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Capstone Design Final Report: SAR Drone Project

Group 9

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1. Overview

1.1 Background

British Columbia's backcountry activities often lead to search and rescue (SAR) operations, which are handled by volunteer groups with limited resources. The high cost and logistical challenges of deploying helicopters make fast responses difficult. Drones present a promising solution, as they are cheaper, require only one pilot, and can enhance SAR efforts. However, existing drones are limited by short flight durations and high costs, making them impractical for volunteer groups. There is a significant need for a low-cost drone with longer flight times, sufficient speed, and thermal cameras to improve SAR efficiency, reduce risks to volunteers, and better assess rescue needs in remote areas.

1.2 Need Statement:

Current BC SAR methods are costly and manpower-intensive, increasing casualties and expenses. There's a need for a low-cost, easily deployable UAV to quickly scan large areas.

1.3 Goal Statement:

The goal is to develop a low-cost UAV capable of scanning large areas for 90 minutes to enhance the efficiency and effectiveness of search and rescue operations in British Columbia.

1.4 Midterm Design

Four designs were considered, these designs consisted of two variations of body type and two variations for flight method. Tilt rotors operate on the same plane for horizontal and vertical flight by only rotating the orientation of the motors. The tail sitter operation rotates the entire body to transition between vertical and horizontal flight.

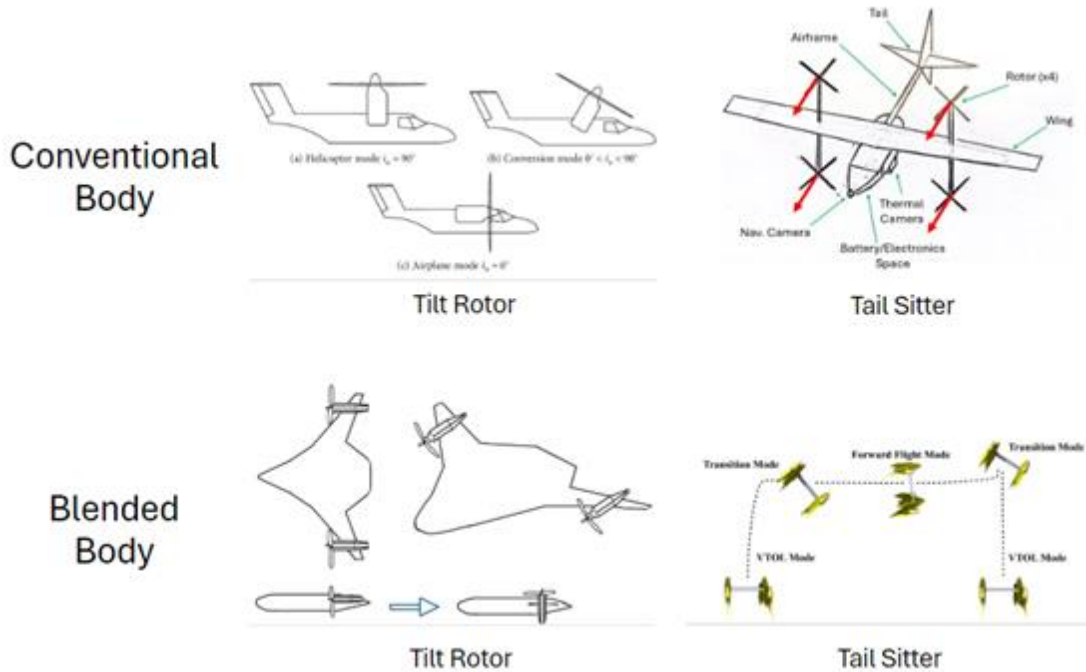


Figure 1: Vertical Takeoff and Landing Drone Options

A conventional body tail sitter was chosen as the final design, its main advantages being simplicity and efficiency. The capability of horizontal flight allows movement at a fraction of the thrust required for vertical flight, this greatly extends the battery life. Conventional body tail sitters also boast easy controls, structural integrity and simple manufacturing.

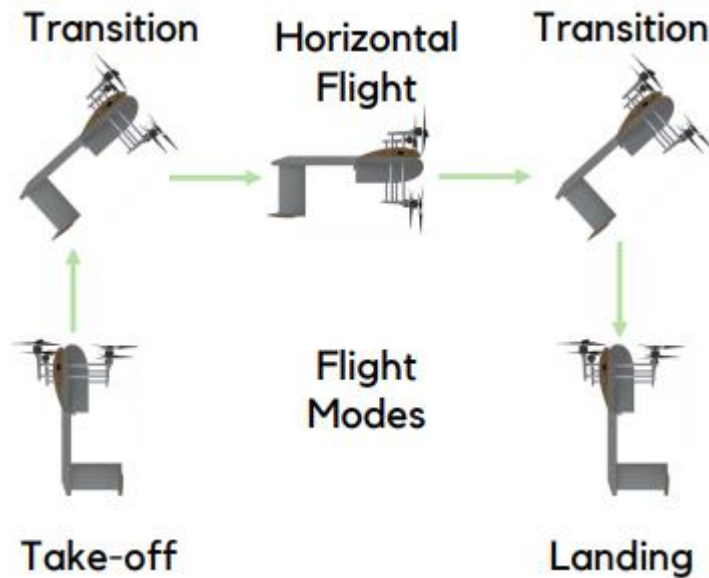


Figure 2: Tail Sitter Operation

Preliminary design was carried out for the wing, tail, fuselage, propulsion system, and electrical system, as outlined in the following sections, and the resulting drone design was modeled and analyzed in the Midterm Report, shown in Figure 3.

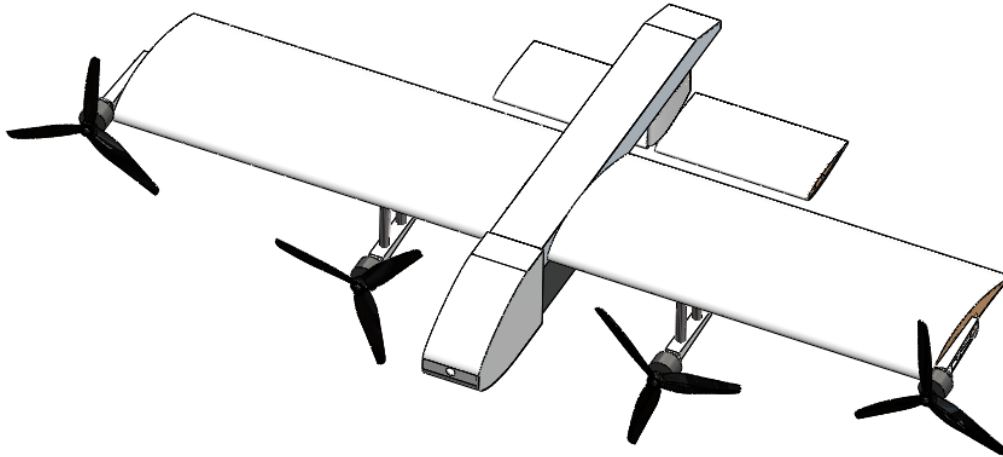


Figure 3: Drone Design as of Midterm Report

This design was estimated to be 1.2m in wingspan, 24 inches in length, and 4.7kg in weight.

2. Problem Analysis

2.1 Horizontal Flight Analysis

Analysis of the wings aerodynamic properties was conducted to ensure the wing provides adequate lift during a range of cruise speeds and provides adequate stability when the aircraft is impacted by wind gusts or other impulse loads.

2.1.1 Wing Analysis

The MH113 airfoil, or profile of the wing, was chosen as it has a thick geometry and can accommodate the brackets and hardware needed within the wing. The wing is required to generate just over 5kg of lift during cruise. The geometric properties listed in Table 1 provide a wing area that satisfies the lift equation shown in appendix.

Table 1: Wing Geometry Parameters

Parameter	Description	Value
Wing Area, S_w	Area of the wing projected from above	0.3 m ²
Wingspan, b	Distance from wing tips	1.2 m
Chord, c	Distance from wing leading edge to trailing edge	0.25 m
Aspect Ratio, AR	A measure of how skinny the wing is - b^2/S_w	4.8

Taper Ratio, λ	Ratio of the root chord to tip chord	1
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Due to manufacturing constraints a constant taper with no offset of the wing tip was chosen. Loading cases found in Appendix D were evaluated during vertical or horizontal flight to determine bending and shear forces. The results are displayed in Table 2 below.

Table 2: Induced Stress

Stress Induced in Wing Tubes				
Tensile Strength of Carbon Fibre (Mpa)		861		
Shear Strength of Carbon Fibre (Mpa)		41.3		
Stress (Mpa)	Case 1: Horizontal Flight		Case 2: Vertical Flight	
	Value	Safety Factor	Value	Safety Factor
σ_y	7.6	113.3	0.34	121.4
τ	27.5	31.3	0.85	48.6
Stress Induced in One Bolt				
Shear Strength of 2024 Aluminium (Mpa)		241		
Stress (Mpa)	Case 1: Horizontal Flight		Case 2: Vertical Flight	
	Value	Safety Factor	Value	Safety Factor
τ	0.62	388.7	1.5	160.7

Large safety factors indicate that there is adequate strength.

2.1.2 Tail Analysis

The tail is required to produce slight negative lift to oppose the pitching moment created by the center of gravity and the wings center of lift. This is achieved by selecting a symmetrical airfoil that is positioned at a negative angle of attack, and for this reason the NACA 0012 airfoil was chosen. Following empirical formulae for the sizing and placement of horizontal and vertical tails, the geometric parameters listed in Table 3 were chosen.

Table 3: Tail Geometric Parameters

Parameter	Description	Value
Horizontal Tail Area, S_{HT}	Area of the tail projected from above	0.075 m ²
Vertical Tail Area, S_{VT}	Area of the vertical tail projected from the side	0.03 m
Horizontal Tail Span, b_{HT}	Distance from horizontal tail tips	0.6 m
Vertical Tail Length, b_{VT}	Length of vertical tail	0.24 m
Horizontal Tail Chord, c_{HT}	Distance from leading edge to trailing edge	0.125 m
Vertical Tail Chord, c_{VT}	Distance from leading edge to trailing edge	0.125 m
Horizontal Tail Taper Ratio	Ratio of the root chord to tip chord	1
Vertical Tail Taper Ratio	Ratio of the root chord to tip chord	1

Additionally, 20 inches was determined as the required distance between the leading edge of the tail and the leading edge of the wing, assuming a static margin (a dimensionless representation of the aircraft's tendency to return to level flight when the pitch of the aircraft is altered) of 10%. Following this assumption, the center of gravity will need to be 100mm behind the leading edge of the wing.

2.2 Propulsion Analysis

Four motors, four propellers, and a battery make up the propulsion system. Using a 3:1 thrust-weight ratio for the maximum available thrust at 100% throttle of a quadcopter. Motors that satisfy this requirement were sourced and scored based on efficiency at various thrusts, weight, and cost. A detailed breakdown is provided in Appendix B. Three flight modes and corresponding thrusts were then assumed for final motor evaluation. Using the current draw of a motor at specific thrusts, multiplied by the time spent in each flight mode, the minimum battery capacity for each motor was found. Table 4 lists the power requirements for the selected motor in each operation mode.

Table 4: Power Requirements for Selected Motor

Motor	V3120 - KV700 - T105x5-3 - 22v				
Flight Mode	Time (minutes)	Estimated Thrust Per Motor (kg)	Amps per Motor	Amps Total	Amp-Hours
Vertical Acceleration (2:1 Thrust - Weight)	2.5	2.5	24	96	4.0
Vertical Hover (1:1 Thrust - Weight)	7.5	1.25	9	36	4.5
Horizontal Cruise (~10 N or 1 kg total)	50	0.25	1.5	6	5.0
Total					13.5

In addition, the power required by the flight controller and infrared camera is listed in Table 5.

Table 5: Hardware Power Requirements

Component	Model	Watts
Flight Controller	Pixhawk 6x	5.0
Infrared Camera	FLIR Vue Pro	2.1
Total		7.1
Current Equivalences for LiPo Battery		
Current with 22v Battery (Ah)		0.32
Current With 32v Battery (Ah)		0.22
Current with 44v Battery (Ah)		0.16

suitable batteries were selected from the battery database, considering a minimum of 10% reserve capacity, outlined in Appendix C. The weight, cost, and capacity of the three batteries that were evaluated are listed in Table 6.

Table 6: Suitable Battery Cost and Weight Data

	Nominal Voltage	Capacity (mAh)	Weight	Cost
6S LiPo 17000	22.2	17000	1907	889
13S LiPo 8000 Lite	48.1	8000	2157	1122
9S LiPo 11000	33.3	11000	1900	903

The T-Motor 3120 700KV was selected alongside the MaxAmps 6S LiPo 17000 as it is the least expensive, second lightest and has a reserve capacity of 23%. This propulsion system design ensures that a flight time of 60 minutes is feasible.

3. Detailed Design

3.1 Final Model

The final design is a vertical take off and landing tail-sitter which rotates with an induced moment to cruise horizontally. Carbon fiber tubes laced through birchwood bulkheads and centered about the aluminum U-channel make up the structure of the main wing. The vertical and horizontal components of the tail are assembled similarly. Centered about the fuselage are carbon tubes which pierce the main wing to support the motors via motor mounts which are in turn centered about the center of mass when the drone is in vertical flight. 3D printed parts house electrical components such as the flight controller, battery, and ESC around the central U-channel.

3.1.1 Assembly

This assembly combines each specially designed component to form a tail-sitter quad propellor drone as shown in Figure 4, without the visual obstruction of wing, tail, or fuselage skins.

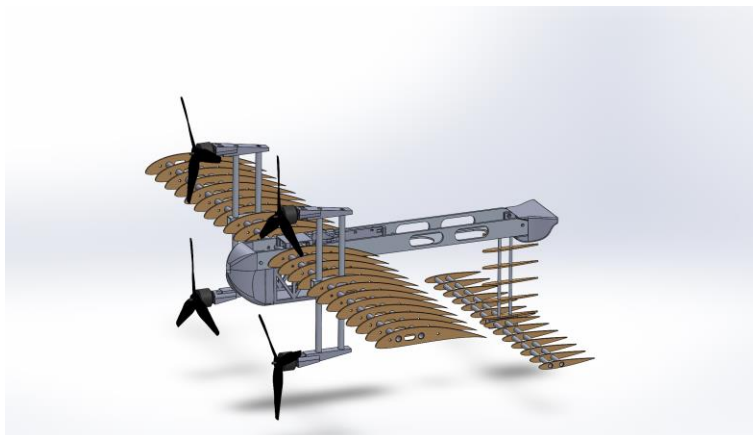


Figure 4: CAD Model of Drone Assembly

3.1.2 Exploded View

The exploded assembly can be seen in Figure 5 displaying each individual component of the design.

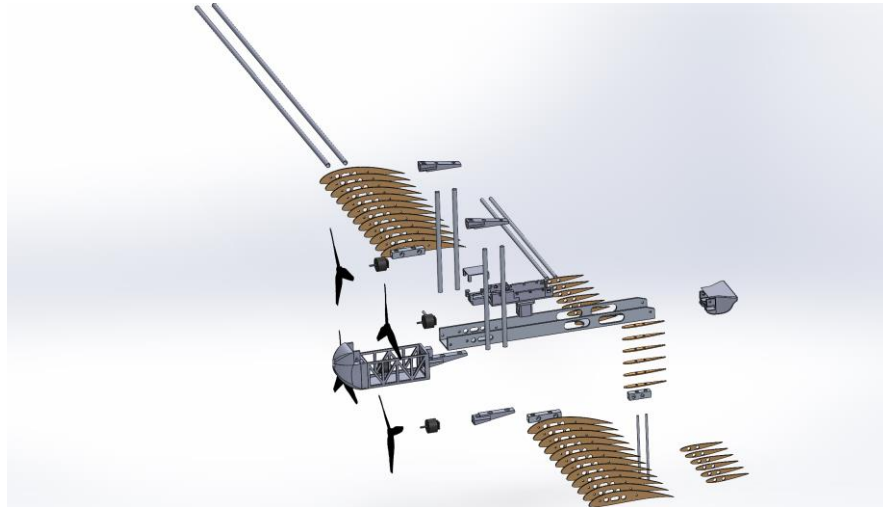


Figure 5: Exploded View of Assembly

3.3.6 Electrical System Design

This section will provide an overview of the drone's electrical system, powered by a Pixhawk 6X and MaxAmps LiPo battery, integrates with ArduPilot software to ensure precise control and advanced flight capabilities.

3.3.6.1 Software

ArduPilot is an advanced, open-source autopilot software for controlling various drones and robotic vehicles, including multicopters and fixed-wing aircraft. It's community-driven, written mainly in C++, and supports a range of hardware. Key features include autonomous flight modes, GPS waypoint navigation, and real-time telemetry. ArduPilot is highly customizable, suitable for both hobbyists and professionals, and comes with extensive documentation. The client has requested its use for this project.

3.3.6.2 Hardware

The drone's controller selection was based on compatibility with ArduPilot software. After evaluating six options shown in appendix, the Pixhawk 6X from Holybro was chosen for its advanced features, including an STM32H743 microprocessor, multiple sensors, and extensive connectivity. The Pixhawk 6X supports ArduPilot, offering robust performance and

easy integration, with a simple plug and play electrical system shown in Figure 6: Electrical Schematic.

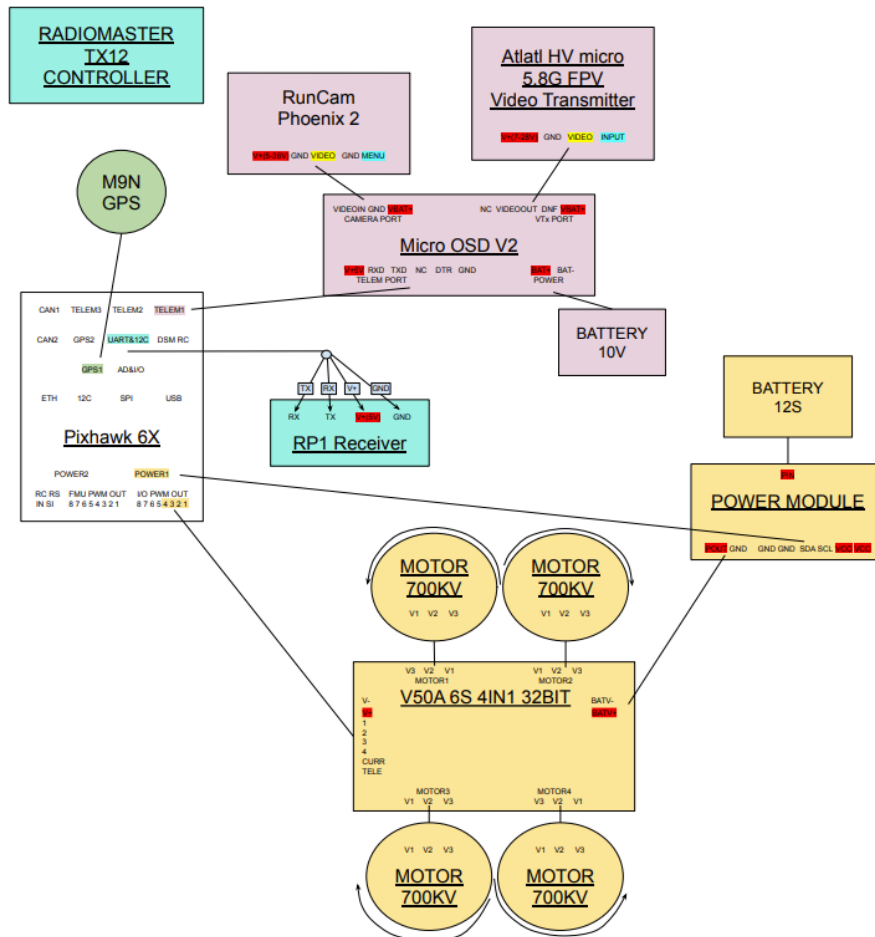


Figure 6: Electrical Schematic

The components currently selected for the system are detailed in Table 8 below. You’ll notice the components for the on screen display aren’t shown in the table 7 below, this is due to the fact that after further consideration for this part of the project they were deemed as out of scope and were removed and will be integrated in the next iteration.

Table 7: Electrical part break down.

Part Number	Description	Quantity	Cost Each	Cost Total	Weight (g)	Weight Total (g)
P-01	T-Motor 3120 700KV	4	\$78	\$312	147	588
E-01	MaxAmps LiPo 16000 6S 22.2v Battery Pack	1	\$889	\$889	1907	1907
E-02	Pixhawk 6X + M9N GPS	1	\$304	\$304	104	104
E-03	FLIR VUE PRO R	1	0	0	113	113

E-04	V50A 6S 4IN1 32BIT - ESC	1	\$84	\$84	19	18.5
			Total	\$1589	Total	2730.5

Key components selected for the system, detailed in a parts breakdown, include motors, a battery pack, a GPS unit, and a thermal camera, totaling \$1850 and 2831.5 grams. Further selection of the receiver/transceiver and ground control system is required to ensure reliable communication and precise control, while meeting weight and cost constraints.

1.3.7 Bill of Materials

The final bill of materials for the prototype is shown in Table 8.

Table 8: Bill of Materials

Item	Part Number	Description	Quantity	Cost Each	Cost Total	Weight (g)	Weight Total (g)
1	F-01	Aluminium U-Channel 3"x1.5"	1	15.64	15.64	700	700
2	W-01	CC Carbon Fiber Tube Twill 13mm x 11.5mm x 1.2m	2	30.04	60.08	110	220
3	T-01	CC Carbon Fiber Tube Twill 10mm x 9mm x 1.2m	2	15.58	31.16	27	54.4
4	W-02	Laser Cut Plywood Airfoil - MH113 250mm chord	22	0	0	8	172
5	T-02	Laser Cut Plywood Airfoil - NACA 0012 125mm chord	20	0	0	3	60
6	W-03	Motor Mount - 3D Printed	4	0	0	25	100
7	W-04	Aluminium Bar Bracket - Wing to Motor Connection	3	3.5	10.5	23	69
8	P-01	T-Motor 3120 700KV	4	78	312	147	588
9	P-02	Propeller	4	17.7	70.8	27	108
10	E-01	MaxAmps LiPo 17000 6S 22.2v Battery Pack	1	889	889	1907	1907
11	E-02	Pixhawk 6X	1	304	304	104	104
12	F-01	10-24x3/4	17	0.235	3.995	3	42.5
13	E-03	FLIR VUE PRO R	1	0	0	113	113
14	E-04	V50A 6S 4IN1 32BIT - ESC	1	84	84	19	18.5
15	E-05	UVIC Elec Capstone Group Components	1	0	0	45	45
16	F-02	Internally Threaded Connecting Rods Alu Large	8	7.5	60	10	80
17	F-03	Internally Threaded Connecting Rods Alu Small	8	7.5	60	7	56
18	E-06	Sky-Drones SmartAP Power Distribution Board	1	123	123	16	16
19	F-04	Epoxy ~ 1g/mL	-	41	41	-	-
20	F-05	Finishing Tape	3	6.5	19.5	-	-
21	F-06	3D Printed Battery Mount	1	0	0	200	200
Total					2065		4453

The final cost for the raw materials involved in the construction of this drone was \$2092. The electrical components make up around 85% of this cost which means this design meets the goal of a cost-effective superstructure design. When shipping and machine costs are considered, the total cost comes to \$3770. Current drones designed for search and rescue cost around \$10000 each, this means this design would save costs by just over 60%. The drone's total weight is 4672g which remains under the original weight approximation of 5kg.

4. Prototyping

4.1 Prototype Features

The final prototype features an inverted T-tail, four motors mounted equal distance apart, a removable battery housing and points of attachment for future work at the end of the wings and along the U-channel. The tail doubles as a set of landing gear due to the center of gravity of the superstructure overlying it, this allows smooth takeoff and landing without extra parts that would impact aerodynamics during flight.

The motors and battery are all easily removable in case of failure or the need for recharging. The battery housing is firmly secured by an internal pin and two screws along the nose, removing those allows it to slide off. The motor wiring contains soldered connections but once those are removed, they can be removed along with the motors mounts by removing the two screws that attach the motor mounts to the carbon fiber tubes. The quadcopter arrangement of motors allows vertical and horizontal flight, in takeoff all motors would spin equally but to transition to horizontal flight all that's required is the top motors spin faster creating a moment that pitch's the drone forward.



Figure 7: Final Prototype Assembly

The VTOL drone's electrical system is designed for high performance and reliability, featuring the Radiomaster TX12 Mark II Radio Controller, which provides precise manual

control over the drone's movements. This controller allows for customizable flight modes and integrates essential safety features like arm and disarm functions to prevent accidental motor activation. The Pixhawk 6X Flight Controller works in tandem with the controller, utilizing advanced flight control algorithms and integrated sensors to ensure stable and accurate flight. It is also compatible with ArduPilot software, offering extensive customization options for autonomous flight and other advanced features.

Powering the system, the T-Motor 3120 700KV motors, paired with V50A 6S 4IN1 32BIT ESCs, deliver the necessary thrust and responsiveness required for vertical takeoff and landing. The MaxAmps LiPo 17000 6S 22.2v Battery Pack provides extended flight time, managed efficiently by the PM06 V2 Power Module to ensure consistent power distribution across all components. Additionally, the ELRS Receiver Series ensures reliable and low-latency communication between the drone and the controller, which is critical for real-time control and responsiveness.

While the on-screen display (OSD) setup was ultimately deemed out of scope due to budget constraints, the system is designed to support telemetry and OSD integration, allowing for real-time monitoring of flight data and enhancing situational awareness. This robust and integrated electrical system ensures that the VTOL drone can perform effectively in various conditions, with the flexibility to adapt to different mission requirements.

To properly configure the VTOL drone's control system, it was essential to adjust several parameters within the ArduPilot software. The Pixhawk 6X flight controller relies on these parameters to interpret input from the Radiomaster TX12 Mark II Radio Controller and manage the drone's flight dynamics. Setting up the parameters involved fine-tuning variables such as throttle response, flight modes, and safety protocols like arming and disarming. Additionally, specific adjustments were necessary to ensure compatibility between the controller and the ESCs, allowing for smooth motor operation and precise control. This step was crucial to ensuring that the drone would respond accurately to pilot commands and operate safely during flight tests. These protocols can be found in Appendix D.

4.1.1 Wing Construction

The wing and tail assemblies used an array of air foils laser cut from 3mm plywood. These airfoils were placed equidistant along central carbon fiber rods and epoxied into position. This resulted in a skeleton that a finishing material could be applied over. The plywood ribs double as protection for the carbon fiber since they would act as a crumple zone in the event of a crash. Since the ribs surround the rods and have a lower failure stress, they

would break and prevent energy from being transferred to the central rods which are more difficult pieces to replace.

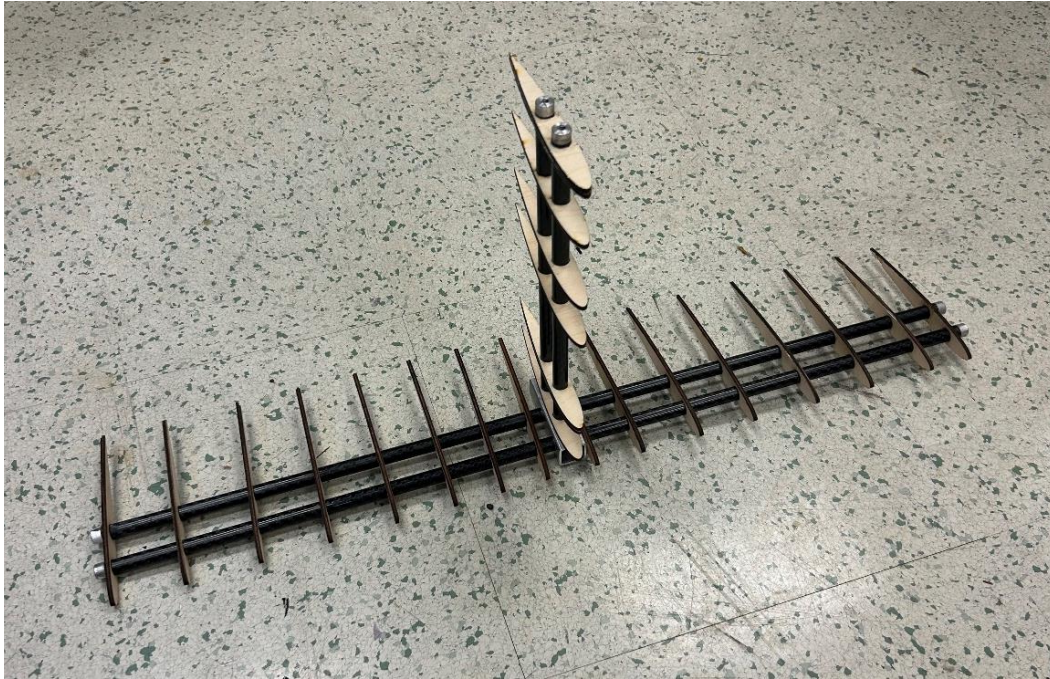


Figure 8: Tail Skeleton Assembly

As it stands, the prototype is using a temporary cover for its wings in the form of a tape commonly found in RC plane builds. This had to be implemented because the monokote covering was found to adhere poorly to the ribs and requires future work. It was found that a 3D printed cover could also be used for the tail assembly but despite providing better shape and thus aerodynamics it was still unable to sustain a monokote covering.

4.1.2 Motor Mounts

The motor mounts were 3D printed and used as the point of connection between the motors and the outlying carbon fiber tubes. They required multiple iterations due to the high moment they are exposed to from the rotating motors. It was found in initial designs that the point where space had been left for the motor screws to be secured was extremely fragile, to combat this as little as possible area was exposed to allow the screws to be attached, the thickness of the face the motor rests on was doubled and the infill of the print was increased to 40%. These changes were found to be effective.

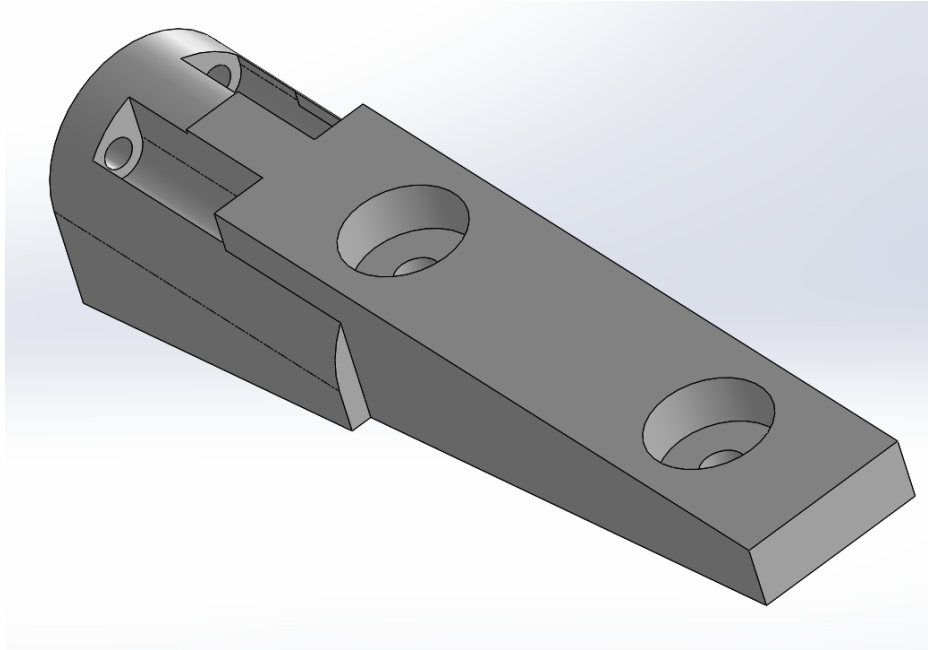


Figure 9: Final Motor Mount

4.2 Testing

4.2.1 Electrical Testing

Testing the VTOL drone's control systems is a critical phase in the development process, ensuring that each component functions correctly and cohesively to achieve stable and reliable flight. The following Detailed Testing Procedure outlines the systematic approach taken to verify and configure the electrical and control systems, including the Pixhawk 6X flight controller, Radiomaster TX12 Mark II Radio Controller, and associated components. By carefully calibrating, wiring, and diagnosing each element, this procedure aims to identify and resolve any issues before the drone's full integration and flight testing, ultimately laying the groundwork for successful operations. Here are the steps taken to test the system:

1. Initial Connection Verification

- **Multimeter Testing:** The testing process began with verifying the viability of all connections using a multimeter. This step ensured that all circuits were intact and free from faults that could cause issues during the power-up phase.

2. Power-Up and Calibration

- **Powering the Pixhawk 6X:** After confirming the connections, the Pixhawk 6X flight controller was powered up. This was followed by a full calibration, as per the manufacturer's instructions, to ensure all onboard sensors were accurately configured for flight operations.

3. Setting Up the TX/RX System

- **Controller and Receiver Configuration:** The next step involved setting up the TX/RX system by binding the Radiomaster TX12 Mark II Radio Controller to the ELRS Receiver. This included configuring various flight modes and safety features such as arm and disarm functions to prevent unintended motor activation.
- **ArduPilot Adjustments:** Necessary adjustments were made within the ArduPilot software to ensure compatibility between the controller and the Pixhawk 6X. This involved tweaking system variables to match the specific requirements of the hardware setup.
- **Wiring Issue:** A wiring error was encountered with the TX and RX wires being incorrectly connected, which caused communication issues. After identifying and correcting this, communication was restored, and the system was re-tested.

4. Motor and ESC Setup

- **Wiring and Testing:** The motors and ESCs were then wired up and connected. Initial motor tests were conducted, skipping some ESC parameters, to check basic functionality.
- **ESC Configuration:** Issues arose when attempting to configure the ESC via the ArduPilot software, resulting in the ESC not working. Various diagnostic tests were run, including direct connection to the ESC via different software, but the problem persisted.
- **Oscilloscope Diagnosis:** An oscilloscope was used to further investigate the issue, revealing that one of the connections was faulty. The faulty ESC was replaced, and after swapping in a new one, the system functioned correctly.
- **Motor Formation and Angle Setup:** With the ESC issue resolved, the motors were arranged in their desired configuration, and the flight controller's takeoff position angle was set.

5. On-Screen Display (OSD) Setup (Out of Scope)

- **OSD Challenges:** The on-screen display setup required a specific receiver to connect to the computer. However, this task was deemed out of scope due to the

extended time required to troubleshoot the controller setup and budget constraints, which prevented the purchase of additional components.

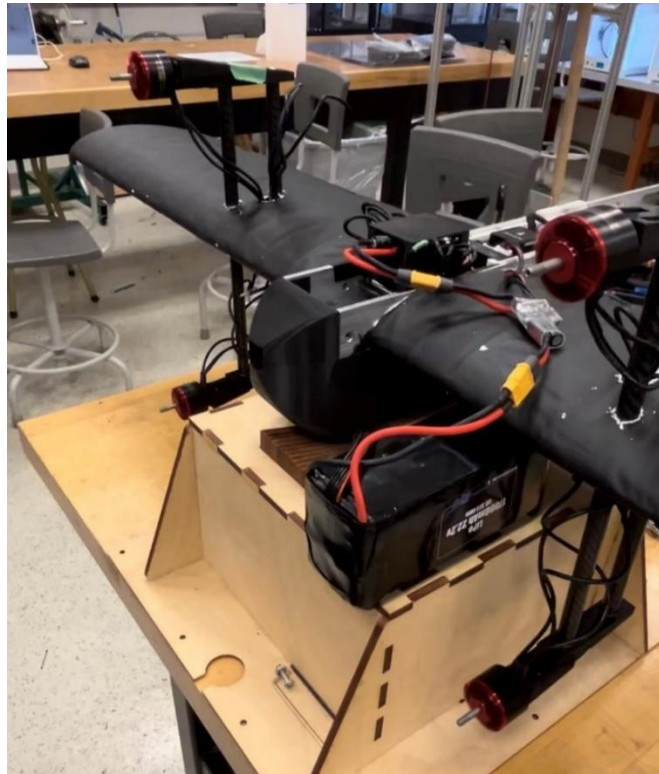


Figure 10: Stationary Motor Testing Configuration

Vertical flight was tested exclusively as future work is still required to prepare the drone for horizontal flight. It was observed during original testing that our electronic speed controller (ESC) was faulty and the right side propellers were spinning at a higher rpm, this resulted in the drone being unable to stabilize itself. After replacing the electronic speed controller and ensuring equal rpms between all four motors, we were able to manually stabilize the drone by coding the controller's joysticks to correspond with pitch and yaw directions.

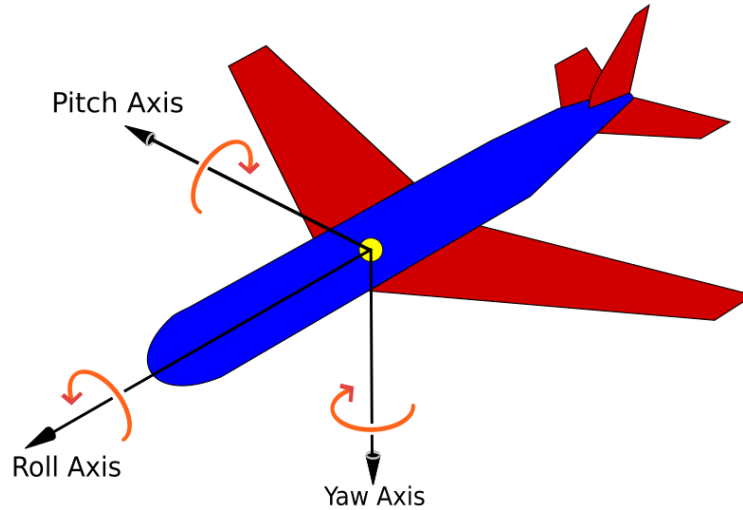


Figure 11: Rotation Variables for an Aircraft

Manual stabilization provided slightly more success. However, it is reliant on human reaction time, which meant it was still difficult to fly and would mostly crash slightly before takeoff when the motors are bearing most of the weight. As a result, controlled flight was only achieved by ignoring stabilization from the controller and forcing the nose to stay vertical by attaching it to a point above and maintaining a taught connection.

Table 9: Test Results

	Flight Achieved	Comments
Broken ESC	NO	Resulting moment from different rpm's made the drone fall over
Broken ESC, forced stabilization	YES	Remained in the air for 10 seconds and landed gently
New ESC, manual stabilization	NO	Flight was briefly achieved by maxing the thrust to the motors but was highly unstable

4.3 Future Work

Future work, as discussed with the client, will focus on improving the overall performance and reliability of this prototype. A significant area for improvement is the wing construction and covering. The current method which involves epoxying several wooden ribs into place is a time intensive process and was found to be vulnerable to fracture at the wing tips. The individual ribs also made it difficult to apply the monokote finish since once the heat shrink mechanic of this material was activated it took a convex shape in the free space between ribs. This would affect the lift and over efficiency of the wings. A solution to this problem is

a 3D printed or shaped aluminum sleeve that encases the ribs. The aluminum solution is preferred since it was found 3D material is vulnerable to melting when exposed to the heat required to adhere the monokote. If a sleeve is being used the number of ribs required could also be minimized, since 2 or 3 ribs would be able to successfully hold a well-made sleeve in the correct orientation. An aluminum solution would also create a rigid finish that protects the wings from fracturing.

Additionally, the flight control that governs the drone's transition from vertical to horizontal flight was not within this project's scope. This critical aspect requires further development to ensure smooth and reliable transitions, particularly under varying environmental conditions. A software team is recommended for this work as they would have a better understanding of the code behind the drone's operation and which variables would need to be altered to allow the flight transition.

Another mechanical aspect that can be improved is the drone's tail stability during takeoff and landing. This was brought to our attention because of a faulty electronic speed controller which resulted in the right side propellers operating at a higher rpm than the left side propellers. This resulted in a moment that pushed the drone to the left. When this happened, it was observed that the T-tail remained firmly on the ground while the U-channel rotated. This is due to these components only being connected by two screws on the same axis, the addition of two screws of a perpendicular axis would create a more secure connection between these components which will aid with a smoother takeoff and landing process.

Another area that warrants attention is the onboard cameras. The navigation camera is currently mounted rigidly in a way that looks forward during horizontal flight. It would be useful to incorporate a gimbal or different mounting orientation that allows the cameras to be used during vertical and horizontal flight. This upgrade wouldn't take precedence since vertical flight will primarily take place in the form of takeoffs and landings which would be within the eyesight of the operator. The mounting of the FLIR camera also needs to be considered. The main body U-channel contains cutouts that can be used as an attachment point, a camera housing needs to be designed to safely hold the FLIR camera as well as securely attach it to the main body of the drone.

7.0 References

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master/default/Manuals/MonoKote-Instructions.pdf. [Accessed 28 June 2024].

Appendix A: Engineering Drawings

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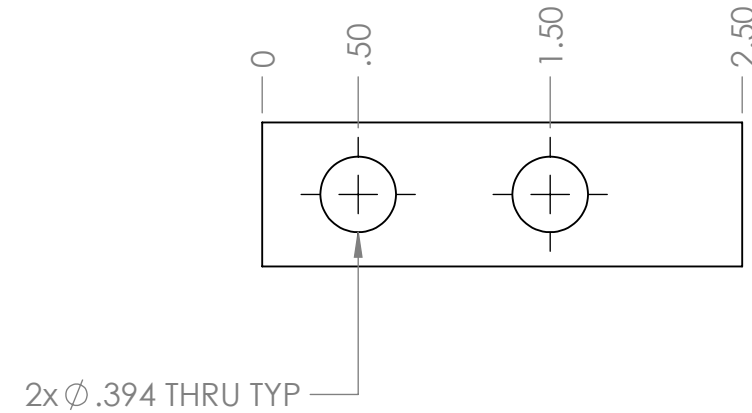
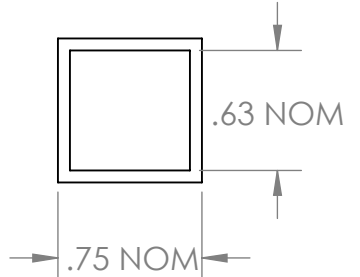
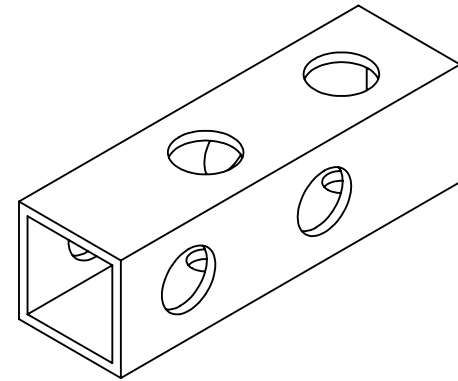
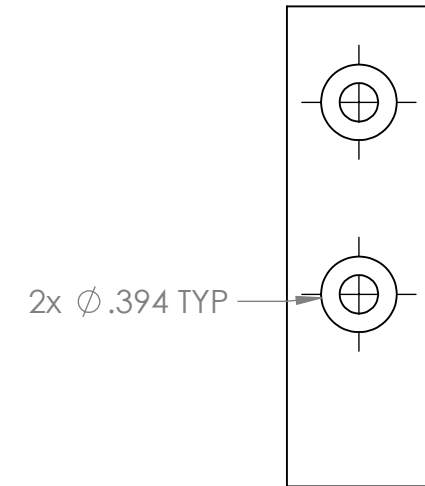
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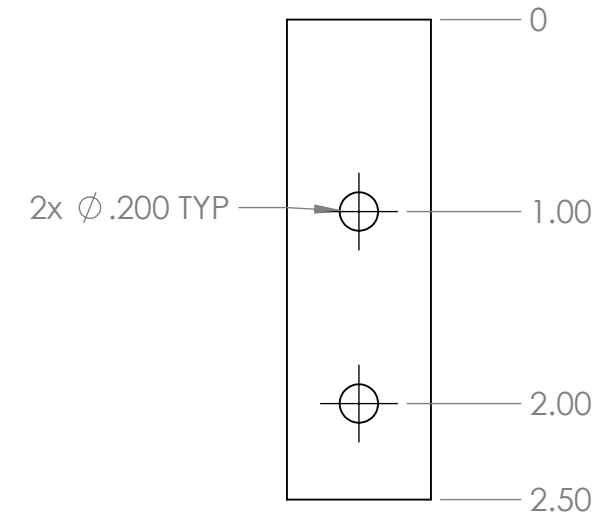
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TOLERANCES:		CHECKED			
TWO PLACE DECIMAL +/-0.05		ENG APPR.			
THREE PLACE DECIMAL +0.05		MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:		Q.A.			
MATERIAL		COMMENTS:		SIZE	
6061 Aluminum		QTY 1		DWG. NO.	
FINISH				B	
DO NOT SCALE DRAWING				400B G9	
				REV	
				SCALE: 1:1	
				WEIGHT: 0.04lbs	
				SHEET 1 OF 1	

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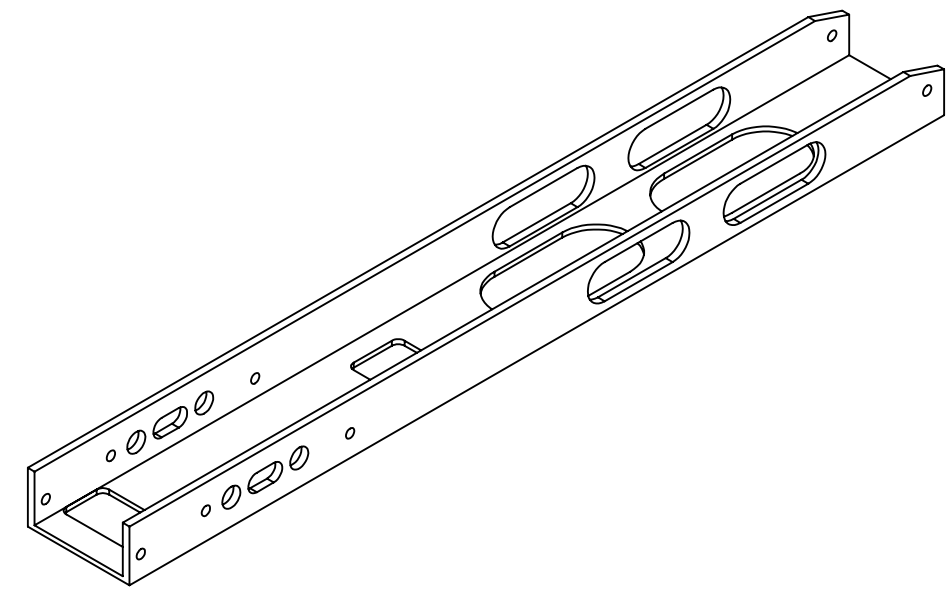
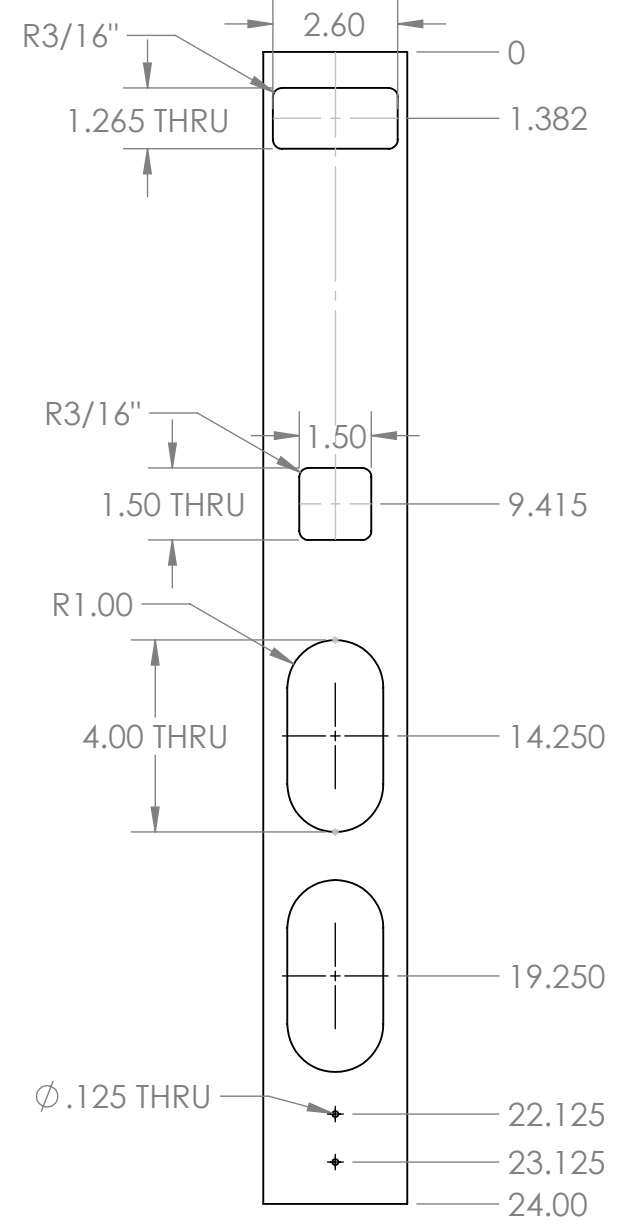
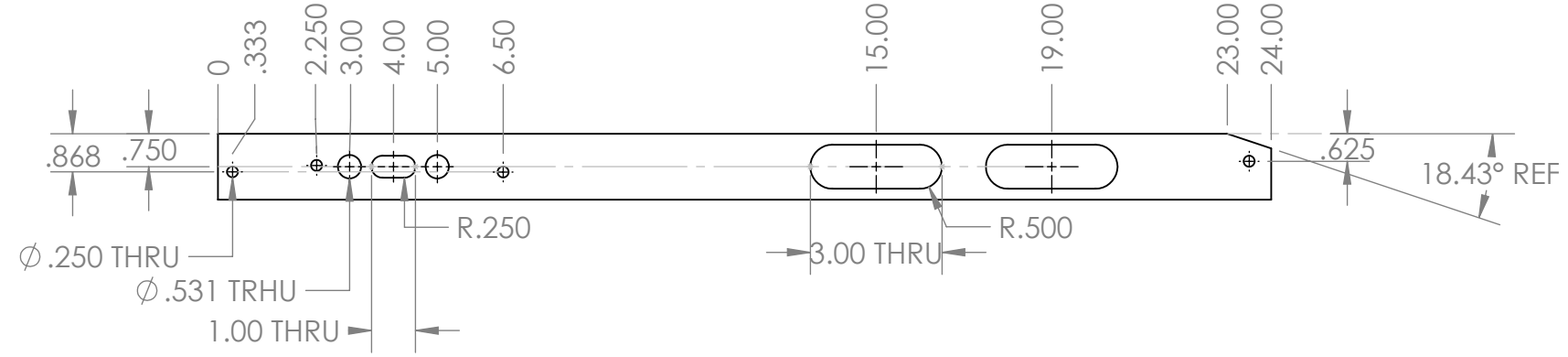
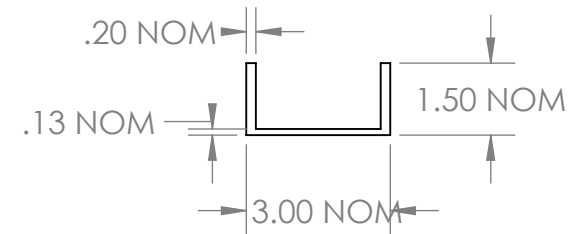
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DIMENSIONS ARE IN INCHES		DRAWN	TB		7/16
TOLERANCES:		CHECKED			
FRACTIONAL ±0		ENG APPR.			
TWO PLACE DECIMAL ±0.05		MFG APPR.			
THREE PLACE DECIMAL +0.005		Q.A.			
INTERPRET GEOMETRIC TOLERANCING PER:		COMMENTS:			
MATERIAL		QTY1			
6061 aluminum		SIZE	DWG. NO.	REV	
FINISH		B	400B G9		
DO NOT SCALE DRAWING		SCALE: 1:4 WEIGHT: 1.68lbs		SHEET 1 OF 1	

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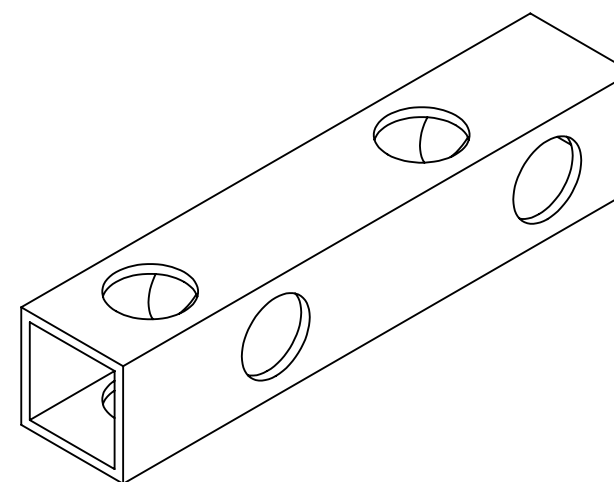
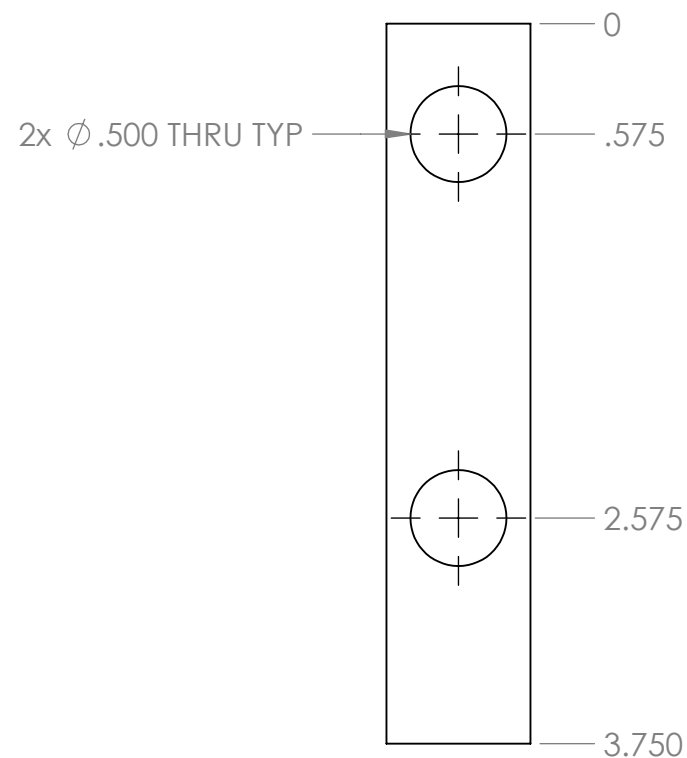
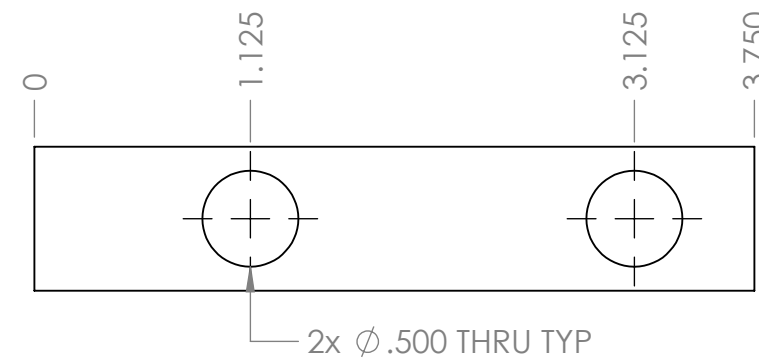
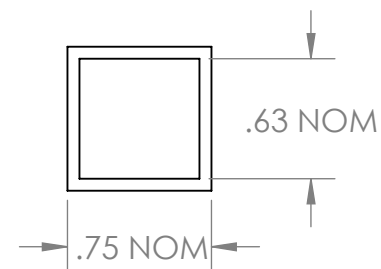
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DIMENSIONS ARE IN INCHES	DRAWN	TB	7/14	
TOLERANCES: TWO PLACE DECIMAL +/-0.05 THREE PLACE DECIMAL +0.005	CHECKED			
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	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 6061 Aluminum	COMMENTS: QTY 2			SIZE DWG. NO. REV
FINISH				B 400B G9
DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: 0.05lbs SHEET 1 OF 1

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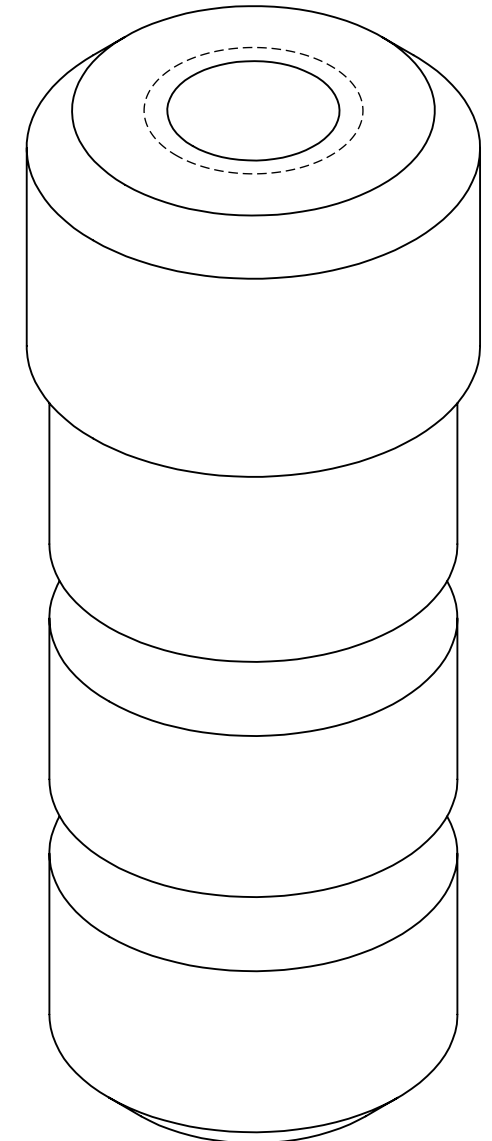
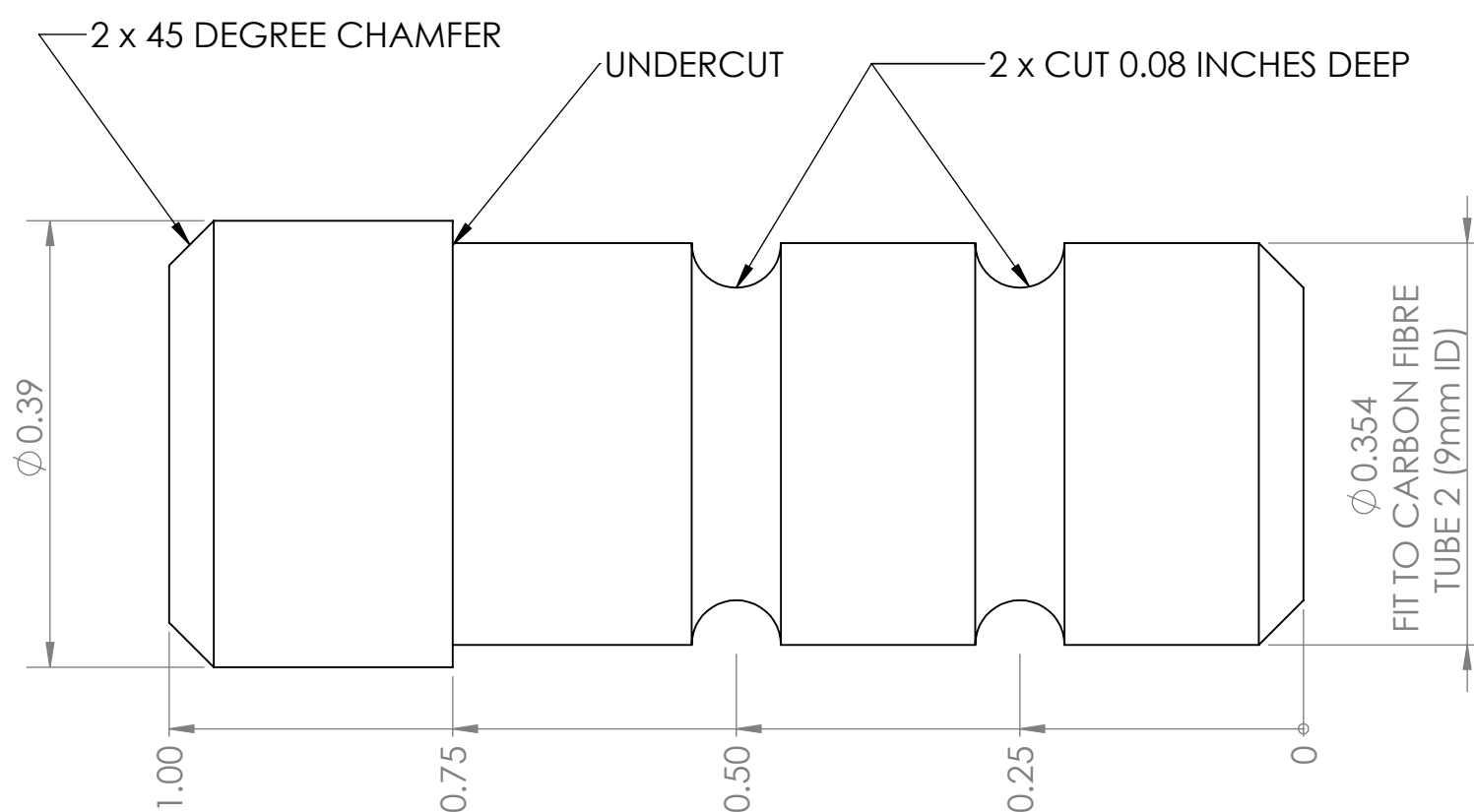
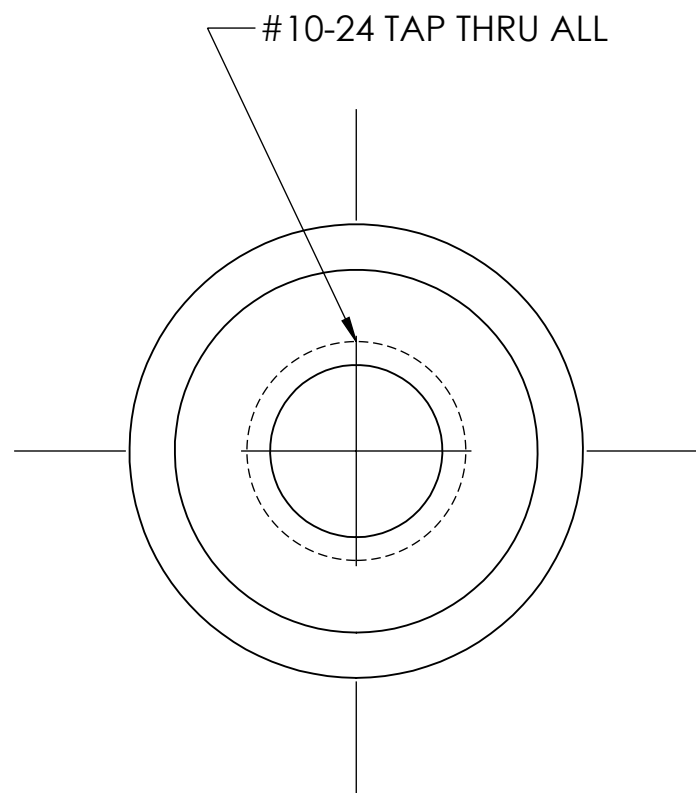
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NOTE
 1. QTY: 8
 2. FIT TO CARBON FIBRE TUBE LABELLED TUBE 2 IN SHOP (9mm ID)

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL +/- 0.010 THREE PLACE DECIMAL +/- 0.003		GROUP 9 - MECH400B	
INTERPRET GEOMETRIC TOLERANCING PER:		TITLE: Threaded Plug 9mm	
MATERIAL 6061 ALUMINIUM	SIZE B	DWG. NO. F-03	REV
FINISH	SCALE: 6:1	WEIGHT:	SHEET 1 OF 1

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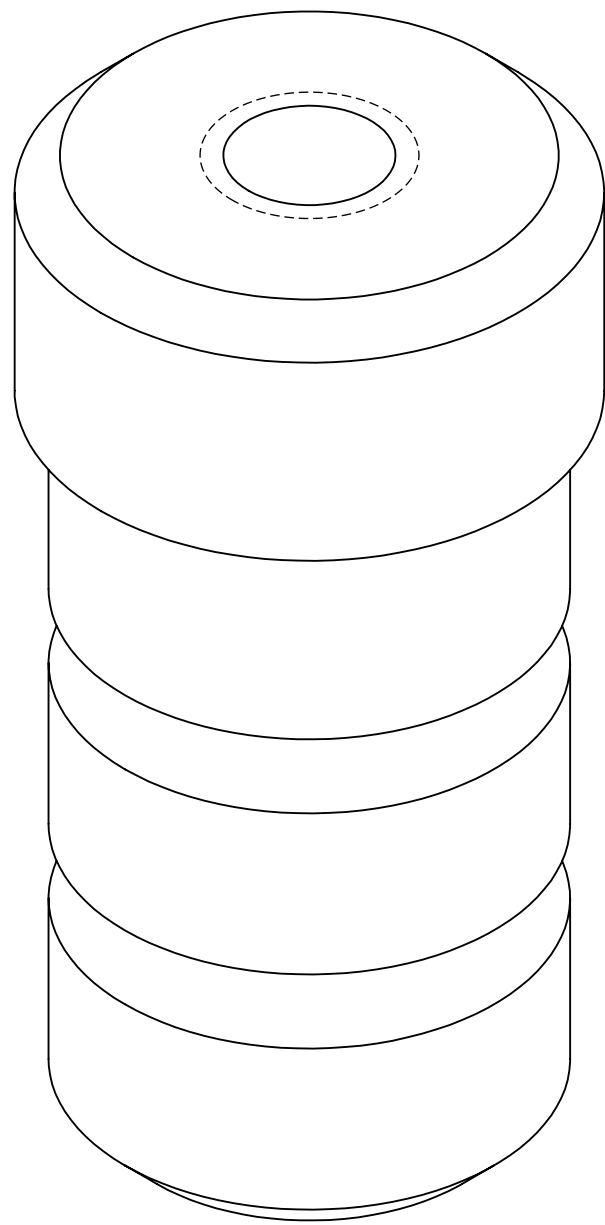
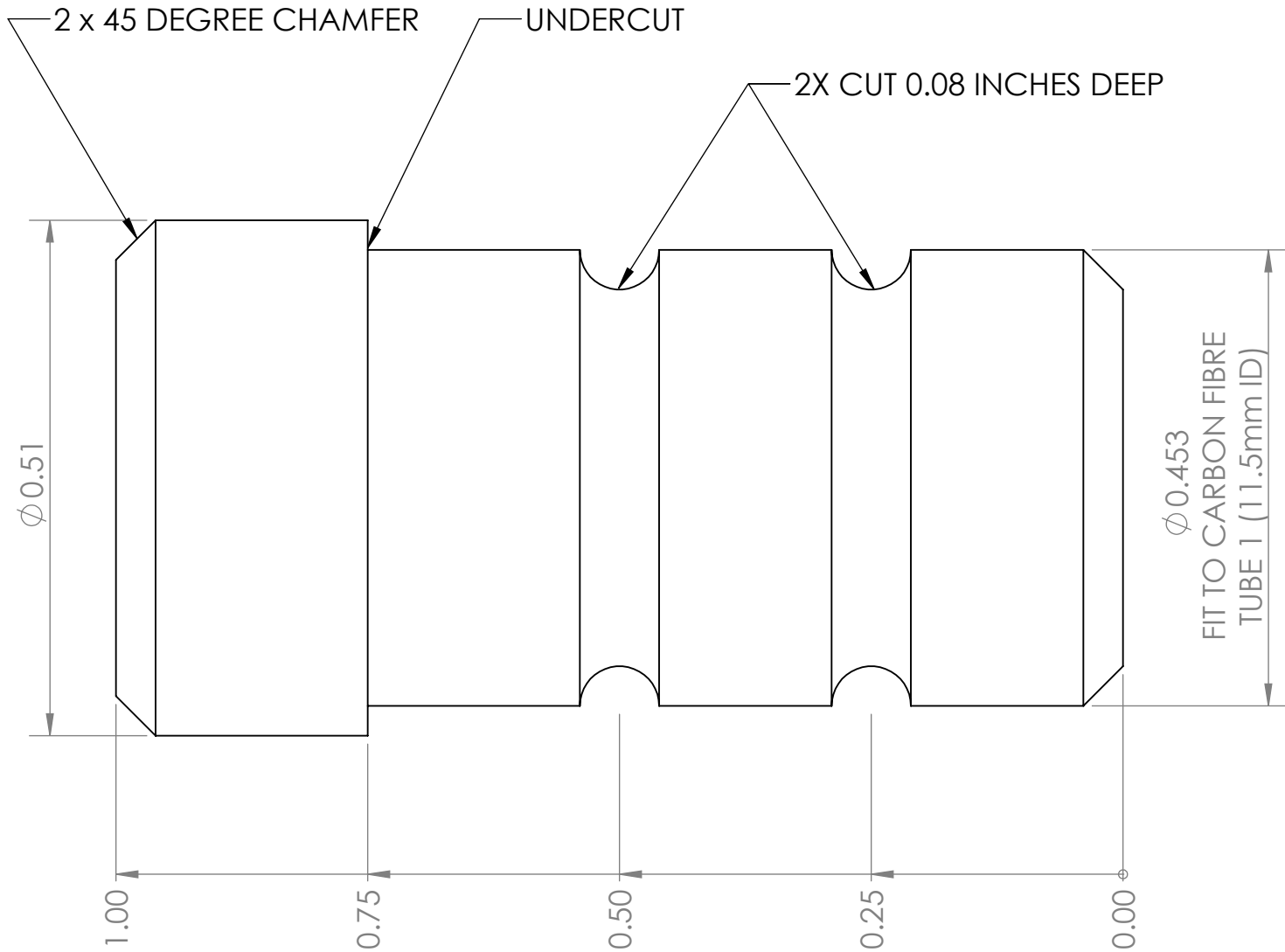
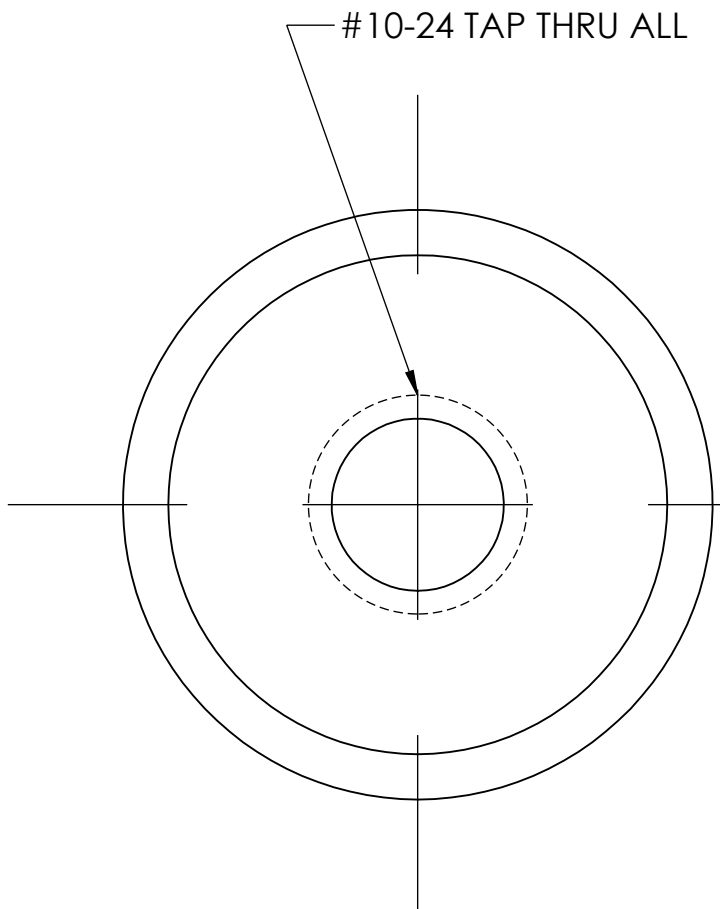
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NOTE
 1. QTY: 8
 2. FIT TO CARBON FIBRE TUBE LABELLED TUBE 1 IN SHOP (11.5mm ID)

UNLESS OTHERWISE SPECIFIED:		GROUP 9 MECH 400B	
DIMENSIONS ARE IN INCHES		TITLE:	
TOLERANCES:		Threaded Plug	
TWO PLACE DECIMAL +/- 0.010		11.5	
THREE PLACE DECIMAL +/- 0.003			
INTERPRET GEOMETRIC TOLERANCING PER:		SIZE	DWG. NO.
		B	F-02
MATERIAL		REV	
6061 ALUMINIUM			
FINISH			
DO NOT SCALE DRAWING		SCALE: 6:1	WEIGHT:
		SHEET 1 OF 1	

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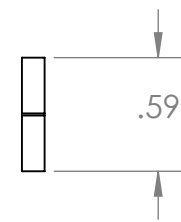
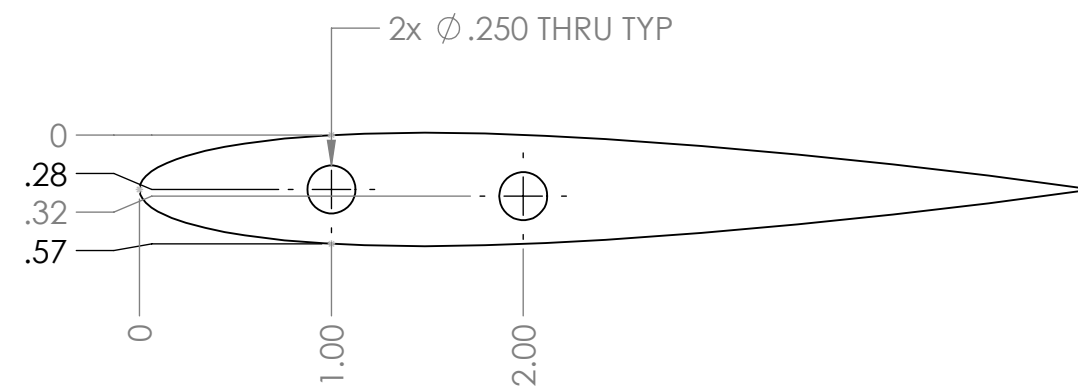
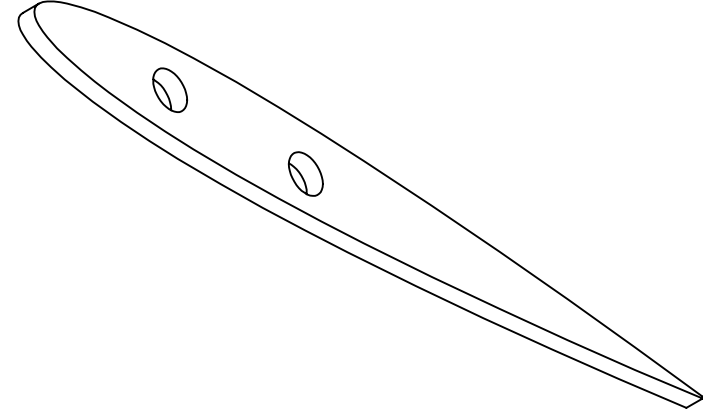
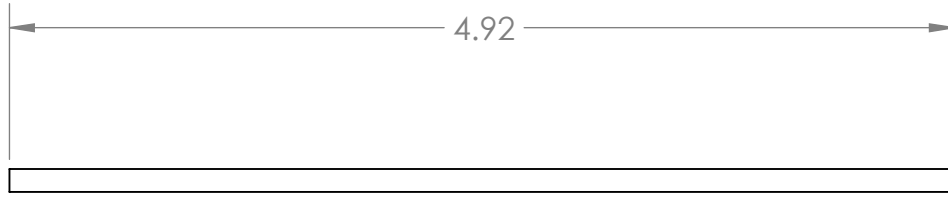
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DIMENSIONS ARE IN INCHES		DRAWN	TB		08/15
TOLERANCES:		CHECKED			
FRACTIONAL ± 0		ENG APPR.			
TWO PLACE DECIMAL ± 0.05		MFG APPR.			
THREE PLACE DECIMAL $+0.005$		Q.A.			
INTERPRET GEOMETRIC TOLERANCING PER:		COMMENTS:		SIZE DWG. NO. REV B 400B G9 SCALE: 1:1 WEIGHT: SHEET 1 OF 1	
MATERIAL		Standard shape for an NACA 0012 airfoil			
FINISH					
DO NOT SCALE DRAWING					

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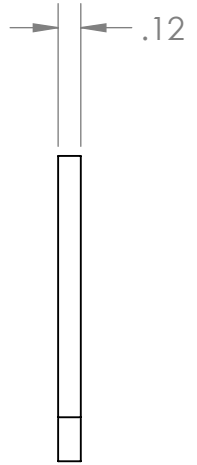
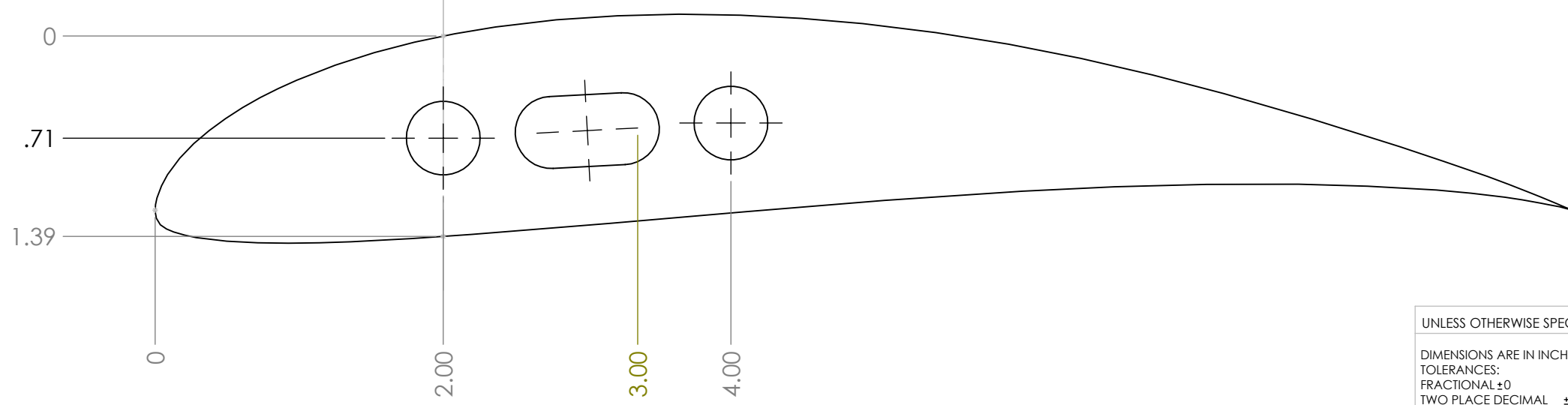
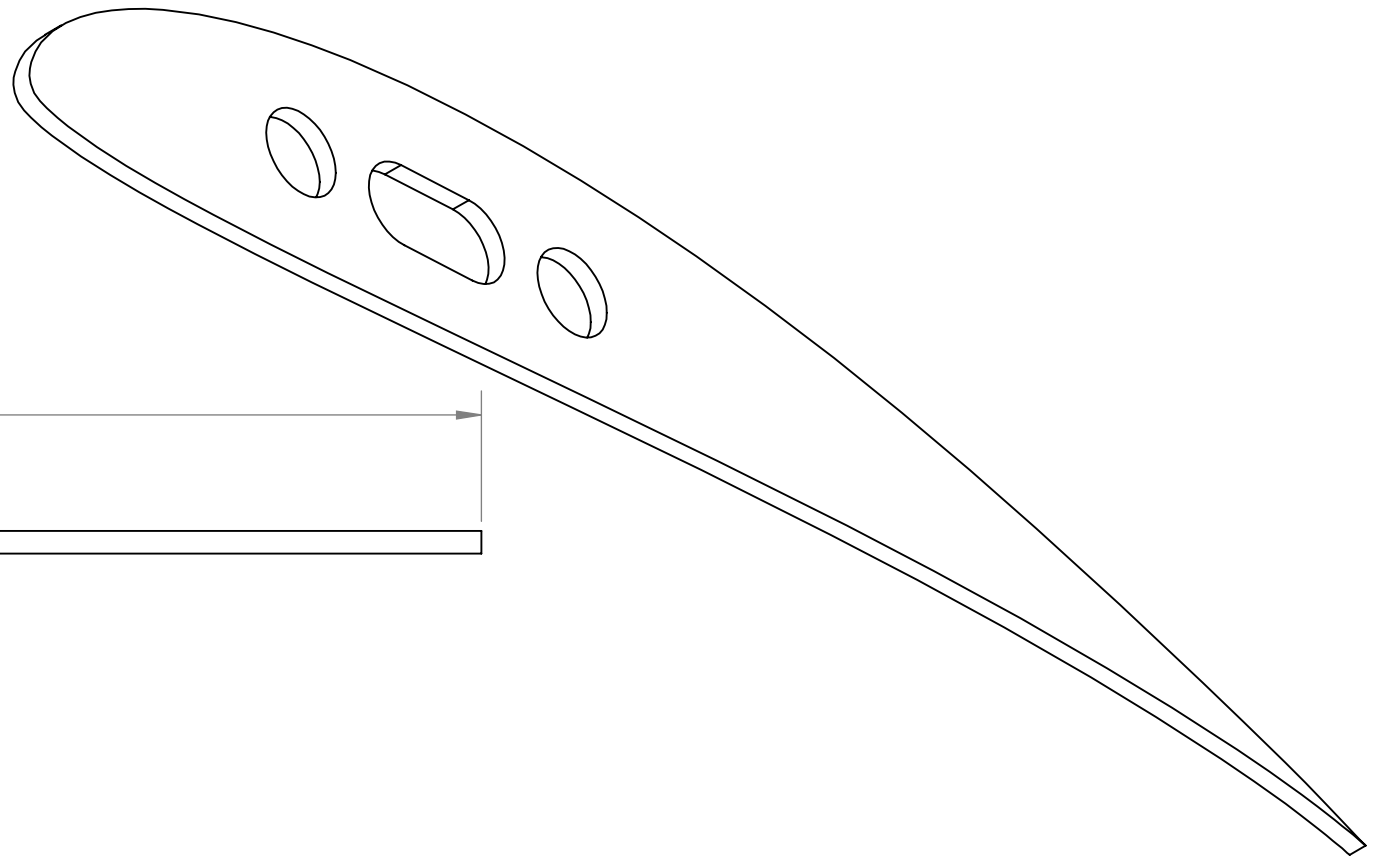
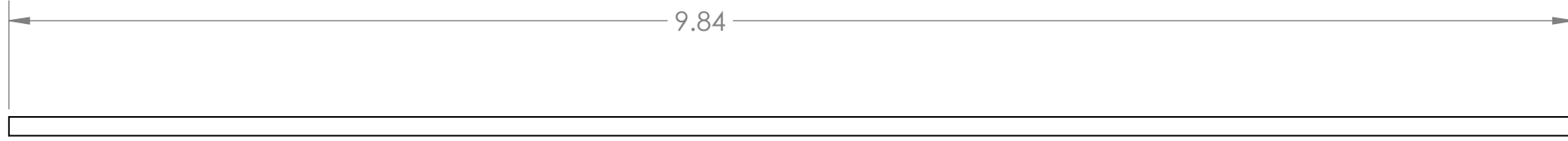
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DIMENSIONS ARE IN INCHES		DRAWN	TB		08/15
TOLERANCES:		CHECKED			
FRACTIONAL ±0		ENG APPR.			
TWO PLACE DECIMAL ±0.05		MFG APPR.			
THREE PLACE DECIMAL +0.005		Q.A.			
INTERPRET GEOMETRIC TOLERANCING PER:		COMMENTS: Standard shape for an MH13 airfoil			
MATERIAL 3mm PLY		SIZE	DWG. NO.	REV	
FINISH		B	400B G9		
DO NOT SCALE DRAWING		SCALE: 1:1	WEIGHT:	SHEET 1 OF 1	

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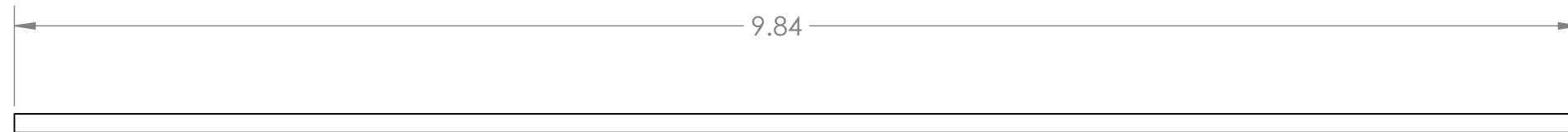
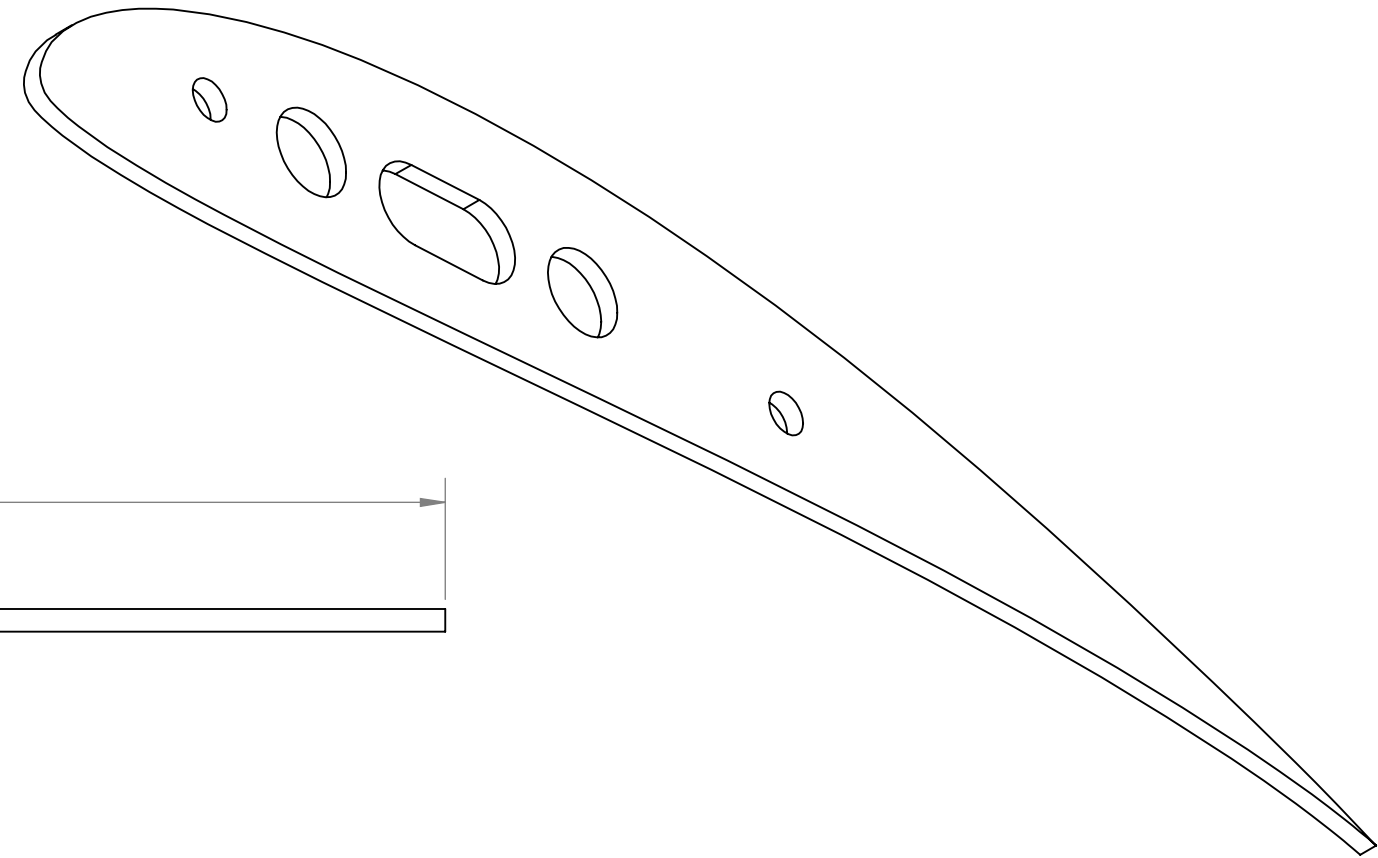
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2x ϕ .512 THRU TYP

2x ϕ .250 THRU TYP

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL ± 0
 TWO PLACE DECIMAL ± 0.05
 THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
3mm PLY

FINISH

DO NOT SCALE DRAWING

NAME

DATE

DRAWN

TB

08/15

CHECKED

ENG APPR.

MFG APPR.

Q.A.

COMMENTS:
Standard shape for an MH13 airfoil

TITLE:

Root Bulkhead

SIZE

B

DWG. NO.

400B G9

REV

SCALE: 1:2

WEIGHT:

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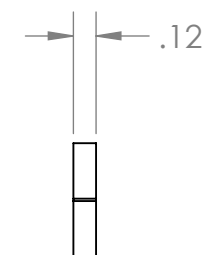
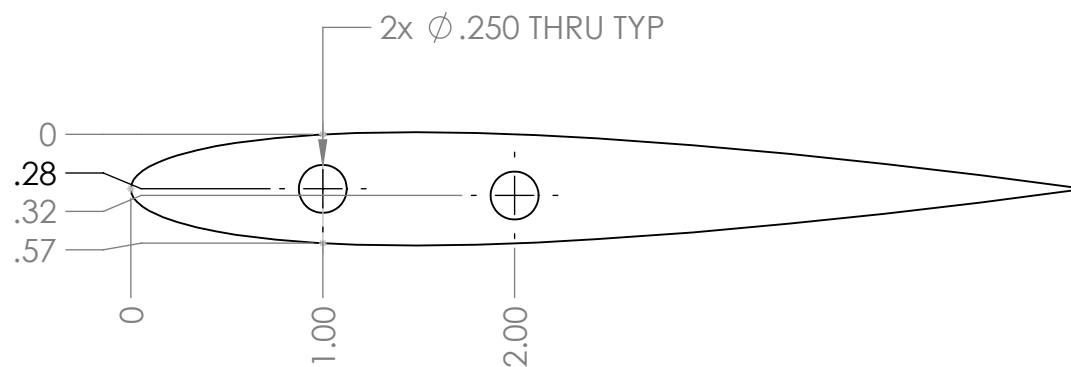
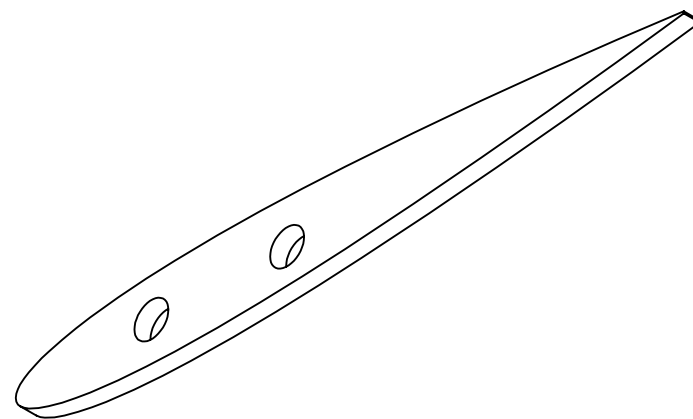
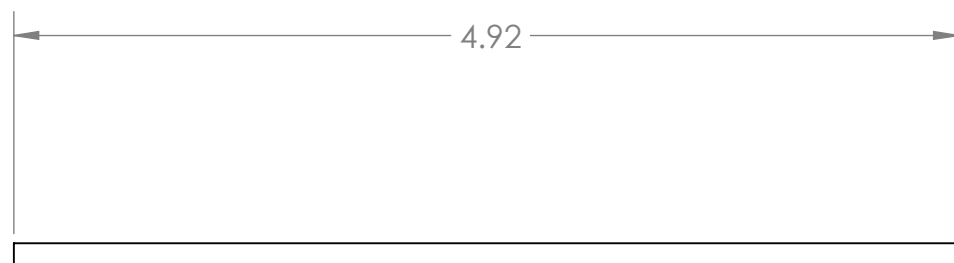
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UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: Vertical Tail Bulkhead	
DIMENSIONS ARE IN INCHES		DRAWN	TB		08/15
TOLERANCES:		CHECKED			
FRACTIONAL ± 0		ENG APPR.			
TWO PLACE DECIMAL ± 0.05		MFG APPR.			
THREE PLACE DECIMAL $+0.005$		Q.A.			
INTERPRET GEOMETRIC TOLERANCING PER:		COMMENTS: Standard shape for an NACA 0012 airfoil		SIZE	
MATERIAL 3mm PLY				DWG. NO. 400B G9	
FINISH				REV	
DO NOT SCALE DRAWING				SCALE: 1:1	
				WEIGHT:	
				SHEET 1 OF 1	

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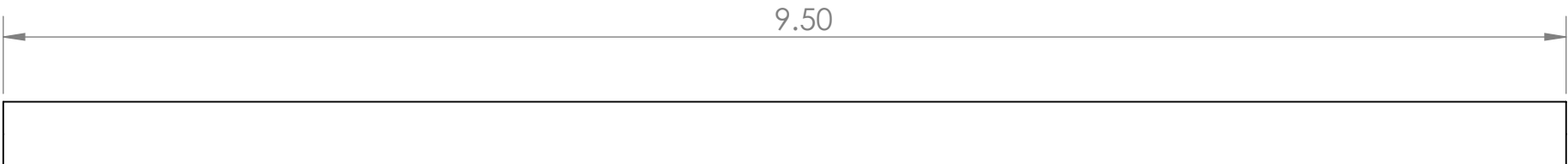
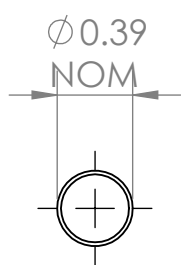
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NOTE
 1. QTY: 2
 2. CUT FROM TUBE LABELLED TUBE 3 IN SHOP

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ONE PLACE DECIMAL +/- 0.015 TWO PLACE DECIMAL +/- 0.010 THREE PLACE DECIMAL +/- 0.003		GROUP 9 - MECH400B	
INTERPRET GEOMETRIC TOLERANCING PER:		TITLE: HORIZ TAIL TUBE	
MATERIAL CARBON FIBRE	SIZE B	DWG. NO. T-02	REV
FINISH	SCALE: 1:1	WEIGHT:	SHEET 1 OF 1
DO NOT SCALE DRAWING			

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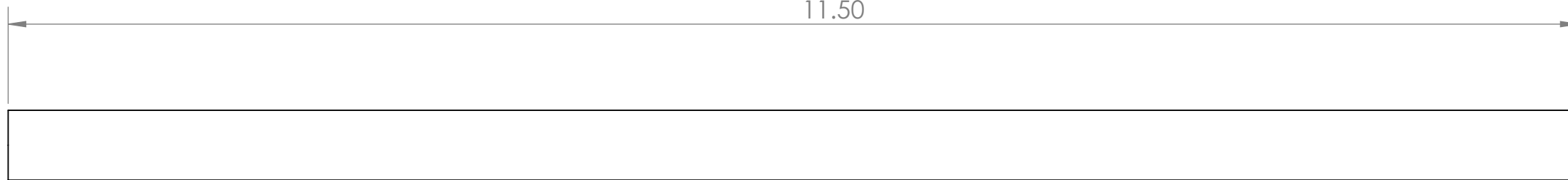
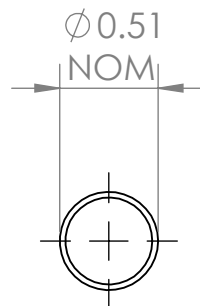
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UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL +/- 0.010 THREE PLACE DECIMAL +/- 0.003		GROUP 9 - MECH400B	
INTERPRET GEOMETRIC TOLERANCING PER:		TITLE: MOTOR TUBES	
MATERIAL CARBON FIBRE	SIZE B	DWG. NO. W-06	REV
FINISH	SCALE: 1:1	WEIGHT:	SHEET 1 OF 1
DO NOT SCALE DRAWING			

- NOTE
1. QTY: 4
 2. CUT FROM TUBE LABELLED TUBE 1 IN SHOP

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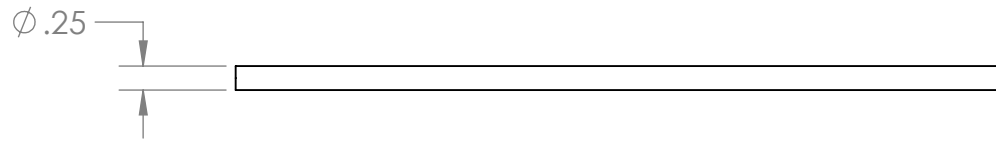
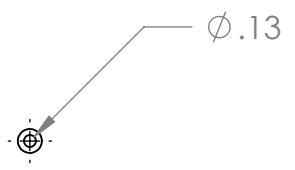
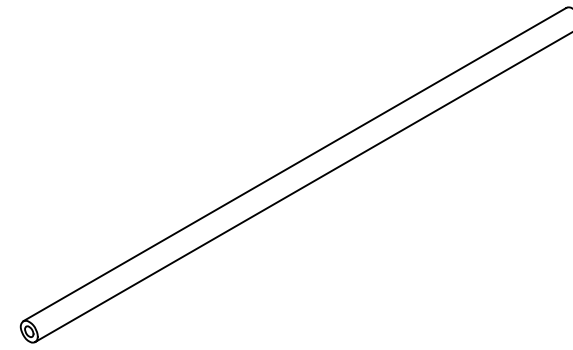
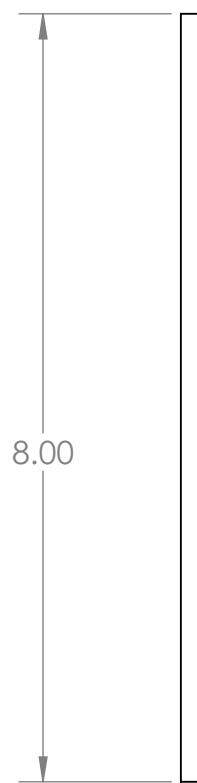
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UNLESS OTHERWISE SPECIFIED:		Group 9-MECH400B	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		TITLE: Vertical Tail Tube	
INTERPRET GEOMETRIC TOLERANCING PER:		SIZE	DWG. NO.
MATERIAL: Carbon Fiber		B	T-04
FINISH			REV
DO NOT SCALE DRAWING		SCALE: 1:2	WEIGHT: SHEET 1 OF 1

Note:
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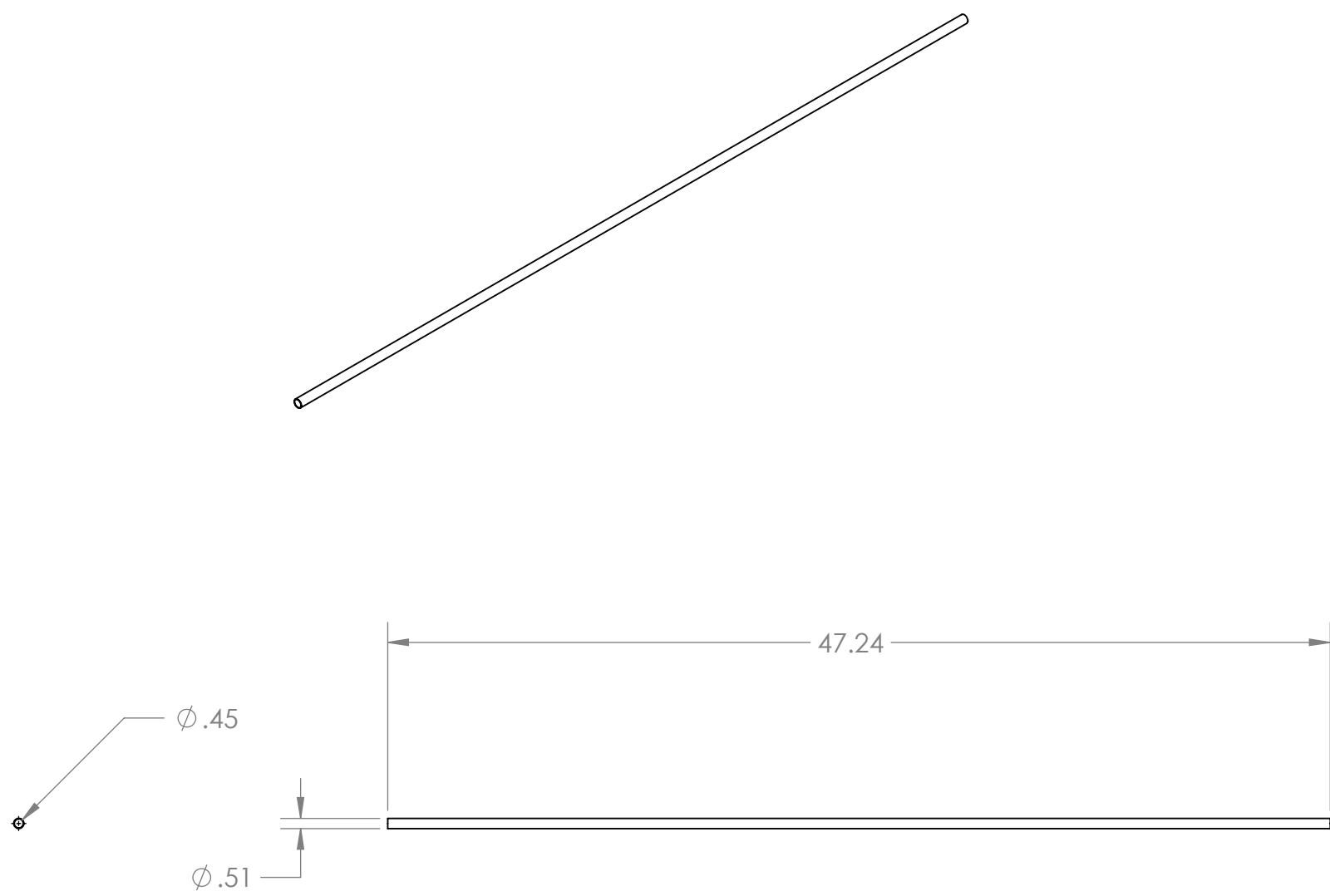
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UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES			
TOLERANCES:			
FRACTIONAL \pm			
ANGULAR: MACH \pm BEND \pm			
TWO PLACE DECIMAL \pm			
THREE PLACE DECIMAL \pm			
INTERPRET GEOMETRIC TOLERANCING PER:			
MATERIAL: Carbon Fiber			
FINISH			
DO NOT SCALE DRAWING			
TITLE: Group 9-MECH400B Wing Tube		SIZE B	DWG. NO. T-03
SCALE: 1:8		WEIGHT:	REV
SHEET 1 OF 1			

Note:
Qty: 4

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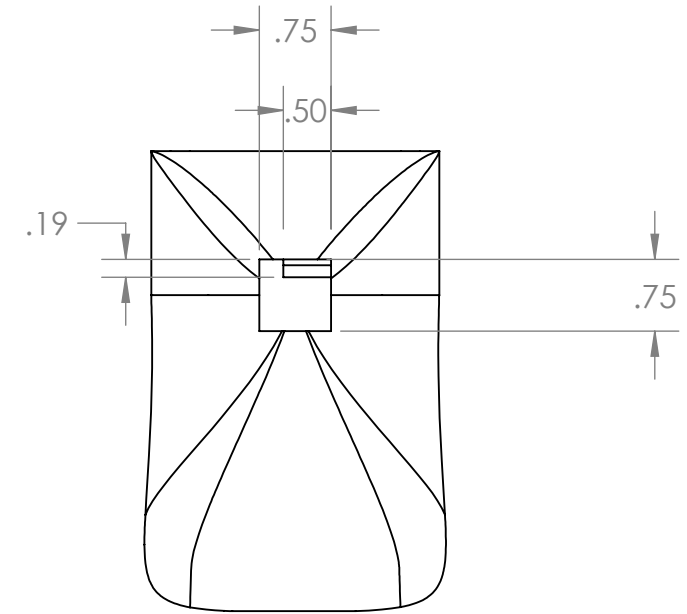
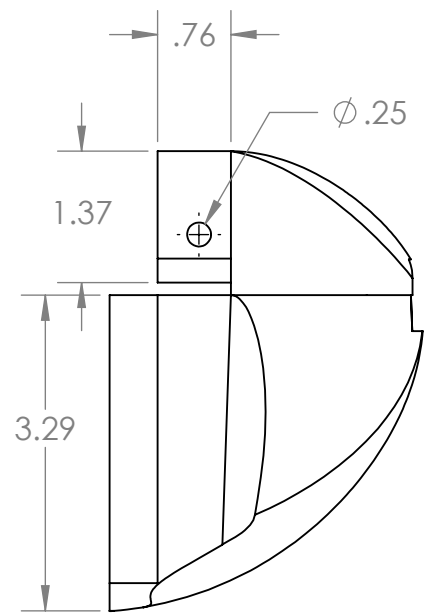
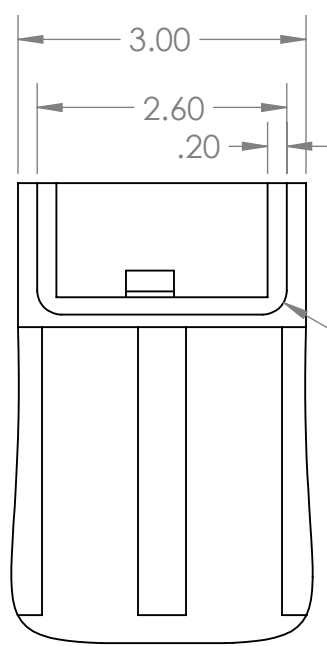
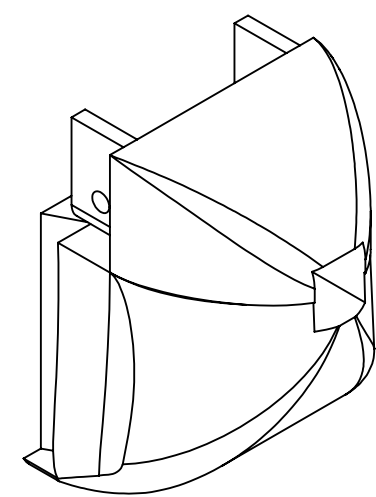
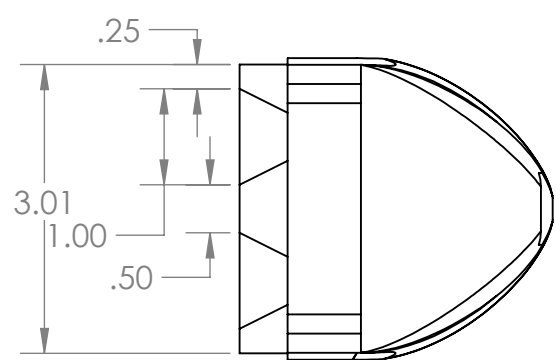
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UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES			
TOLERANCES:			
FRACTIONAL ±			
ANGULAR: MACH ± BEND ±			
TWO PLACE DECIMAL ±			
THREE PLACE DECIMAL ±			
INTERPRET GEOMETRIC TOLERANCING PER:			
MATERIAL	SIZE	DWG. NO.	REV
PLA	B	N-01	
FINISH	SCALE: 1:2		WEIGHT:
DO NOT SCALE DRAWING			SHEET 1 OF 1

Note:
Qty: 1
To be 3D printed

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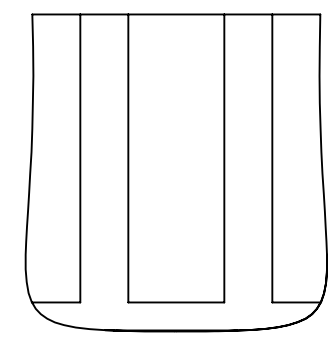
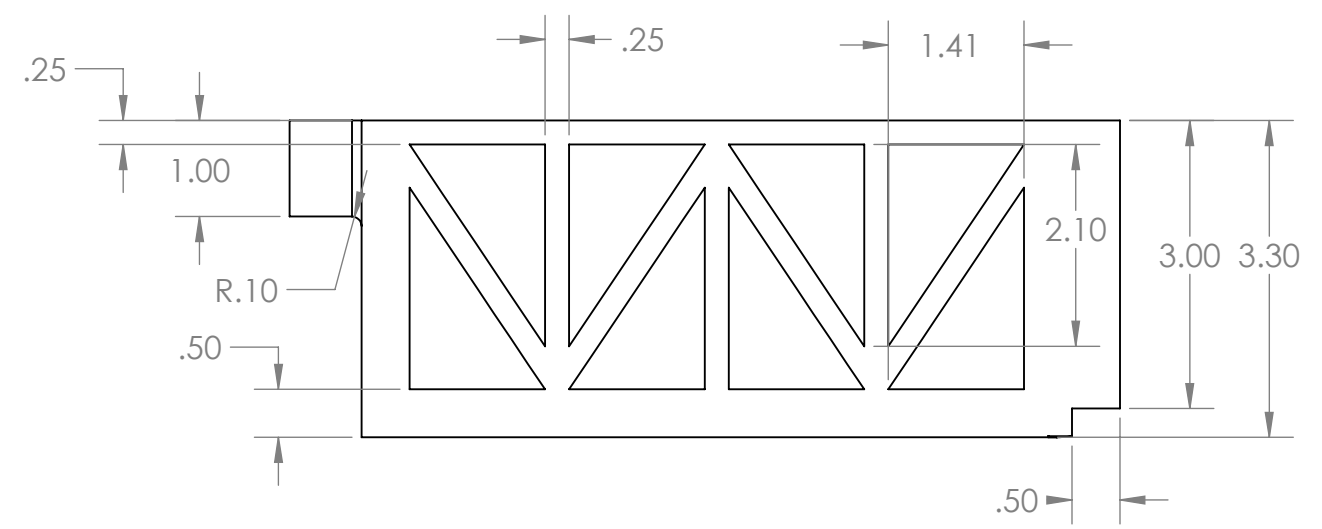
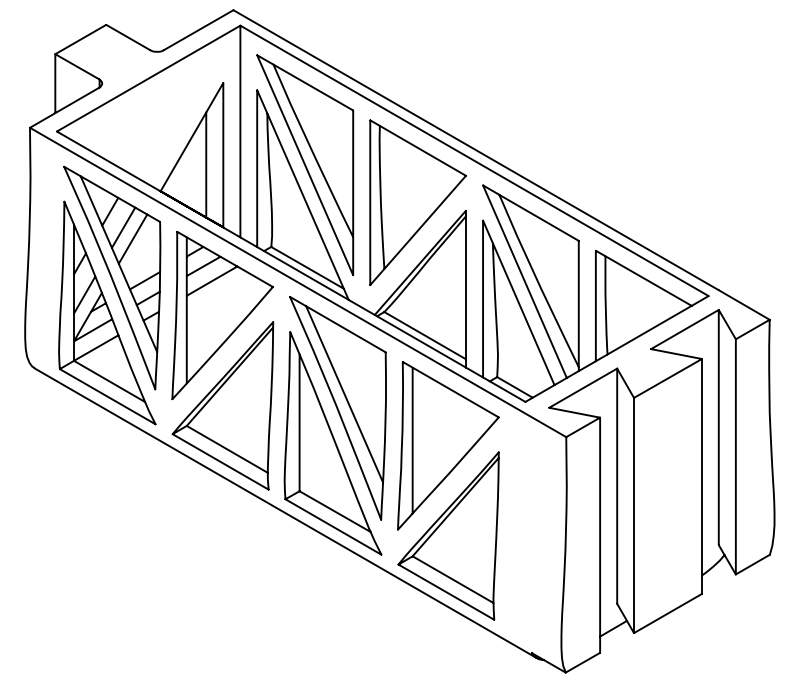
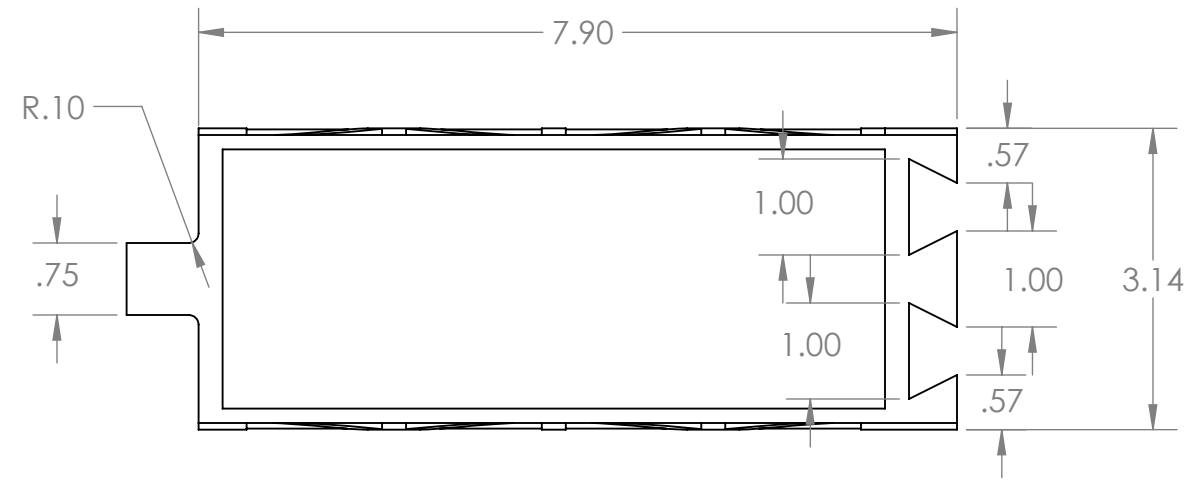
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UNLESS OTHERWISE SPECIFIED:		Group 9-MECH400B	
DIMENSIONS ARE IN INCHES		TITLE:	
TOLERANCES:		Battery Mount	
FRACTIONAL ±		3D Print	
ANGULAR: MACH ± BEND ±		SIZE	DWG. NO.
TWO PLACE DECIMAL ±		B	N-02
THREE PLACE DECIMAL ±		MATERIAL	REV
INTERPRET GEOMETRIC		PLA	
TOLERANCING PER:		FINISH	
DO NOT SCALE DRAWING		SCALE: 1:2	WEIGHT:
Note:		SHEET 1 OF 1	
Qty: 1			
To be 3D printed			

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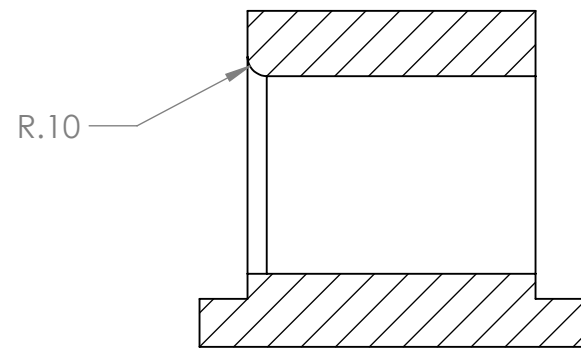
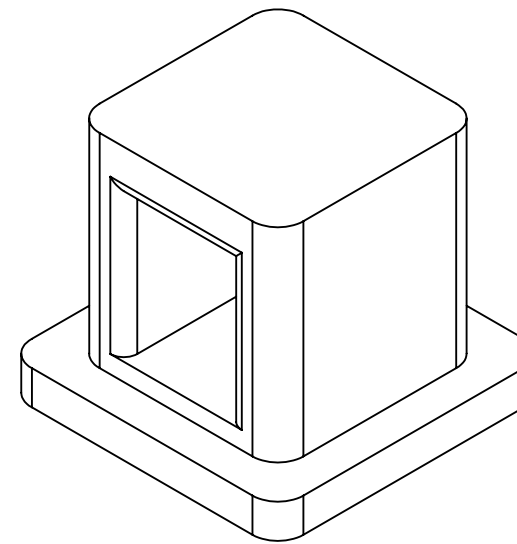
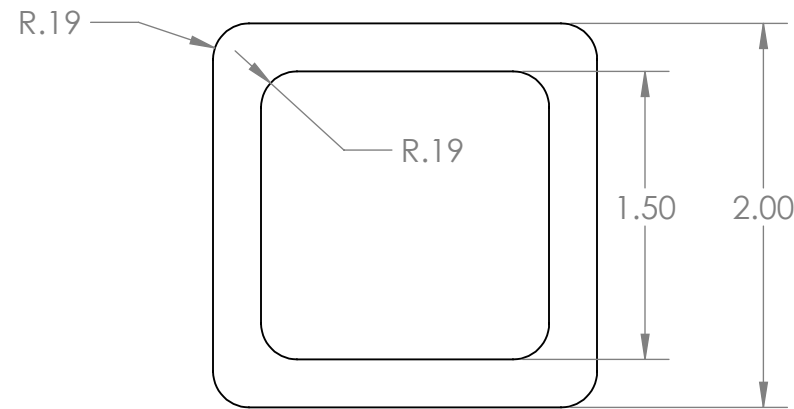
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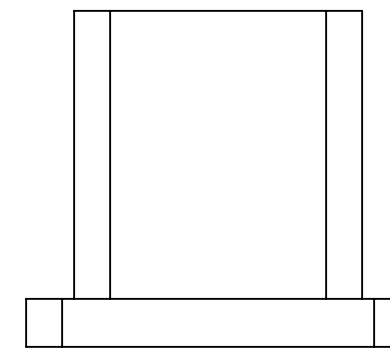
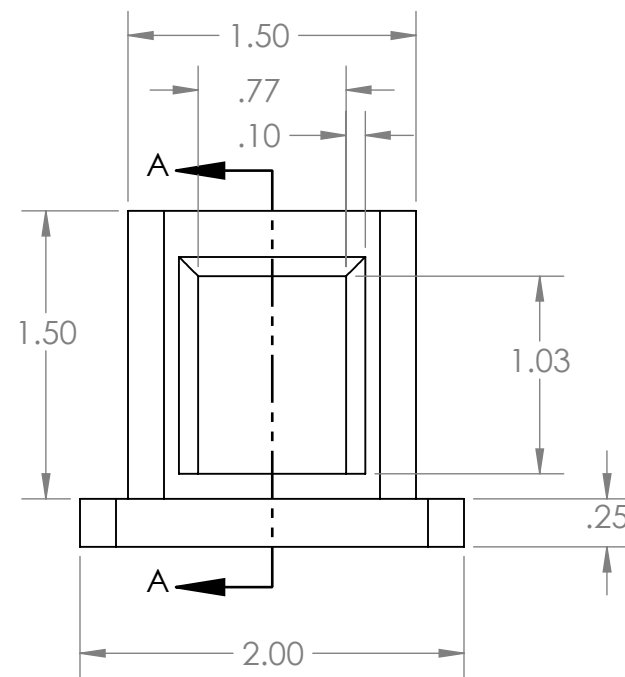
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SECTION A-A



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DIMENSIONS ARE IN INCHES			
TOLERANCES:			
FRACTIONAL ±			
ANGULAR: MACH ± BEND ±			
TWO PLACE DECIMAL ±			
THREE PLACE DECIMAL ±			
INTERPRET GEOMETRIC TOLERANCING PER:			
MATERIAL			
PLA			
FINISH			
DO NOT SCALE DRAWING			
TITLE:		Group 9-MECH400B	
TITLE:		Rear Lock 3D Print	
SIZE	DWG. NO.	REV	
B	N-03		
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1	

Note:
Qty: 1
To be 3D printed

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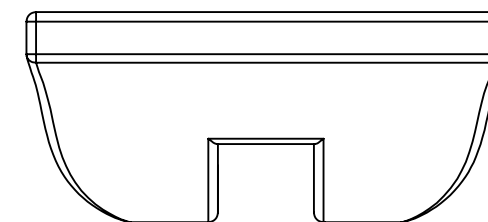
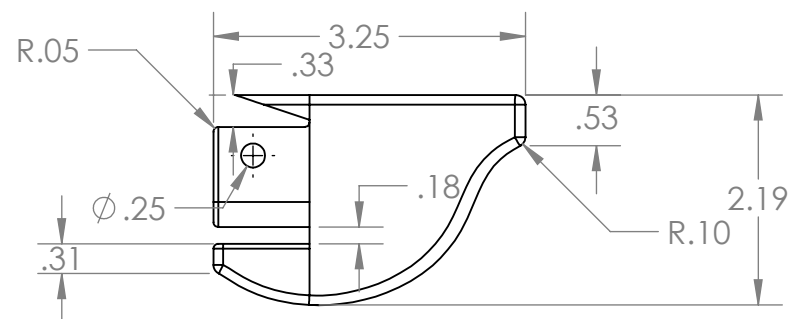
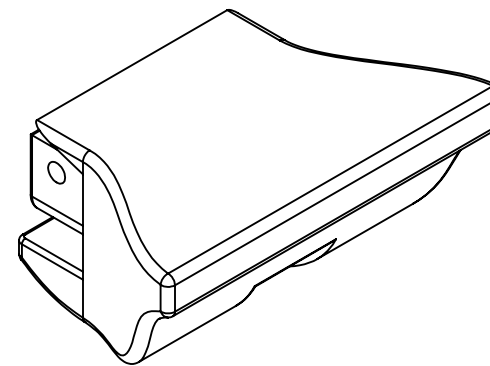
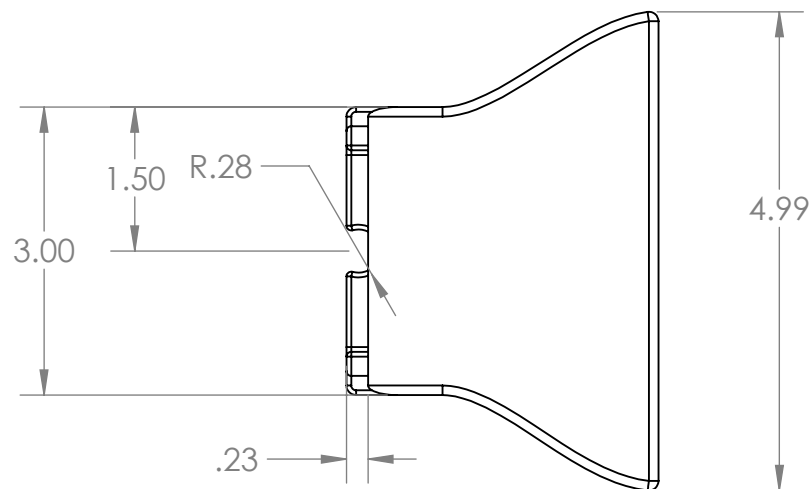
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UNLESS OTHERWISE SPECIFIED:	
DIMENSIONS ARE IN INCHES	
TOLERANCES:	
FRACTIONAL ±	
ANGULAR: MACH ± BEND ±	
TWO PLACE DECIMAL ±	
THREE PLACE DECIMAL ±	
INTERPRET GEOMETRIC TOLERANCING PER:	
MATERIAL	PLA
FINISH	
DO NOT SCALE DRAWING	

Note:
Qty: 1
To be 3D printed

Group 9-MECH400B		
TITLE: Tail 3D Print		
SIZE	DWG. NO.	REV
B	N-03	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

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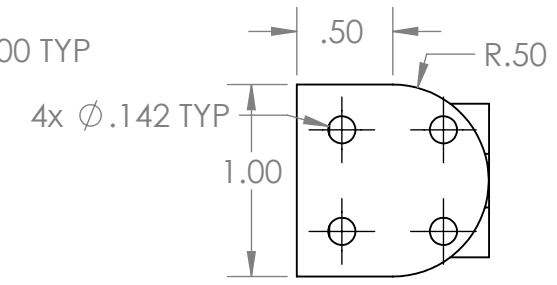
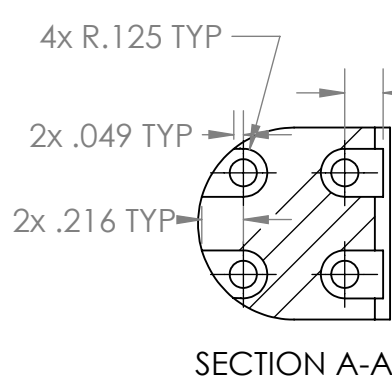
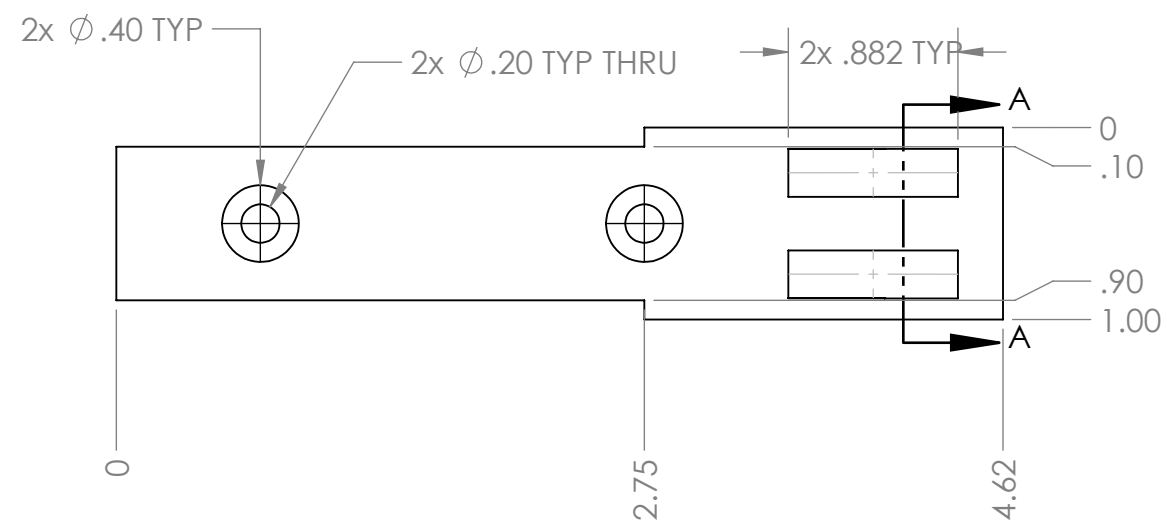
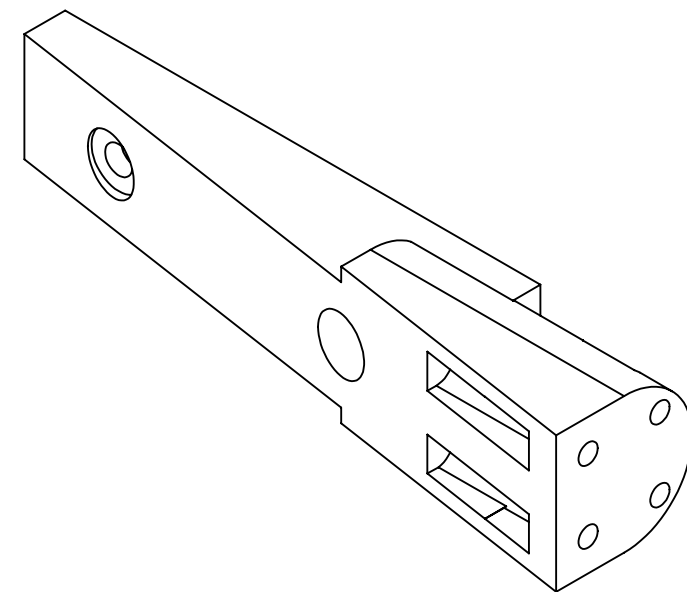
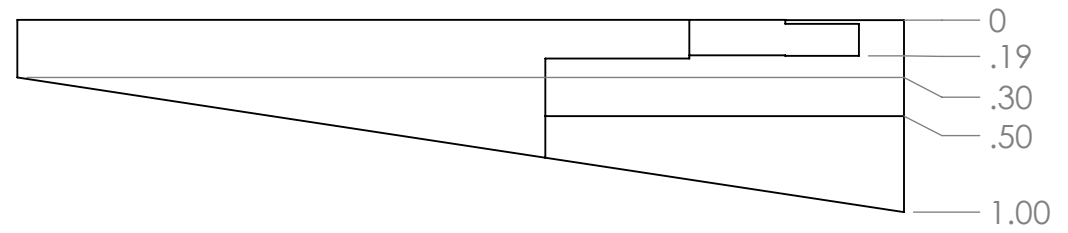
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UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: Motor Mount	
DIMENSIONS ARE IN INCHES		DRAWN	TB		08/15
TOLERANCES:		CHECKED			
FRACTIONAL ±0		ENG APPR.			
TWO PLACE DECIMAL ±0.05		MFG APPR.			
THREE PLACE DECIMAL +0.005		Q.A.			
INTERPRET GEOMETRIC TOLERANCING PER:		COMMENTS:			
MATERIAL	PLA	SIZE	DWG. NO.	REV	
FINISH		B	400B G9		
DO NOT SCALE DRAWING		SCALE: 1:1	WEIGHT:	SHEET 1 OF 1	

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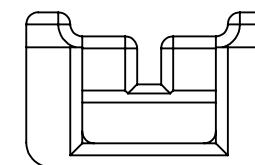
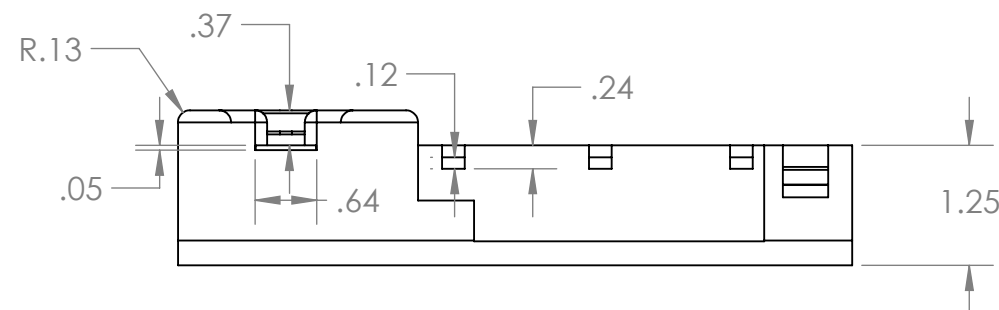
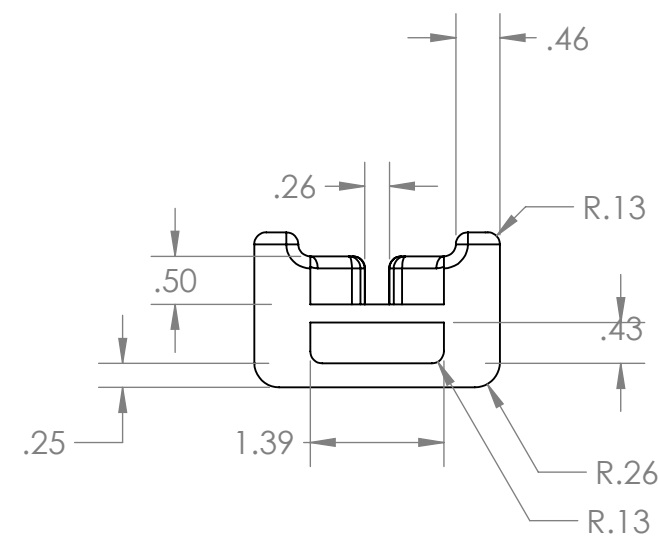
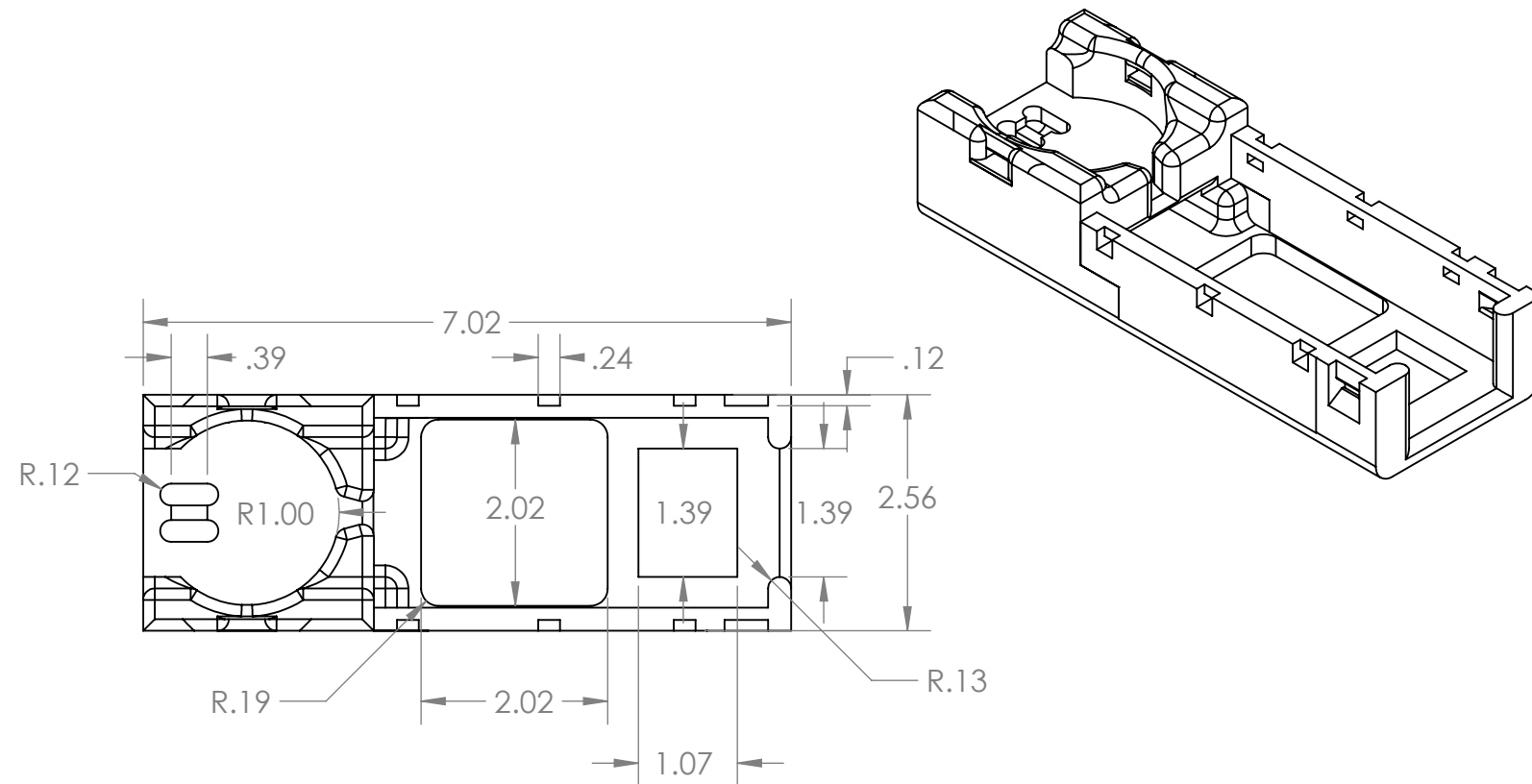
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UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES			
TOLERANCES:			
FRACTIONAL ±			
ANGULAR: MACH ± BEND ±			
TWO PLACE DECIMAL ±			
THREE PLACE DECIMAL ±			
INTERPRET GEOMETRIC TOLERANCING PER:			
MATERIAL			
PLA			
FINISH			
DO NOT SCALE DRAWING			
TITLE: Group 9-MECH400B			
PixHawx Housing			
3D Print			
SIZE	DWG. NO.	REV	
B	N-03		
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1	

Note:
Qty: 1
To be 3D printed

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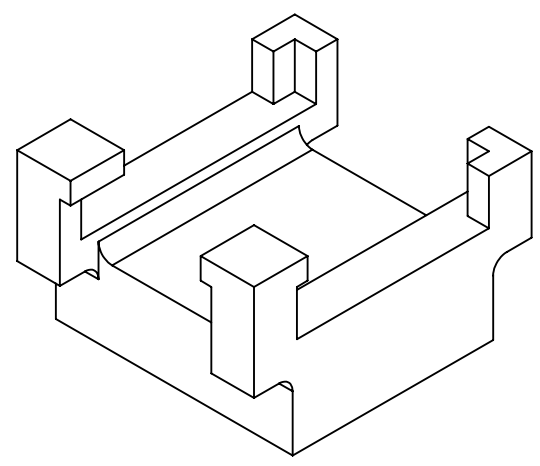
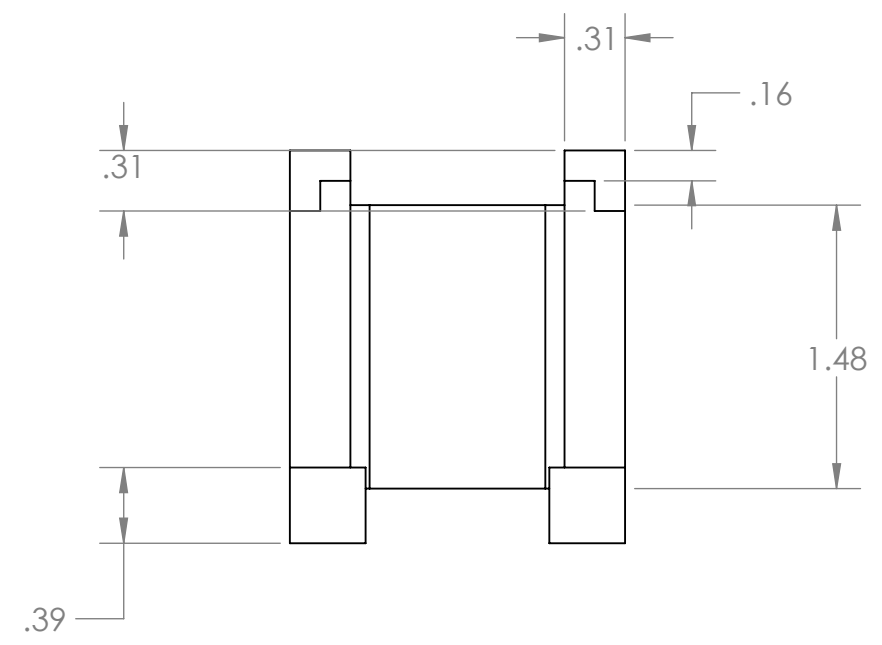
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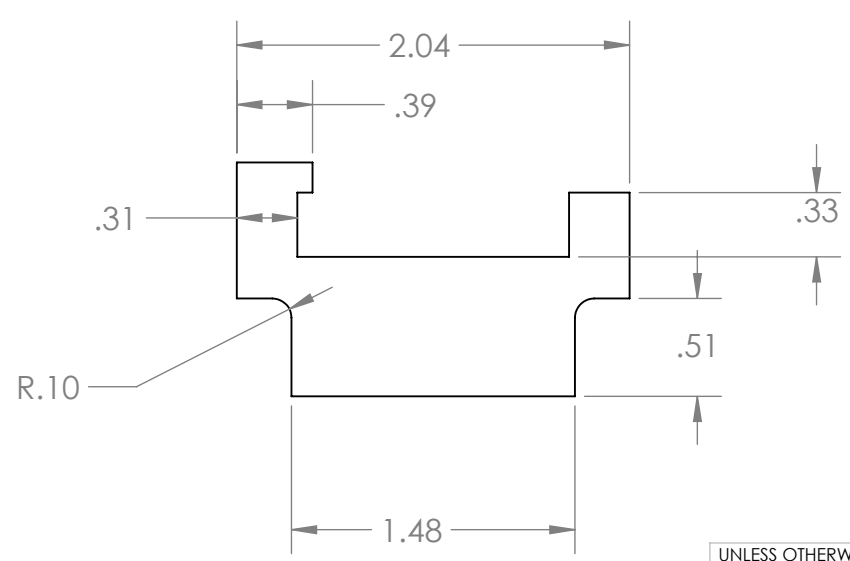
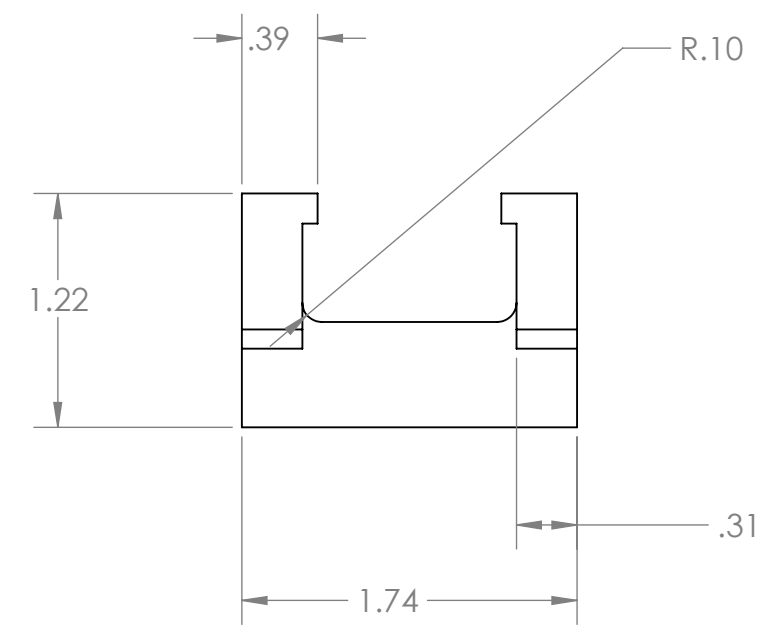
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UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL ±
 ANGULAR: MACH ± BEND ±
 TWO PLACE DECIMAL ±
 THREE PLACE DECIMAL ±
 INTERPRET GEOMETRIC
 TOLERANCING PER:
 MATERIAL
 PLA
 FINISH
 DO NOT SCALE DRAWING

Note:
 Qty: 1
 To be 3D printed

Group 9-MECH400B		
TITLE: Velox V50A Housing 3D Print		
SIZE B	DWG. NO. N-03	REV
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

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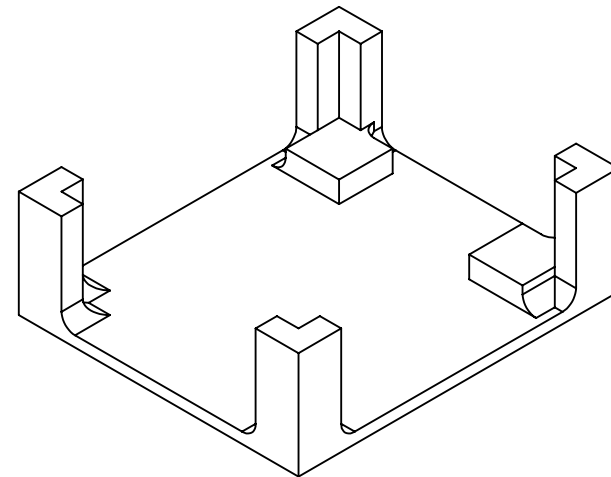
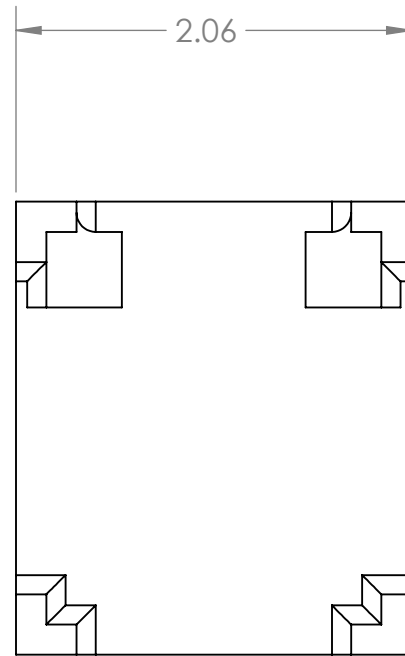
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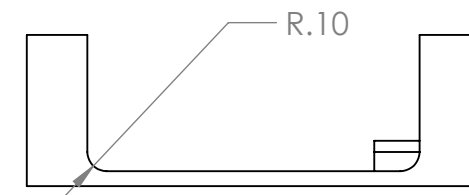
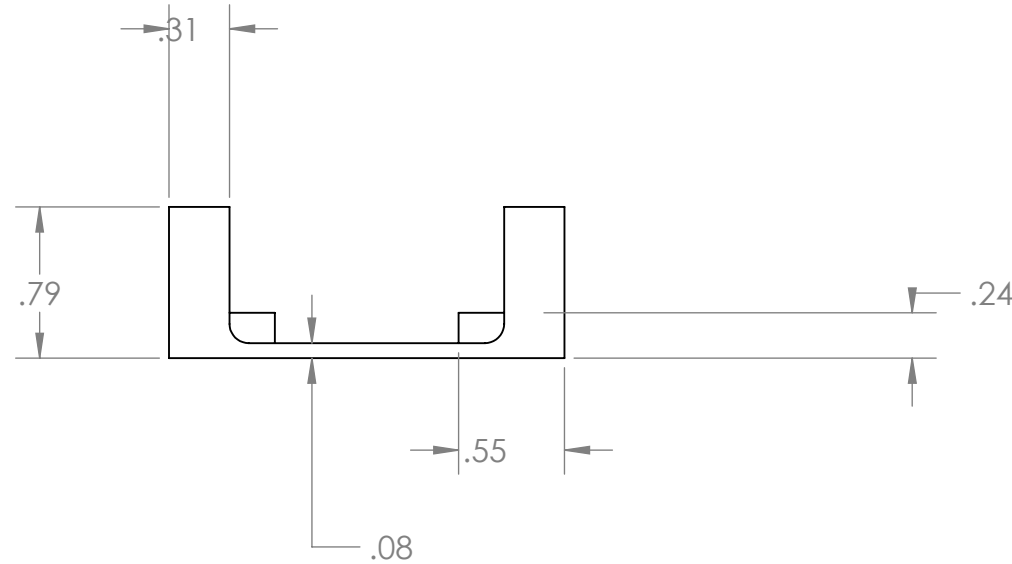
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UNLESS OTHERWISE SPECIFIED:		
DIMENSIONS ARE IN INCHES		
TOLERANCES:		
FRACTIONAL ±		
ANGULAR: MACH ± BEND ±		
TWO PLACE DECIMAL ±		
THREE PLACE DECIMAL ±		
INTERPRET GEOMETRIC TOLERANCING PER:		
MATERIAL	SIZE	DWG. NO.
PLA	B	N-03
FINISH	SCALE: 1:1	WEIGHT:
DO NOT SCALE DRAWING		SHEET 1 OF 1

Note:
Qty: 1
To be 3D printed

Group 9-MECH400B

TITLE:
Velox V50A Cap
3D Print

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“Crisp schematics and drawings”

Appendix B: Motor Data and Scoring

The motor selection process focused on finding a balance between performance, efficiency, and compatibility with the overall system requirements.

Grading Scale

Table 10: Motor Score Break Down

KV	
1	< 200
2	< 300
3	< 400
4	< 500
5	< 600
6	< 700
7	< 800
8	< 900
9	< 900
100% VERTICAL THRUST	
4	< 1300
3	< 1500
2	< 2000
1	> 2000
50% VERTICAL THRUST	
1	< 3750
2	< 5000
3	< 6250
4	> 6250
COST	
1	< 60
2	< 80
3	< 90
4	< 100
5	< 110
6	< 120
7	< 130
8	> 130
WEIGHT	
1	< 100
2	< 200
3	< 300
4	< 400
5	> 400
SCORE Range	
9	good
21	bad

Motor specifications provided by companies analyzed and scored

MECH 400B – Capstone Design Project

Midterm Report: SAR Drone Project

Table 11: Motor Evaluation

cost	Home	WEIGHT (g)	100%	50%	Propeller D	Propeller P	# of Blades	KV	KV2	COST	WEIG	100m2	50%2	FINALSCORE
45.99	XING2 3110 FPV CineLifter Motor	77	4013.8	1902.9	8	4	3	900	8	1	1	3	2	15
45.99	XING2 3110 FPV CineLifter Motor	77	3742.3	1891.4	8	4	3	1250	9	1	1	4	2	17
45.99	XING2 3110 FPV CineLifter Motor	77	3869.9	2632.6	8	4.5	3	1250	9	1	1	3	4	18
45.99	XING2 3110 FPV CineLifter Motor	77	4311.4	1632.5	9	5	3	900	8	1	1	3	3	16
29.99	GEPRC EV3115	115	4032	1665	10	5	HOPROD mq 10-5	960	8	1	2	3	3	17
56.9	T-MOTOR V3120	146.7	3929	1120	10.5	3	2	500	5	1	2	3	1	12
56.9	T-MOTOR V3120	146.7	5837	2376	10.5	3	2	500	5	1	2	1	4	13
56.9	T-MOTOR V3120	148.1	3936	1216	10.5	3	2	700	7	1	2	3	1	14
56.9	T-MOTOR V3120	148.1	6028	2045	10.5	3	2	700	7	1	2	2	4	16
92.9	XC5500 CRIMSON brushless motor	324	3976	1202	12	8	3	505	5	4	4	3	1	17
92.9	XC5500 CRIMSON brushless motor	324	3986	1202	12	8	3	505	5	4	4	3	1	17
92.9	XC5500 CRIMSON brushless motor	324	5186	1646	12	8.5	2	505	5	4	4	2	3	18
92.9	XC5500 CRIMSON brushless motor	324	6119	1983	12	8	3	505	5	4	4	2	3	18
92.9	XC5500 CRIMSON brushless motor	324	6119	1983	12	8	3	505	5	4	4	2	3	18
92.9	XC5500 CRIMSON brushless motor	321	5089	1770	12	8	3	635	6	4	4	2	3	19
92.9	XC5500 CRIMSON brushless motor	324	5186	1646	13	6.5	2	505	5	4	4	2	3	18
92.9	AT3530 3D Fixed Wing Airplane Long Shaft Brushless Motor	298	4022	1653	13	8	2	580	5	4	3	3	3	18
92.9	XC5500 CRIMSON brushless motor	324	4382	1586	13	12	3	505	5	4	4	3	3	19
92.9	XC5500 CRIMSON brushless motor	324	4382	1586	13	12	3	505	5	4	4	3	3	19
92.9	XC5500 CRIMSON brushless motor	321	4579	1481	13	6.5	2	635	6	4	4	3	2	19
79.99	AT3520 Long Shaft Fixed Wing Uav Power	218	4116	1408	14	7	2	650	5	2	3	3	2	15
89	X4219 VTOL Airplane Drone Motor	285	4425	1413	14	7	2	600	6	3	3	3	2	17
81.99	AT3520 Long Shaft Fixed Wing Uav Power	221	3354	1469	14	7	2	650	5	2	3	3	2	16
80.99	AT3520 Long Shaft Fixed Wing Uav Power	219	4316	1583	14	7	2	720	7	3	3	3	3	19
100.99	AT3530 3D Fixed Wing Airplane Long Shaft Brushless Motor	298	4085	1795	14	7	2	580	5	5	3	3	3	19
120.99	AT4130 3D Fixed Wing Airplane Long Shaft Brushless Motor	405	6283	1796	14	7	2	300	3	7	5	1	3	19
109.99	AT4120 Long Shaft 3D Fixed Wing Airplane Power	300	4909	1832	14	7	2	560	5	5	4	3	3	20
89	X4219 VTOL Airplane Drone Motor	284	5801	1723	15	8	2	270	2	3	3	3	3	18
109.99	AT4120 Long Shaft 3D Fixed Wing Airplane Power	305	5909	1602	15	10	2	250	2	5	4	2	2	16
109.99	AT4120 Long Shaft 3D Fixed Wing Airplane Power	304	5504	1574	15	8	2	250	2	5	4	2	3	16
89	X4219 VTOL Airplane Drone Motor	286	4913	1589	15	8	2	550	5	3	3	3	3	17
115.99	AT4125 3D Fixed Wing Uav Long Shaft Brushless Motor	350	5838	1631	15	8	2	250	2	6	4	2	3	17
89	X4219 VTOL Airplane Drone Motor	285	4952	1812	15	8	2	600	6	3	3	3	3	18
109.99	AT4120 Long Shaft 3D Fixed Wing Airplane Power	305	4670	1701	15	10	2	500	5	5	4	3	3	20
109.99	AT4120 Long Shaft 3D Fixed Wing Airplane Power	305	4714	1603	15	8	2	500	5	5	4	3	3	20
109.99	AT4120 Long Shaft 3D Fixed Wing Airplane Power	300	5580	2168	15	8	2	560	5	5	4	2	4	20
120.99	AT4130 3D Fixed Wing Airplane Long Shaft Brushless Motor	405	7787	2342	15	8	2	300	3	7	5	1	4	20
115.99	AT4125 3D Fixed Wing Uav Long Shaft Brushless Motor	355	5537	2205	15	8	2	540	5	6	4	2	4	21
94.88	5008 IPE V3.0 brushless motor	181	4403	1256	16	5.4	2	200	2	3	2	3	1	11
89	X4219 VTOL Airplane Drone Motor	284	3448	1448	16	8	2	270	2	3	3	1	4	13
89	X4219 VTOL Airplane Drone Motor	146	3788	1415	16	5.4	2	450	4	3	2	3	2	14
89-109	X4229 VTOL Airplane Drone Motor	397	6234	1811	16	8	2	230	2	3	4	2	3	14
109.99	AT4120 Long Shaft 3D Fixed Wing Airplane Power	306	6717	1899	16	8	2	250	2	5	4	1	3	15
89-109	X4229 VTOL Airplane Drone Motor	397	6182	1858	16	8	2	420	4	3	4	1	4	16
89	X4219 VTOL Airplane Drone Motor	286	5500	1987	16	8	2	350	3	3	3	2	3	16
115.99	AT4125 3D Fixed Wing Uav Long Shaft Brushless Motor	350	7058	2303	16	8	2	250	2	6	4	1	3	16
115.99	AT4130 3D Fixed Wing Airplane Long Shaft Brushless Motor	406	6586	1744	16	8	2	230	2	6	5	1	3	17
109.99	AT4120 Long Shaft 3D Fixed Wing Airplane Power	305	5967	2123	16	8	2	500	5	5	4	2	4	20
115.99	AT4125 3D Fixed Wing Uav Long Shaft Brushless Motor	355	6618	2380	16	8	2	540	5	6	4	1	4	20
76-80	5008 IPE V3 brushless motor	141	3850	1192	17	5.8	2	170	1	2	2	3	1	9
84-88	5010 IPE V3.0 brushless motor	181	5181	1570	17	5.8	2	200	2	3	2	2	3	12
84-88	5010 IPE V3.0 brushless motor	176	3900	1312	17	5.8	2	370	3	3	2	2	2	13
76-80	5008 IPE V3 brushless motor	141	4072	1371	17	5.8	2	450	4	2	2	3	2	13
89-109	X4229 VTOL Airplane Drone Motor	397	7036	2364	17	10	2	230	2	3	4	1	4	14
89-109	X4229 VTOL Airplane Drone Motor	397	6411	2398	17	10	2	420	4	3	4	1	4	16
120.99	AT4130 3D Fixed Wing Airplane Long Shaft Brushless Motor	405	6577	1903	17	10	2	300	3	7	5	1	3	19
120.99	AT4130 3D Fixed Wing Airplane Long Shaft Brushless Motor	408	7630	2285	17	10	2	230	2	7	5	1	4	19
120.99	AT4130 3D Fixed Wing Airplane Long Shaft Brushless Motor	408	6584	2362	17	10	2	480	4	7	5	1	4	21
76-80	5008 IPE V3 brushless motor	142	4166	1150	18	5.7	2	240	2	2	2	3	1	10
76-80	5008 IPE V3 brushless motor	142	3926	1172	18	6.1	2	240	2	2	2	3	1	10
76-80	5008 IPE V3 brushless motor	141	4595	1406	18	6.1	2	170	1	2	2	3	2	10
76-80	5008 IPE V3 brushless motor	141	4790	1550	18	5.7	2	170	1	2	2	3	3	11
76-80	5008 IPE V3 brushless motor	136	3797	1259	18	6.1	2	340	3	2	3	1	4	11
76-80	5008 IPE V3 brushless motor	136	3994	1422	18	5.7	2	340	3	2	2	3	2	12
84-88	5010 IPE V3.0 brushless motor	176	4996	1681	18	5.7	2	470	3	3	2	3	3	14
84-88	5010 IPE V3.0 brushless motor	176	4553	1519	18	6.1	2	370	3	3	2	3	3	14
89-109	X4229 VTOL Airplane Drone Motor	397	7757	2514	18	8	2	400	4	3	4	1	4	16
120.99	AT4130 3D Fixed Wing Airplane Long Shaft Brushless Motor	405	7231	2061	18	8	2	380	3	7	5	1	4	20
120.99	AT5220A 20-25CC Airplane Fixed Wing Long Shaft Brushless Motor	465	6528	2215	18	10	2	380	3	8	5	1	4	21
120.99	AT4130 3D Fixed Wing Airplane Long Shaft Brushless Motor	408	7017	2556	18	8	2	450	4	7	5	1	4	21
134	AT5220A 20-25CC Airplane Fixed Wing Long Shaft Brushless Motor	465	6733	2367	18	8	2	380	3	8	5	1	4	21
76-80	5008 IPE V3 brushless motor	136	3924	1309	19	5.7	2	340	3	2	2	3	2	12
76-80	AT5220A 20-25CC Airplane Fixed Wing Long Shaft Brushless Motor	465	7916	2584	19	10	2	380	3	8	5	1	4	21
84-88	5010 IPE V3.0 brushless motor	177	4308	1413	20	6	2	310	3	3	2	3	2	13
84-88	5010 IPE V3.0 brushless motor	177	4866	1644	21	6.3	2	310	3	3	2	3	3	14
76-80	5008 IPE V3 brushless motor	142	4037	1400	22	7	2	240	2	2	2	3	2	11
84-88	5010 IPE V3.0 brushless motor	181	3717	1224	22	7	2	200	2	3	2	4	1	12
84-88	5010 IPE V3.0 brushless motor	181	4119	1332	22	7	2	240	2	3	2	3	2	12
84-88	5010 IPE V3.0 brushless motor	177	4939	1619	22	6.6	2	310	3	3	2	3	3	13
84-88	5010 IPE V3.0 brushless motor	177	4993	1869	22	7	2	310	3	3	2	3	3	14
84-88	5010 IPE V3.0 brushless motor	181	3983	1284	24	7.2	2	200	2	3	2	3	1	11
35.99	A8212 900KV CINEFLITER	75.53	4100	1450	GF1050-3R	HQ1050-3R	GF1050-3R	900	8	1	1	3	2	15
56.9	T-MOTOR V3120	146.7	6716	2227	HQ 1050-3	HQ 1050-3	HQ 1050-3	500	5	1	2	1	4	13
56.9	T-MOTOR V3120	148.1	5873	1892	HQ 1050-3	HQ 1050-3	HQ 1050-3	700	7	1	2	2	3	15
56.9	T-MOTOR V3120	146.7	7848	2884	HQ 1145-3	HQ 1145-3	HQ 1145-3	500	5	1	2	1	4	13
56.9	T-MOTOR V3120	146.1	8236	2910	HQ 1145-3	HQ 1145-3	HQ 1145-3	700	7	1	2	2	4	16

Top scored motors for our design is based off of over all score and smallest propeller length and best score.

Table 12: Top Motor selection

SCORE	Website	Name	KV	Voltage @ 100% Throttle	AMPS @ 100% Throttle	Amps for 4 motors	Voltage @ 254.842g	AMPS @ 254.842g	Amps for 4 motors
9	roboticscomponents.com	5008 IPE V3 brushless motor	170	47.72	14.89	59.56	26	0.40	1.60
10	roboticscomponents.com	5008 IPE V3 brushless motor	240	31.66	24.93	99.72	16	0.62	2.47
12	v3120-500kv-700kv-cinematic	T-MOTOR V3120	500	32	33.04	132.16	32	1.22	4.87
13	v3120-500kv-700kv-cinematic	T-MOTOR V3120	500	47	68.91	275.64	48	0.88	3.53
14	v3120-500kv-700kv-cinematic	T-MOTOR V3120	700	23	48.7	194.8	32	1.35	5.40

Appendix C: Battery Data and Scoring

The consistent values for our motor have been set to the values below.

Table 13: Battery Parameters

Battery Voltage	3.7	V
# of motors	4	
max discharge %	80%	
Flying Load %	15%	
AMPS from other	1.5	A

Flight time equations are as shown:

$$I_{\max \text{ full load}} = I_{\text{other}} + I_{\text{motor}} \times N_{\text{motors}}$$

$$I_{\text{flying load}} = I_{\max \text{ full load}} \times L_{\text{flying}}$$

$$t_{\text{flight}} = \frac{\frac{Q}{1000}}{I_{\text{flying load}}} \cdot 60$$

Q is the LiPo battery capacity in mAh

$$N_{\text{bat req}} = \left\lceil \frac{I_{\max \text{ full load}}}{\frac{QC_{\text{rate}}}{1000}} \right\rceil$$

$$W_{\max} = I_{\max \text{ full load}} \times V_{\text{bat nominal}}$$

Using the calculations above the parameters of the batteries can be found.

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Table 14: Battery Evaluation

		Voltage @ 100% Throttle (V)	AMPS @ 100% Throttle (A)	I _{max} Load A	I _{flying} load 30%					
		47.72	14.89	611	9.2					
		Name	Rated Capacity Ah Cbat	N _{bat} req	MIN flight time (min)	MAX Flight time (min)	time flight 80% (min)	V _{max} (V)	TOTAL COST	TOTAL WEIGHT
SCORE 9 Name 5008 IPE V3 brushless motor KV 170	4S Drone batteries	25	1	25	184	131	903.7	\$	358.00	1280
		28	1	28	183	147	803.7	\$	399.00	1430
	6S Drone batteries	10	3	10	66	52	1355.5	\$	747.00	2430
		12	2	12	79	63	1355.5	\$	578.00	1950
		16	2	16	105	84	1355.5	\$	730.00	2350
		20	2	20	131	105	1355.5	\$	895.00	3440
		22	1	22	144	115	1355.5	\$	508.00	1955
		25	1	25	164	131	1355.5	\$	539.00	1920
		28	1	28	183	147	1355.5	\$	599.00	2190
		30	1	29	197	157	1355.5	\$	639.00	2230
	32	1	31	210	168	1355.5	\$	679.00	240	
	35	1	34	229	183	1355.5	\$	729.00	2600	
	20	1	20	131	105	2711.1	\$	858.00	3089	
		Voltage @ 100% Throttle (V)	AMPS @ 100% Throttle (A)	I _{max} Load A	I _{flying} load 30%					
		31.68	24.33	101.2	15.2					
		Name	Rated Capacity Ah Cbat	N _{bat} req	MIN flight time (min)	MAX Flight time (min)	time flight 80% (min)	V _{max} (V)	TOTAL COST	TOTAL WEIGHT
SCORE 10 Name 5008 IPE V3 brushless motor KV 240	4S Drone batteries	25	2	15	99	79	369.0	\$	712.00	2560
		28	2	17	111	89	369.0	\$	795.00	2860
	6S Drone batteries	10	4	10	40	32	553.4	\$	936.00	3240
		12	3	7	47	38	553.4	\$	867.00	2925
		16	3	9	63	51	553.4	\$	1,095.00	3825
		20	2	10	79	63	553.4	\$	898.00	3440
		22	2	12	97	70	553.4	\$	1,038.00	3900
		25	2	15	99	79	553.4	\$	1,078.00	3840
		28	2	17	111	89	553.4	\$	1,188.00	4300
		30	2	18	119	95	553.4	\$	1,278.00	44520
	32	2	19	125	101	553.4	\$	1,358.00	4600	
	35	1	21	138	111	553.4	\$	729.00	2600	
	20	2	12	79	63	1106.9	\$	1,796.00	6178	
		Voltage @ 100% Throttle (V)	AMPS @ 100% Throttle (A)	I _{max} Load A	I _{flying} load 30%					
		32	33.04	153.7	20.0					
		Name	Rated Capacity Ah Cbat	N _{bat} req	MIN flight time (min)	MAX Flight time (min)	time flight 80% (min)	V _{max} (V)	TOTAL COST	TOTAL WEIGHT
SCORE 12 Name T-MOTOR V3120 KV 500	4S Drone batteries	25	2	11	75	60	489.0	\$	712.00	2560
		28	2	13	84	67	489.0	\$	798.00	2860
	6S Drone batteries	10	4	10	30	24	733.5	\$	1,444.00	4460
		12	4	5	36	29	733.5	\$	1,156.00	3900
		16	3	7	48	38	733.5	\$	1,095.00	3825
		20	3	9	60	48	733.5	\$	1,347.00	5160
		22	3	10	66	53	733.5	\$	1,527.00	5885
		25	2	11	75	60	733.5	\$	1,078.00	3840
		28	2	13	84	67	733.5	\$	1,188.00	4300
		30	2	13	90	72	733.5	\$	1,278.00	44520
	32	2	14	96	77	733.5	\$	1,358.00	480	
	35	2	16	105	84	733.5	\$	1,458.00	5200	
	20	2	9	60	48	1457.0	\$	1,796.00	6178	
		Voltage @ 100% Throttle (V)	AMPS @ 100% Throttle (A)	I _{max} Load A	I _{flying} load 30%					
		47	68.91	277.1	41.6					
		Name	Rated Capacity Ah Cbat	N _{bat} req	MIN flight time (min)	MAX Flight time (min)	time flight 80% (min)	V _{max} (V)	TOTAL COST	TOTAL WEIGHT
SCORE 13 Name T-MOTOR V3120 KV 500	4S Drone batteries	25	4	5	36	29	1019.9	\$	1,424.00	5120
		28	4	6	40	32	1019.9	\$	1,596.00	5720
	6S Drone batteries	10	8	2	14	12	4629.8	\$	2,490.00	800
		12	8	2	17	14	4629.8	\$	2,312.00	760
		16	6	3	20	18	4629.8	\$	2,194.00	7460
		20	6	4	24	23	4629.8	\$	2,248.00	800
		22	5	3	32	25	4629.8	\$	2,545.00	9775
		25	4	5	36	29	4629.8	\$	2,156.00	7680
		28	4	6	40	32	4629.8	\$	2,396.00	8600
		30	4	6	43	35	4629.8	\$	2,556.00	8940
	32	3	7	46	37	4629.8	\$	2,037.00	720	
	35	3	8	51	40	4629.8	\$	2,187.00	7800	
	20	3	4	28	23	3059.6	\$	2,694.00	9267.00	
		Voltage @ 100% Throttle (V)	AMPS @ 100% Throttle (A)	I _{max} Load A	I _{flying} load 30%					
		23	48.7	196.3	29.4					
		Name	Rated Capacity Ah Cbat	N _{bat} req	MIN flight time (min)	MAX Flight time (min)	time flight 80% (min)	V _{max} (V)	TOTAL COST	TOTAL WEIGHT
SCORE 14 Name T-MOTOR V3120 KV 700	4S Drone batteries	25	3	8	51	41	720.8	\$	1,068.00	3840
		28	3	9	57	46	720.8	\$	1,197.00	4290
	6S Drone batteries	10	7	3	20	15	4084.1	\$	1,174.00	6670
		12	6	4	24	20	4084.1	\$	1,734.00	6860
		16	6	5	33	26	4084.1	\$	1,826.00	6276
		20	4	6	41	33	4084.1	\$	1,796.00	6880
		22	3	7	45	36	4084.1	\$	1,527.00	5855
		25	3	8	51	41	4084.1	\$	1,617.00	5760
		28	3	9	57	46	4084.1	\$	1,797.00	6450
		30	3	9	61	49	4084.1	\$	1,917.00	66780
	32	3	10	65	52	4084.1	\$	2,037.00	720	
	35	2	11	71	57	4084.1	\$	1,459.00	5200	
	20	2	6	41	33	2162.3	\$	1,796.00	6178	

Appendix D: Structural Analysis Calculations

SkyCiv was used to populate beam diagrams and solve for bending moment and shear diagrams. Bending stress and shear force were then calculated per the following equations:

$$\sigma_y = \frac{Mc}{I}$$

$$\tau = \frac{F}{A}$$

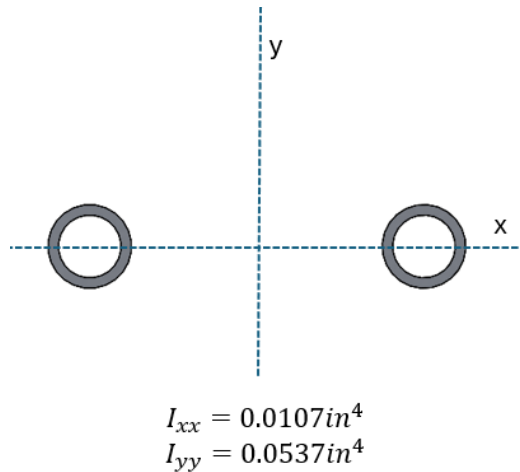


Figure 12: Area Moment of Inertia of Wing Tubes

Case 1 – Horizontal Flight

Since there is no taper lift can be assumed to have a rectangular distribution.

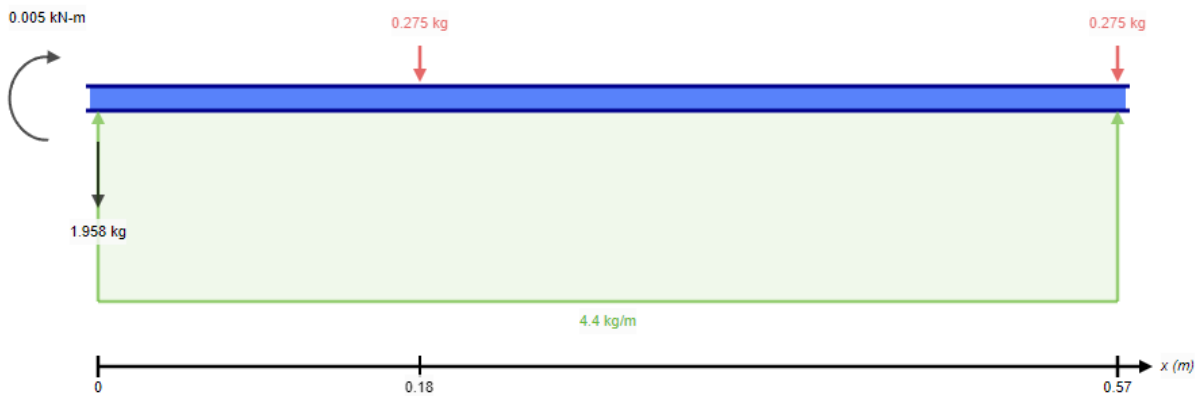


Figure 13: Wing Loading During Horizontal Flight at Cruise

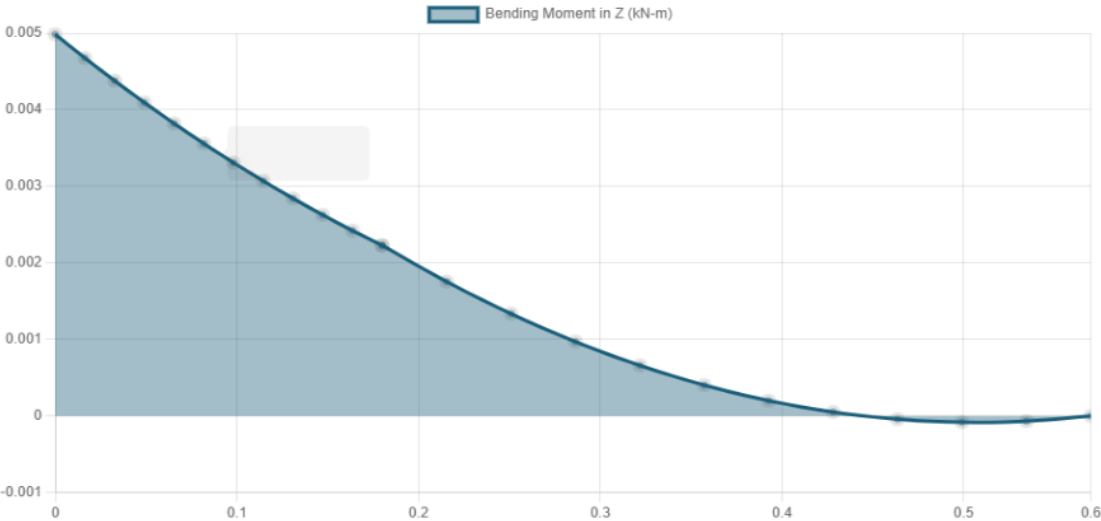


Figure 14: Bending Moment Diagram for Horizontal Flight

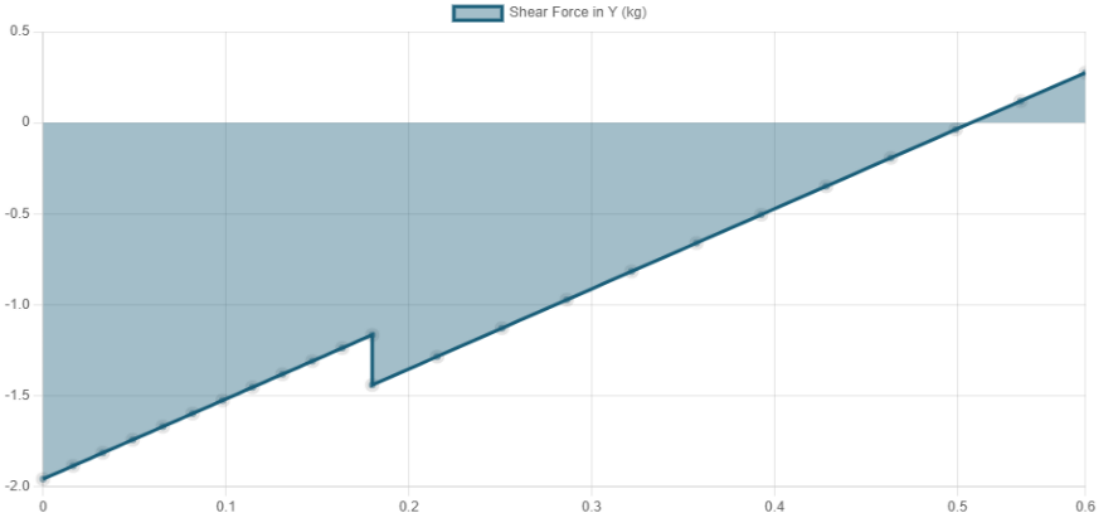


Figure 15: Shear Diagram for Horizontal Flight

$\sigma_y = 7.6 \text{ MPa}$

$\tau = 0.68 \text{ MPa}$

Case 2 – Vertical Acceleration:

In reality the reaction force would be 2.5kg, and therefore the aircraft would accelerate. The assumption of a 5kg reaction force shown in the beam diagram is conservative.

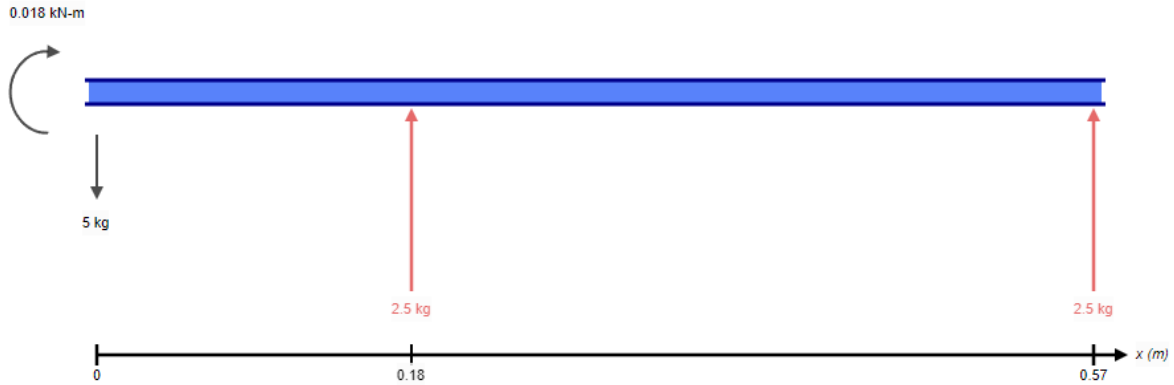


Figure 16: Wing Loading During Vertical Flight Acceleration

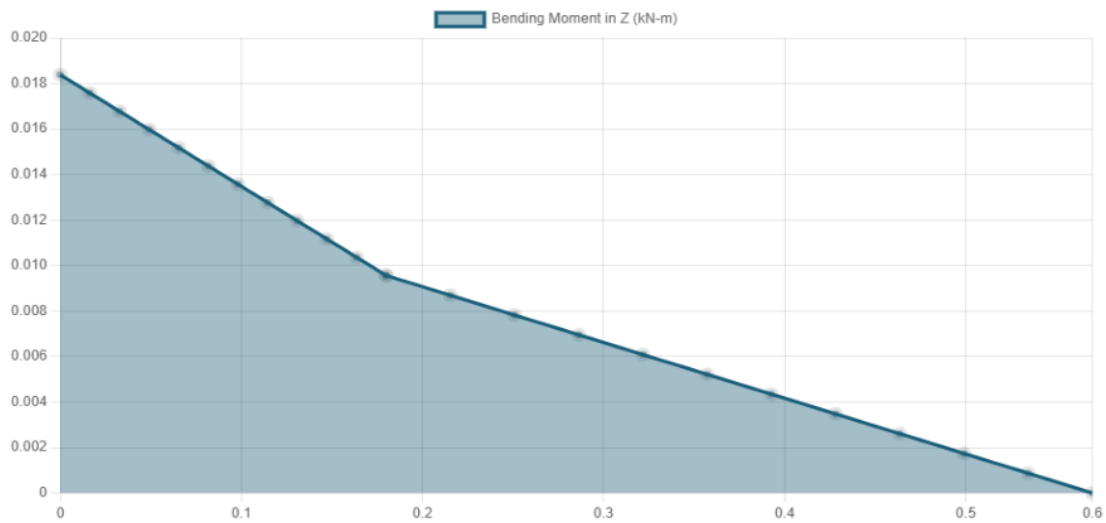


Figure 17: Bending Moment Diagram for Vertical Flight

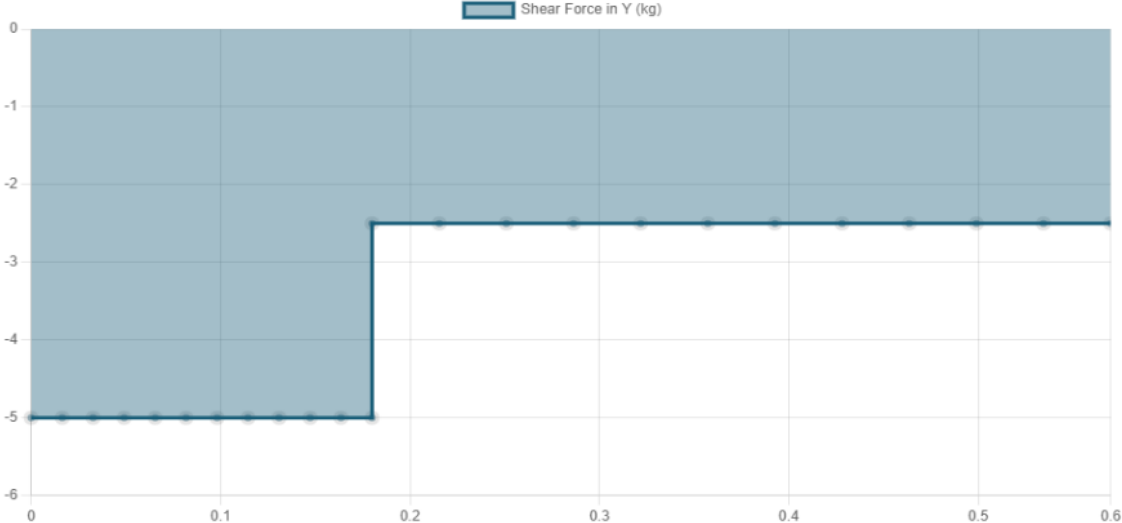


Figure 18: Shear Diagram for Vertical Flight

$\sigma_y = 27.5 \text{ MPa}$

$\tau = 0.85 \text{ MPa}$

Appendix E: ArduPilot Protocols

Ardupilot Peramiters		
Name	Protocol	Value
Motor & ESC Setup	RC_OPTIONS	32
	MOT_PWM_TYPE	5
	SERVO_DSHOT_ESC	2
	SERVO_BLH_OTYPE	5
	SERVO9_FUNCTION	33
	SERVO10_FUNCTION	35
	SERVO11_FUNCTION	34
	SERVO12_FUNCTION	36
	RCMAP_PITCH	2
	RCMAP_ROLL	1
	RCMAP_THROTTLE	3
	RCMAP_YAW	4
ELRS Receivers	SERIAL6_PROTICALS	23
	SERIAL6_OPTIONS	0
	SERIAL6_BAUD	115
	RSSI_TYPE	3
Radiomaster Transfer	FLMODE_CH	6
	RC5_OPTIONS	153
	RC7_OPTIONS	4
	RC8_OPTIONS	69
GPS	SERIAL4_PROTICALS	5
Micro OSD V2	SERIAL1_PROTICALS	1
	SERIAL6_BAUD	57
	OSD_TYPE	5