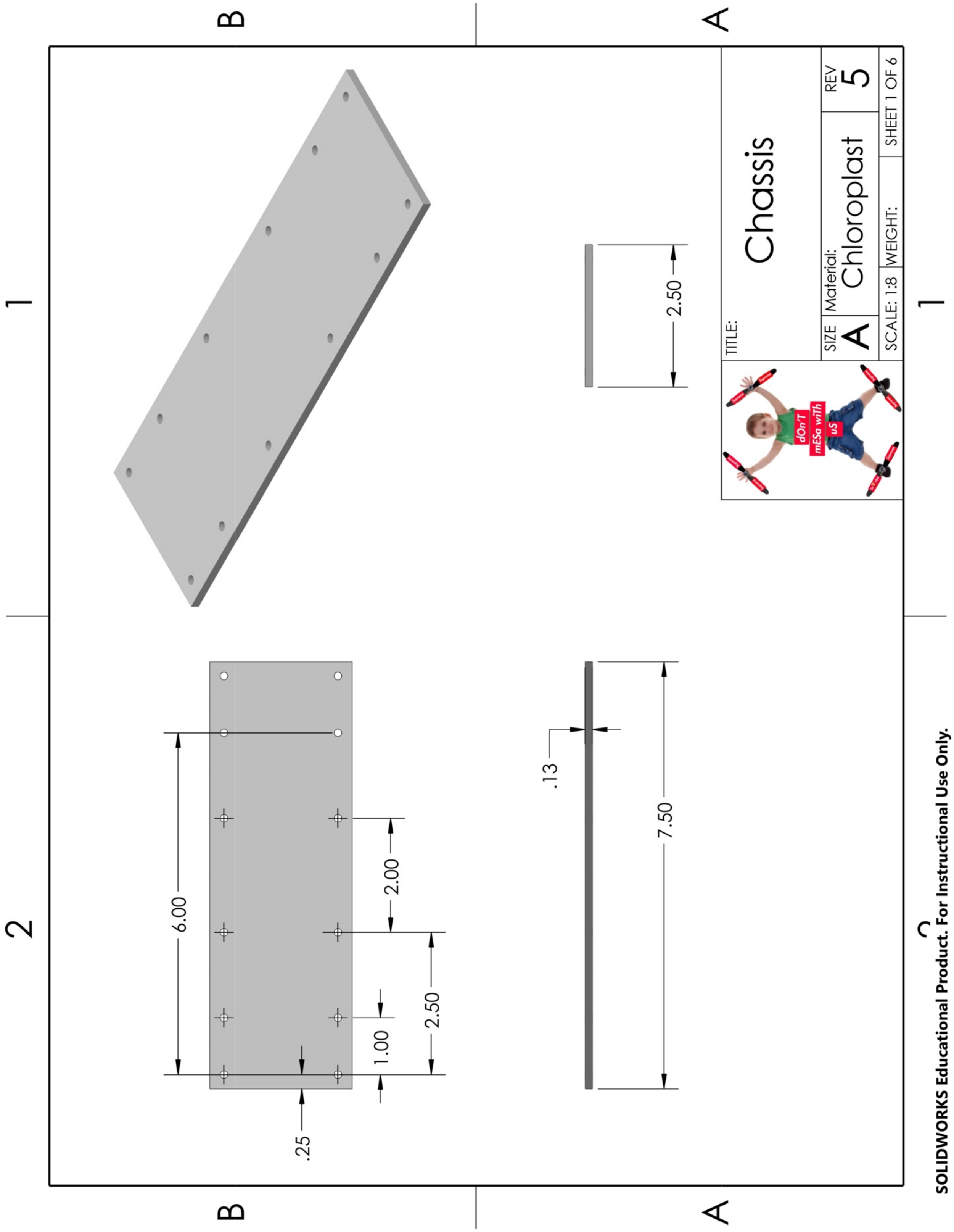
For our quadcopter, we looked to minimize the weight by choosing the lightest materials we could while also finding what parts would need to be made with more rigid materials. We believed we could sacrifice strength with our chassis because our landing gear and our prop guards would most likely absorb impact, so we weighed materials and found chloroplast to be the lightest. For our arms we still wanted to choose a light material but find something stronger than chloroplast, so we chose wood. We didn't scientifically test whether the arm would flex too much under the propellers, but we found it to be rigid enough for our liking when we strained our designs. For the landing gear we chose the solid polycarbonate which we applied foam to along the bottom which would reduce impact. We felt drop tests would not be needed as the foam seemed to be great at absorbing impact when we tested its pliability and the polycarbonate provided great structural support. Our materials that we chose for respective sections of the quadcopter were well thought out, as our quadcopter withstood quite a beating throughout its test flights. The separated arms made from wood were a really good design choice in that they were very easy to replace during the occasions that we snapped our arms in test flights. The wooden arms are supple, yet strong, which allowed them to take the majority of the impact within our two quadcopter crashes. The impact of the crashes was absorbed into the arms and did not affect the main chassis whatsoever, which is significant because the arms had a higher replaceability factor than our main chassis. Using chloroplast for these arms would not have yielded the same results and more of the force might have been transferred to the chassis causing more difficult and costly repairs. The landing gear was also well executed as the foam underneath the landing sleds consistently absorbed the brunt of the impacts of landing and allowed our quadcopter to remain undamaged while landing.

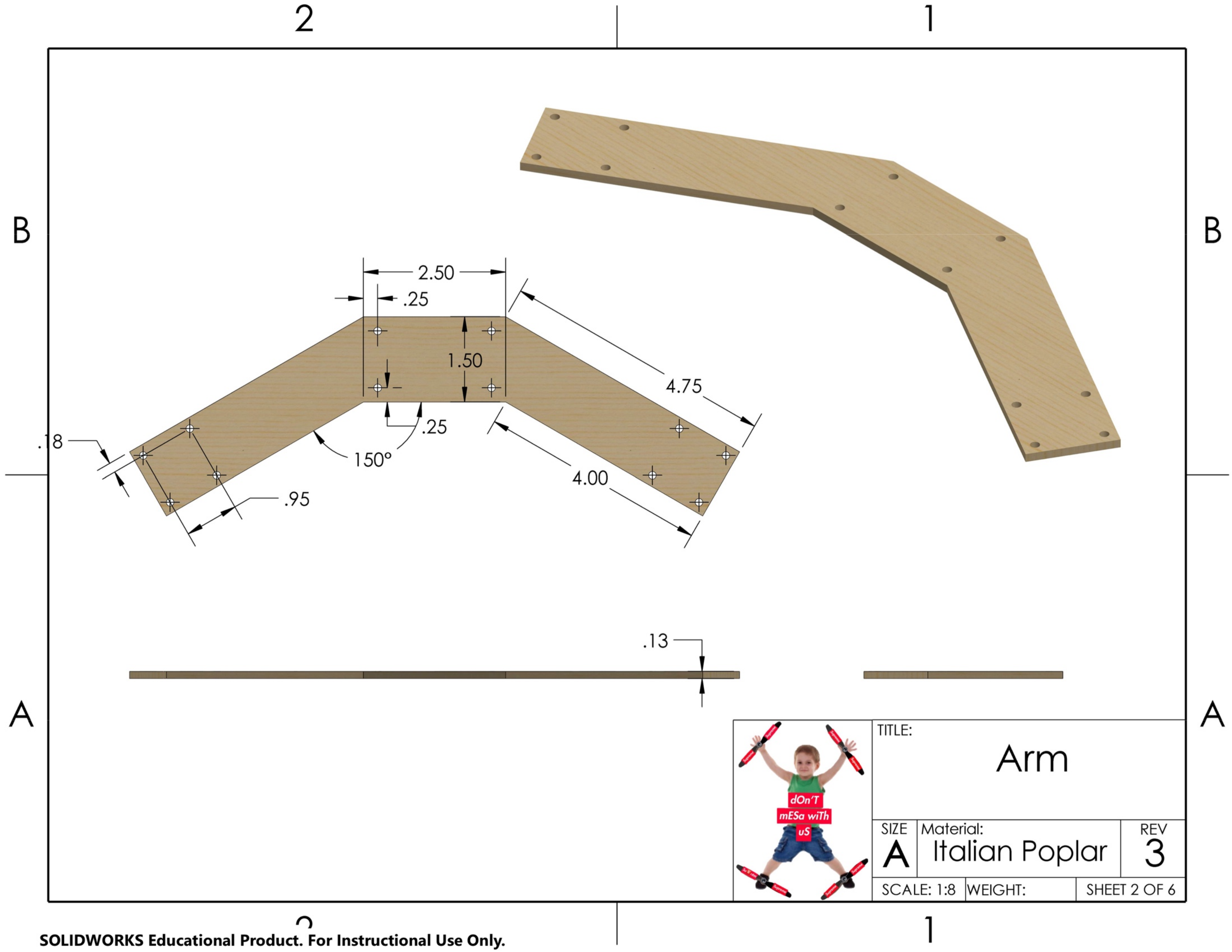
Results & Discussion

Because we used such light materials, our quad was quite nimble and fast, maybe even too fast, and we had no issue getting off the ground. Our quad was also quite stable as we tried our best to make our quad symmetrically in terms of manufacturing parts constantly to spec as well as dispersing weight over the body. However, we found that stronger arms could have been better as we did break two arms during our initial practice flights due to a NAZA configuration error that caused our quad to flip when starting up because our motors were spinning in the wrong directions. However, once we fixed this issue and stayed careful in not colliding into anything with our arms we found our flights to be quite successful.

There were definitely lessons to be learned that we experienced as a team during our weeks of designing, manufacturing, and finally flying. Budgeting our time became an apparent issue early on that we had to overcome, whether it be due to schedule conflicts or other commitments, however we found the time to come together to work on our project. We also learned to work more efficiently by planning ahead and dividing our work evenly to ensure everyone on the team had a part to play and so we could get our work done as quickly as possible. Our failures during our initial flight tests taught us to be more observant and double check for issues, and when they do arise, we learned to come together and stay level headed to solve the problem.

Appendix A: SOLIDWORKS Drawings

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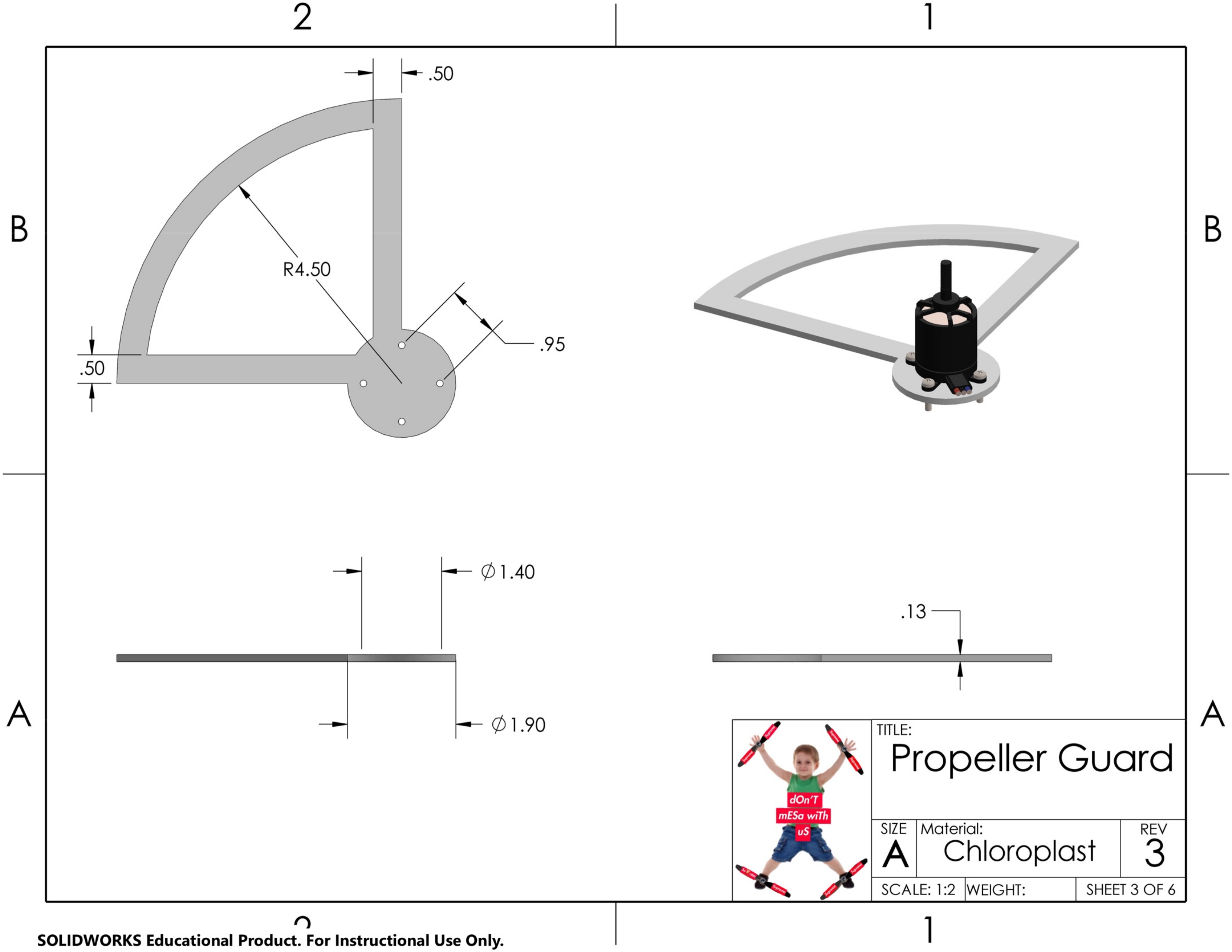

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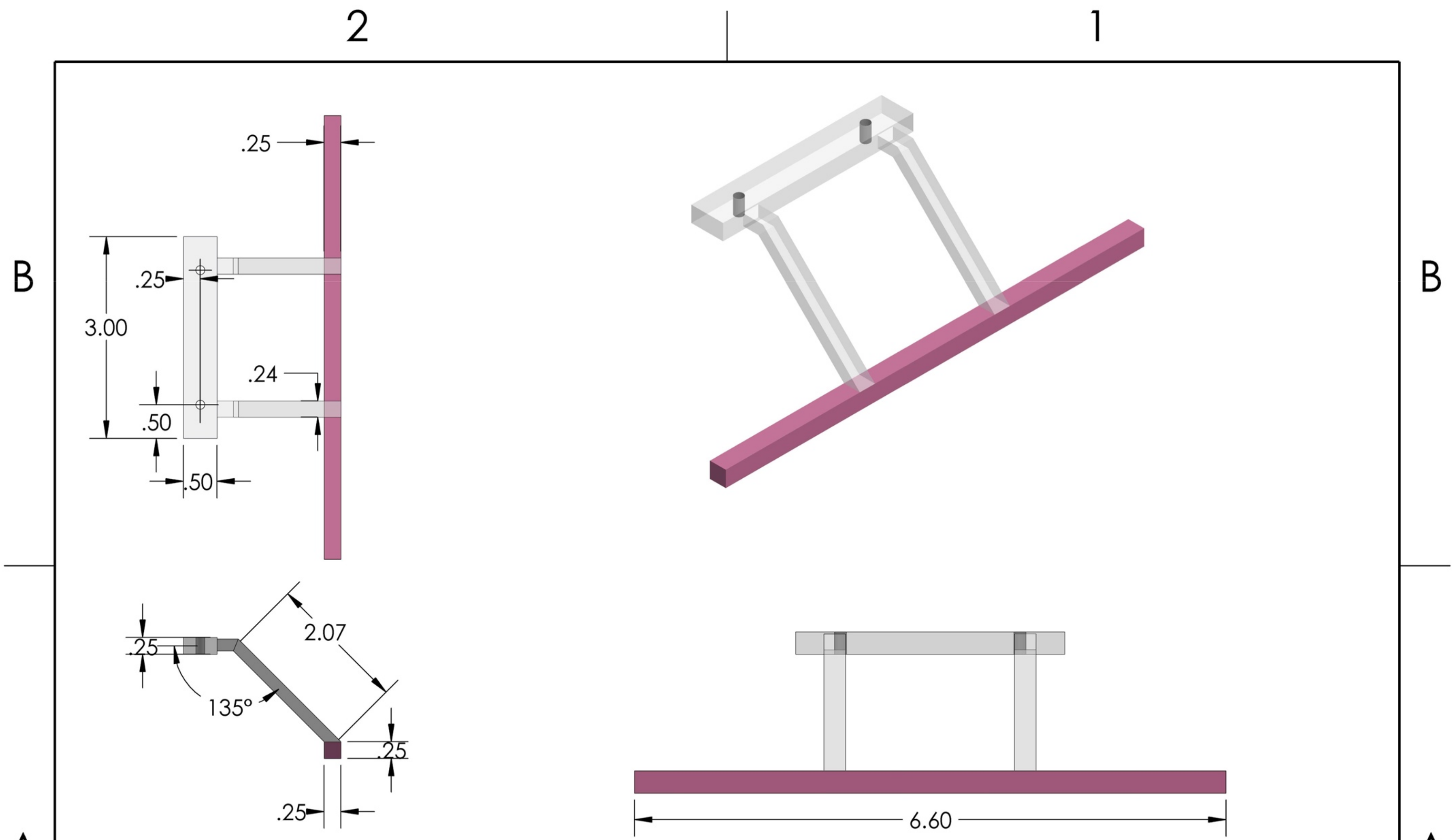
SOLIDWORKS Educational Product. For Instructional Use Only.



TITLE: Landing Gear			
SIZE A	Material: Polycarbonate/Foam		REV 2
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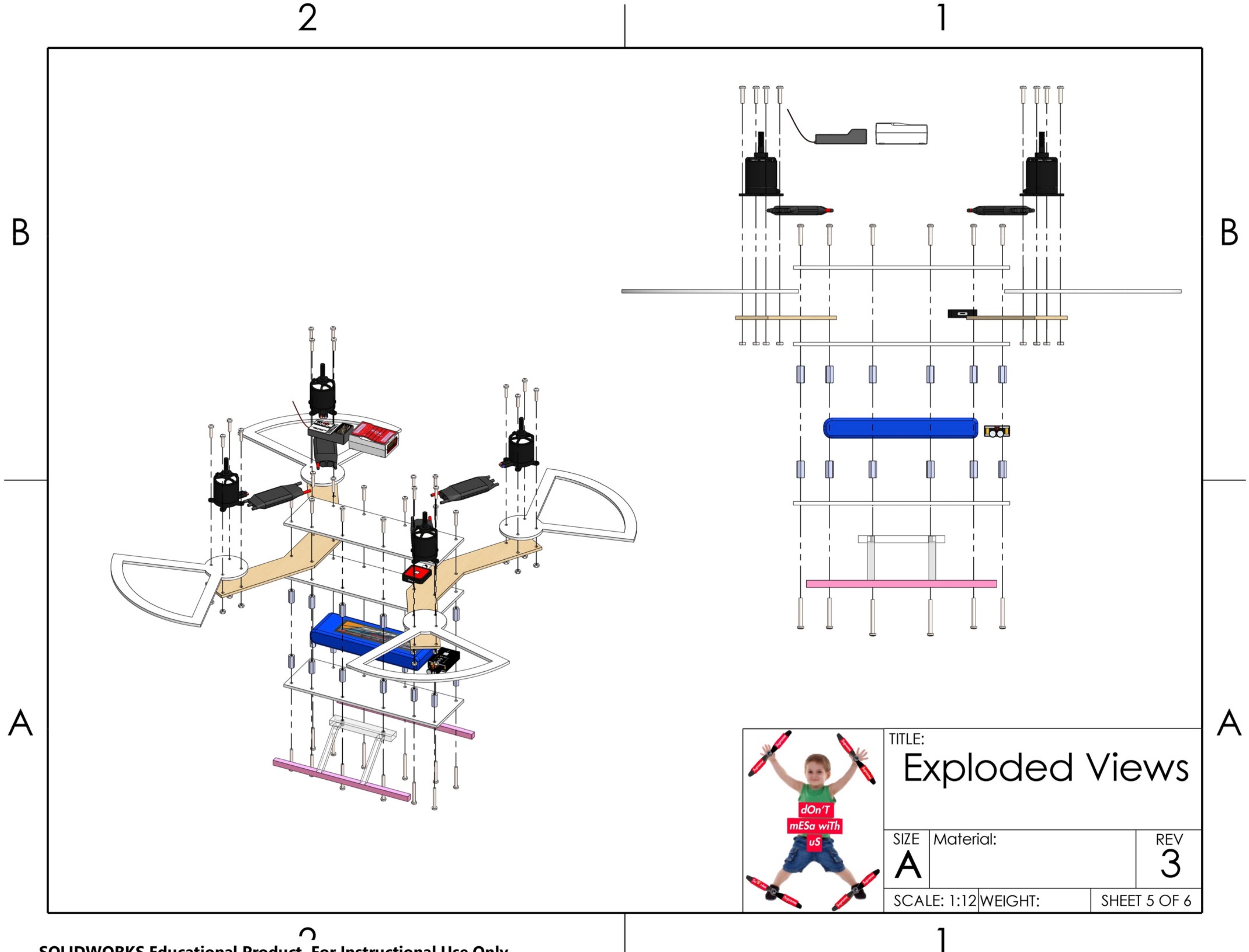
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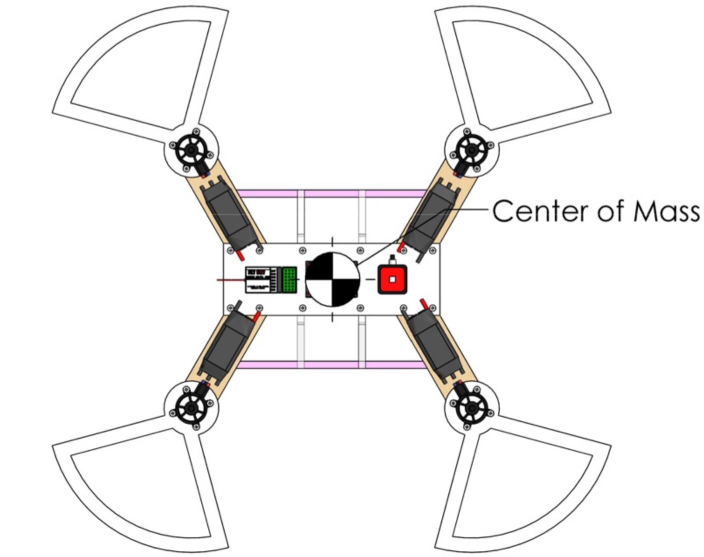

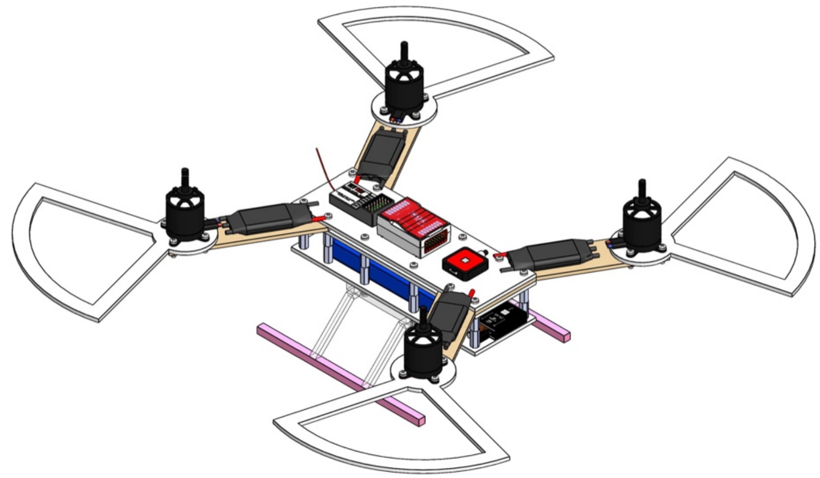

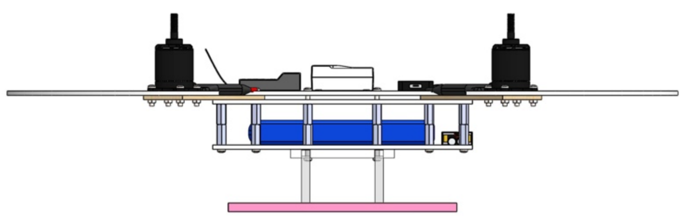

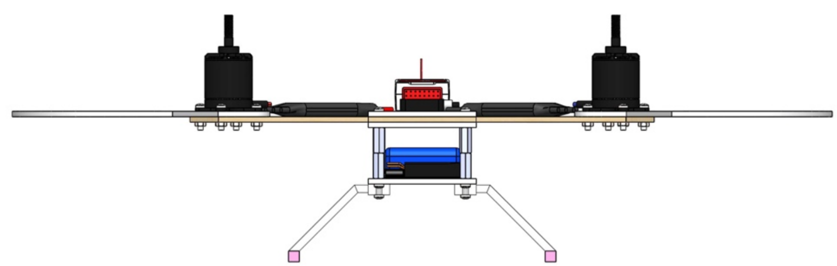

A

TITLE:

Model View

SIZE	Material:	REV
A		7

SCALE: 1:8	WEIGHT:	SHEET 6 OF 6

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Appendix B: Bill of Materials

PURCHASE ORDER FORM

The Henry Samueli School of Engineering

Upload your purchase order (PO) for quadcopter parts on EEE Dropbox, Due 11/9/2018

One PO per team. Parts will be given to you after submitting the PO. The props and motors will be given on a first come first served basis.

Requested By:*	Don't Mesa With Us Team Name	***Phone:**	1(808)796-8833	***E-Mail:**	adrabeck@uci.edu
Delivery Address:*	Engineering Tower *Building Name (or Abbreviation)		421 *Room #	**Date of Request:**	11/06/18
Lab Instructor Name:*	Dorsa Shirazi			**Lab Section:***	Thursday, 10:00 a.m.-11:50 a.m.
Account Name:*	ENGR 7A				

Account*	Fund*	Sub	Project	% (If split funding)	Amount	Accounting Review
ENGR 7A	56123	03	7A	100%	**$336.09**	
				0%	**$0.00**	

Quantity*	Unit	Company*	Item Description*	Catalog #*	Unit Price*	Estimated Extended Price*
4	ea	BUDDYRC	Sunnysky 1400 KV Brushless Motor	SNS-X2212-KV1400	$16.30	$65.20
1	ea	DJI	NAZA Multi-rotor Lite (Excludes GPS)		$49.00	$49.00
1	ea	AMAZON	FlySky FS-R6B 6-channel		$14.99	$14.99
4	ea	VALUE HOBBY	Hobyywing Flyfun 30A Esc	HWG-SC-0238	$19.99	$79.96
1	ea	HOBBY KING	Zippy 3000mA 20C Li-PO 3-cell	Z30003S-20	$16.76	$16.76
4	ea	ROBOTSHOP	8" propeller	RB-Gem-07	$3.60	$14.40
12	ea	FASTENER SUPERSTORE	M3-.05 x 15 mm (Male-Female)	801467	$0.19	$2.28
12	ea	FASTENER SUPERSTORE	M3-0.5 x 15 mm (Female-Female)	802211	$0.19	$2.28
5	ea		1/4 whitecoroplast 16"x16"		$1.94	$9.70
5	ea		ItalianPoplar 16"x16"		$2.78	$13.90
1	ea		Pink Insulation Foam 16"x16"		$0.89	$0.89
1	ea		1/16 Polycarbonate 16"x16"		$3.61	$3.61
1	ea	GETFPV.COM	Bullet Connectors		$2.99	$2.99
4	ea	AMAZON	Breakout Cables/ Wiring		$8.99	$35.96
				Subtotal		**$311.92**
I Need My Order Delivered By This Date:*			**11/08/18**			
				***Tax rate:**	**7.75%**	$24.17
				TOTAL ORDER PRICE		**$336.09**