Senior Project Final Presentation

Group 4 (I-MAJHN)





Meet the Team

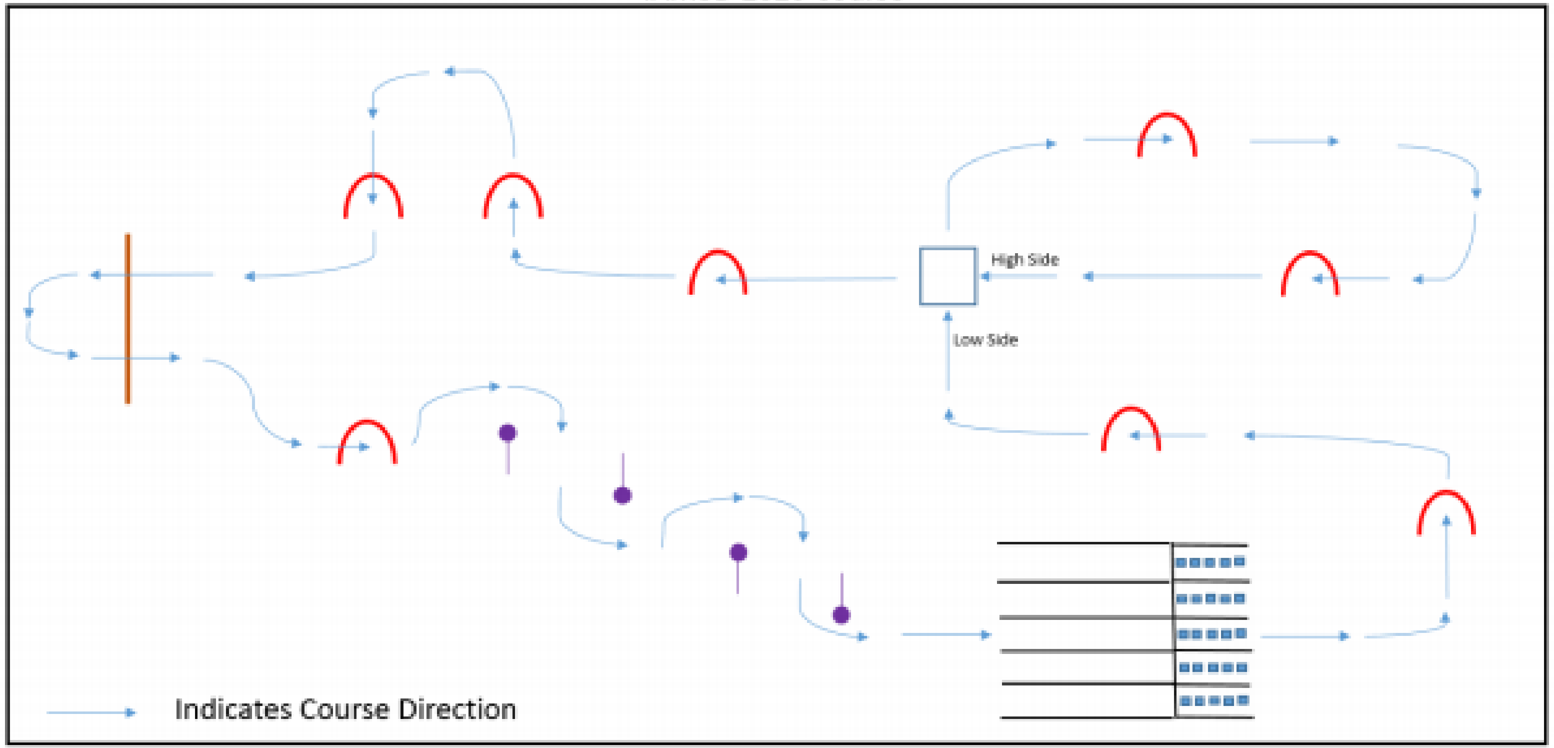
Alli Ashby
Melissa Douglas
Jordan Fraser
Hanny Kourani
Nefertari Parks

Problem Statement:

Design and manufacture an Unmanned Aerial Racing Cargo Vehicle (U.A.R.C.V.) using additive manufacturing.

The U.A.R.C.V will need to be able to race in five team flights for five laps through an obstacle course picking up and delivering one payload (1-inch by 1-inch block with a small ferromagnetic washer on top) per lap.

IAM3D 2020 Course



*Course outer dimension is 100 X 50 feet. Obstacles are not shown to scale. Obstacle placement may vary and is not to scale. Course Legend is on Following Pages. Obstacles may be lit with LED lighting.

Requirements

Problem Requirements:

Course Requirements:

- Reach no more than 10 feet altitude during flight
- Vehicle Size: max of 33 cm measured diagonally from motor center to motor center and 25 cm in height
- Maximum battery specifications 4S and 4.2 Volts per cell
- Maximum 15 minutes of flight time for 5 laps

Competition scoring (point system)

- Design Report (/2500)
- Use of additive manufactured part (/5000)
- Obstacle course (/2000) + 200 per payload
  - 1st place in the competition 1000 points, 2nd place is 500 points and 3rd place is 250 points.

Subsystems

Breakdown of chosen design

Coding Subsystem

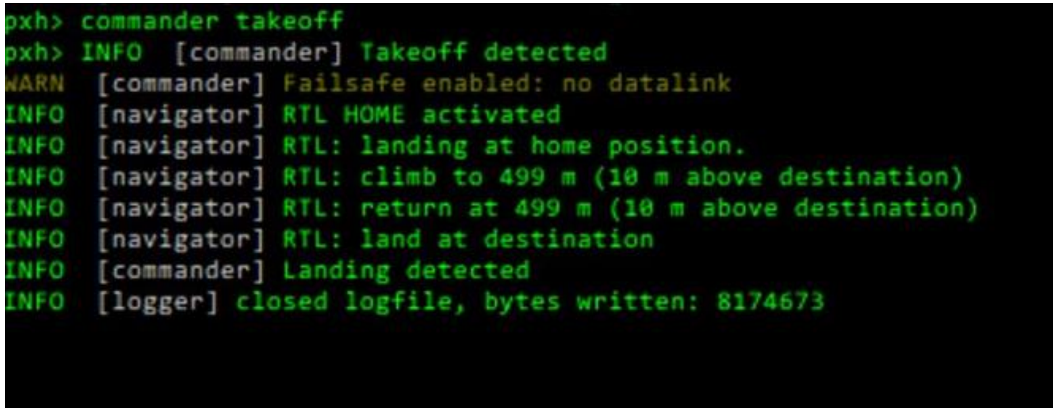
Requirements

- **Compatibility**: compatible with all other hardware components.
- **Available Documentation**: readily accessible online and user friendly.
- **Price:** value for money
- **Light + Compact**: minimize overall drone weight and bulkiness

Solution: Pixhawk PX4 F.C.

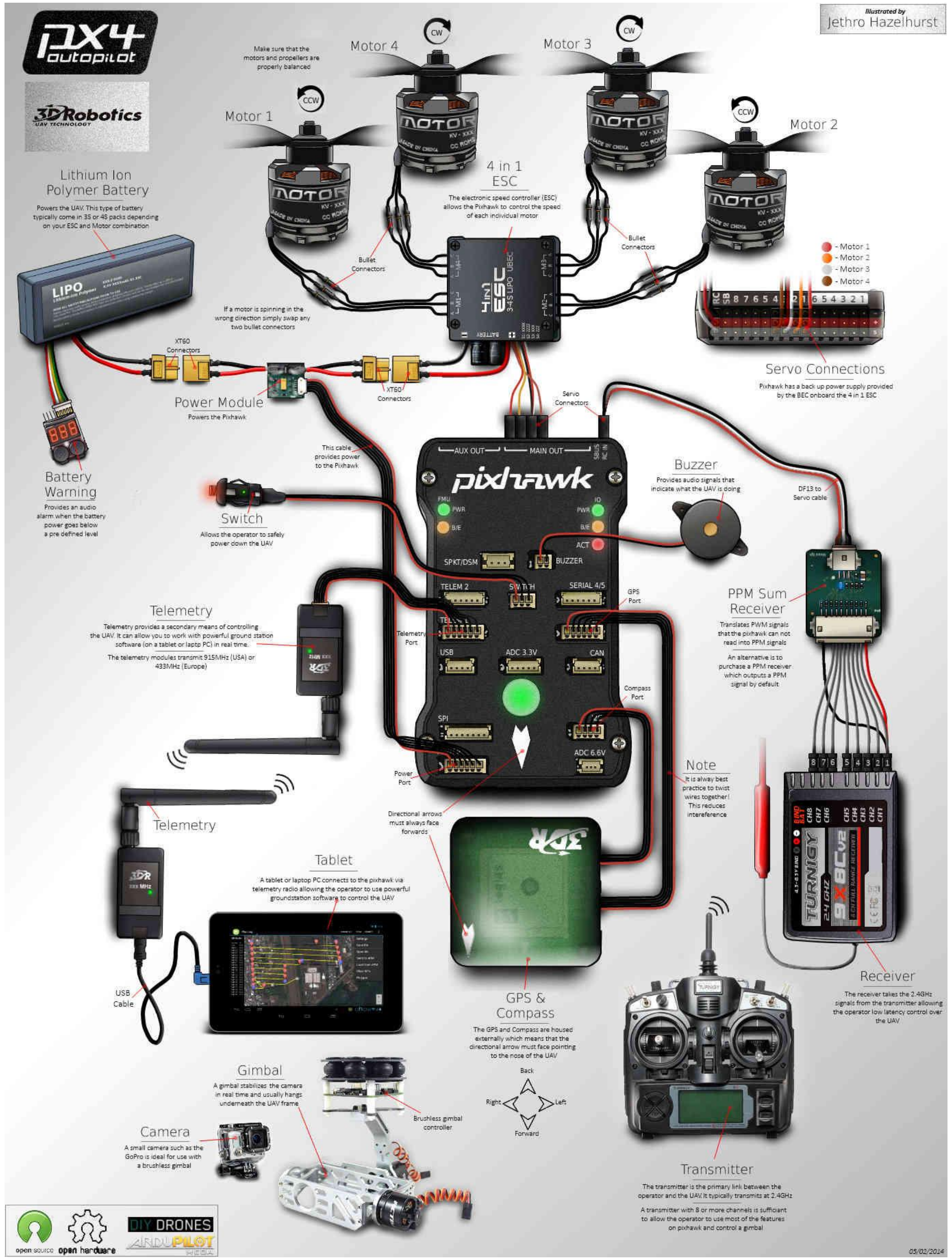
- Meets all requirements
- Comes preloaded with code for flight
- Software and SITL investigated but without hardware are not beneficial

Pixhawk FC , Simulation Screenshot, Code Screenshot



Electronics & Propulsion Components

- The basic components of this subsystem include motors, propellers, battery, cameras, Pixhawk microcontroller, and telemetry.
- All items are commercially produced and were chosen based on factors such as weight, overall efficiency, and market availability.
- The motors and propellers were the main components that drove decision making, hence will be discussed further.



Motor Requirements

Component	Current Draw (mA)
Electro-permanent Magnet	10
Camera x2	80
Motor x 4	Unknown
Pixhawk	175
GPS	55
Compass	5
Telemetry Radio	35
Safety Switch	10

Battery Life

Battery Capacity: 1550 mAh

Device Consumption: 4300 mA

Consumption Rate: 0.7

Estimated Hours: = 0.2523255814

*mAh / Load Current in mA * 0.70*
The factor of 0.7 makes allowances for external factors which can affect battery life.

Requirements

Deliver a 2:1 TWR (thrust to weight ratio) at max thrust. (Expected Weight : 800g)

Minimum impact to aerodynamic efficiency.

Constraints

Allowance for motor: 3930mA
0.98A per motor on average

Max diameter for propeller : 8 in

Motor Solution

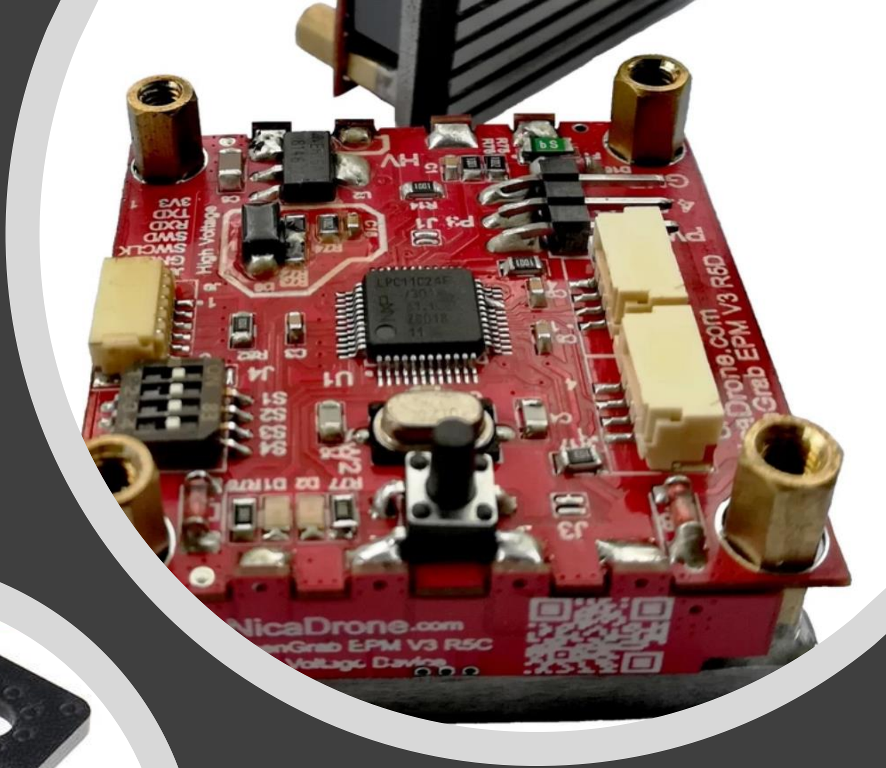
- ***T-motor F40 Pro III 1600KV 4-6S CW Thread Brushless Motor***
  - ***Weight:*** 33g
  - ***Max thrust delivered for take-off :*** *634 g*
  - ***Max Current needed for take-off:*** *7.48 A*
  - ***Rated Efficiency:*** *4.36*
  - ***Price:*** *$26.90*

Gripping Mechanism Requirements

- Must be able to fit in design constraints and requirements.
- Must be able to pick up Payload and washer of max 94 grams
- Must be able to coordinate with electrical components.
- Must work with a of Battery Specs 4S and 4.2 Volts per Cell.

Gripping Mechanism Options Based on Requirements:

- Electromagnet
- Electro Permanent Magnet
- Mechanical Gripper

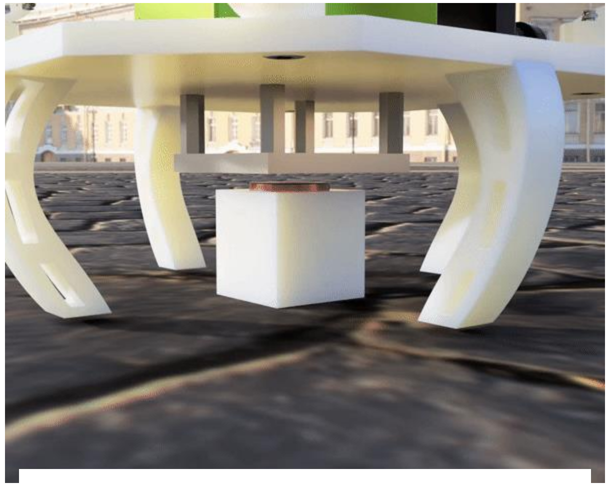


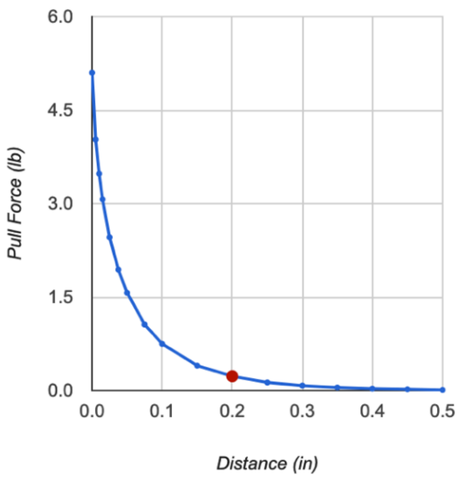
Solution: Electro Permanent Magnet

- *Electromagnet was ruled out because it would draw too much Power from the battery***

- Lighter
- Draws less Power
- More "Flight Friendly"
- Less possible modes of failure

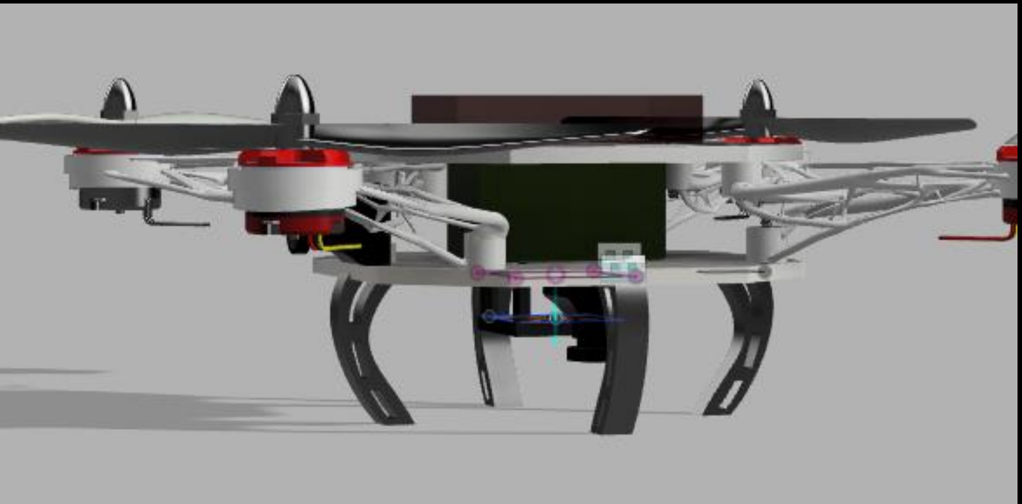
- Calculations show that the magnet can draw the payload from up to 0.2 inches away.





Grade = N40
Outer Diameter = 0.5"
Inner Diameter = 0.25"
Thickness = 0.125"
Distance = 0.2"
0.23 lb

Detailed Design



Embodiment Design

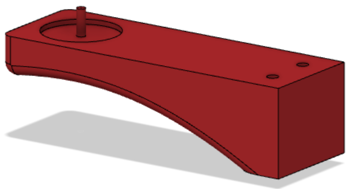
Generative Design

Generative design is an iterative design process that involves a program that will generate a certain number of outputs that meet certain constraints

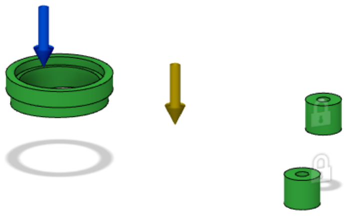
Used to lightweight the arms of the drone (the heaviest part initially)

- Goal: minimize mass
- Bear 20N during ascent and 10N during descent
- Safety factor minimum : 2.0
- Manufacturing: 3D printed ABS, max overhang 60

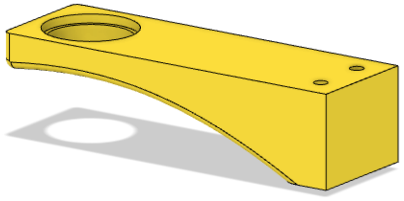
Reduced weight to 12g each (14% of original mass)



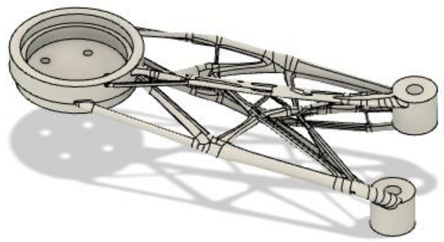
Obstacle Geometry



Preserve Geometry



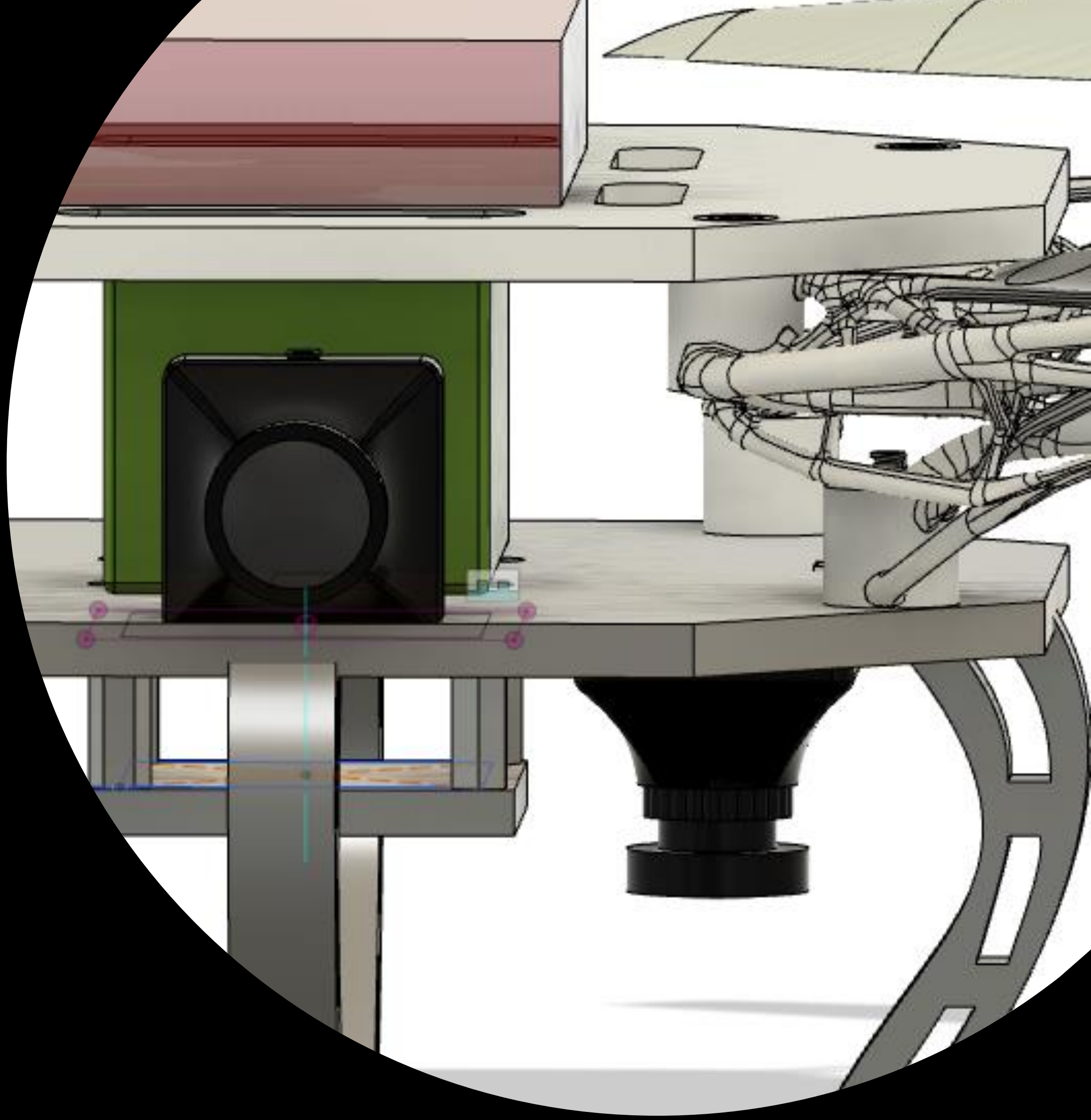
Starting Shape



Result

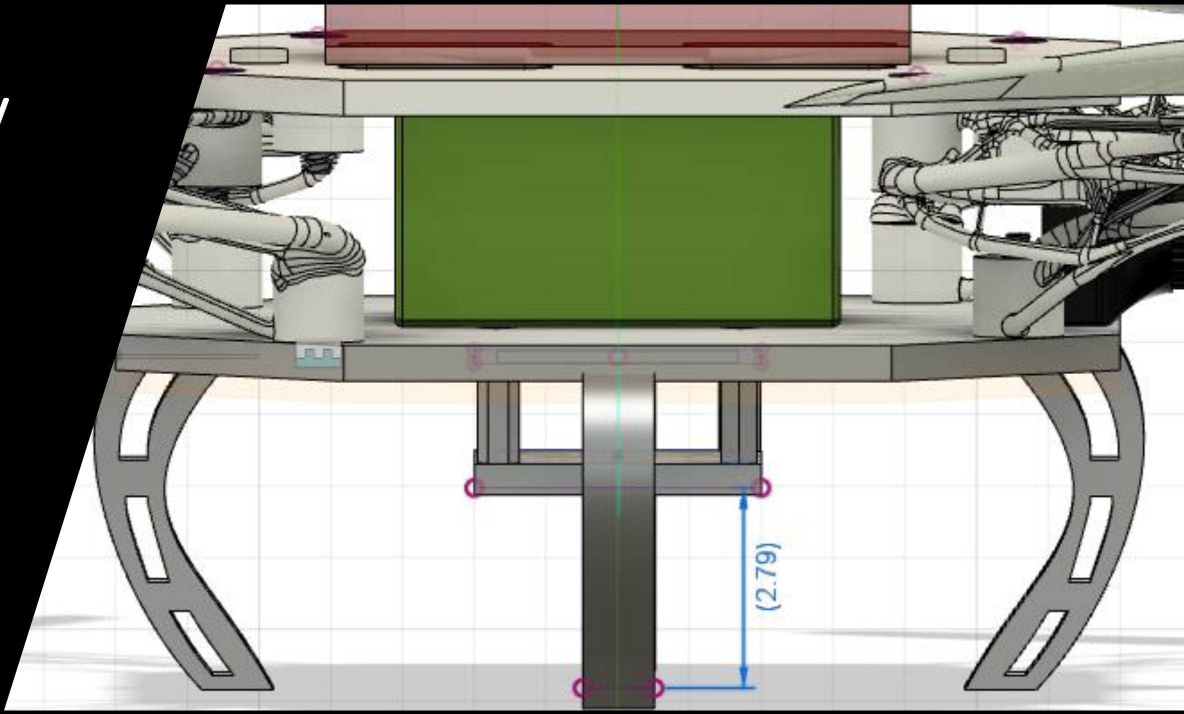
Camera Placement

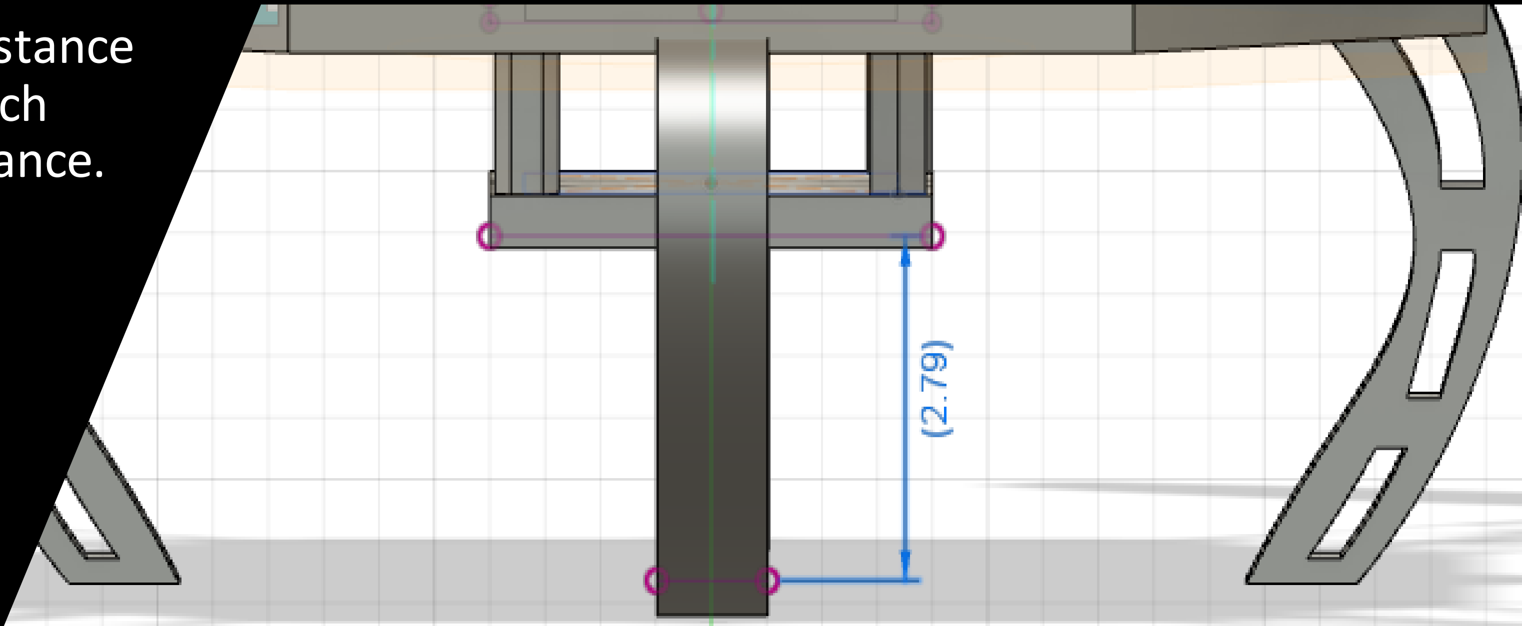
- In order to see the obstacles clearly, the camera is placed in between the two plates. The camera cad file is approximately the same size as the real camera that we will be purchasing which is 2.8 cm in height.
- There is also another camera facing on the bottom plate that will be used to see the payload pickup.



Landing Gear/Electromagnet/ Payload Pickup/Dropoff

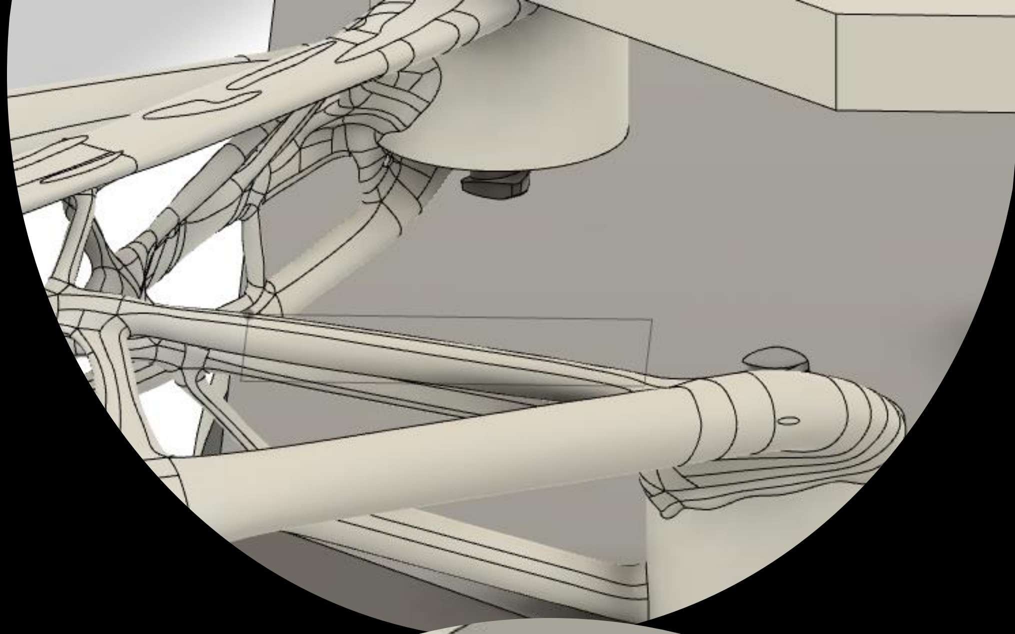
- Distance from the end of the electromagnet to the end of the landing gears needed to have a constraint of a maximum of 1.1 inch to ensure that the magnet will be able to effectively pick up payload without any interference.
- The current measurements for the distance between the two ends is 2.79 cm which is 1.0984 inch leaving a .0016 in tolerance.

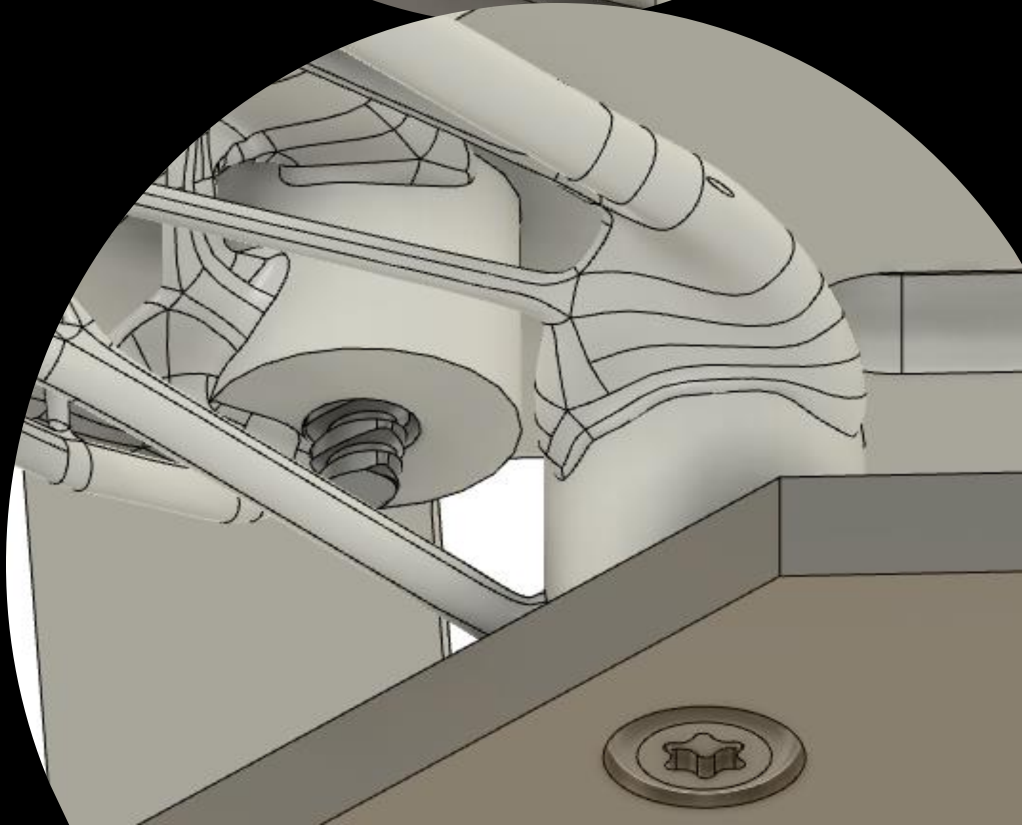




Screw Placement Analysis

- The screws are positioned so that there are two aligned diagonally connected to two cylindrical holders that are connected via the arms.
- This design avoids the redundancy of a 4 screw design and will overall reduce the mass of the drone.





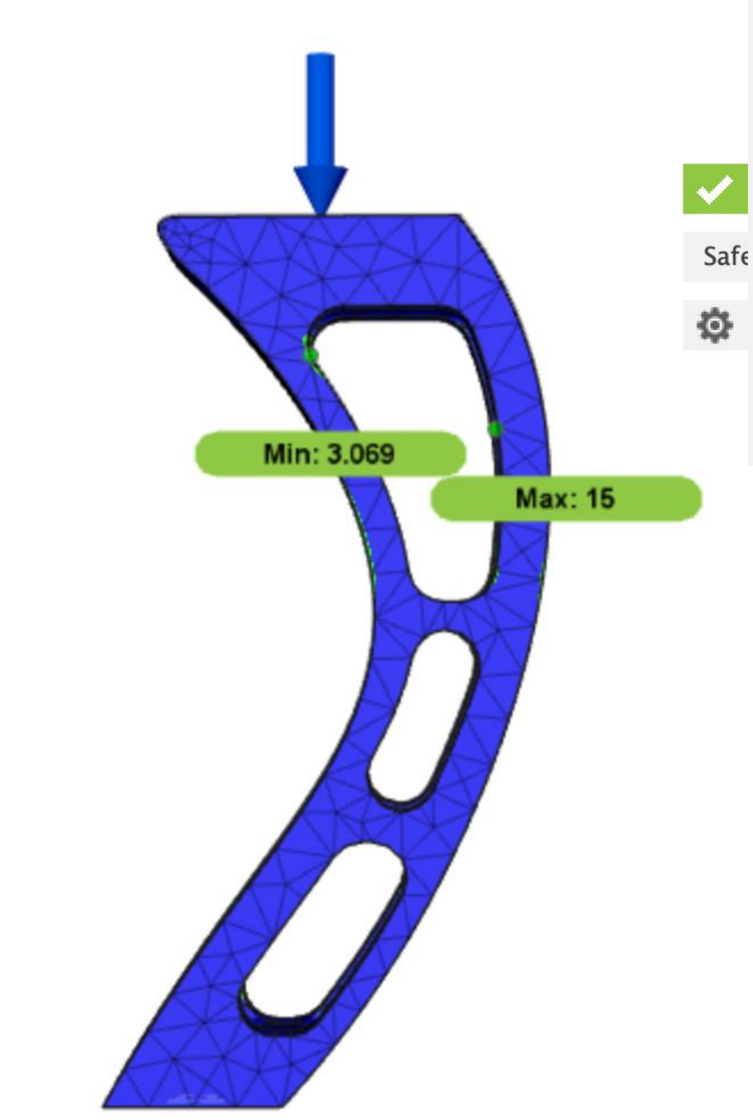
Mass/Load Calculation for Landing Gear Finite Element Analysis

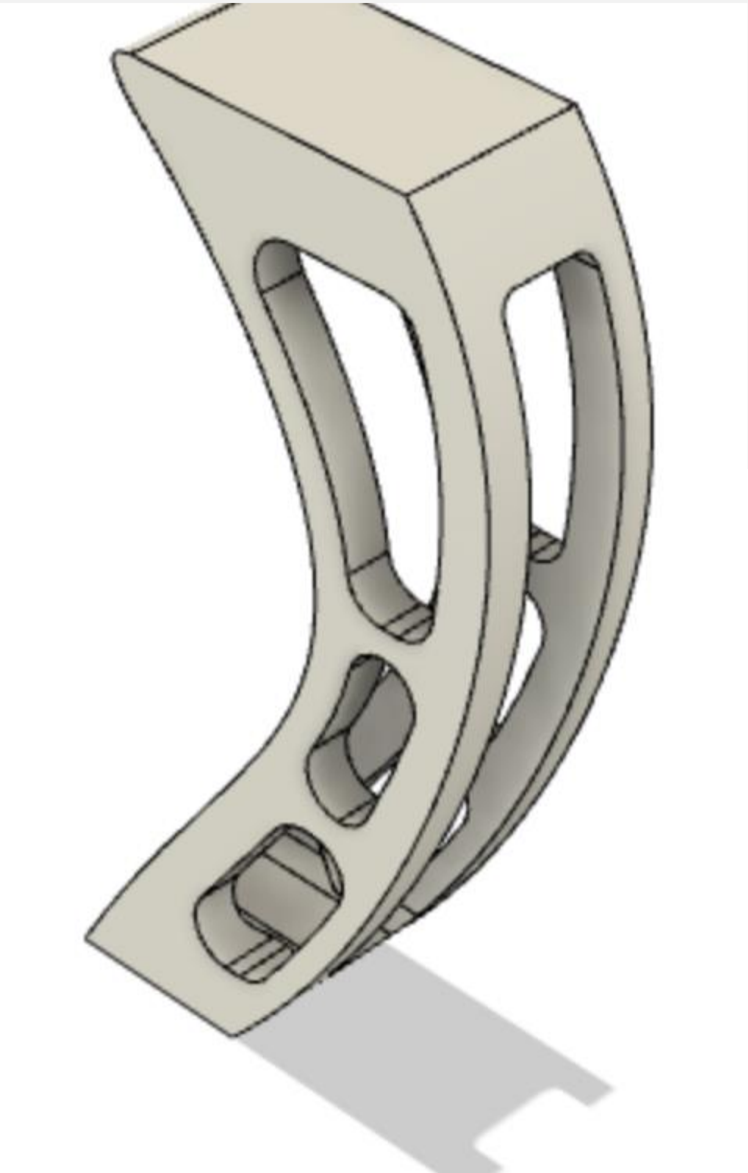
Below are all components that will contribute to the applied load on the landing gear attached. This mass total will be used in FEA analysis.

- Upper Plate = 139.85
- Lower Plate = 137.21
- Arms = 47.44
- Motors = 128 g
- Propellers = 24 g
- Camera = 5.5 g
- Microcontroller = 38 g
- Battery = 192 g
- Total = 740 g ⇒ 7.4 N (8.5 N)

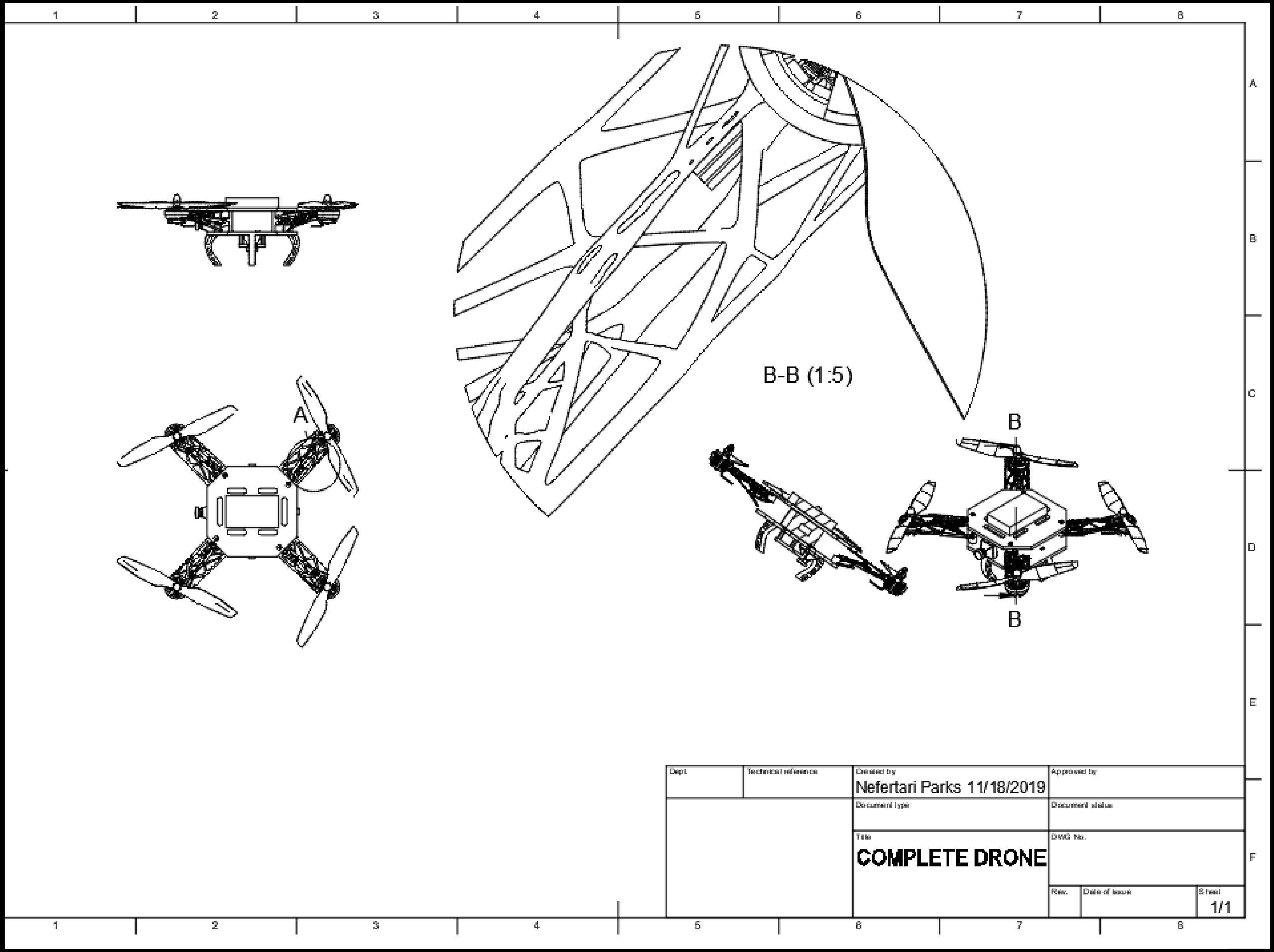
Original Leg Design

- Leg Designed to minimize weight
- Weight: 2.408 grams (per leg)
- Min Safety Factor (with weight of drone): 3.069

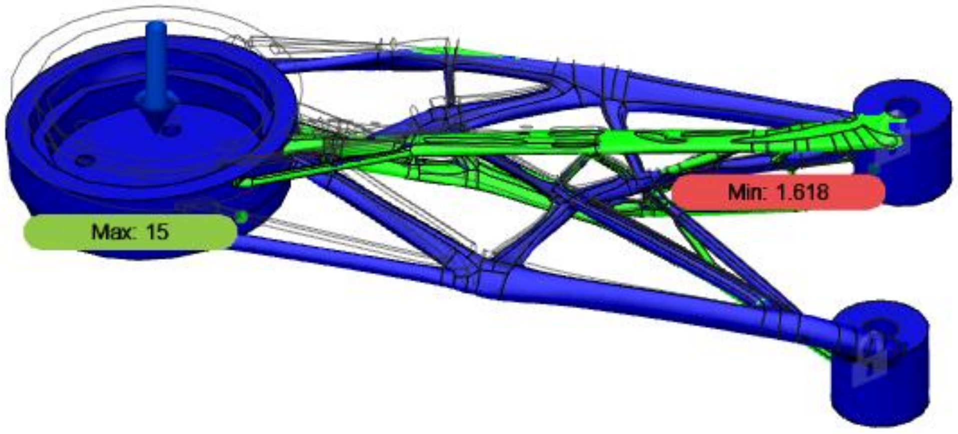


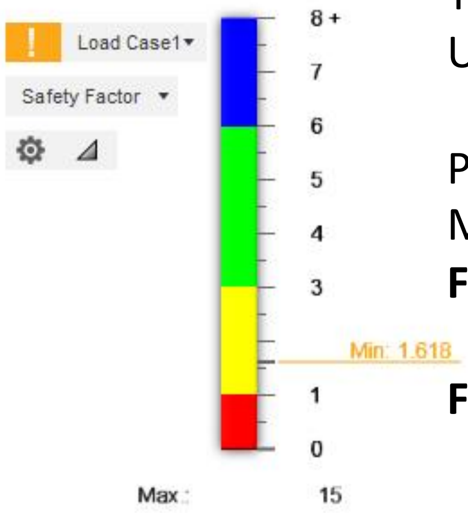


Design Drawing



Static Load



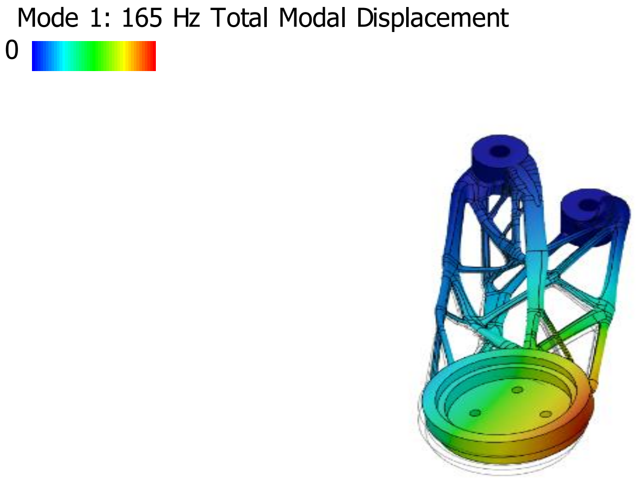


3D printed ABS assumed to have
Yield Strength : 17 MPa
UTS : 22MPa

Propeller details
Max Thrust : 930g
Force = 9.13 N

FOS: 1.6

Vibration Analysis

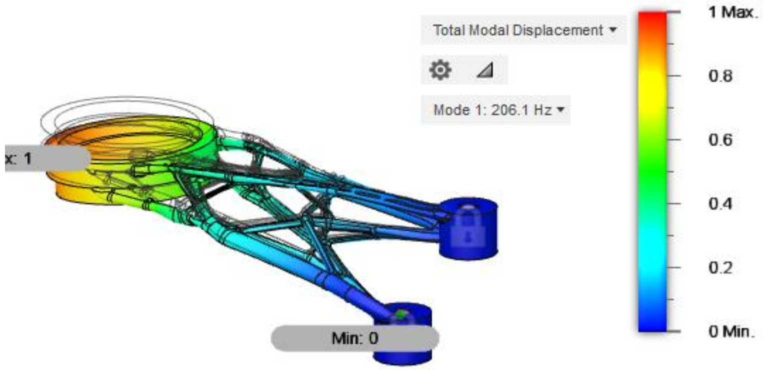


Frequency	Participation X	Participation Y	Participation Z
Mode 1: 165 Hz	4.88119982	44.4362998	2.56629996
Mode 2: 190.3 Hz	1.23150004	8.2487002	1.30329998
Mode 3: 358.7 Hz	26.9811988	1.92910004	22.0765993

Resonance at 165Hz (9900 RPM)
Max RPM: 23680 RPM

To reduce vibration

- Stiffening of design (increase resonance frequency to 12366 RPM)



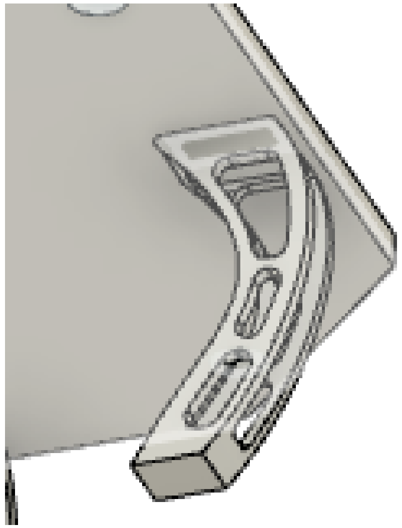
- Adding dampers (e.g. ear plugs) to critical regions
- Using vibration isolation for key electronics

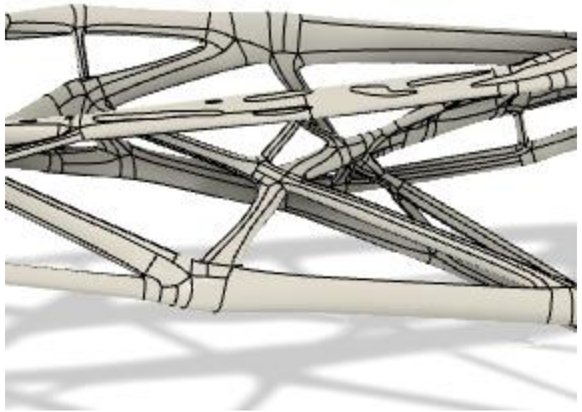
Design for Additive Manufacturing

Parts consolidation

Topology optimization / Generative design

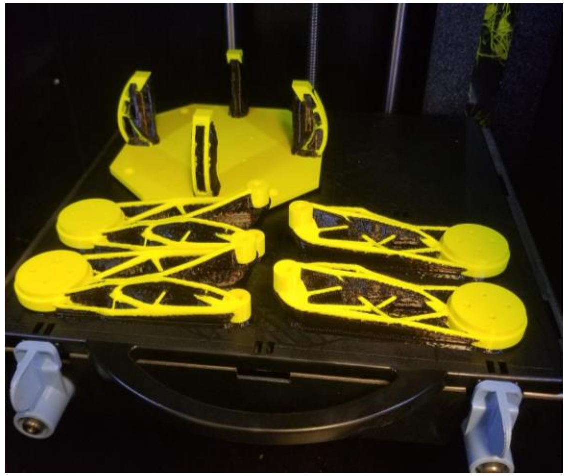
Design for mass customization

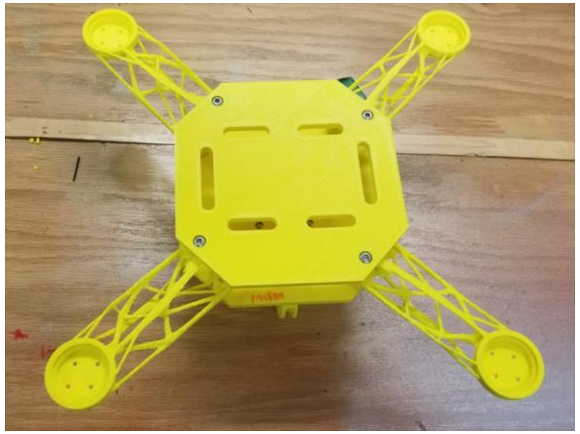




3D Printing Process

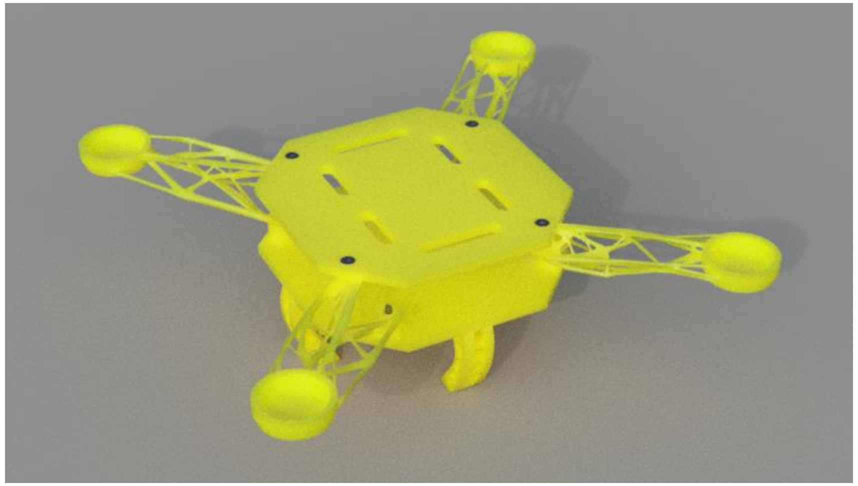
- The upper plate, lower plate and 4 arms were printed in the DimensionEX printer
- Oriented to reduce the need for support material
- After each part was printed it was placed in a solution bath to dissolve support material.
- The bath used was the SCA 1200HT Solution Bath with WaterWorks Soluble Concentrate.





CAD vs Prints

- Total Build Time: ~ 8 hrs
- Prints expected to be 15-30g lighter than expected (i.e. around 230g) based on print parameters
- Load bearing parts printed with higher density
- Initial design needed were adjusted for screw hole compatibility



Fusion 360 Render of 3D printed parts

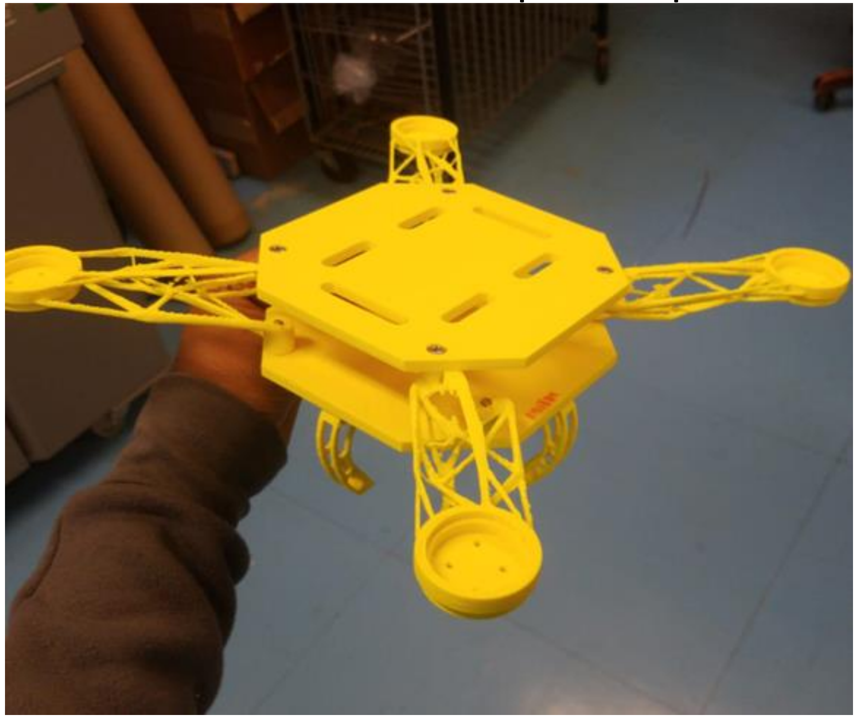
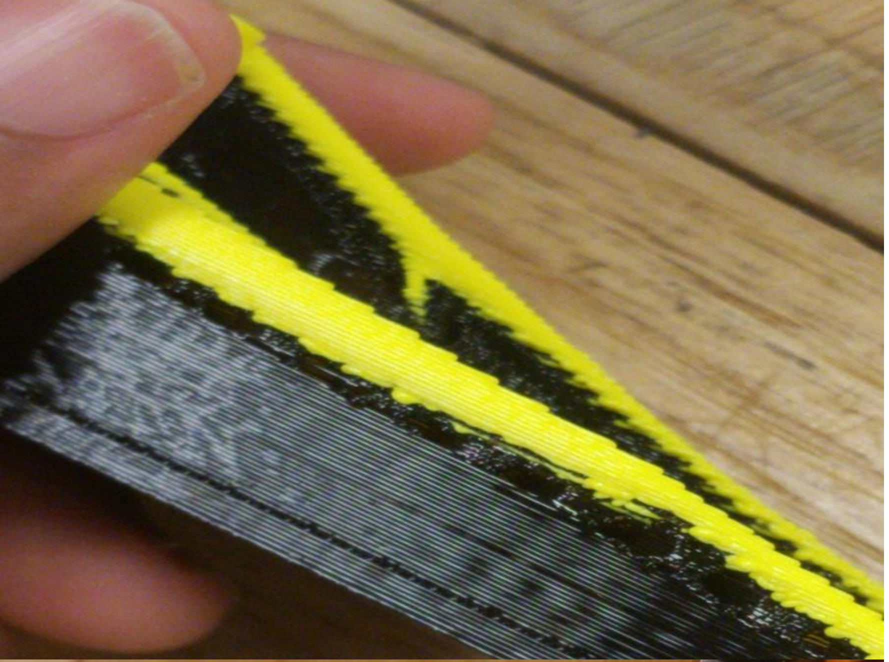
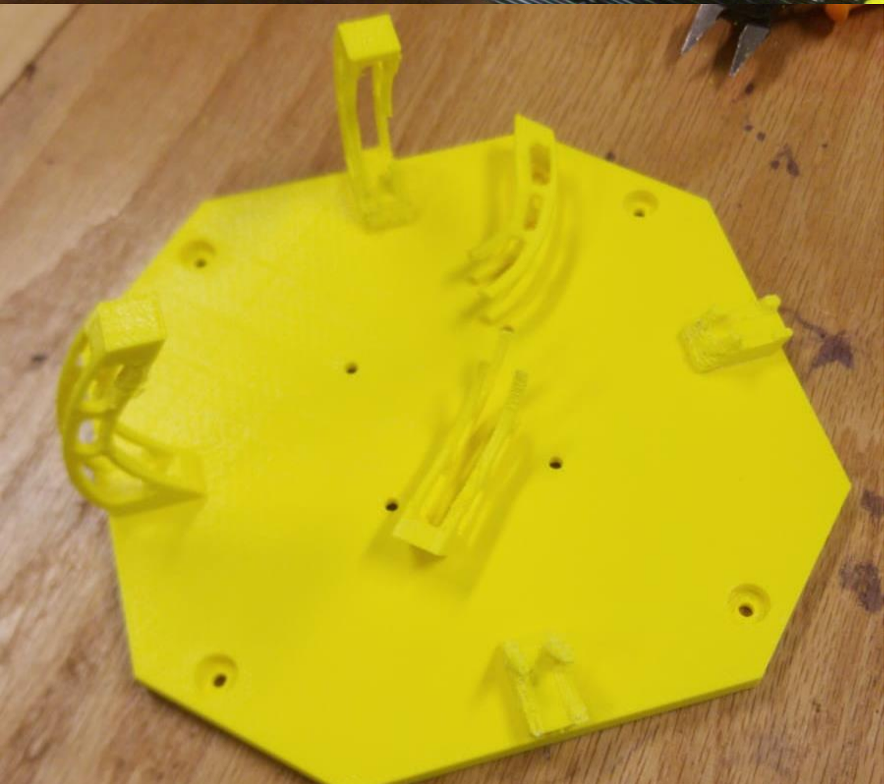


Image of 3D printed parts

Testing plans

- Determining any mechanical difference between
  - 0/90 and 45/45 build
  - Bead sizes (0.3302 and 0.254mm)
  - Infill (solid, high density and low density)
- Comparing FEA to physical load capacity
  - Loading parts with masses and constraining in critical areas





Printing Issues

Arms

- Low Resolution print of organic arm design. Could potentially reduce the mechanical strength

Solutions/Experimentation

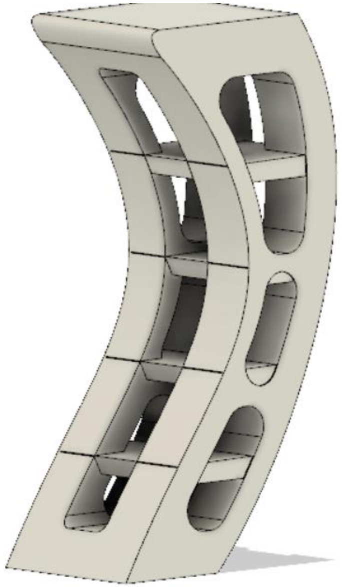
- Testing on the Objet printer with a different material for higher resolution and water-soluble support material
- Redesign of arms for less organic solution
- Testing current low res. options for unexpected mechanical failure

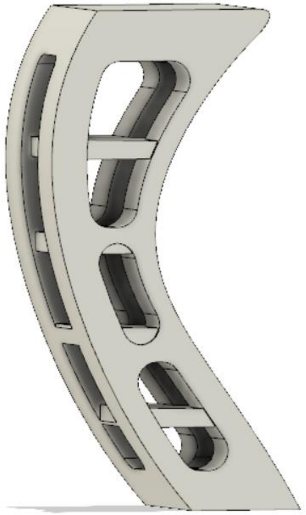
Legs of Lower Plate

- Legs brittle; breaking upon contact after dissolving support material

Solutions / Experimentation

- 3 Redesigns of legs done to increase mechanical strength and/or reduce the need for support material
- Using Objet Printer for higher quality print
- Adjusting length of time in solution bath





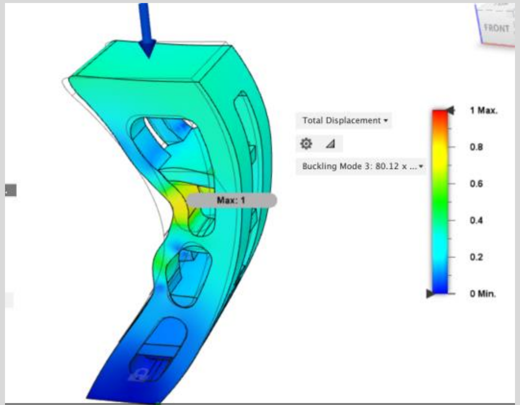
Landing Gear Design Update Iteration #2

Due to failure of landing gear after 3D printing, a new design needed to be created.
Support Bars were added in the structure, and the legs were thickened to add more stability to design.

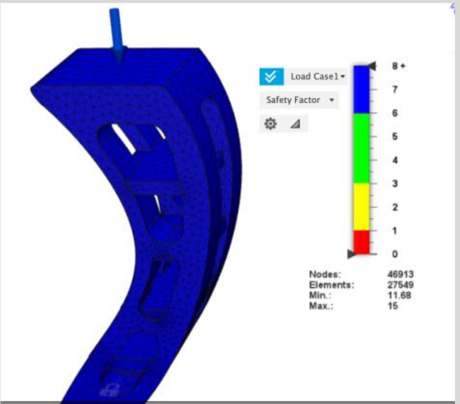
- Weight: 6.183 grams (approximately 3 grams heavier)

Landing Gear Analysis & Load Simulations:

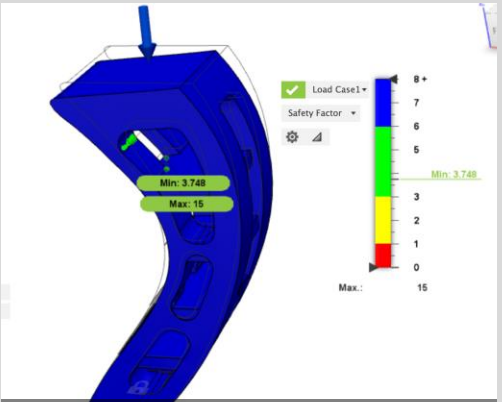
- Analysis 1: Force of Weight of Drone on Legs
  - Min Safety Factor of 15
- Analysis 2: Force of Weight of Drone falling from the sky at 10 feet
  - Min Safety Factor: 3.748
- Analysis 3: Buckling Analysis
  - Buckling Mode 3 showed the worse deformation at 400.6 x Load



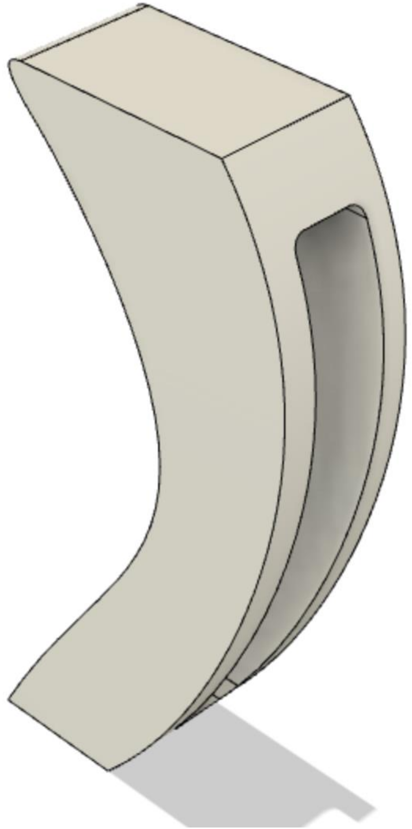
Analysis #3



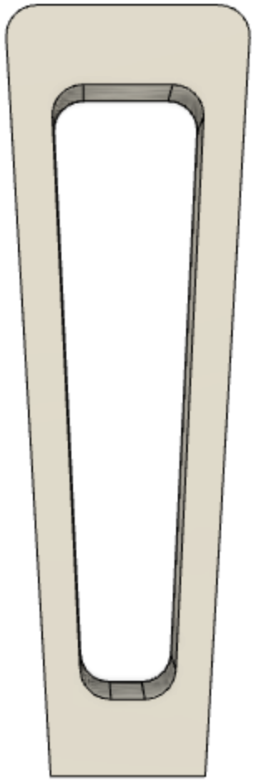
Analysis #1



Analysis #2



Design Option #1



Design Option #2

These designs aim to decrease the amount of support material needed to produce the part and/or produce support material that is more easily removed.

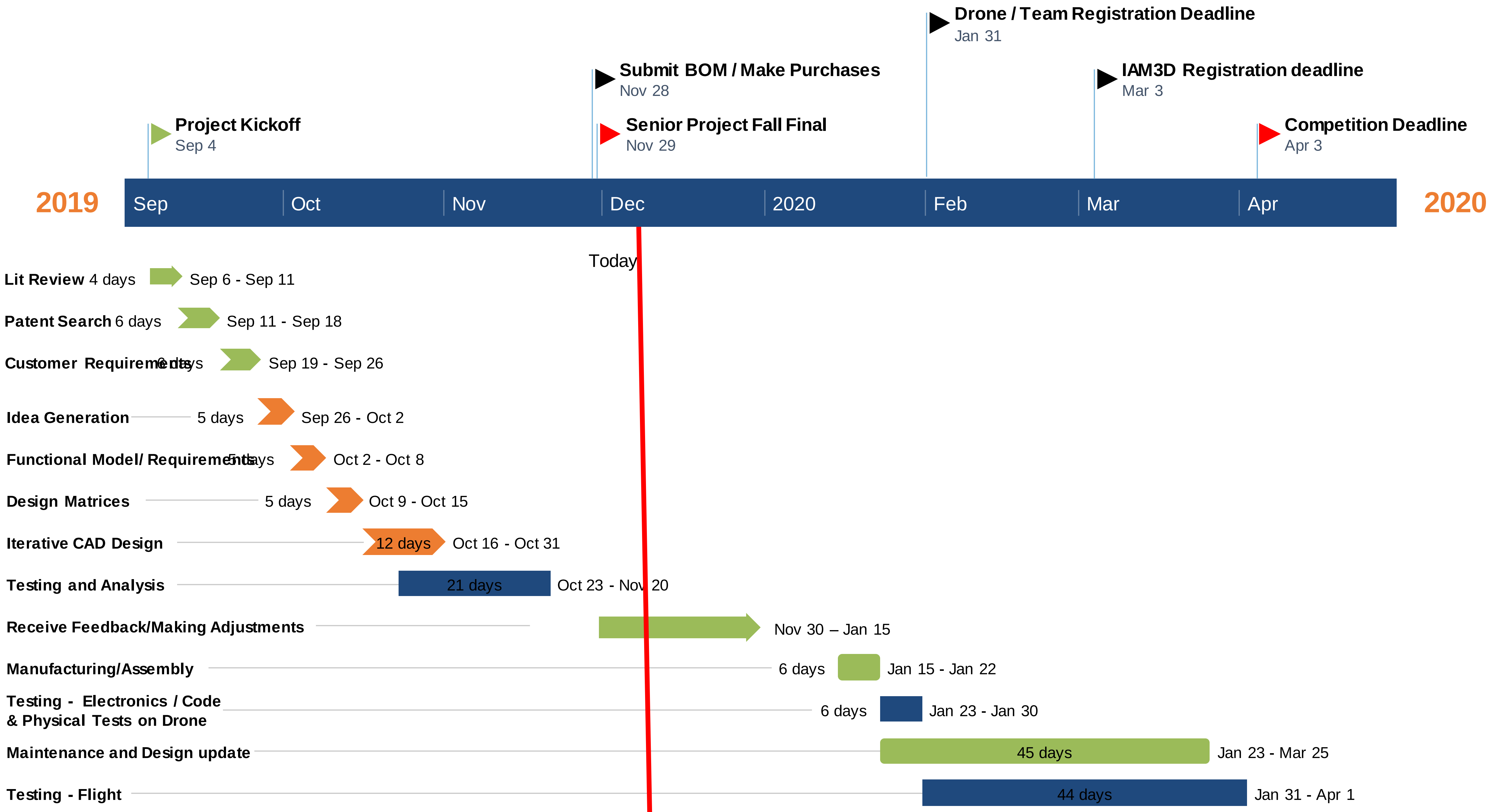
Option #1:

- Removes all small holes, and only features one hole in the middle so possible support material can be broken off or pushed out

Option #2:

- A straight leg design that should reduce the amount of support material significantly.

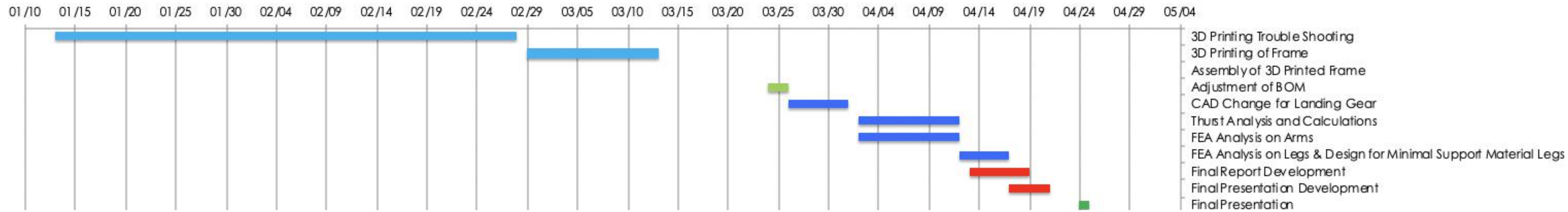
Other Landing Gear Options



Drone / Team Registration Deadline
Jan 31
Submit BOM / Make Purchases
Nov 28
IAM3D Registration deadline
Mar 3
Project Kickoff
Sep 4
Senior Project Fall Final
Nov 29
Competition Deadline
Apr 3
2019
Sep
Oct
Nov
Dec
2020
Feb
Mar
Apr
2020
Today
Lit Review 4 days
Sep 6 - Sep 11
Patent Search 6 days
Sep 11 - Sep 18
Customer Requirements 6 days
Sep 19 - Sep 26
Idea Generation
5 days
Sep 26 - Oct 2
Functional Model/ Requirements 5 days
Oct 2 - Oct 8
Design Matrices
5 days
Oct 9 - Oct 15
Iterative CAD Design
12 days
Oct 16 - Oct 31
Testing and Analysis
21 days
Oct 23 - Nov 20
Receive Feedback/Making Adjustments
Nov 30 – Jan 15
Manufacturing/Assembly
6 days
Jan 15 - Jan 22
Testing - Electronics / Code & Physical Tests on Drone
6 days
Jan 23 - Jan 30
Maintenance and Design update
45 days
Jan 23 - Mar 25
Testing - Flight
44 days
Jan 31 - Apr 1

iMAJHN SENIOR PROJEFCT TIMELINE SPRING SEMESTER 2020

AT RISK	TASK NAME	SUB TASK NAME	STATUS	ASSIGNED TO	START DATE	END DATE	DURATION in days	COMMENTS
☐	3D Printing Trouble Shooting	Testing Parts in on different 3D pritners as well as fixing 3D printers	Completed	iMAJHN	01/13	02/28	46	
☐	3D Printing of Frame		Completed	iMAJHN	02/29	03/13	13	
☐	Assembly of 3D Printed Frame		Completed	IMAJHN	03/14	03/14	0	
☐	Adjustment of BOM		Completed	Jordan	03/24	03/26	2	
☐	CAD Change for Landing Gear	Editing existing parts to be strong enough to wistsand 3D print and bath	Completed	Nefertari	03/26	04/01	6	
☐	Thurst Analysis and Calculations	Further analysis on thrust and its affect on the drone	Completed	Hanny	04/02	04/12	10	
☐	FEA Analysis on Arms	Vibrational and Stress Analysis on Arms	Completed	Melissa	04/02	04/12	10	
☐	FEA Analysis on Legs & Design for Minimal Support Material Legs		Completed	Alli	04/12	04/17	5	
☐	Final Report Development			iMAJHN	04/13	04/19	6	
☐	Final Presentation Development			iMAJHN	04/17	04/21	4	
☐	Final Presentation			iMAJHN	04/24	04/25	1	



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☐	FEA Analysis on Arms	Vibrational and Stress Analysis on Arms	Completed	Melissa	04/02	04/12	10	
☐	FEA Analysis on Legs & Design for Minimal Support Material Legs		Completed	All	04/12	04/17	5	
☐	Final Report Development			IMAJHN	04/13	04/19	6	
☐	Final Presentation Development			IMAJHN	04/17	04/21	4	
☐	Final Presentation			IMAJHN	04/24	04/25	1	
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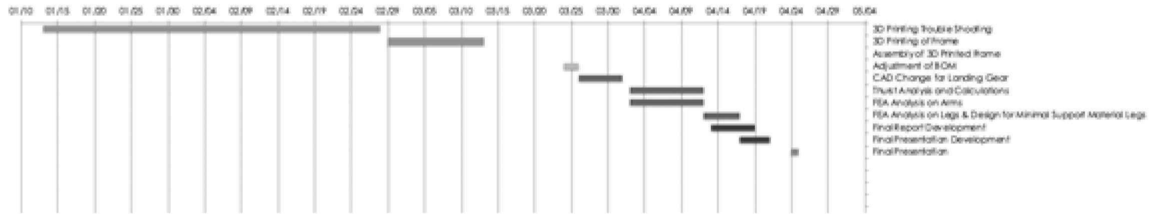
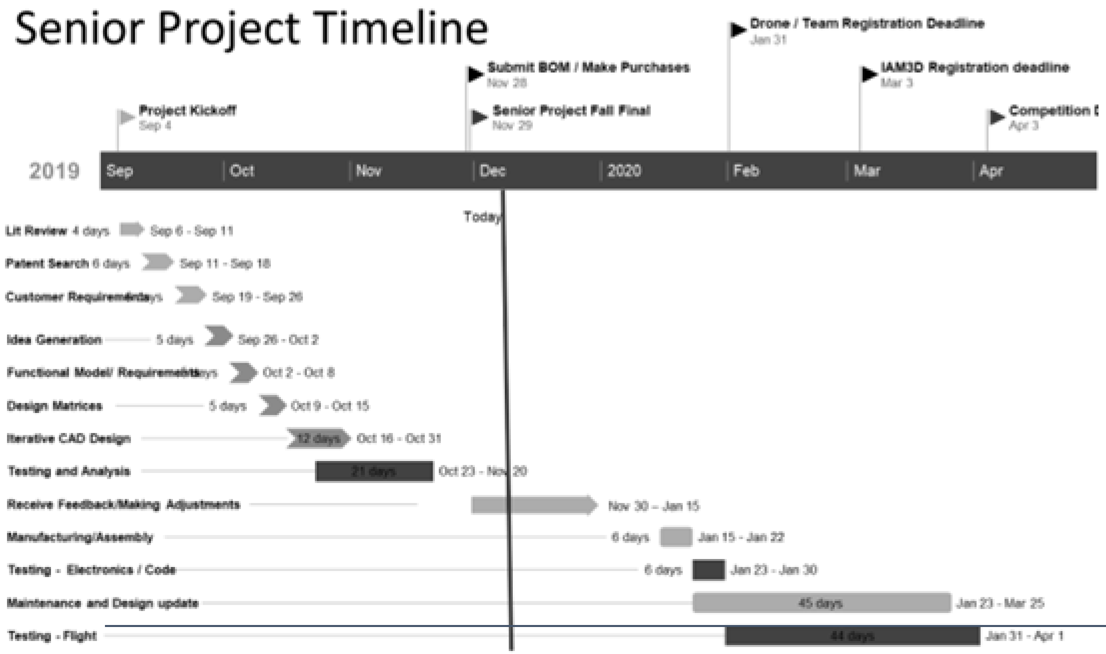




Senior Project Timeline Comparison

Major Timeline Differences and Alterations:

- 3D Printer issues which delayed our manufacturing process
- Difficulty sourcing the necessary components from the right vendors
- 3D printed Parts: Landing Gear came out of chemical bath extremely brittle and we could not determine why. Because no further testing could be done, to determine the reason behind this, new landing gear along with other options were created
- Vibrational Analysis shows vibration reaches resonance, so vibration dampening methods would have had to be explored and implemented

Potential Plan Moving Forward

- Due to the COVID-19 Pandemic many unforseen events interfered with our original action plan. They mainly include:
  - The cancellation of the IAM3D Competition
  - University closure in the middle of the semester.
- Hence, we were unable to continue printing, fulfilling orders for commercial electronic components, and testing.
- Without the disruption we would have continued fulfilling the orders of the electronic components, continued to assembling printed frame and electronics, then testing.

Questions

Back up Slides

BOM

Number	Quantity	Item (generic)	Item Full name	Price each	Total Price	Link to Vendor(s)
1	1	Microcontroller	Pixhawk PX4 PIX 2.4.8 Flight Controller NEO-M8N GPS 3DR 915Mhz Radio Wireless Telemetry Set OSD Module PPM Module I2C Splitter Expand Module Power Module for FPV Quadcopter	$ 128.86	$ 128.86	Amazon
2	1	Remote Control	Flysky FS-i6X 10CH 2.4GHz AFHDS RC Transmitter w/ FS-iA6B Receiver	$ 48.99	$ 48.99	Amazon
3	4	ESC	Hobbypower SimonK 30A ESC Brushless Speed Controller BEC 2A for Quadcopter F450 X525 (Pack of 4 pcs)	$ 24.97	$ 99.88	Amazon
4	1	Balanced propellers	GEMFAN 6042 6" 2-BLADE PROPELLERS (8 Pack)	$ 3.26	$ 3.26	Amazon
5	2	FPV Camera	RunCam Racer 2	$ 15.40	$ 30.80	Amazon
6	1	Camera Switcher	VIFLY Dual FPV Camera Switcher	$ 6.99	$ 6.99	Amazon
7	1	4S Battery	Ovonic 14.8V 1550mAh 100C 4S LiPo Battery Pack with XT60 Plug for FPV Racing RC Quadcopter Helicopter Airplane Multi-Motor Hobby DIY Parts	$ 18.99	$ 18.99	Amazon
8	1	Video Transmitter	TS832 48Ch 5.8G FPV Transmitter	$ 15.89	$ 15.89	Amazon
9	4	Brushless motors	T-motor F40 Pro III 1600KV 4-6S CW Thread Brushless Motor for RC Drone FPV Racing	$ 25.49	$ 101.96	Amazon
10	1	Proximity Sensor	Ultrasonic proximity sensor, EZ, MB1013	$ 35.00	$ 35.00	Amazon
11	1	Video Receiver	FPV Receiver, EACHINE ROTG01 UVC OTG 5.8G 150CH Full Channel FPV Receiver for Android Mobile Phone Tablet	$ 29.99	$ 29.99	Amazon
12	1	Camera Switcher	VIFLY Dual FPV Camera Switcher	$6.99	6.99	Amazon
13	1	Charger for 4S battery	Tenergy TN267 1-4 Cells Li-Po/Li-Fe Balance Charger for Airsoft & RC Car Battery Packs with 1S to 4S XH Type Balance Connector	$24.99	24.99	Amazon
14	1	LiPo Safe Bag	LiPo Fireproof Explosionproof Safety Bag |ExpertPower|for Lithium Battery & DJI Mavic & DJI Phantom 3 Battery|Guard Charging and Storage Safe Bag (7.3 x 3.0 x 2.5 Inches)	$ 7.99	$ 7.99	Amazon
15	1	Alkaline Batteries	AmazonBasics AA 1.5 Volt Performance Alkaline Batteries - Pack of 20	$ 8.48	$ 8.48	Local Store / Amazon
16	1	Power Distribution Board	HOBBYMATE XT60 PDB Power Distribution Board - Support 3-6S Input, 5V/12V Output Support The LC Filter, w/Current Sensor	$ 12.90	$ 12.90	Amazon
17	1	Insert Screws	QLOUNI 330Pcs M2 M3 M4 M5 Female Thread Knurled Brass Threaded Insert Embedment Nut Assortment Kit	$ 12.99	$ 12.99	Amazon
18	1	Nuts Volt Screw Kit	DYWISHKEY 360 Pieces M3 x 6mm/8mm/10mm/12mm/16mm/20mm, 12.9 Grade Alloy Steel Hex Socket Head Cap Bolts Screws Nuts Kit with Hex Wrench	$ 10.69	$ 10.69	Amazon

Introductory/ Requirements

- Customer Statements
- Design Brief
- Matrixes

Customer Statements

- Majority of vehicle components should be manufactured using additive manufacturing.
- Should be no larger than 33 cm measured diagonally from motor to motor and no taller than 25 cm.
- Should be able to accommodate FPV (First Person View) method of piloting.
- Must be powered by a 4S, 4.2V per cell rechargeable battery.
- Should be able to complete the obstacle course of the 2020 ASME IAM3D Competition in under 15 minutes.
- Should be able to secure, transport, and release payloads located along the obstacle course. (a 3D printed (PLA) one-inch cube with 30% infill).

Design Brief

Competition Date: April 3rd- 5th 2020, Michigan State University

Budget: Approximately $1,500

- Design will be at least 33.33% additive manufacturing
- Finish all 5 laps in under 15 minutes
- Have a functioning Drone and have an eligible entry for the competition (meaning meets all eligibility requirements such as constraints)
- Create a gripping mechanism/ something to pick up payload with
- Must not collide with other drones and must be controllable enough to navigate

Design Brief

The team decided we will derivation of a typical drone quadcopter.

- Multi-rotor drones are easy control and maneuver
- They have the ability to hover
- They can take off and land vertically
- Are very stable

For the Gripping Mechanism on the drone we decided to use an electromagnet for the following reasons

- An electromagnet will most likely be lighter than any gripper we could create
- Leads to less parts meaning less materials needed
- Will be easier to control
- Compatible with payload of competition
- More compatible with Pixhawk and overall drone design and parts

Requirements Matrix

REQUIREMENT #:	DESCRIPTION OF REQUIREMENT:	RELATED FACTORS:	SUBSYSTEM:
1	4S Battery, 4.2 Volts Per Cell	Electronics	Electronics
2	Be able to pick up and drop off payload	Code Frame Gripping Mechanism	Gripping Mechanism
3	Use of Additive Manufacturing for Drone	Propulsion Frame	Frame
4	Dimensions: 33 cm measured diagonally from motor center, no taller than 25 cm height	Propulsion Electronics	Frame
5	Finish Competition/Laps in under 15 minutes	Speed Weight Electronics	Propulsion
6	Navigate through obstacles in competition	Code	Code
7	Reach no more than 10 feet in amplitude during competition	Code Propulsion	Code

Calculations

- Thrust to weight Calculations
- Frame/Motor Size/ Propeller Size Chart
- Payload Calculations
- Propeller vs Motor Chart

Thrust to Weight Calculations:

Quadcopter weight :800g

Actual drone weight : 740.3g (frame plus all electronic components)

Propeller Characteristics :

Diameter = 8'' Pitch = 4.5

Motor Characteristics:

Kv = 1600 Volts = 14.8(4S battery)

RPM Generated by Motor:

RPM = Kv . Volts

=1600×14.8

=23,680 RPM

Motor Power Output = Power Absorption of Propeller:

Propeller Constant, K = 5.3×10^-15

Power = K.(RPM)^3.(diameter)^4.(pitch)

= (5.3×10^-15) × (23,680)^3 ×(8)^4 ×(4.5)

=1297.16W

Amp. Rating of Battery:

Amp Hours = 1.55 Discharge Rate = 100C

Amp Rating = Amp Hours × Discharge Rate

= 1.55 ×100

=155 Amp

Max. Motor Wattage:

Max. Wattage = Volts × Amp Hours

= 14.8 × 1.55

=22.94 W

Static Thrust in (N) produced by a Propeller:

Air density, ρ = 1.1839 @ 25C (77F)

Thrust, T = [pi/2(0.0254d)^2 × ρ × (power)^2]^½

= [pi/2(0.0254(0.2032))^2 × (1.1839) × (1297.16)^2]^½

= 9.13 N

Max Thrust = T × 4

=(9.13)(4)

= 36.52 N

Thrust to weight: 3723.97/800 = 4.7 : 1 (TWR should be at least 2:1)

Frame size, propeller and motors

Frame Size (mm)	Propeller size (inches)	Motor size	KV
150	3	1306 or smaller	3000
180	4	1806	2600
210	5	2204 - 2206	2300 - 2600
250	6	2204 - 2208	2000 - 2300
350	7	2208	1600
450	8	2212 or larger	1000 or lower

Comparing chosen motor with different propellers

		Propeller		Motor/Propeller Combination		
Motor (Kv)	Motor power(W)	Diameter(inches)	Pitch	Thrust(N)	Max thrust(N)	TWR
1600	1729.55	8(2-bladed)	4.5	9.13	36.52(3723.97g)	4.7
	383.07	6(3-bladed)	4.2	2	8(815.773g)	1.0
	709.679	7(3-bladed)	4.2	4.99	19.98(2037.39g)	2.6

Gripping Mechanism Matrix:

Gripping Mechanism:	Mass (approximate):	Force:	Current & Voltage:	PixHawk Compatibility:	Cost:	Power Requirement:
Mechanical Gripper (All Gripper specs are taken from a sample gripper that would be similar to the gripper we would design)	Motor = 45 grams Gripper = 61.1 grams Total = 106.1 grams	Gripper Force: Dependent on Gripper Design	1.2 Amps at 4.8- 6.0 V	Yes	$12.99 (cost of motor)	Ideally would only draw power when opening gripper to pick up payload and closing gripper to drop off payload Power Draw: Medium-Low
Electromagnet	23 grams	Holding Force: 25 Kg/55 lbs Weight of Object: 5 kg/ 10 lbs max	0.6 Amps at 5V	Compatible with a Raspberry Pi (Ubuntu) So everything will have to be adjusted for Pixhawk	$19.95 + cost of Cricket Board ($29.95)	Must Draw Power when Electromagnet is on. Meaning the entire time the drone is carrying the payload, the magnet will be drawing power: Power Draw: High
Electro Permanent Magnet	65 grams	Holding Force: 15 Kg/30 lbs Weight of Object: 3 kg/ 6 lbs max	0.6 Amps at 5V	Yes	$159.99	Magnet draws power to turn magnet “off” so it will only draw power when dropping payload Power Draw: Low

Payload Pickup

Criteria	Weighting	Mechanical Gripper		Electromagnet		Electro Permanent Magnet	
		Score	Total	Score	Total	Score	Total
Size	3	3	9	5	15	4	12
Weight	5	3	15	5	25	4	20
Holding Force	4	3	12	5	20	4	16
User Friendliness	4	2	8	3	12	4	16
Pixhawk Compatibility	5	3	15	1	5	5	25
Power Requirement	5	3	15	1	5	4	20
Cost	3	3	9	5	15	1	3
	Total		83		97		112

0.189 lbs washer + 0.022 lb cube = 0.211 lb payload

Lbf = (0.211 lb)(32.174049 ft*lb/sec)

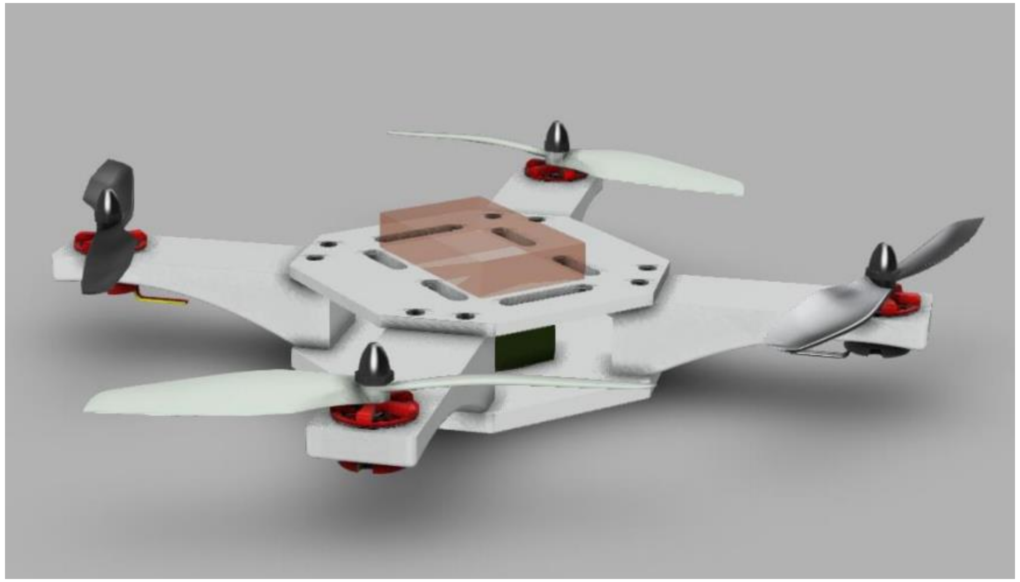
= 0.21 lbf

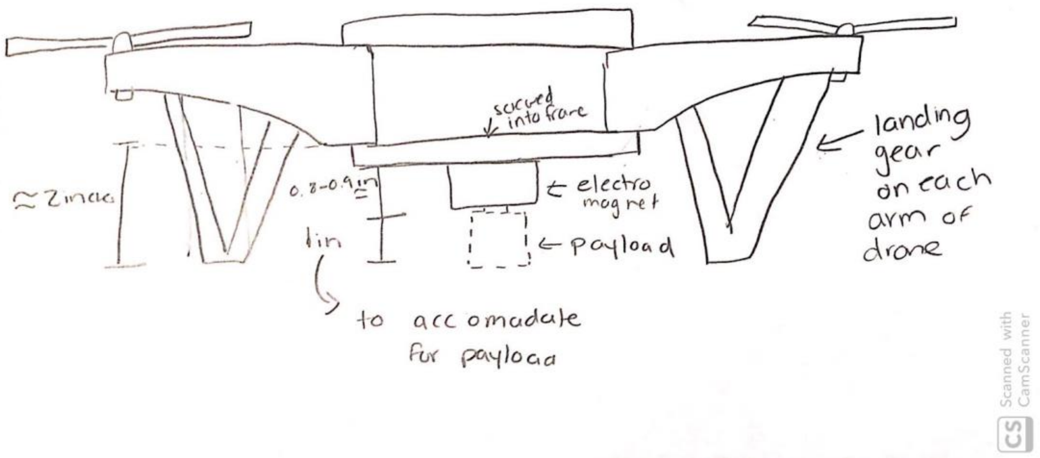
Drone Design

- Chosen Conceptual Design
- Drone Design
- Generative Design Arms
- Generative Design Output
- Arm Design

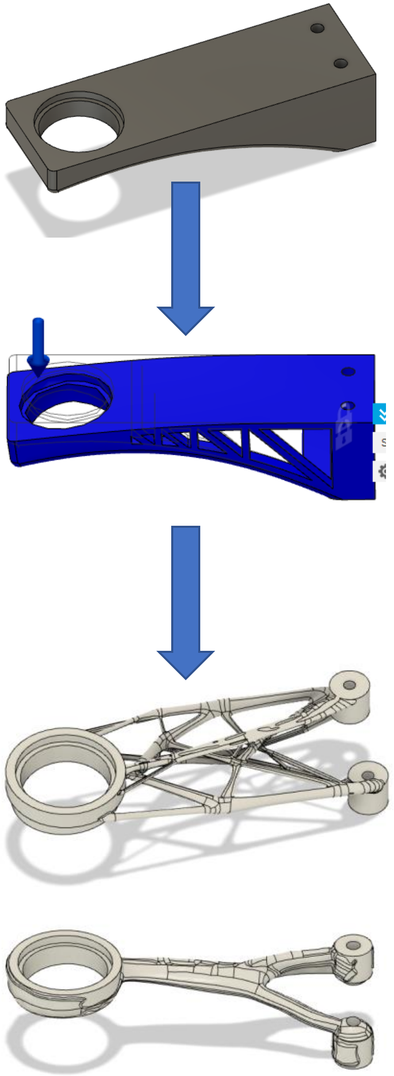
Chosen Conceptual Design

- General Quadcopter Drone
  - 4 arms & 4 propellers
  - Open Middle Body to minimize weight and material
- Electromagnet:
  - Attached to the bottom of the frame
  - The landing gear will be approximately 2 inches





Light-weighting – Arms



Iterative Design

(1) *Initial Design*

87g FOS : 15

(2) *Manual Reduction*

46g FOS: 8.4

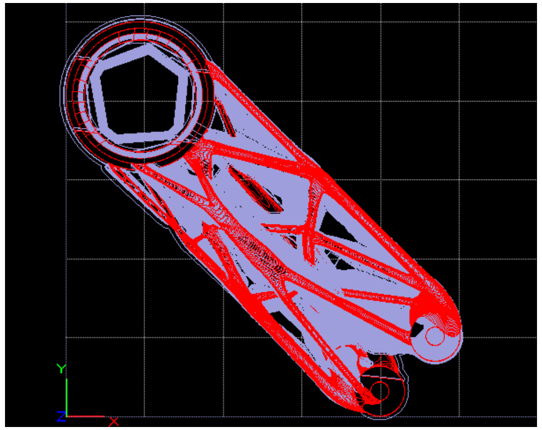
(3a) *Gen Design A*

11g FOS: 2.1

(3b) *Gen Design B*

14g FOS: 2.0

- Primary goal: Reduce mass and maintain structural integrity
- Expected failure: Bending/Shear Force
- FEA analysis + manual testing of Prints
- FDM properties vary from solid ABS
- Manufacturing capabilities limited



← A has more support material than B →

Arm Design

A

Study 1 - Generative - Outcom...
Iteration 45 (final)

Properties

Status	Converged
Material	ABS Plastic
Orientation	-
Manufacturing method	Unrestricted
Visual similarity	Ungrouped
Volume (mm^3)	1.001e+4
Mass (kg)	0.011
Max von Mises stress (MPa)	9.6
Factor of safety limit	2
Min factor of safety	2.07
Max displacement global (mm)	1.69

B

Study 1 - Generative - Outcom...
Iteration 46 (final)

Properties

Status	Converged
Material	ABS Plastic
Orientation	X+
Manufacturing method	Additive
Visual similarity	Ungrouped
Volume (mm^3)	1.341e+4
Mass (kg)	0.014
Max von Mises stress (MPa)	10
Factor of safety limit	2
Min factor of safety	2
Max displacement global (mm)	5.11

Engineering Design Matrix

Topic	Multiplier		Options A	B	C	D (N/A)
			5	4.5	1	2
Weight	5	x	25	22.5	5	10
			5	4	5	5
Minimum FOS	4	x	20	16	20	20
			5	3	2	3
Aesthetics	2	x	10	6	4	6
		Total	55	44.5	29	36

C

ORIGINAL

motor spacing_Arm design v8

Area 164.618 cm^2

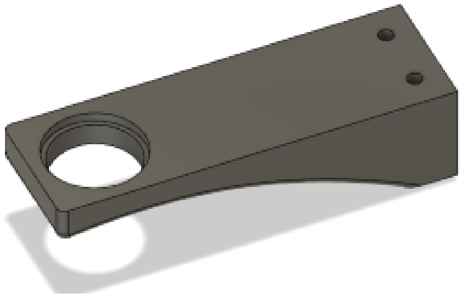
Density 1.06 g / cm^3

Mass 86.574 g

Volume 81.674 cm^3

Physical Material ABS Plastic

Min safety factor is 15



D

MANUALLY ADJUSTED DESIGN

motor spacing_Arm design v5

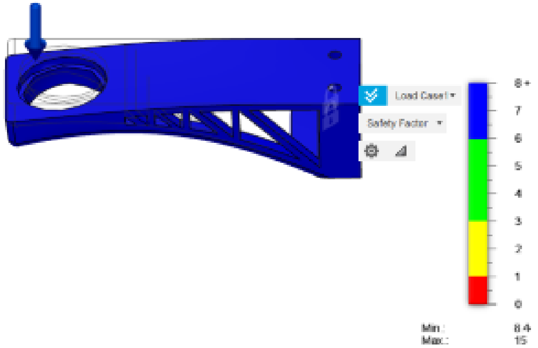
Area 219.703 cm^2

Density 1.06 g / cm^3

Mass 46.077 g

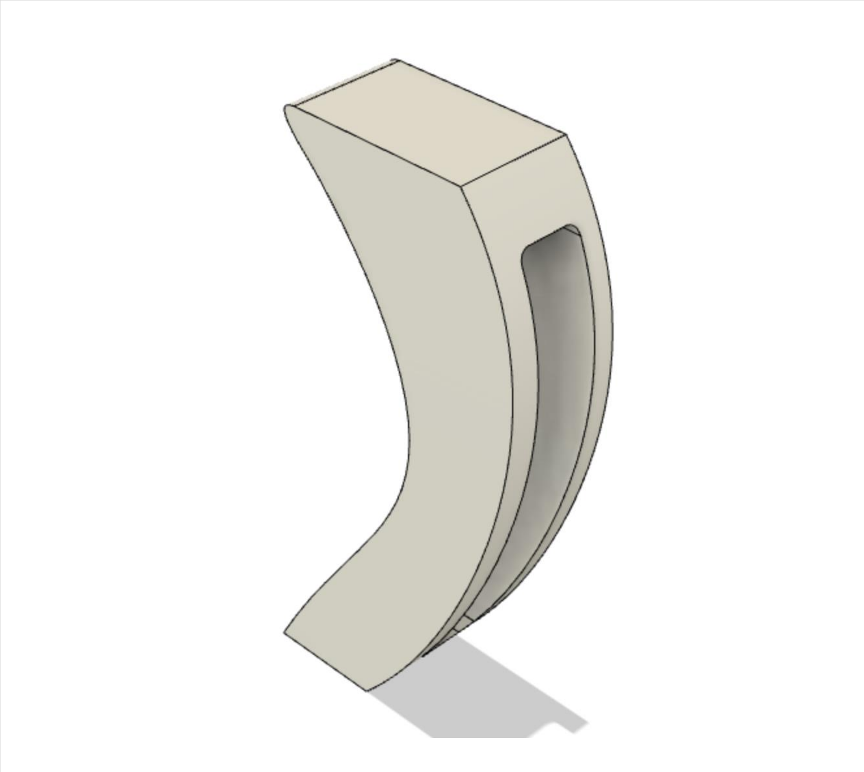
Volume 43.469 cm^3

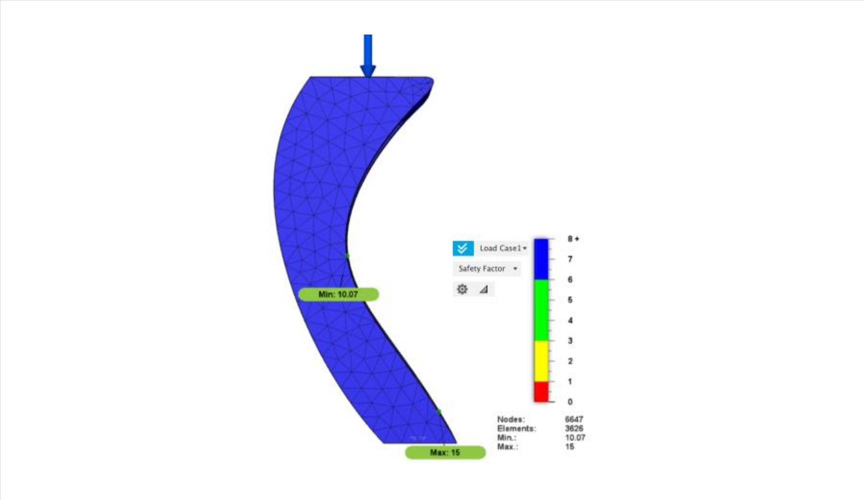
Physical Material ABS Plastic

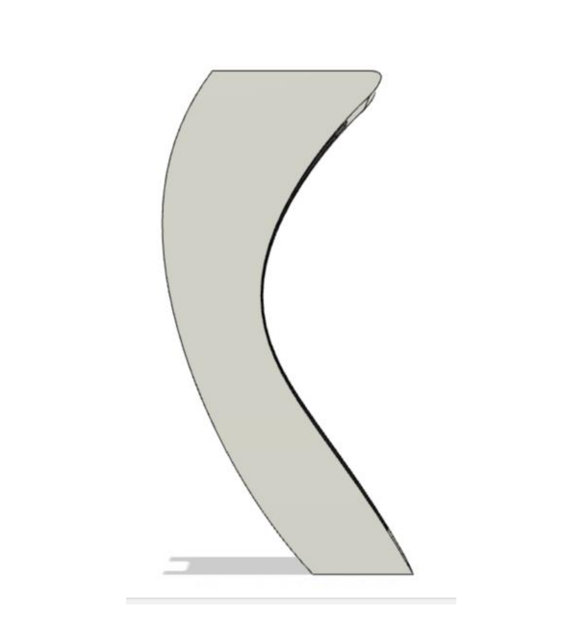


Leg Design Update Iteration #3

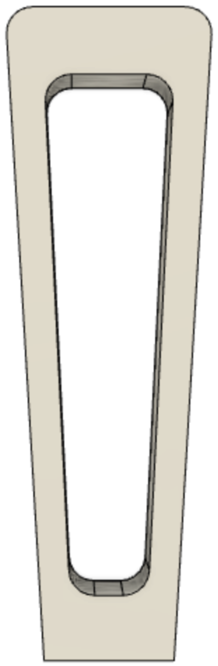
- Theoretical Design Iteration the minimize the need for support material

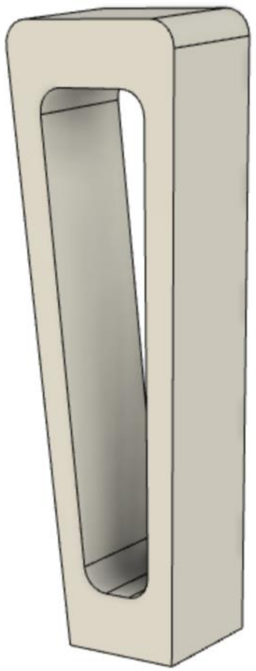


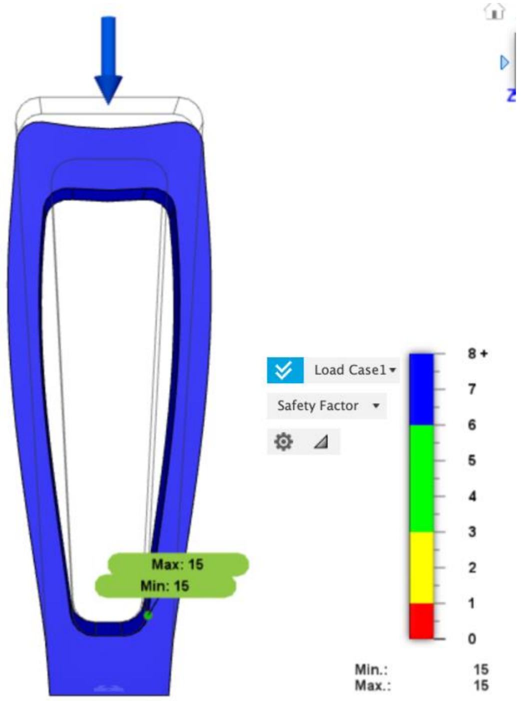




Leg Design Update Options #4







Design Analyses

- Landing Gear (all iterations) Analyses

Leg Design Iterations Analysis #1

Analysis tested Force of Weight of Drone:

Original Design:

- Min Safety Factor: 3.069

Design Iteration #2:

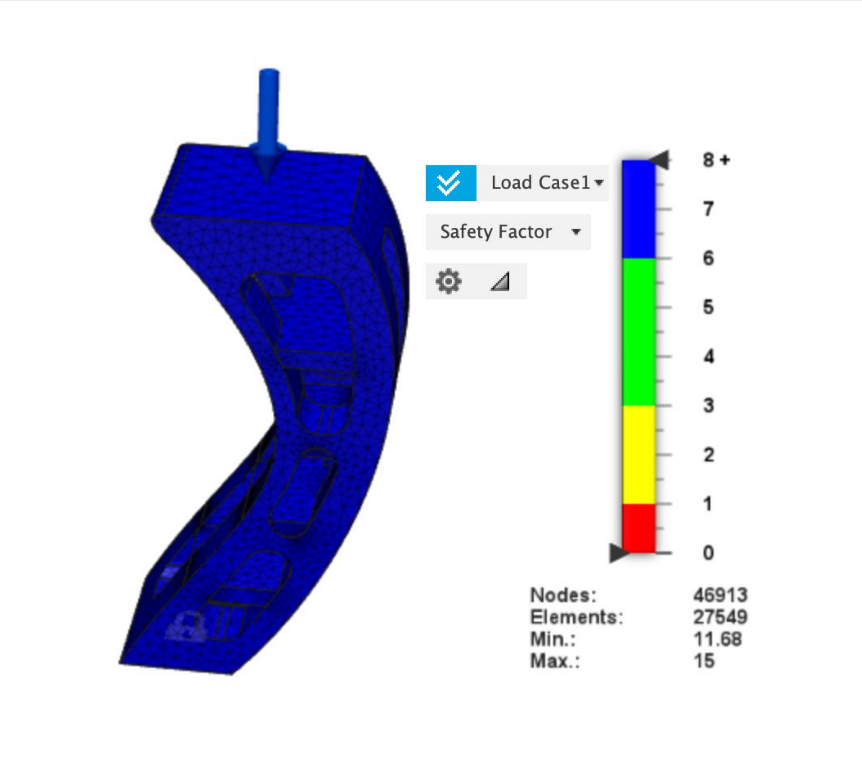
- Min Safety Factor: 15

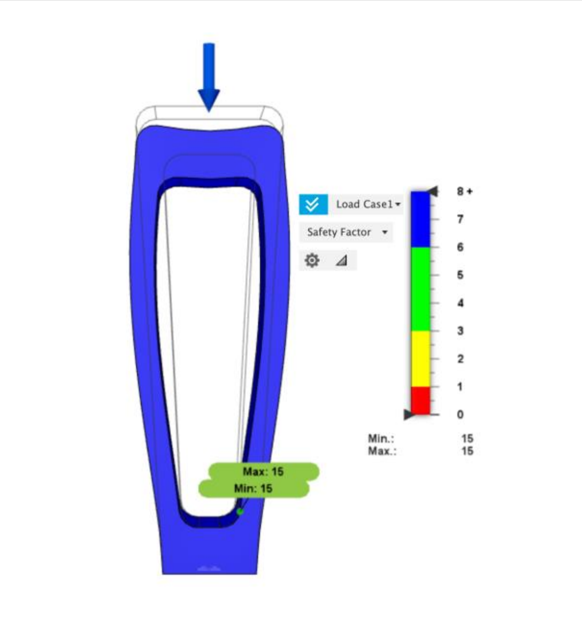
Design Option #3:

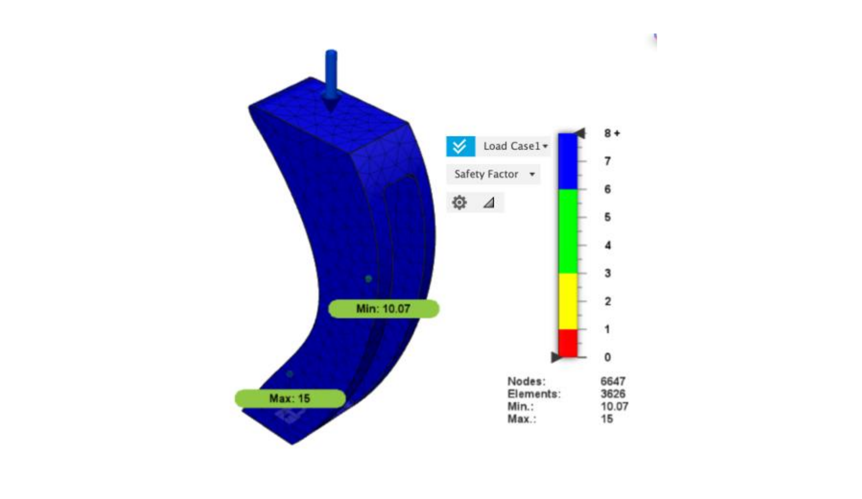
- Min Safety Factor: 10.07

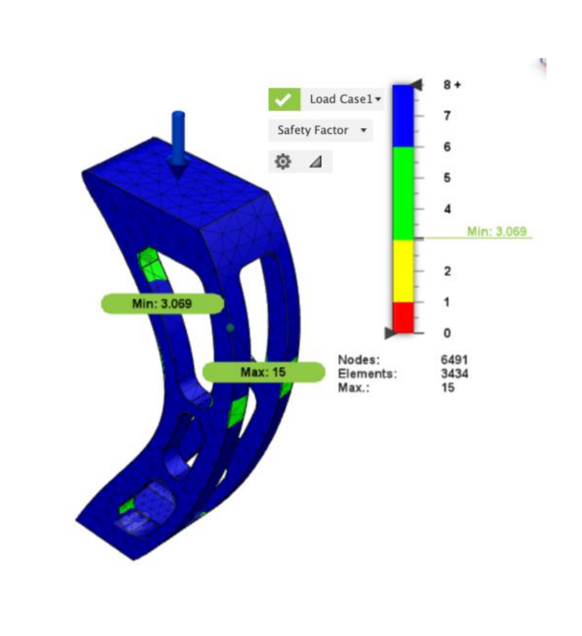
Design Option #4:

- Min Safety Factor: 15









Leg Design Iterations Analysis #2

Static Analysis Failure Scenario: If drone falls from 10 Feet in the air

Original Design:

- Min Safety Factor: 1.122

Design Iteration #2:

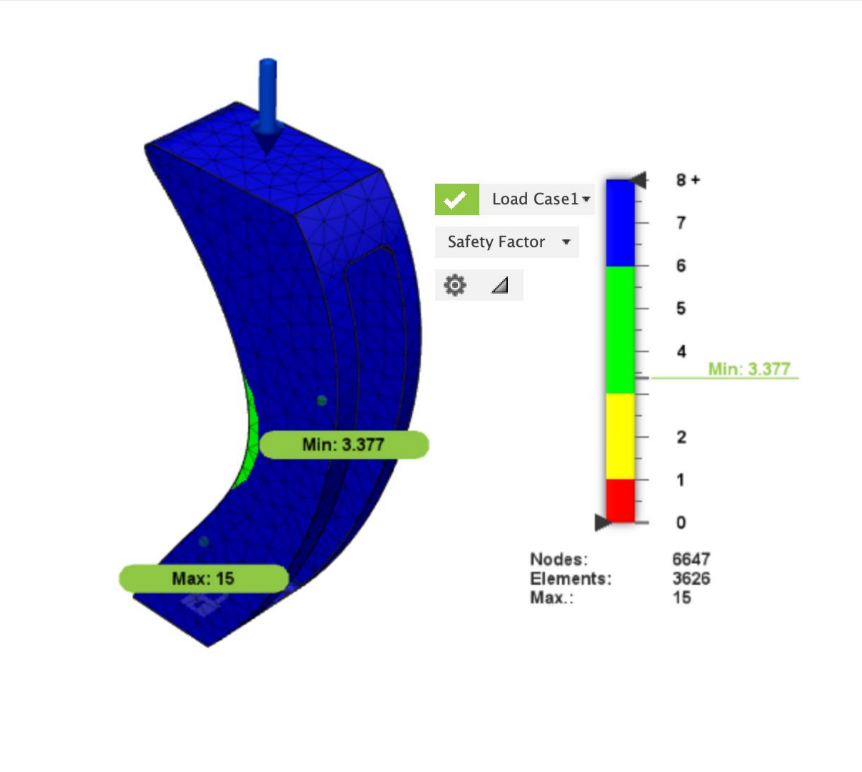
- Min Safety Factor: 3.748

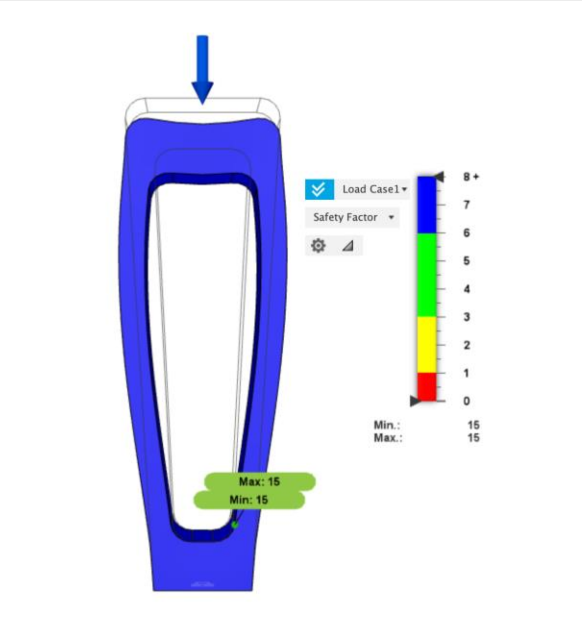
Design Option #3:

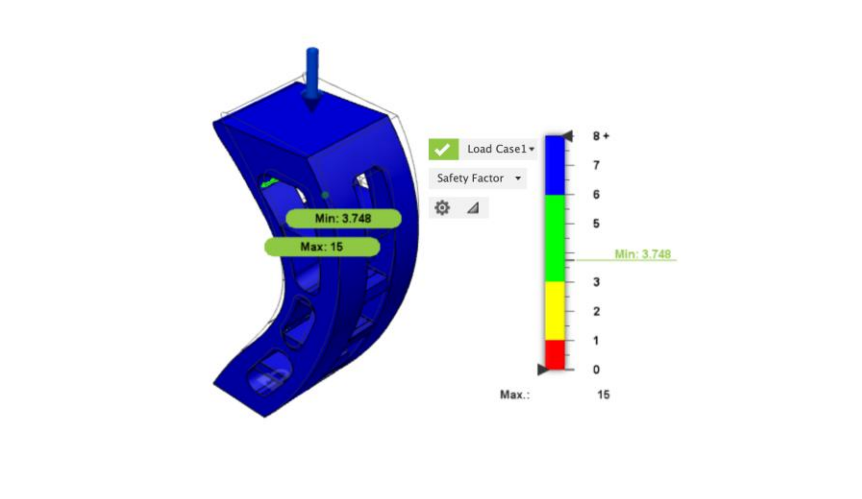
- Min Safety Factor: 3.377

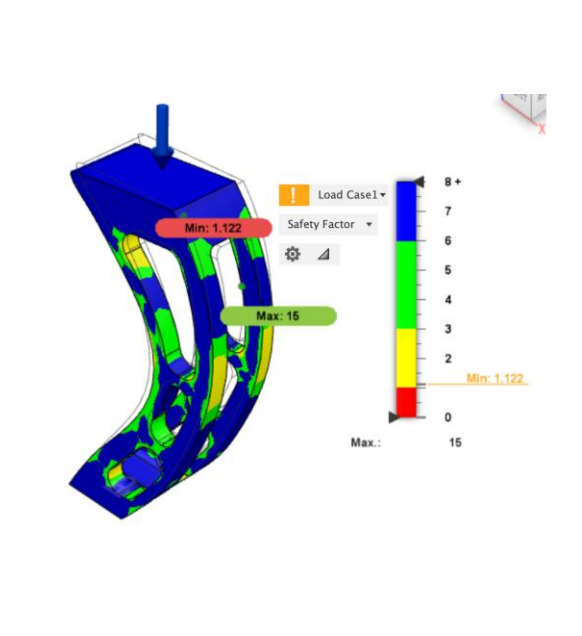
Design Option #4:

- Min Safety Factor: 15







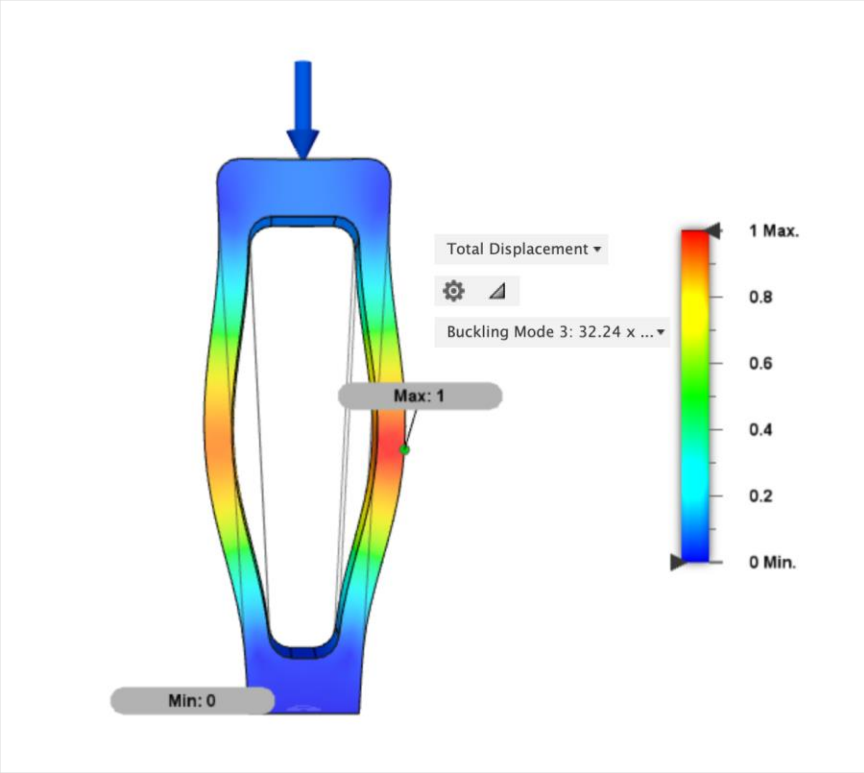


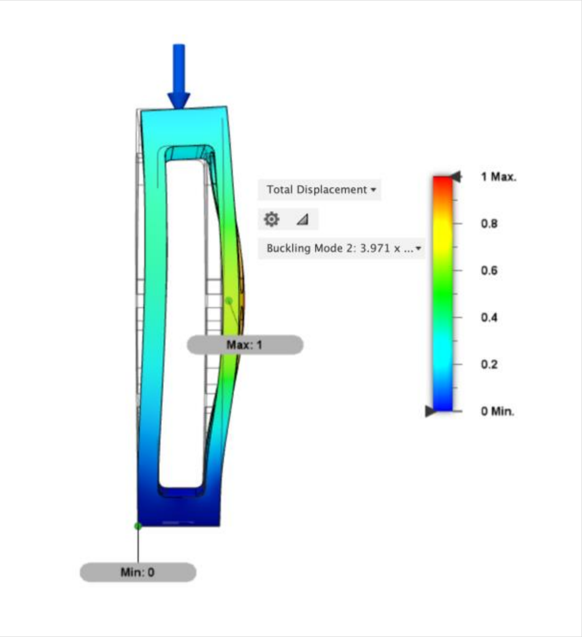
Leg Design Iterations Analysis #3

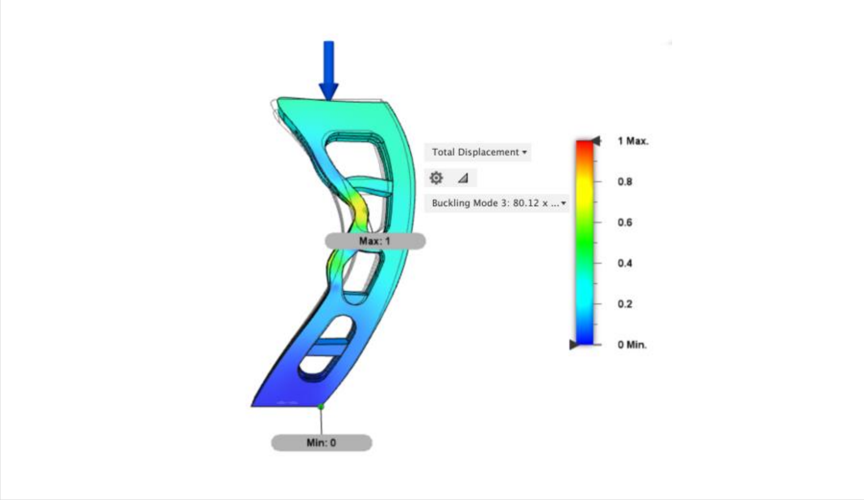
Buckling Analysis done with a Force 5 times the weight of the drone

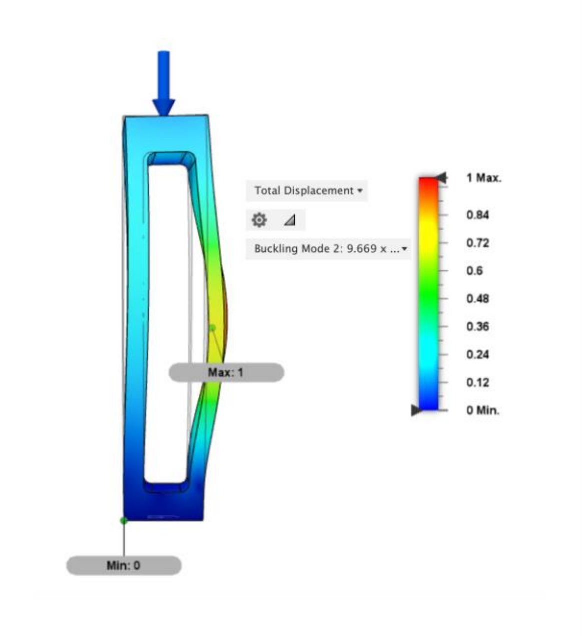
Buckling Ranking: (1-3 worse buckling to least buckling)

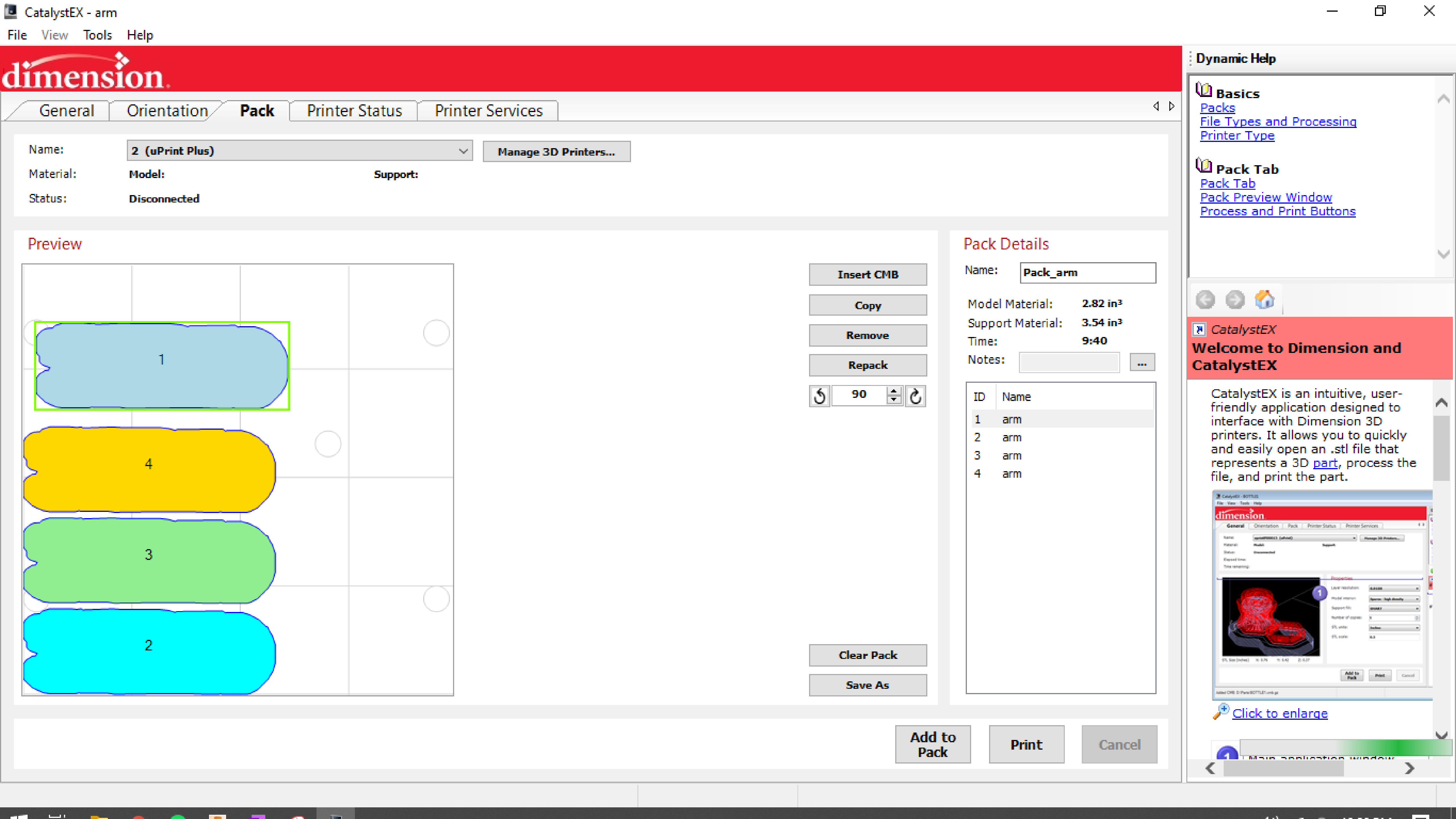
- Design Option #4: 1
- Design Iteration #2: 2
- Original Design & Design Option #3: Tied: 3







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File View Tools Help
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Printer Status
Printer Services
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Manage 3D Printers...
Material: Model: Support:
Status: Disconnected
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1
4
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2
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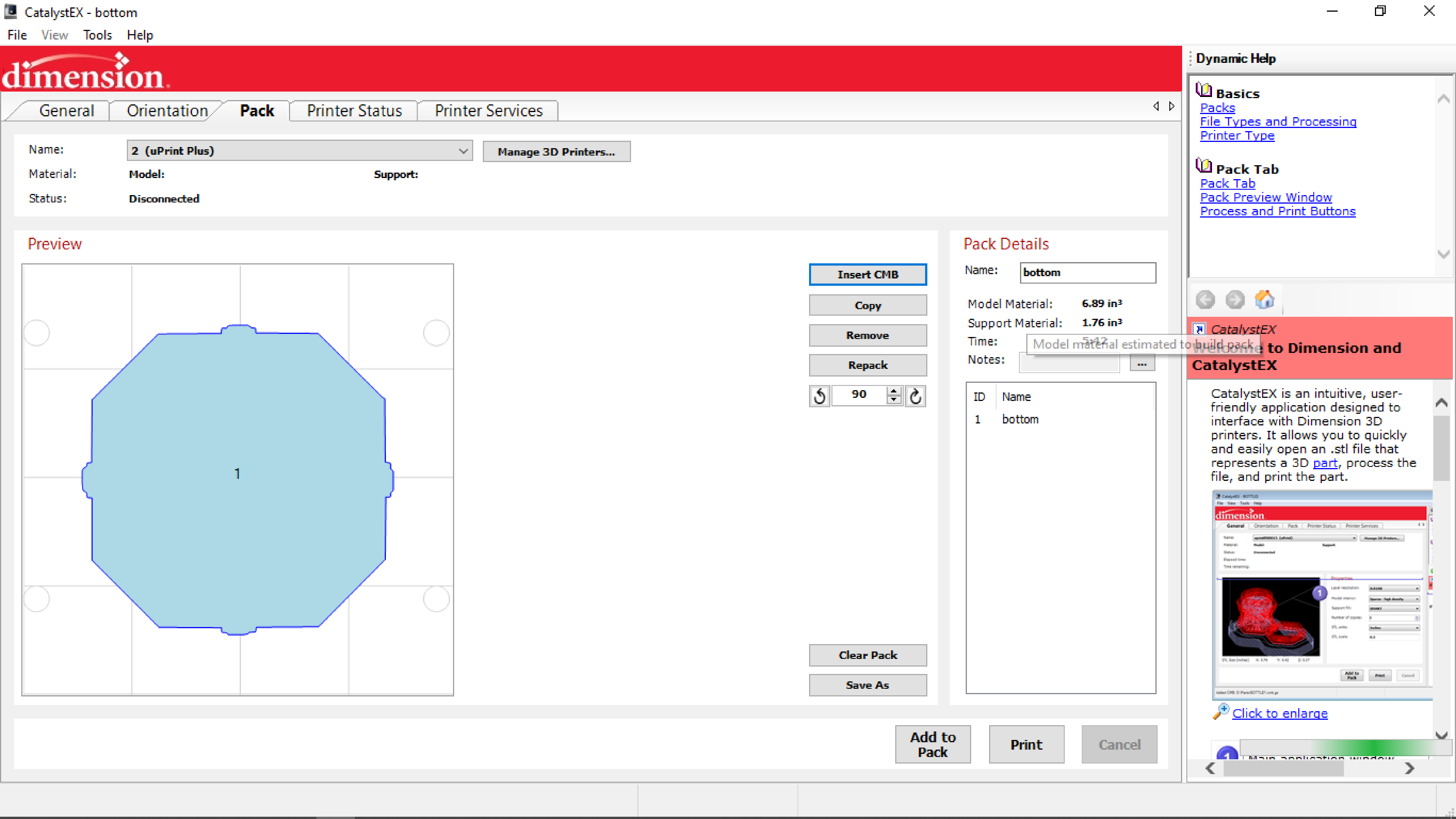
Pack Details
Name: Pack_arm
Model Material: 2.82 in³
Support Material: 3.54 in³
Time: 9:40
Notes:
ID Name
1 arm
2 arm
3 arm
4 arm
Add to Pack
Print
Cancel
Dynamic Help
Basics
Packs
File Types and Processing
Printer Type
Pack Tab
Pack Tab
Pack Preview Window
Process and Print Buttons
CatalystEX
Welcome to Dimension and CatalystEX
CatalystEX is an intuitive, user-friendly application designed to interface with Dimension 3D printers. It allows you to quickly and easily open an .stl file that represents a 3D part, process the file, and print the part.
Click to enlarge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File View Tools Help
dimension
General Orientation Pack Printer Status Printer Services
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Material: Model: Support:
Status: Disconnected
Preview
1
Insert CMB
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90
Clear Pack
Save As
Pack Details
Name: bottom
Model Material: 6.89 in³
Support Material: 1.76 in³
Time:
Notes:
Model material estimated to build pack
ID Name
1 bottom
Add to Pack
Print
Cancel
Dynamic Help
Basics
Packs
File Types and Processing
Printer Type
Pack Tab
Pack Tab
Pack Preview Window
Process and Print Buttons
CatalystEX
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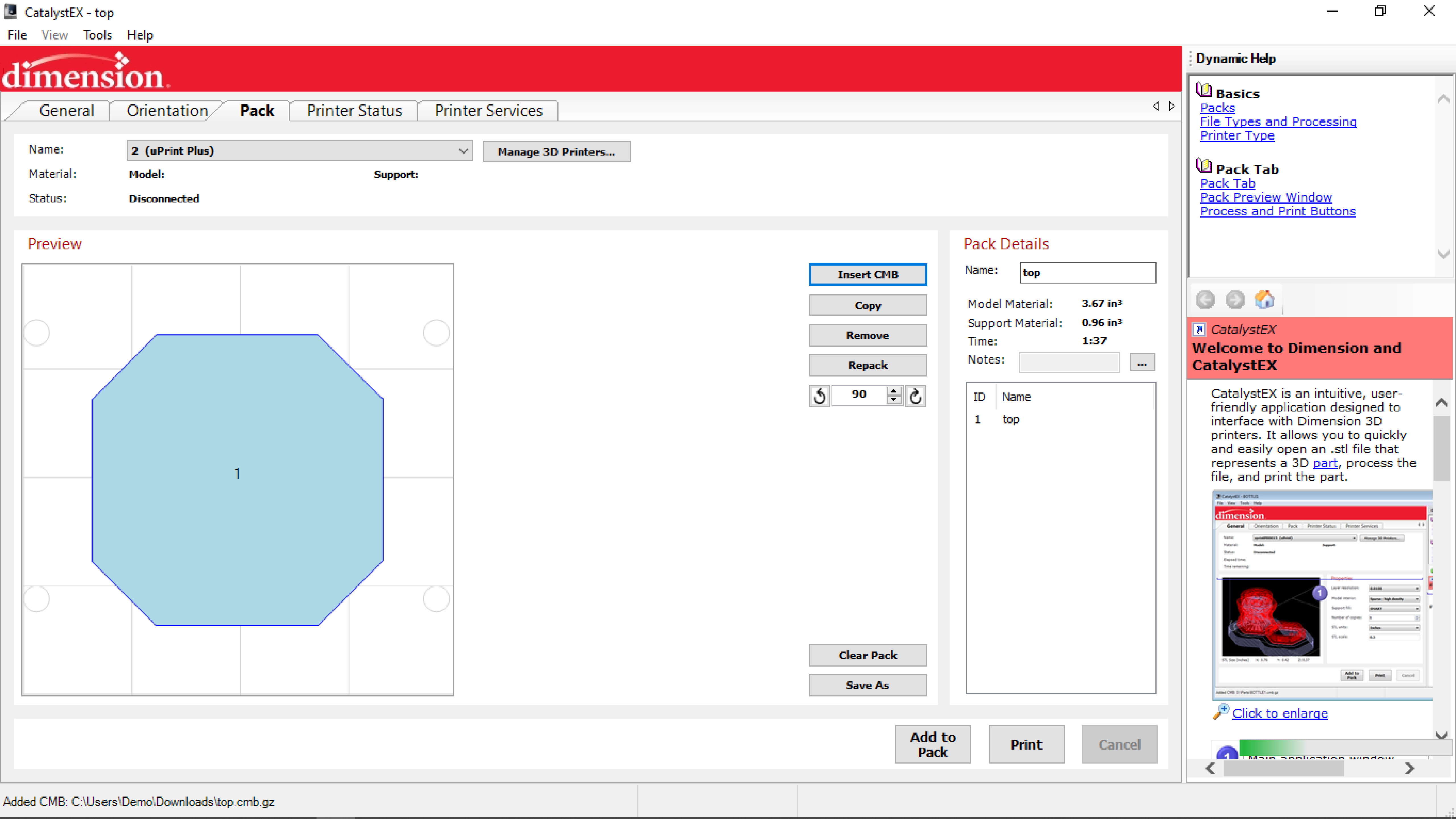
Click to enlarge


CatalystEX - top
File View Tools Help
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General Orientation Pack Printer Status Printer Services
Name: 2 (uPrint Plus)
Manage 3D Printers...
Material: Model: Support:
Status: Disconnected
Preview
1
Insert CMB
Copy
Remove
Repack
90
Clear Pack
Save As
Pack Details
Name: top
Model Material: 3.67 in³
Support Material: 0.96 in³
Time: 1:37
Notes:
ID Name
1 top
Add to Pack
Print
Cancel
Dynamic Help
Basics
Packs
File Types and Processing
Printer Type
Pack Tab
Pack Tab
Pack Preview Window
Process and Print Buttons
CatalystEX
Welcome to Dimension and CatalystEX
CatalystEX is an intuitive, user-friendly application designed to interface with Dimension 3D printers. It allows you to quickly and easily open an .stl file that represents a 3D part, process the file, and print the part.
Click to enlarge
Added CMB: C:\Users\Demo\Downloads\top.cmb.gz

Weight Calculations for 3D prints

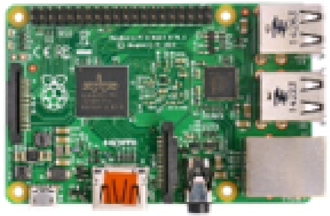
- Density of ABS: 1.07 g/cm^3
- Total Volume : 13.38 in^3 or 219.2 cm^3
- Total Mass based on printing parameters : 234.544g
- Expected mass from Fusion 360 : 248.62g

- Total mass of drone is 712g

Design Matrices

- Mitrocoller Design Matrix
- Propeller & Motor Design Matrix
- Properites of ABS Chart

Microcontroller

			
Option	A: Pixhawk PX4	B: Qualcomm Flight Pro	C: Raspberry Pi 2 Navio2
Price	$180-300USD	$949.00 USD	$213 USD
Weight	15.8g	40	54.6 g
Dimensions	44x84x12mm	75x36mm	55x65mm
Software	Linux, Mac, Windows	Linux	Linux
Connection	Wifi / Radio: ESP8266 external	Wi-Fi, Radio, Bluetooth 4.2	Wifi Radio
Notes	Open hardware flight controllers that run PX4 on NuttX OS. For hobbyists and amateurs	Requires advanced level of software, electronic and mechanical assembly	

Engineering Design Matrix

			Options			
Topic	Multiplier		A	B	C	D (N/A)
			5	3	3	
Compatibility	5	x	25	15	15	0
			5	2	4	
Available Documentation /	5	x	25	10	20	0
			5	1	4	
Price	5	x	25	5	20	0
			4	5	5	
Compactness	1	x	4	5	5	0
			5	3	2	
Lightness	1	x	5	3	2	0
		Total	84	38	62	0

Decision Matrix

Engineering Design Matrix							
Category	**Multiplier**		Option				
			T-motor F40 Pro III 1600KV 4-6S CW Thread Brushless Motor 	EMAX RS1408 Performance Brushless Motor 3600KV 	EMAX RS1108 Performance Brushless Motor 5200KV 	EMAX RS1606 - Brushless Racing Motor 	EMX-MT-1534- EMAX Multicopter motor MT2213 
Max Thrust *Max Thrust of 642.59g needed for take-off*	5	x	634.33 g **Score: 5 = 25**	667 g **Score: 5 = 25**	436 g **Score: 2 = 10**	670 g **Score: 5 = 25**	670 g **Score: 5 = 25**
Weight	4	x	33.5 g **Score: 2 = 8**	14 g **Score: 3 = 12**	8.2 g **Score: 5 =20**	15.8 g **Score: 3 = 12**	53 g **Score: 1 = 4**
Recommended Propeller Compatibility *Whether or not the manufacturer recommended propeller is compatible with the airframe of the UAV*	5	x	German Fan 6042  Diameter: 6" Pitch: 4.2" Price: $3.39 **Score: 5 = 25**	AVAN 3.5x2.8x3  Diameter: 3.5" Pitch: 2.8" Price: $2.99 **Score: 3 = 15**	German Fan 3020  Diameter: 3" Pitch: 2" Price: $5.99 **Score: 3 = 15**	GF 4052  Diameter: 4" Pitch: 5.2" Price: $2.92 **Score: 4 = 20**	EMAX 1045  Diameter: 10" Pitch: 4.5" Price: $1.06 **Score: 0**
Max Current *Current required at Max Thrust*	5	x	7.48A **Score: 5 = 25**	15.2A **Score: 3 = 12**	17.5A **Score: 3 = 12**	25.1 A **Score: 2 = 8**	9.6 A **Score: 5 = 25**
Price *Per unit in USD*	3	x	$26.90 **Score: 2 = 6**	$12.99 **Score: 4 = 12**	$12.99 **Score: 4 = 12**	$12.99 **Score: 4 = 12**	$15.50 **Score: 3 = 9**
Efficiency *The ratio of mechanical output to electrical input*	5	x	4.36 **Score: 4 = 20**	2.09 **Score: 3= 15**	1.56 **Score: 2 = 10**	2.12 **Score: 3 = 15**	6.3 **Score: 5 = 25**
		Total	**109**	**91**	**79**	**92**	**88**

** Thrust calculations revealed that due to the design's changing weight, the propeller selection would have to be modified to obtain a satisfactory thrust to weight ratio. The team selected the same type of propeller (German Fan 6042), just with an increased pitch of 4.5 inches instead of 4 inches.

Properties of 3D Printed ABS

- K. Hibbert, G. Warner, C. Brown, O. Ajide, G. Owolabi, and A. Azimi, “The Effects of Build Parameters and Strain Rate on the Mechanical Properties of FDM 3D-Printed Acrylonitrile Butadiene Styrene,” *Open Journal of Organic Polymer Materials*, vol. 09, no. 01, pp. 1–27, 2019.

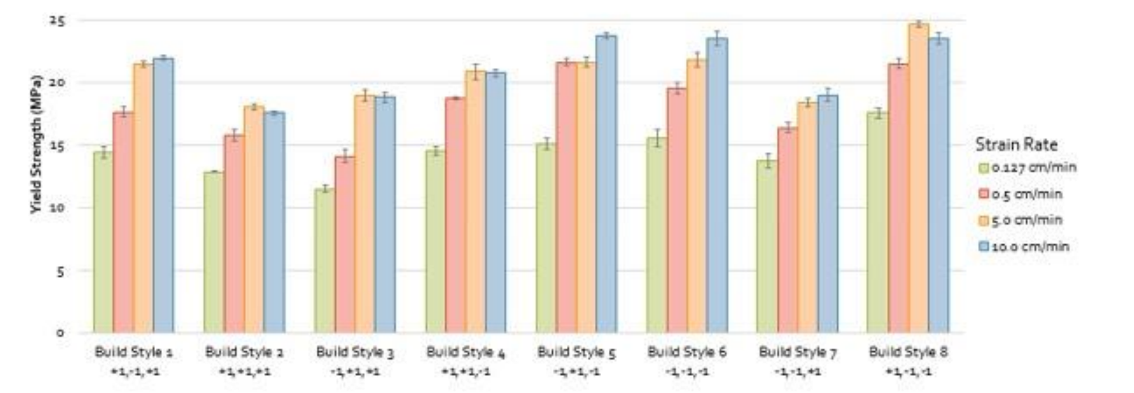


Figure 3.18: Effect of Strain Rate on Yield Stress

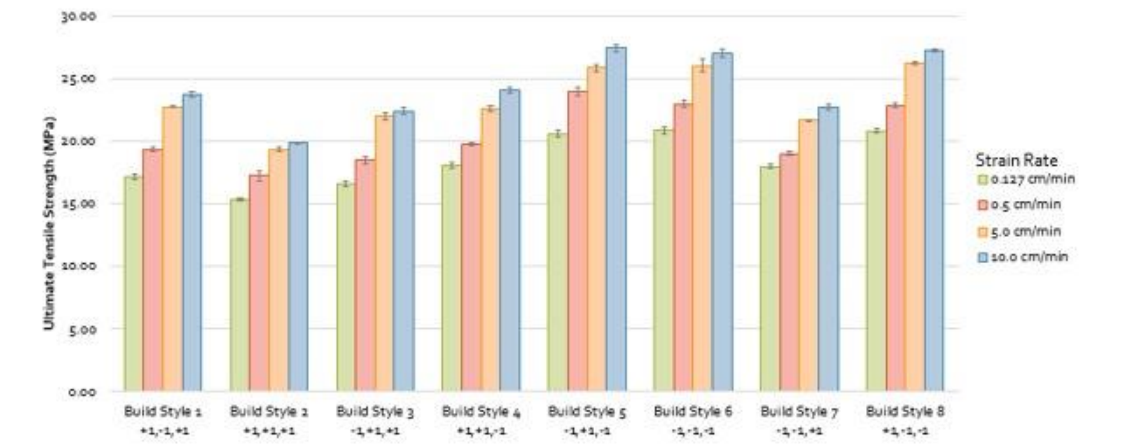


Figure 3.19: Effect of Strain Rate on Ultimate Tensile Strength

Design Matrices

- Design Specification
- Criteria of Concept Selection

Design Specification -
Physical Specifications

- Any LED's on Handheld Controller should be easily visible
- Handheld controller should be adjustable or be able to fit various size hands
- Handheld Controller should be comfortable to control
- Exposed wiring should be kept to a minimum on the Handheld Controller.
- PCB encasing for Handheld Controller should be kept light weight to avoid strain on the user
- Drone should ideally be able to lift around 2-3 lbs. worth of cameras and batteries.
- Any components attached to the drone should be easily removable and modifiable.
- Drone size should be capable of meeting racing requirements

Design Specification - Hardware Specifications

- Components must run off (Insert planned battery voltages) or less
- Drone should be able to run for at least 15 minutes per race requirement
- Handheld Controller should be able to run off powered USB connection.
- Drone must have a physical kill switch located on the vehicle or controller for safety.
- All batteries must be stored in a LiPo safe bag for safety.

Design Specification- Software Specifications

- Source Code should be written using a Pixhawk series controller
- Pixhawk series controller should be flexible in terms of hardware peripherals that can be attached
- Programming should not exceed given memory space on chosen Microcontroller and similar variants
- Should be able to upload to microcontrollers through USB connection.
- Should be kept on an easily accessible repository and properly maintained

Criteria for Concept Selection

Motor:

The aircraft motor was chosen on the constraints of power for the least amount of weight. To improve efficiency characteristics such as a brushless motor and non-ferrite magnets should be used. Since the UAV's weight is of major interest to the team, the motor selection is limited to thrust, current draw and weight. Also, one that could be used to turn the chosen propeller. From the necessary characteristics, a motor study was done from available UAV's. Through the study, the best motor for the UAV was chosen to be the T-Motor F40 PRO III KV1600 Grey brushless Motor for FPV rc Drone This motor is brushless and boasts very high quality made external rotor motor. It has improved Material selection, built-in fans as well as Präzisionsgewuchtete bell to ensure a high level of efficiency and long service life. The motor can spin as fast as 23,680 rpm . The motor can be seen here:

Figure 1: T-Motor F40 PRO III KV1600 Grey brushless Motor for FPV rc Drone

Criteria for Concept Selection (cont'd)

Propeller:

The propeller affects several aspects of the UAV. It affects the thrust of the UAV, the speed of the aircraft, and the amount of power required from the motor in order to fly at a specific speed. The efficiency of the propeller also has a large effect on the range and endurance of a UAV. Due to the requirements of our UAV, as well as the desire to keep development and acquisition costs as low as possible, existing model UAV propellers became the focus of the selection process. There are several UAV propellers available, varying both in geometry and material. There are quite a few different types of materials such as wood, aluminum, plastic, nylon, and composite material available in the current market. Since weight is a major consideration, choosing a lightweight propeller is of major importance. The lightest propellers are made of nylon, and are very flexible, which would aid in survivability on landing. However, the efficiency of a nylon propeller is very low, and would not achieve the necessary flight performance in order to operate. Composite propellers are both lightweight and efficient, but they are not very rugged and are more expensive than most other types of propellers. Aluminum propellers are efficient, but very heavy. A 2-bladed plastic propeller is the best choice for our UAV, as it has a good balance of efficiency, low weight, and durability._A two bladed propeller was chosen oven a three or four bladed propeller because it cruises faster compared to the others. Also, they work efficiently at high altitudes compared to the 3 or 4 bladed ones.

Criteria for Concept Selection (cont'd)

In conducting trade studies and analysis of different types of propeller geometry several variables were considered. These variables were propeller rotation speed, propeller pitch and diameter, thrust provided and power consumed. The chosen propeller has a pitch of 4.5 inches in addition to the 8-inch diameter. A plastic propeller of these dimensions is readily available from many different suppliers, costing approximately \$0.75 – \$3. Compared to the overall cost of the UAV, this is a small amount. The low cost also enables easy replacement of any propeller that may be broken on landing.