Senior Design 1 - Spring 2025 Detailed Design Report

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Total Effort 110 Hrs

Contents

1 Project Management

1.1 Organigram

The organigram highlighting the relevant organization structure and invested persons in this project can be seen in figure . There have been no changes in the organigram since the proposal of this project.

1.1.1 Mission Need Statement

Fly a predefined path for at least 10 minutes per flight, carrying and deploying two distinct sensor payloads in separate flights. The UAV must complete a flight without a payload, a stability test with a dummy payload, and two flights deploying the sensor packages to designated targets with predefined impact energy. Payloads must be interchangeable within one hour without substantial modifications to the airframe. The UAV must comply with FAA and NFPA regulations and operate safely under AMA guidelines.

1.1.2 Project Objective Statement

Demonstrate a fully functional, fixed-wing UAV capable of autonomous flight and payload deployment by completing four successful test flights. The UAV must be designed and built within three months by a team of four students, using commercially available components within a $2,750 budget provided by MCEC and the UofSC Honors College.

1.2 Gantt Chart

Figure in the appendix shows the Gantt chart as of March 31st, though behind the most optimistic schedule, ample time has been left as a buffer to ensure completion of the project by major deadlines.

1.3 Version Control

Version control was maintined through OneDrive. Major revisions of the project were put into new folder (v0.1-v0.4). OneDrive was left to handle minor versioning through the file history record. Below is a table briefly outlining the changes made between the 4 major versions.

Table 1: Table outlining the major versions of the aircraft and key changes.

Version v0.1	Initial design of aircraft without landing gear or detailed avionics layout
Version v0.2	Fueselage was changed to move the CG forward, the wings were lengthened to provide more lift
Version v0.3	Detailed interior fuselage layout was made, including hard points for various avionics devices
Version v0.4	Preliminary landing gear design was added and the tail boom was shortened

1.4 Requirements List

Requirements should be organized into separate sections so that necessary parts can be identified and progress can be effectively tracked. An easy way to visualize this is through a requirements tree that separates and identifies constraints and requirements attached to the project. Constraints include regulations like FAA or EPA compliance, while functional requirements are based on stakeholder expectations. The UAV requirements list can be found in figure .

1.5 Functional Breakdown Structure

Expected functions of the UAV must be identified before solutions can be determined. These functions represent problems that must be solved in order to satisfy customer expectations. The functional breakdown structure serves to represent these needed functions and can be found in figure . No substantial changes have been made to the FBS since the design proposal.

1.6 Functional Flow Diagram

The key difference between the FFD and FBS is that the FFD is organized in chronological order, all else is the same as the FBS. The FFD seeks to detail the functions of the UAV as it relates to the design mission. The FFD is made up of 4 main components such as propulsion, stability, payload management, and communication. The FFD can be found within figure . No substantial changes have been made to the FBS since the design proposal.

2 Functional and Constraint Requirements

Functional requirements are those that are necessary for the function of the proposed product. These requirements include key design considerations such as airworthiness. Constraints are limitations placed on a design that heavily influence the choices made in the design process. Some such constraints can be found in the necessity of our aircraft to follow FAA regulations and obtain proper pilot certification.

2.1 Killer and Secondary Requirements

Killer requirements are requirements that are vital for the fulfillment of the MNS and POS. Without these requirements being fulfilled, the project will fail. Similarly important but lower impact, secondary requirements are necessary to fulfill the killer requirements but are not innately required to fulfill the MNS and POS.

3 Detailed Design

3.1 Aerodynamics and Performance

A series aerodynamic calculations were performed to select the airfoil, predict aerodynamic performance and estimate range and endurance. The first class estimations were performed with elementary aerodynamic calculations and statistical models from similar aircraft. Some parameters had to be adjusted to make the predictions possible; namely, a cruise velocity of 25 m/s, take-off distance of 80 m, and a power loading of 0.08.

3.1.1 Airfoil Selection and Wing Design

To get reasonable lift and wing loading the NACA 2412 was chosen with a initial angle of attack of 6 deg relative to the fuselage. This give a Cl of of 1.05 and a cd of 0.02. A straight taper wing with an Oswald efficiency factor of 0.8 was chosen, with an aspect ratio of 4 and a taper ratio of 0.4. The wing span is 2.64 m with a root cord of 0.33 m. With this in mind a wing loading of 127.5 N/m^2 was selected.

Figure 1: A top down view of the wing assembly.

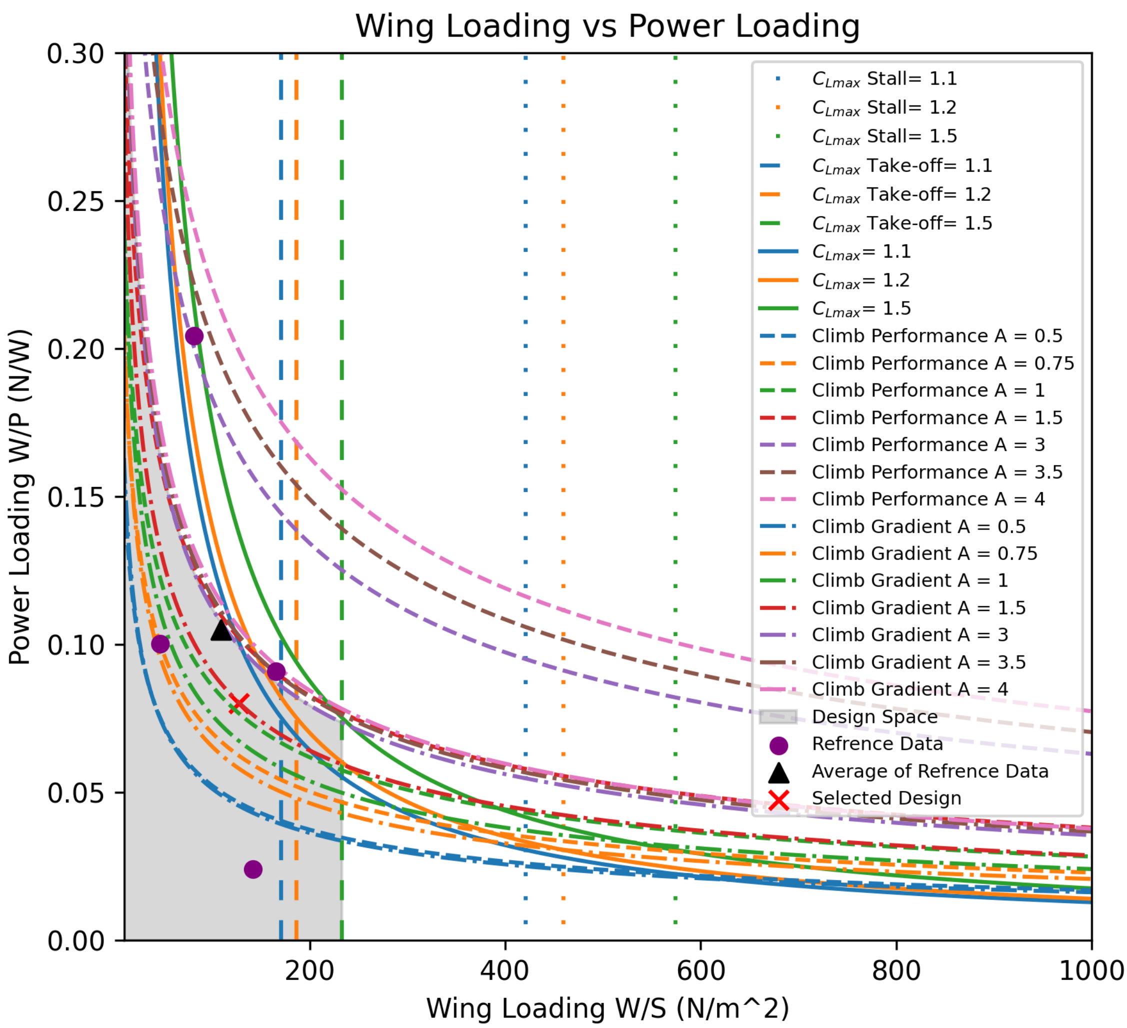


Figure 2: Wing loading vs power loading diagram for wing parameter selection.

3.1.2 Drag, Range and Endurance

Using the estimated drag from the wings and fuselage, the estimated endurance using a 16 Ah Battery at a cruise velocity of 20 m/s is 40 minutes with a range of 48 Km. Note the range is actually governed by FAA regulations to line of sight or generally 5 Km. A drag polar was calculated to predict the aircrafts' wings drag conditions, the given the exceptionally low speed of flight the fueselage is assumed to have minimal contribution.

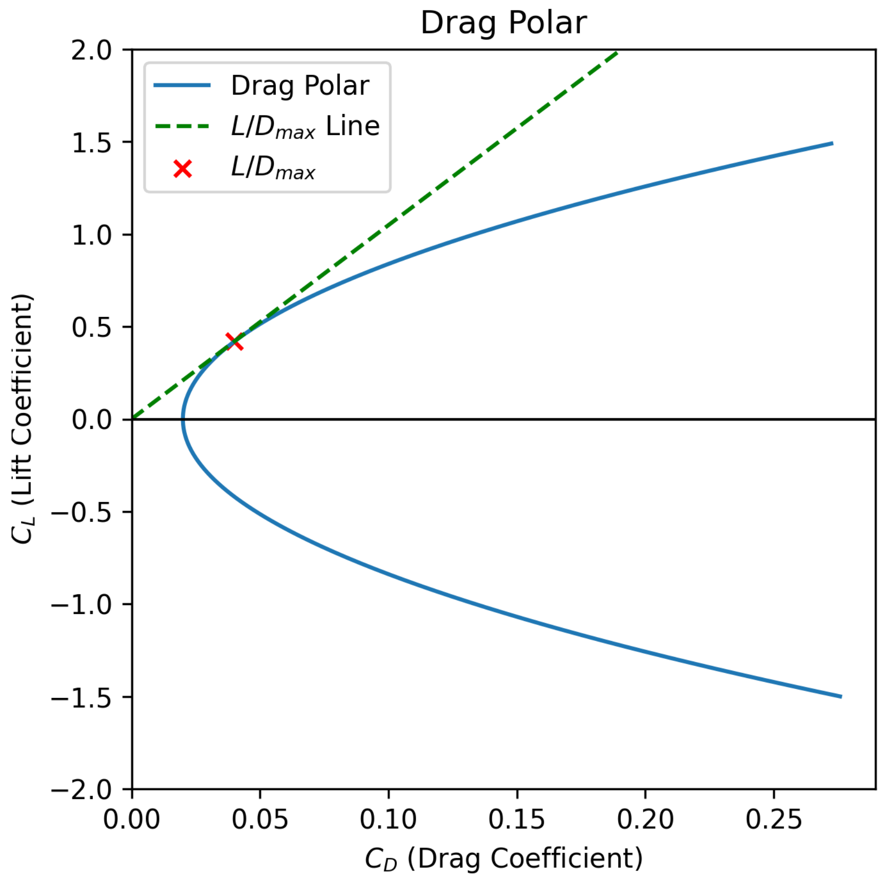


Figure 3: Drag polar.

3.2 Structural Design

The section below outlines the structural calculations used to make major decisions for the design of the UAV. Given the target demographic of novice pilots and rough take-off areas this UAV will use, substantial factors of safety were added to most sizing requirements, on the order of 5. The two highest loads in the aircraft are the Booms and Wing, in this design both boast a massive safety margin.

3.2.1 Wing Integrity

With a wing loading of only 127.5 N/m^2 the strength of the wing section was of minimal concern. To ensure structural integrity of the wing given their substantial length, aluminum spars were added. The spars are circular tubes with a nominal diameter of 19.05 mm the wall thickness is 2.79 mm. The spars were designed to support the weight of the tail which is cantilevered off of the wing section.

3.2.2 Boom Design

The tail is cantilevered off of the wing section by 1.12 m. With a tail weight of 1.5 Kg, the total bending moment is approximately 16.5 Nm.

The bending stress in the boom is given by:

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

where:

- $M = 16.5$ Nm (Bending moment)
- $c = \frac{D}{2} = \frac{26.67}{2}$ mm
- $I = \frac{\pi}{4}\left(\frac{D^4 - d^4}{D}\right)$ (Moment of inertia)
- $D = 26.67$ mm (Outer diameter)
- $d = D - 2t$, with $t = 0.11$ inches

The estimated necessary nominal diameter is 10 mm, a 26.67 mm boom was selected to allow for a substantial factor of safety and minimize aeroelastic effects.

3.2.3 Weight Estimation

With all of the major components selected a final high fidelity weight estimation was performed. The weight of the 3D printed components was calculated from the 3D printing slicer, the rest of the weights are the per-components weights from manufacturers. The table below outlines the full weight breakdown.

Component	Weight (Kg)
Fuselage and Wings	5.25
Avionics	0.24
ESC	0.25
Motor	0.6
Propeller	0.12
Landing Gear	0.85
Boom and Spar	2.50
Assorted Hardware	0.5
Total Weight	**10.31**

Table 2: Component Weights

The initial estimated ETOW was 10 Kg so the final design is in very good agreement, no further iterating is needed to accommodate the change in final weight. With a maximum thrust of 14.8 Kg and a maximum sustained thrust of 9 Kg the TWR will range from 1.44 to 0.873.

3.2.4 3D Printing

The objective of the design is to make an open source platform for sensor package deployment and environmental monitoring. To increase the accessibility of the design the fuselage manufacturing is done with 3D printing which has become a readily accessible manufacturing approach for all manners of rapid prototyping.

3.2.5 Shock Isolation

The GPS and flight controller are both rather sensitive to large shocks. To account for take off and landing vibrations, both are mounted on sizable shock absorbers.

3.2.6 Material Selection

To minimize weight a novel 3D printing filament was used for most aerodynamic parts of the fuselage. Traditional ASA filament is the go to choice for outdoor, high impact applications due to its great UV resistance and material properties. However with a density of 1.1 g/cm^3 it is quite heavy. ASA aero was chosen for the wings, and non-structural fuselage parts, ASA is 45-60% lighter while being 80% as strong in terms of stiffness bending modulus. The rest of the components are traditional ASA. As compared to an ASA only fuselage the ASA aero components reduces the reduces the weight from 7.5 Kg to 5.25 Kg.

3.2.7 Fuselage Design

The fuselage is made up of small 3D printable section that are pegged and epoxyed together. The nose houses a camera and a series of antennas, the front middle section houses the avionics, the rear middle houses the deployment mechanism and the battery the rear section houses the motor. Attached in the appendix are a series of figures showing the component layout.

3.2.8 Landing Gear Design

In the version discussed in this report the landing gear were designed with no structural analysis or thought. During testing they failed partially during a takeoff run. This was due to the epoxy used to hold the struts to the wing failing. Due to time constraints the landing gear have no yet been re-evaluated. However to outline the procedure that will be used to develop landing gear in the future; Static loading analysis will be used assuming 10G loading on the gear to simulate extreme impact on landing. This translates to 110 Kg total or approximately 27.5 Kg per wheel. With fastened, aluminum construction this is feasible. No adhesives will be used in the mounting of gear in the future. 20-20 aluminum extrusion has been proposed as a means of mounting in the future.

3.3 Subsystems

3.3.1 Avionics and Control Systems

Our avionics system consists of a Holybro Pixhawk 6X Autopilot H753 Flight Controller which communicates with a handheld TX16S controller. The Holybro was selected as it allows for an unparallel ease of integration due to its wide input selection and provides a higher level of redundancy than its competitors. The TX16S was selected for its relative simplicity, allowing for those who are novices in the field of drone piloting to learn how to control their aircraft relatively easily. Inputs from the controller are communicated via radio signal, onboard a TBS Crossfire Nano RX acts as the radio receiver while a TBS Crossfire TX transmits all relevant signals back to the controller. The TBS Crossfire Nano RX and TBS Crossfire TX were selected as they have an incredibly high rate of obstacle penetration combined with a lightweight and small power consumption, making them perfect for a fixed wing drone platform like ours. In addition to radio control, a live video feed is needed for long-distance guidance of the aircraft. Thus, a Walksnail Avatar HD Kit V2 video transmitter and camera will be installed within the aircraft nose. The Walksnail was chosen for our aircraft as it has a fairly low base latency and provides high-definition video footage for a competitive price.

Figure 4: A PixHawk flight controller module.

Figure 5: A Tx16S flight Controller.

3.3.2 Power Systems

The Power system of the aircraft is compromised of two integral parts, the Battery and the BEC. For our battery a 13000 Ah LiPo battery was chosen as it provides a sizable charge that can allow our aircraft to fly and complete its stated objectives while adding minimal excess load to the aircraft weight. The Maximum wattage ranges from 6300 W at max charge to 5550 W at nominal voltage.

3.4 Propulsion Systems

Due to the nature of its Mono-pusher design the aircraft is propelled by a single mono prop and mono motor propulsion system. The prop, a 22x10 falcon propeller, was selected for its large lift production, low weight, and low drag. All of these aspects combine to make the 22x10 falcon propeller ideal for fixed wing applications making it a perfect choice for our aircraft. For the motor a X7215 eVTOL Airplane Drone Motor was selected for its high efficiency allowing for a high torque output for a small power expenditure. In addition, it has a low KV rating of 160-200KV which aligns with our efficiency focused design outlook. Lastly the propulsion system is integrated into the power system of the aircraft using a AMPX 120A (5-14S) Drone ESC. The ESC was selected as it is designed for with LiPo integration in mind, making it a perfect match for our power system. In addition, the ESC is designed with rapid cooling in mind, allowing for increased efficiency in torque production, further aligning with our low weight high endurance design philosophy.

Figure 6: A figure of the selected motor.

3.4.1 Wiring Diagram

The figure below outlines the standard pixhawk ecosystem.

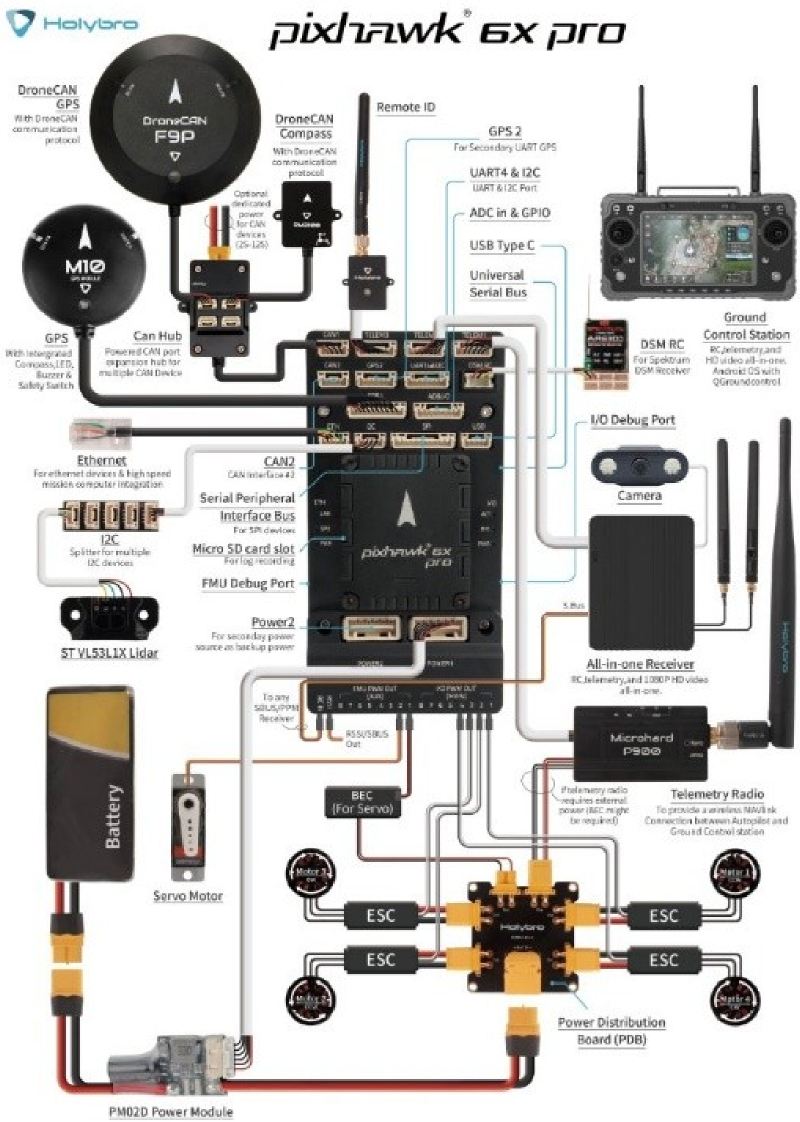


Figure 7: A picture of the standard PixHawk Ecosystem.

4 Component Power Consumption and Cost

The table below outlines the cost and power consumption of every major component in the UAV. The vast majority of the power is consumption comes from the motor with the VTx also contributing some.

Part Name	Power Consumption (W)
Holybro Pixhawk 6X Autopilot	9
Holybro 500mW SiK Radio	0.5
Walksnail Avatar HD Kit V2	25.2
MATEKSYS Micro BEC	0
TBS Crossfire Nano RX	8
TBS Crossfire TX	0
TX16S	0
KST DS215MG (4x)	67.2
300mm Servo Extensions (4-pack)	0
X7215 eVTOL Motor	3600
22x10 Falcon Propeller	0
AMPX 120A ESC	0
Bambu ASA Aero	0
Boom	0
Landing Gear	0
Spar	0
Max Total Power Consumption	3709.9

Table 3: Component Power Consumption

Part Name	Cost (USD)
Holybro Pixhawk 6X Autopilot	470.89
Holybro 500mW SiK Radio	76.51
Walksnail Avatar HD Kit V2	187.14
MATEKSYS Micro BEC	17.66
TBS Crossfire Nano RX	41.14
TBS Crossfire TX	170.67
TX16S	235.40
KST DS215MG (4x)	164.73
300mm Servo Extensions (4-pack)	12.95
X7215 eVTOL Motor	222.45
22x10 Falcon Propeller	104.75
AMPX 120A ESC	76.51
Bambu ASA Aero	176.55
Boom	48.30
Landing Gear	26.00
Spar	33.69
Total Cost	2065.34

Table 4: Component Cost

5 Risks and Mitigation

5.1 Risk Assessment

While individual items from the requirements section, such as proving cooling capabilities or control surface controllability, are not specifically stated, the tests are constructed in such a way that their compliance will be verified nonetheless. The risk map for our aircraft design shows the most significant risks, measured on a scale of severity and likelihood. These risks are addressed through focused mitigation strategies.

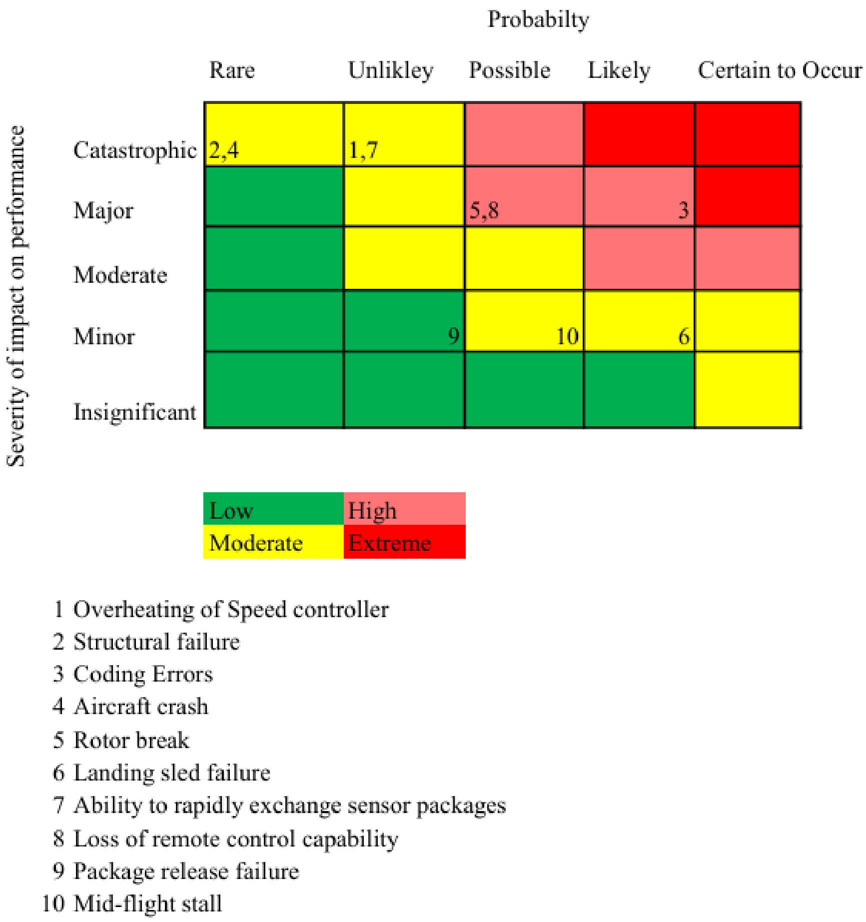


Figure 8: Risk Map for selected configuration.

5.2 Testing Campaign for Compliance

The proposed aircraft design must be shown to comply with all previously stated requirements and constraints. To allow for compliance to be demonstrated, the following testing campaign was generated:

1. **Take-off and landing flights:**
   Proves take-off capabilities.

2. **Five-minute flights with no package:**
   Proves aerodynamic capabilities.

3. **Thirty-minute flights with dummy package:**
   Proves aircraft endurance and capacity.

4. **Two minimum 10-minute flights with dummy package swap in between:**
   Proves interchangeability of packages.

5. **Two minimum 10-minute flights with real sensor packages swapping in between:**
   Proves final product requirement compliance.

5.3 Risk Mitigation Approach

The process of mitigating each possible risk varies greatly with respect to the nature of the risk in question. However, the core approach to all risks is to design, test, and iterate to reduce risk as much as possible. For example:

1. Risks such as rotor failure or coding failure can be mitigated by extensive pre-flight testing.

2. Concerns like speed controller overheating were mitigated through iterative design and the inclusion of a heat sink.

5.4 Identified Risks During Testing

During testing, we experienced failures in two of the acknowledged risk sections:

1. Structural Failures: The aircraft suffered catastrophic structural failures in the ailerons and landing gear. Transit caused these failures, as the structure was not robust enough for transport.

2. Landing Gear Failures: The landing gear was insufficiently rigid to provide a stable platform for takeoff and landing.

5.5 Failure to Mitigate Landing Gear Risk

While the failure of the ailerons and wings occurred during transit, the primary failure during testing was the landing gear, which was not properly designed to handle the expected loads.

6 Manufacturing

6.1 Wings

The wings were manufactured using ASA Aero 3D printing filament. This filament provided the necessary strength to support the calculated flight loads. Despite the advantages, the printing process was time-consuming, requiring two weeks of continuous printing.

Figure 9: Table outlining the methods tested for fastening components of the assembly.

6.2 Fuselage

The fuselage was made using ASA Aero filament as well, with components printed separately and joined using plastic welds and wooden dowels. Mounting brackets were also printed and bonded inside the fuselage to allow the attachment of the wing box. However, some of these solutions failed, and steel cable was used to ensure proper assembly.

6.3 Tail

The tail was constructed from PLA filament due to insufficient ASA Aero filament availability. This material choice impacted weight but was necessary to meet project timelines.

6.4 Construction Techniques Tested

Several assembly methods were tested, including:

1. Wooden dowels (epoxied)
2. Plastic welds
3. Steel rods
4. 3D printed fasteners
5. Epoxy

Each method has been evaluated for its performance, with wooden dowels and steel rods proving most effective for structural integrity. Plastic welding was insufficient for bending loads as demonstrated by the wing tip failure. Figure 9 outlines the tested methods.

6.5 Final Weight

Component	Weight (Kg)
Fuselage and Wings	5.25
Avionics	0.3
ESC	0.5
Motor	0.6
Propeller	0.12
Landing Gear	0.85
Boom and Spar	2.50
Assorted Hardware	1.0
Total Weight	**11.12**

Table 5: Component Weights

The final weights were only notably higher for the ESC and assorted hardware. The weight of the high amperage wires used by the ESC caused an increase, the assorted hardware was also higher than expected. The avionics was only marginally heavier due to wiring. The total weight was 11.12 Kg which was approximately 7% off from the high fidelity weight estimation. The maximum and sustained TWR would therefore be 1.33 and 0.81 respectively.

7 Initial Testing and Evaluation

7.1 Avionics Test

An avionics test was conducted to ensure all control systems functioned as expected. The following items were tested during the avionics test:

1. Ailerons were deflected from -15 to 15 degrees, successfully
2. The V-tail control surfaces were deflected -12 to 12 degrees, successfully
3. The Camera was powered and video was streamed 20 meters for a duration of 10 minutes before failing due to heat, after the planned heat sink was added the camera was tested for 30 minutes without fail.
4. The Primary GPS was tested to ensure accuracy, after 1 second of fixing, the location was accurate to one meter.
5. The Compasses were tested and each were accurate to the the limit of the testing bench, 0.1 degrees.
6. RC antenna the RC antenna was tested to 300 meters while in line of sight, successfully
7. The telemetry radio was tested to 300 meters while in line of sight, successfully
8. The remote transmitter was tested to 300 meters while in line of sight successfully

7.2 Propulsion Test

The propulsion system was tested under various conditions to verify thrust and efficiency.

7.3 Control Surface Tests

The control surfaces were tested to ensure responsiveness and stability in the air.

8 On-site Testing

8.1 Taxiing Test

The testing campaign highlighted critical failures within the design. First and foremost was the structural failure of the landing gear. Due to resource limitations and structural hazards presented by welding next to 3D printed material, the aluminum spars which supported the aircraft landing gear were unable to be properly secured using strong methods of attachment like aluminum welding. Due to this constraint, a mixture of 3D printed adapters and epoxy glue were used to secure these mission-critical aircraft structures. Before the physical testing campaign, this did not present any serious issues, and it was found that during payload interchangeability, avionics, and static propulsion tests, the landing gear was structurally adequate. Thus, the product was found to be compliant with requirements 5, 6, and 7. Outside of these requirements, however, all others were not met.

The first major failure of the product was identified following a runway taxi test. The motor was spun up to full throttle, and the aircraft was allowed to drive down a dirt road by its own power. After reaching around 30 miles an hour, it was deemed more than capable of this task, and the engines were throttled down and the power disconnected. During transport back to the lab, serious structural issues presented. First and foremost, the front two landing gear, which were secured through epoxy, fell off. Due to the stress put on the landing gear from the weight of the aircraft, vibration from throttling the motor to full power, and suboptimal testing runway conditions, the epoxy was stressed to failure. It would be known by the team at this time, but this failure would not be recoverable. As the epoxy failed, the aluminum spars levered themselves into the aircraft wing, shearing off much of the 3D printed material, which would have held them in place while the epoxy was allowed to cure. As a result, the front two landing gear would not recover to an operational capacity during the testing campaign.

8.2 Transport

Following the initial taxi test, the rear landing gear was also reinforced through the addition of steel support wiring. However, during transport to the flight test location, the stress of transport resulted in a shear failure of one of the 3D printed adapters, which fastened the left rear landing gear to the aircraft. This left the entire landing gear system nonoperational, leading to an inability to safely perform a flight test. As a result of these failures, the product was non-compliant with requirements 1, 2, and 3.

8.3 Payload Attachment Mechanism

Additionally, during the initial taxiing test, issues with the operability of the magnetic payload mounting system were reported. Upon closer inspection, it was found that the internal circuitry of the system had corrupted at some undetermined point between the parts acquisition and its installation. This failure occurred too late in the engineering process for any alternative system to be implemented. Thus, concerning requirement 4, the product failed to meet compliance.

8.4 Additional Failures

In addition to these critical failures, additional lesser failures also occurred that likely would have further hindered the product's ability to meet compliance requirements.

8.4.1 Wing Tips

First, concerning the wing, the internal aluminum spar used to support the wing structure did not extend all the way through the wing tips of the aircraft. As a result of the wing tips lacking any internal support, during a wingtip stress test, the plastic weld which bonded the tip to the rest of the wing failed, leading to the detachment of the wing tip. This detachment also rendered the ailerons inoperable, as the wing tip held the control pin in place for the aileron servo.

8.4.2 Ailerons

As previously mentioned, the transport of the product to the flight-testing location put incredible strain on the product. In addition to the failure of the rear landing gear, the ailerons also saw failure because of transport stress. The ailerons were each constructed from two separate 3D printed parts that were plastic welded together; this plastic weld failed due to the transport stresses, rendering the ailerons unsafe for operation.

8.4.3 Tail

Due to a lapse in foresight during the printing process, normal ASA instead of lightweight ASA was used in the printing process of the tail and its control surfaces. This resulted in the tail being heavier than initially anticipated, resulting in a sizable movement of the aircraft's center of gravity (CG) to the rear. This CG movement was to such a degree that aircraft stability in flight would have likely been lost shortly after takeoff. This would thus have resulted in a flight failure and crash of the aircraft, leading to a failure of compliance even if the landing gear issues had not been present.

9 Safety Approach

The following safety risks were determined to be the most probable and catastrophic.

1. Battery fire safety
2. Safety regarding the high power motor

9.1 LiPo Safety

LiPo's are known to be prone to lighting fire under a few circumstances:

1. Water Exposure
2. Electrical Shorting
3. Cell Puncturing
4. Charging Malfunction

Several methods were used to mitigate the risk, however the primary method to ensure safety was flying the prototype plane in uninhabited, clear cut land. Future versions would include multiply redundant methods.

1. **Water Exposure: The high amperage connections were water proofed and the cells the battery are water proofed behind several layers of plastic**
2. **Electrical Shorting: Wires between the motor, mother board and battery were insulated with several redundant methods, primarily consisting of heat shrinking tubes and XT60 connections with builtin insulators.**
3. **Cell Puncturing: The battery was protected from puncturing with plastic wrapped sections and was securely mounted in the fuselage which is 15 mm thick.**
4. **Charging Malfunction: LiPo's can on rare occasion cook off due to faulty charges, to minimize fire risk, LiPo safe fire bags were used when charging.**

9.2 Motor Safety

The motor, being rather strong, requires special attention when testing and operating it. For testing the propeller was taken off so that throttling could be done on benchtop. When operating a triply redundant arming system is used. The GPS possesses and Arm/Disarm Switch, the drone also needs to be armed and unsafed through a ground station before flight. To tell ground crews when the plane is safe, the motor beeps when disabled. The twin boom, as a consequence of its design also acts as a safety envelope, substantially reducing the risk of the prop striking personnel in the unlikely event of a motor run-away.

10 Standards and Codes

10.1 FAA

All FAA regulations concerning the operation of our product are detailed in FAA code 44809 part 107. The drone is required to remain under 55 lbs, to fly under a 400ft altitude, to always fly within line of sight, and maintain a ground speed below 100 mph. Additionally during operation the aircraft is required to yield to all other in the flight area. Additionally, the aircraft is required to be registered with the FAA and operators need to complete the TRUST or (The Recreational UAS Safety Test) before operating the aircraft. Additional limitations exist concerning the operation of the aircraft in controlled airspace, in heavily populated areas, moving vehicles, and during the nighttime, however the necessary scope of testing does not put the aircraft in any situation where these would be present.

10.2 Fire Codes

In order to remain within local fire codes, the following precaution were taken. No operation of the vehicle will occur in the case of a malfunction LiPo battery or other electrical system malfunction. Launches were also not conducted within areas of large dry vegetation which are prone to rapid combustion when introduced to significant heat sources (electrical short, UAV crash, etc.). Additionally in the case of a TFR due to wildfire or red flag warning all flight operations would be halted until these restrictions are lifted. Lastly during testing two fire extinguishers would be present for rapid fire suppression and any all-flammable materials would be cleared from the testing area before any testing could begin.

11 Product Evaluation

In the following section the product will be evaluated through addressing success and failures to meet previous compliance thresholds as well as critically analyzing areas of the engineering and manufacturing process that did not meet team expectations. By reviewing these failures and highlighting the successes of the product we can come to a better understanding of the origins of critical compliance failures and highlight the strengths that led to compliance successes.

11.1 Compliance Verification Table Post Test

Below is a table outlining the major project requirements and their status. Many will need to be tested on site.

Number	Requirements	Method of Compliance	Compliance
1	Fly predefined path for at least 10 minutes without a payload	Flight tests	Fail
2	Complete a stability test with a dummy payload	Flight tests	Fail
3	Carry and deploy two distinct sensor payloads in separate flights	Flight tests	Fail
4	Payload interchangeability within one hour, no substantial modifications	Ground tests	Fail
5	Comply with FAA regulations	Design Review	Comply
6	Comply with NFPA regulations	Design Review	Comply
7	Operate safely under AMA guidelines	Design Review	Comply

Table 6: Compliance Verification table

11.2 Needed Product Design Improvements

Several product design improvements could be made to the aircraft to better meet compliance requirements. Beyond the necessary adjustments needed to address the problems that led directly to product compliance failure, changes in fuselage and wing construction, tail construction, nose construction, and wing box construction are needed.

Concerning the fuselage and wing, additional internal structural support is needed, nearly all plastic welds used in the construction of the two critical aircraft parts failed during the testing campaign, thus a stronger adhesion method like epoxy would have been an needed improvement.

Additionally, attempts were made to secure the parts of the fuselage to one another and the wing box using screws. This method failed, as insufficient infill existed within the 3D parts for screws to properly bind too. To prevent this problem parts would be designed for peg-holes and epoxy construction between 3D printed parts. The parts would also be printed with a higher level of infill so that more material was present to bind parts together. Concerning tail construction three main improvements could be made. First and most critically, the inverted v tail would be flipped into a normal v tail configuration, this would be done to allow for the simplification of the rear landing gear configuration. The bottom of the v tail would serve as the structural base for a single wheel rear landing gear configuration. This would increase rear stability and would reduce tail weight by halving the rear landing gear weight contribution. Secondly the tail's rudder/elevators were designed too small. They were only a fraction of the size needed to properly control the aircraft. An improved design would see a set of rudder/elevators that span the entire length of the tail structure. The third and final tail improvement that would be implemented would be through printing the tail parts using lightweight ASA to further reduce the tail weight contribution further.

The Fuselage nose also would have served as a much better internal access point for in fuselage adjustments. Thus, the improved design would seek to implement a removable aircraft nose as opposed to the current design's detachable wing box.

Lastly concerning the wing box of the aircraft two improvements would be made. For one a much higher infill would be used to print the wing box so that more internal surface area would be available to secure the wing box and fuselage parts to one another. The wing box would also be designed with no holes for security using screws. Instead, a system of pegs and holes secured using epoxy would be employed ensuring greater security of assembly between the wing and fuselage.

11.3 Engineering Process Improvements

Several issues with the final design could have been addressed during the engineering process. The most significant of these is the assembly of the aircraft's aluminum components. Due to a lack of expertise in the field of aluminum welding the landing gear and tail spars were secured to the wing spar using inadequate methods. Thus, a major improvement to the engineering process could be made through securing the aluminum components to one another using aluminum welding instead of epoxy. During the installation of the ailerons the implementation of an internal wooden spar and a steel servo connector rod would have prevented the structural failure during transport to the flight test location. The failure of the wingtips could have been prevented by the implementation of two internal wooden spars running several inches in line along the aluminum spar which supported the rest of the wing structure. An additional avenue for engineering improvements is through 3D printing speed. Due to significant time constraints levied upon the team because of part delivery delays 3D printing was forced to be rushed. As a result of this rushed printing process significant warping occurred in critical aircraft parts like the wing box. An engineering process improvement to counter this would be the use of slower printing times, lowering print heat and warp tendency. A final recommendation for engineering process improvement would have been a more holistic approach to component testing. Due to the lack of intermittent testing of the magnetic payload mechanism the team did not have enough time to replace the faulty part upon its discovered failure. Thus, a process improvement could be made by implementing period components testing campaigns in order to ensure component operability.

11.4 Product Evaluation Statement

While the product only managed to comply with three of the 7 compliance requirements significant engineering prowess was still displayed in the product design. Adherence to all regulatory commissions was maintained throughout the whole of the design demonstrating the products dedication to safety and lawful adherence. Additionally, the product displayed robust and functional avionics, propulsion, and control systems. Even following the damage to the structure incurred during the testing campaign and transportation to the flight-testing location all these systems remained operable and would have likely remained operable if the aircraft had achieved flight. Ultimately however the goal of an aircraft is to achieve flight, something it did not do. The product sadly proved itself incapable due to myriad structural failures incurred by the product. While the team worked hard to produce it, the aircraft is still in violation of 4 of the 7 compliance requirements resulting in a failure to meet the established expectations of the project. It is a hard thing to say but product evaluation would label the aircraft as a failure.

12 Broader Impacts

This aircraft when finalized will provide an affordable, open source solution for heavy payloads for environmental monitoring and scientific research. Our open-source, cost-effective heavy-lift unmanned aerial vehicle (UAV) platform aims to significantly advance capabilities for environmental monitoring and scientific research, featuring a highly modular design suitable for numerous use cases at local, state-wide, national, and international levels.

At the local level, the UAV can greatly enhance community responses to environmental threats and natural disasters. By deploying sensor packages for water quality monitoring, communities can quickly detect contaminants or environmental changes in rivers, lakes, and reservoirs, safeguarding public health and local ecosystems. Additionally, by providing detailed, real-time data in wildfire conditions, emergency services can deploy resources more strategically, improving resident safety and reducing environmental damage.

State-wide impacts include enhanced environmental management and disaster response across larger geographic regions. State environmental agencies can utilize these modular UAVs to regularly and cost-effectively monitor critical infrastructure such as levees, dams, and reservoirs, preventing catastrophic failures through early detection of structural issues. Regular aerial data collection contributes to better-informed state policies regarding land use, conservation, and disaster preparedness.

Nationally, the versatility and accessibility of this modular UAV platform democratize scientific research capabilities, enabling smaller institutions, universities, and agencies to conduct high-quality research previously constrained by financial barriers. Expanded research capabilities can support improved environmental regulations and enhance understanding of complex phenomena such as climate change impacts, air pollution dispersion, and ecosystem health, thereby fostering informed policymaking and efficient resource allocation.

Globally and internationally, this UAV platform serves as a critical resource for nations with limited technological resources, significantly bridging the gap in environmental monitoring and disaster response between wealthier and developing countries. The open-source and modular nature of the UAV ensures adaptability to specific regional needs without restrictive licensing costs, encouraging international collaboration and knowledge sharing.

Politically, widespread adoption of this modular UAV can enhance international cooperation on environmental monitoring, enabling effective cross-border data sharing and supporting global initiatives addressing climate change, disaster management, and sustainability. Its deployment highlights responsible, transparent, and inclusive innovation, maximizing positive societal impacts and reinforcing ethical technological applications.

Overall, the UAV's highly modular and adaptable design provides transformative potential, empowering broader access to vital environmental monitoring and scientific research tools, while promoting responsible global innovation.

13 Appendices

Appendix A: Meeting Minutes - Friday, Jan 17th (12:15 – 1:00 PM)

Location: 300 Main
Goals:

1. Downey Pitch
2. Admin

Action Items:

- Draft the POS for Downey Pitch
- Draft the MNS for Downey Pitch
- Estimate the budget for the project

Appendix B: Meeting Minutes - Friday, Jan 25th (12:15 – 1:00 PM)

Location: 300 Main
Goals:

1. Develop Table of requirements

Action Items:

- Draw up 3 preliminary drawings

Appendix C: Meeting Minutes - Friday, Feb 11th (12:15 – 1:00 PM)

Location: 300 Main
Goals:

1. Task out Design Proposal work

Action Items:

- Assign tasks for the Design Proposal

Appendix D: Meeting Minutes - Friday, Feb 25th (12:15 – 1:00 PM)

Location: 300 Main
Goals:

1. Finish Wing Design

Action Items:

- Finalize the wing design

Appendix E: Approved Deviations

There are no deviations from the original assignment.

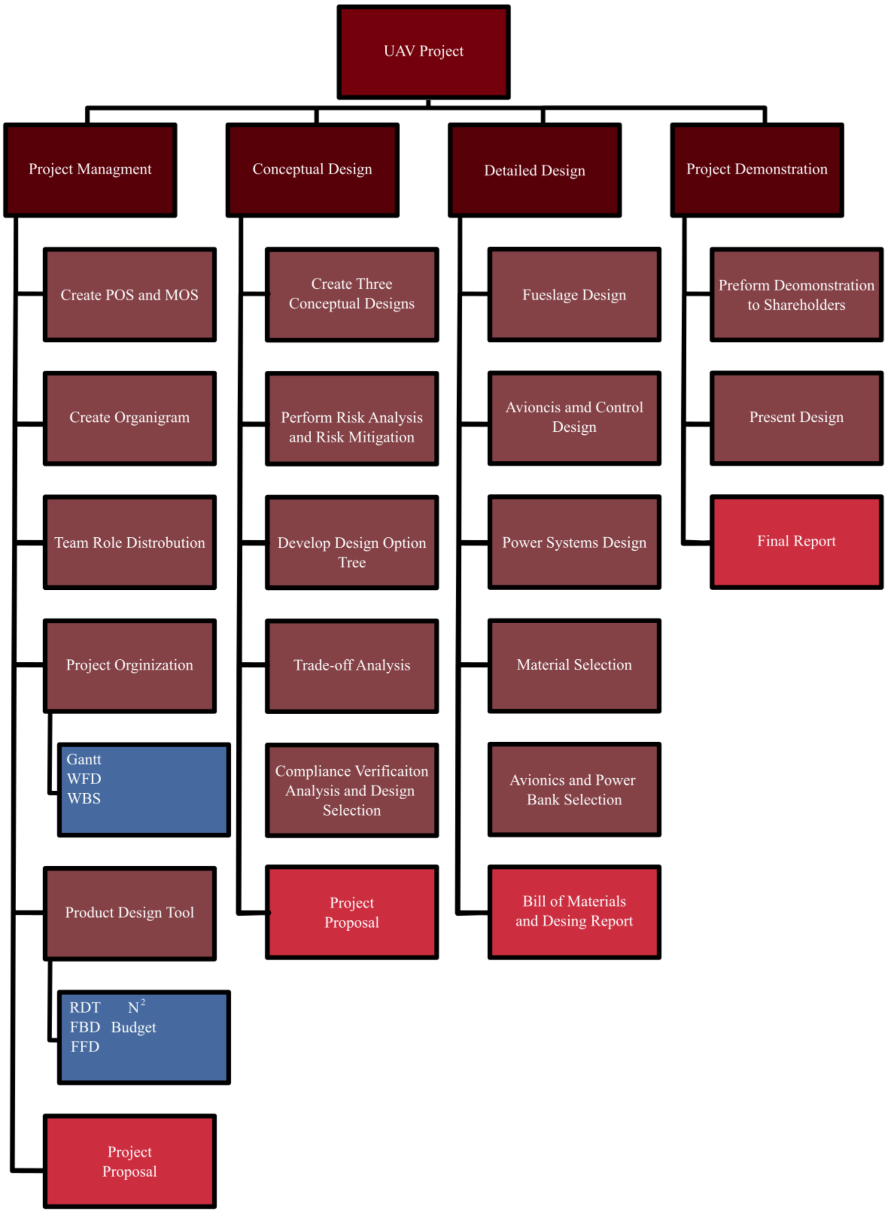
Appendix F: Product Specification Sheet

Specification	Value	Unit
ETOW (Empty Takeoff Weight)	11.12	Kg
MTOW (Max Takeoff Weight)	15.31	Kg
Cost	2065.34	USD
Endurance	40	mins
Range (Legal)	5	Km
Battery Capacity	13	Ah
Wingspan	2.6	m
Take-off Length	50	m
Landing Length	100	m

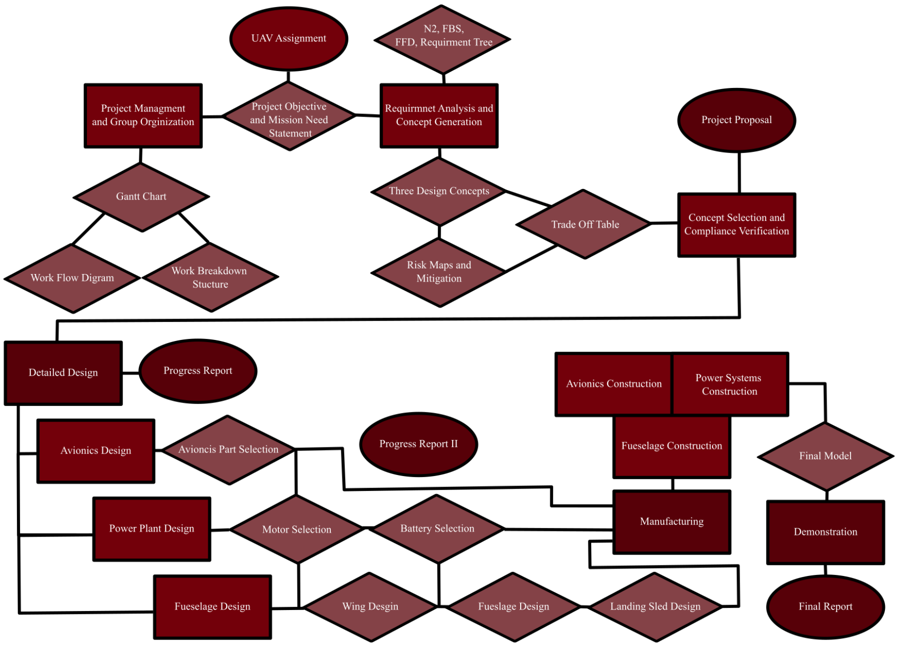
Table 7: Product Specification table

Appendix G: Selected Images

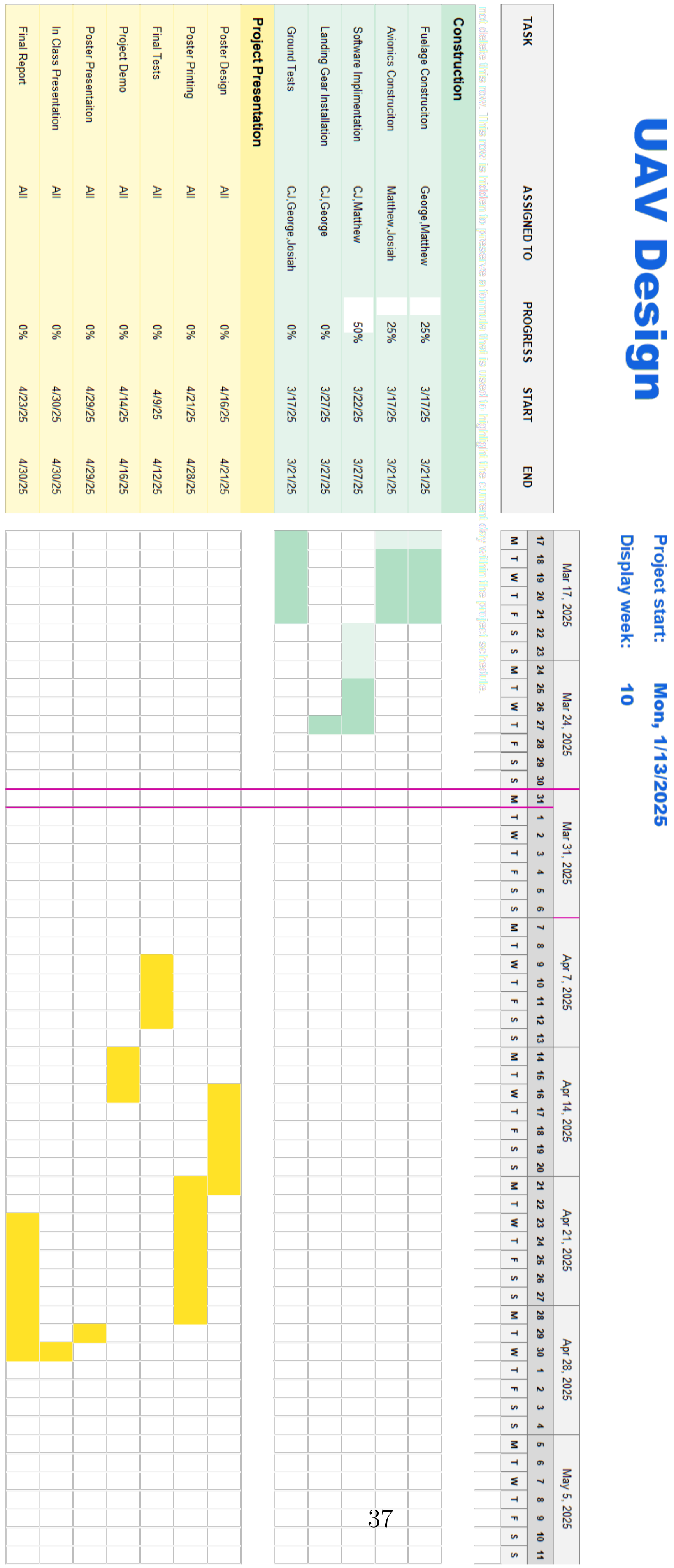
Appendix H: Work Breakdown Structure



Appendix I: Workflow Diagram

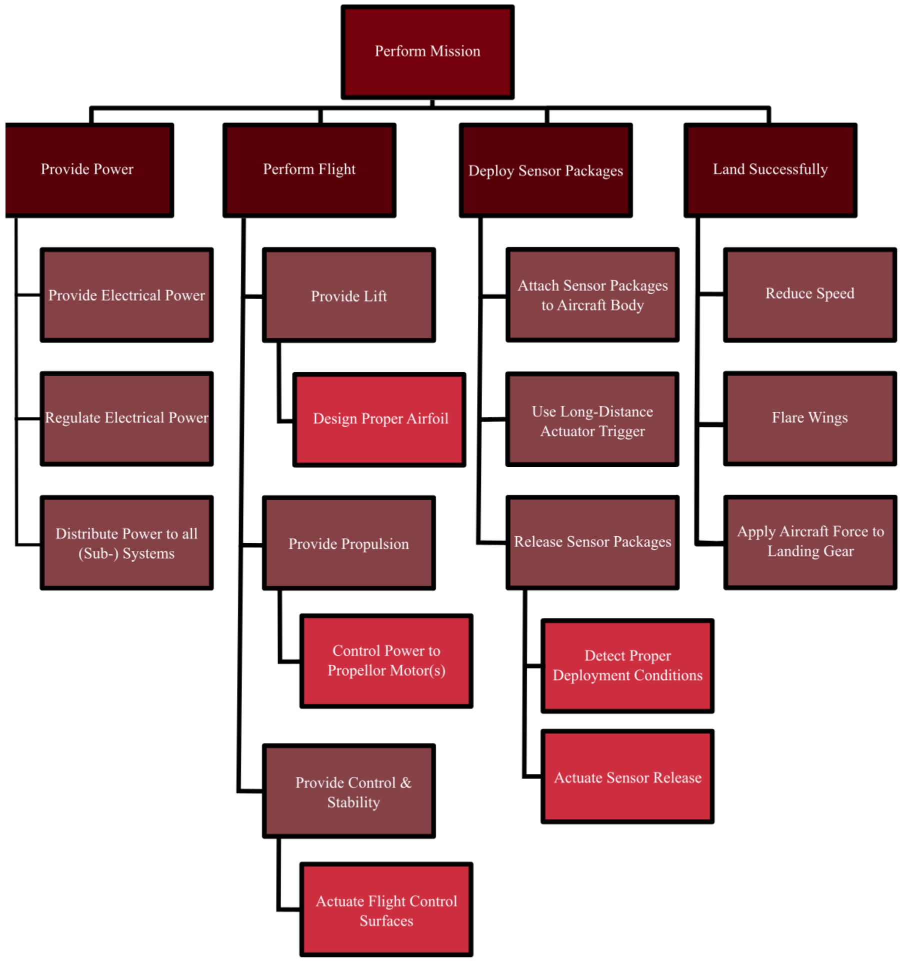


Appendix J: Gantt Chart Project Management

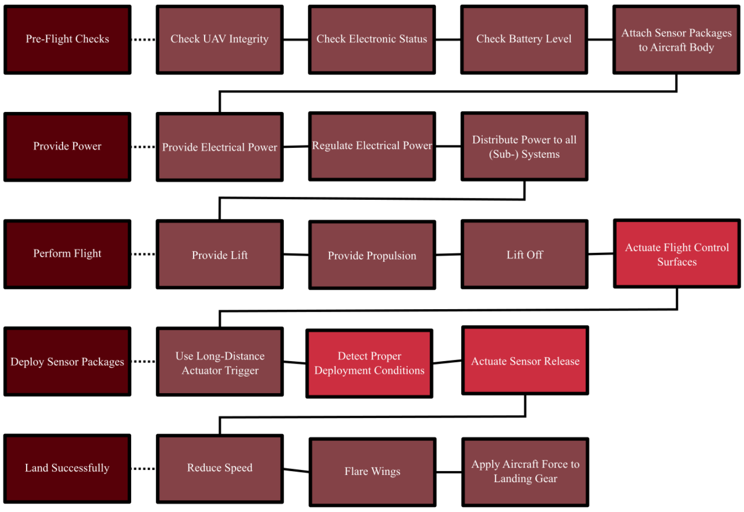


TASK	ASSIGNED TO	PROGRESS	START	END
Construction				
Fuelage Construciton	George,Matthew	25%	3/17/25	3/21/25
Avionics Construciton	Matthew,Josiah	25%	3/17/25	3/21/25
Software Implimentation	CJ,Matthew	50%	3/22/25	3/27/25
Landing Gear Installation	CJ,George	0%	3/27/25	3/27/25
Ground Tests	CJ,George,Josiah	0%	3/17/25	3/21/25
Project Presentation				
Poster Design	All	0%	4/16/25	4/21/25
Poster Printing	All	0%	4/21/25	4/28/25
Final Tests	All	0%	4/9/25	4/12/25
Project Demo	All	0%	4/14/25	4/16/25
Poster Presentaiton	All	0%	4/29/25	4/29/25
In Class Presentation	All	0%	4/30/25	4/30/25
Final Report	All	0%	4/23/25	4/30/25

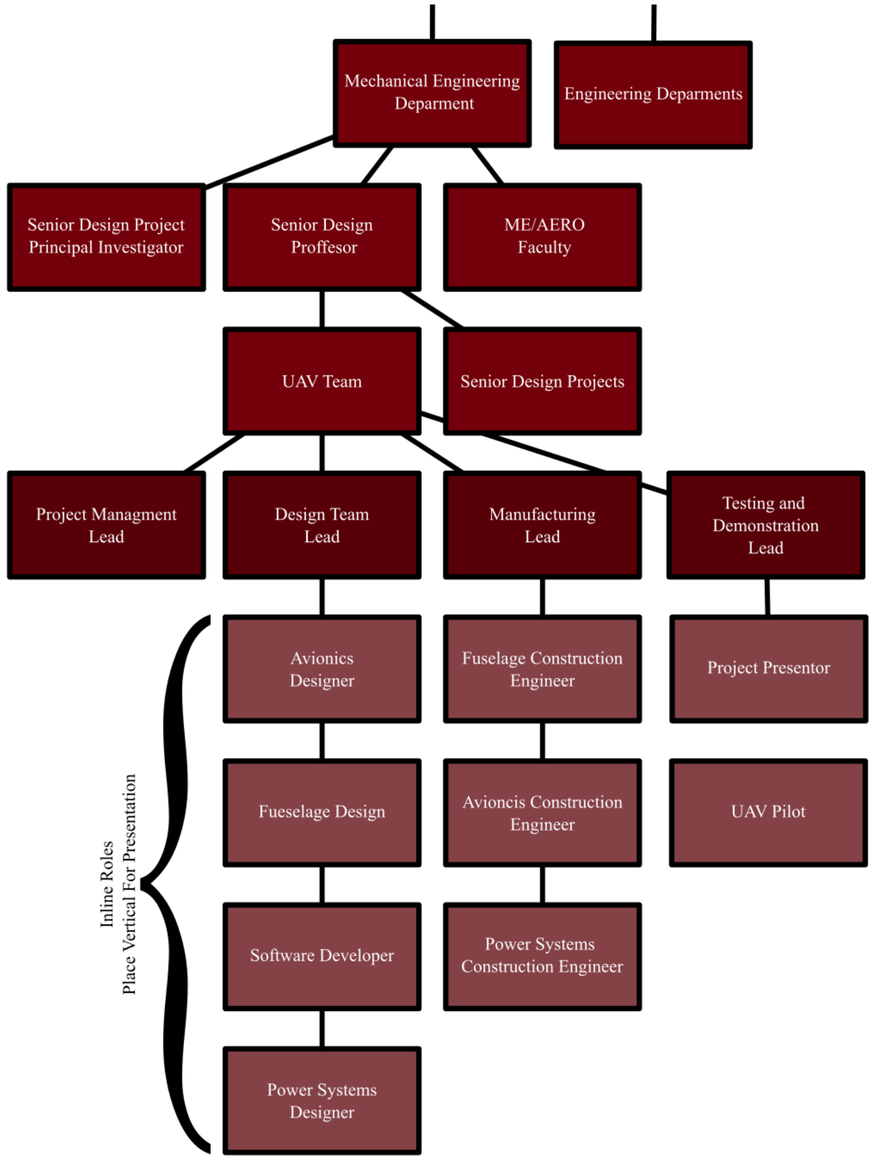
Appendix K: Functional Breakdown Structure



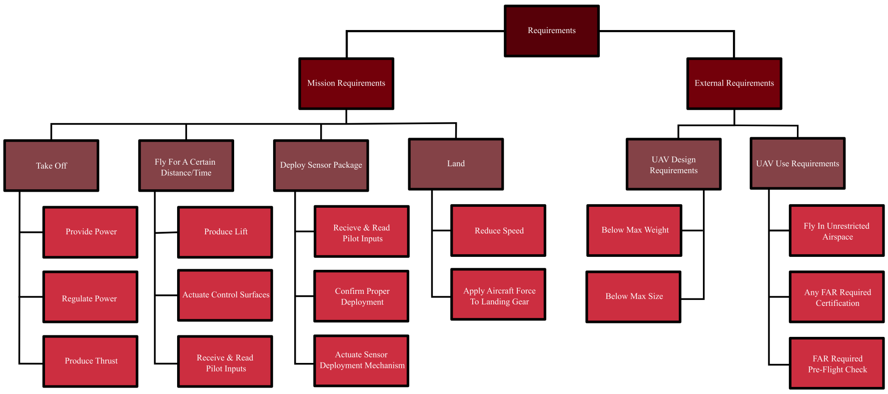
Appendix L: Functional Flow Diagram

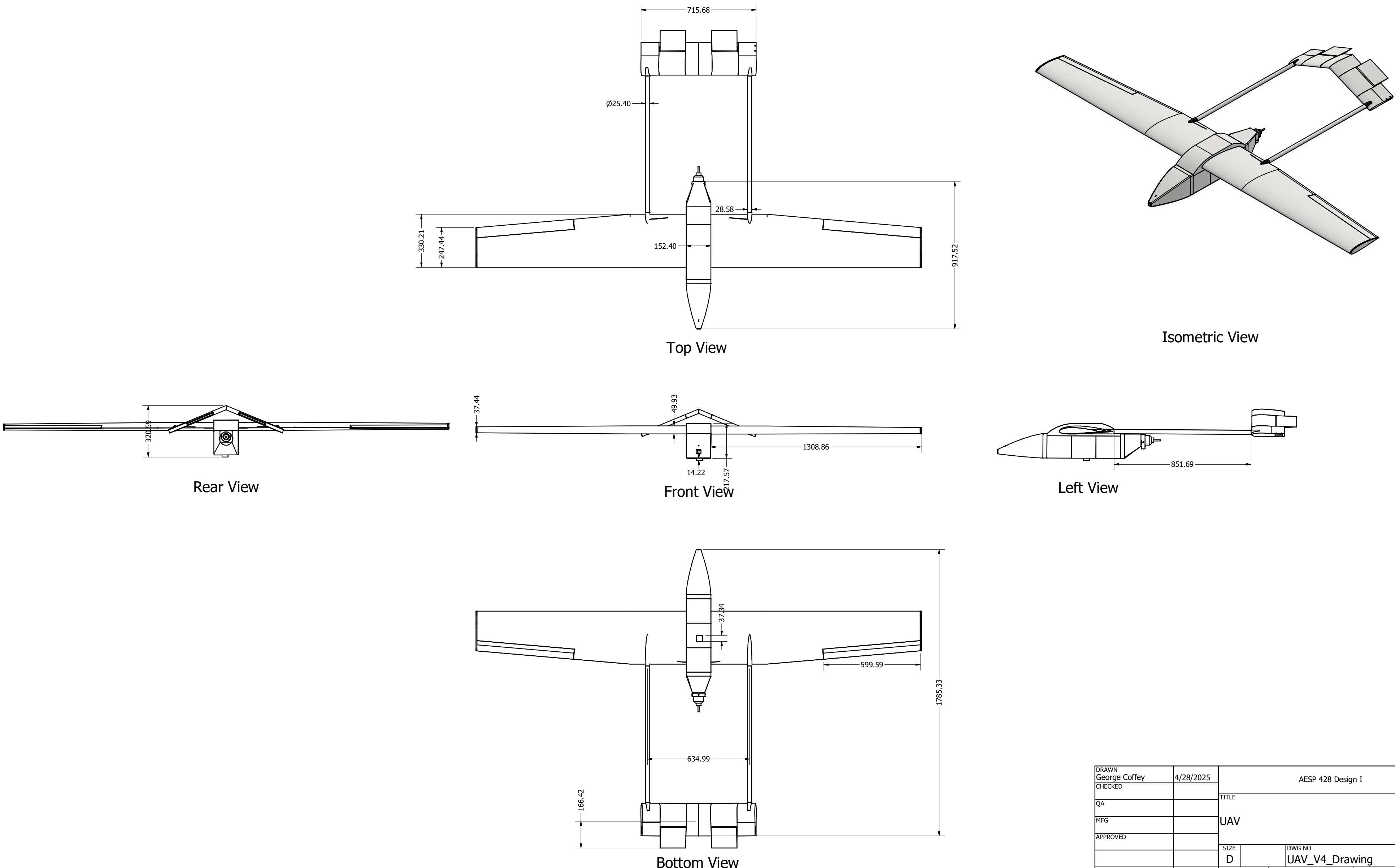


Appendix M: Organigram



Appendix N: Requirements List





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MFG		
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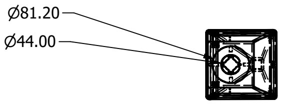

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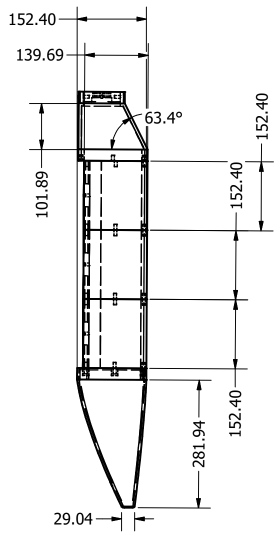

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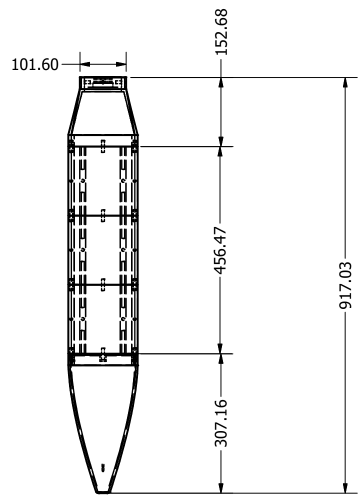

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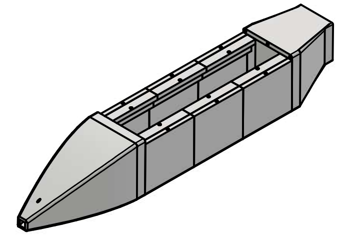

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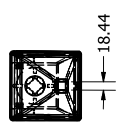

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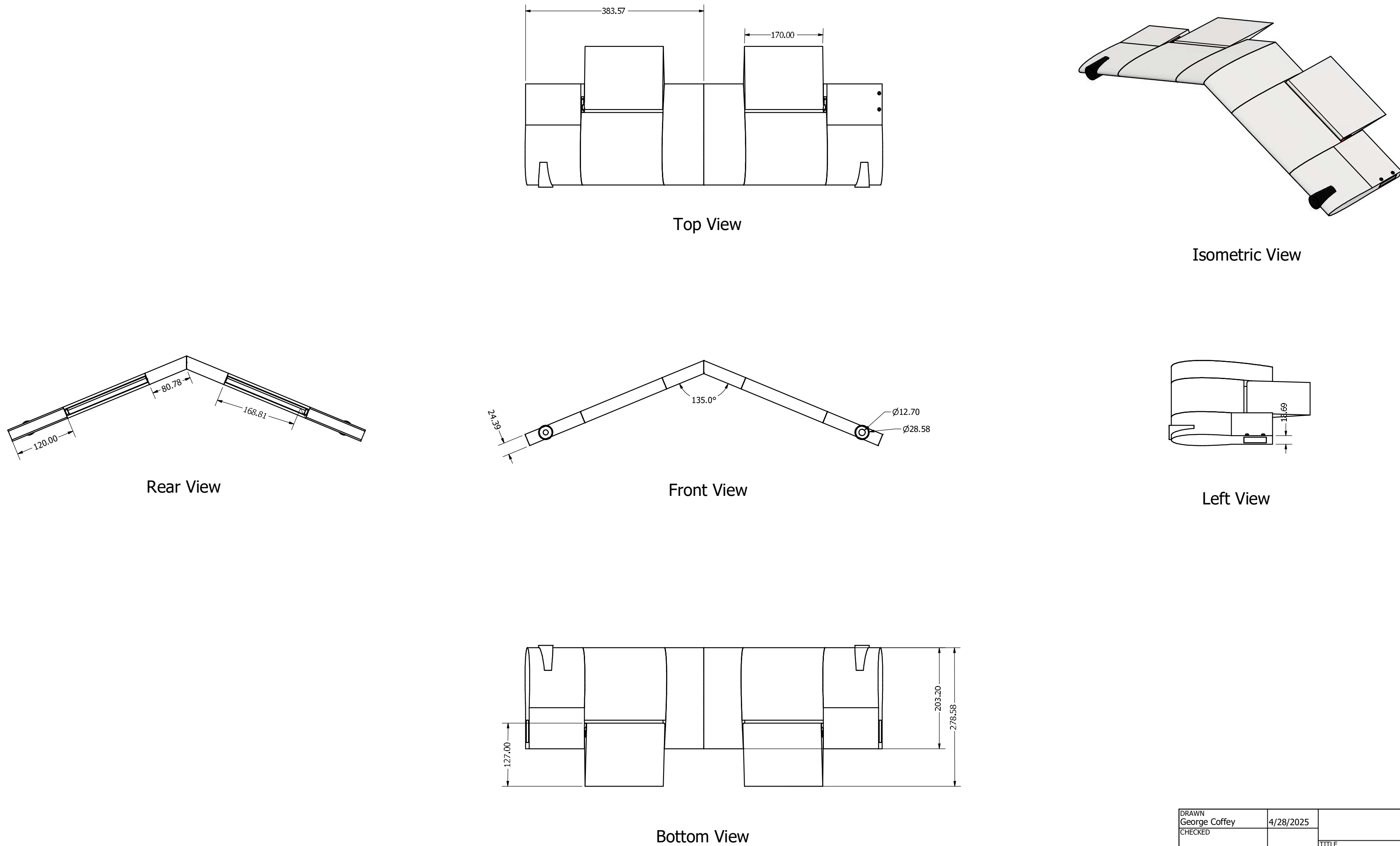

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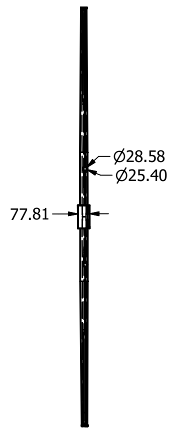

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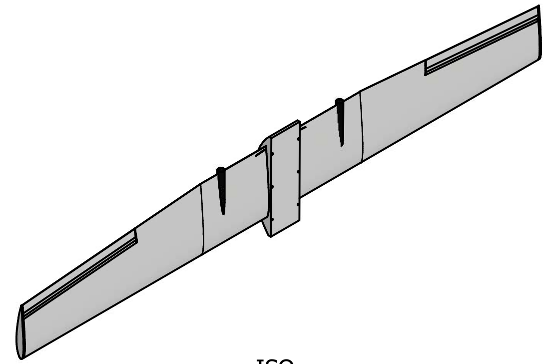

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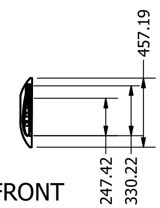

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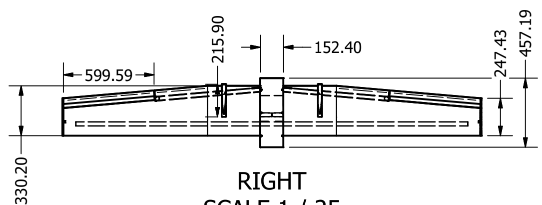

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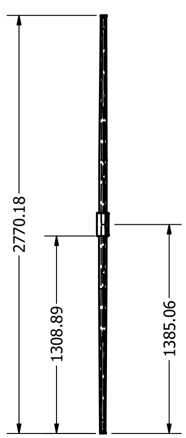

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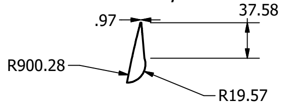

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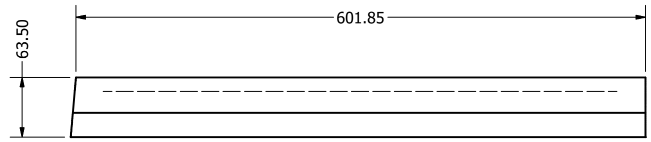

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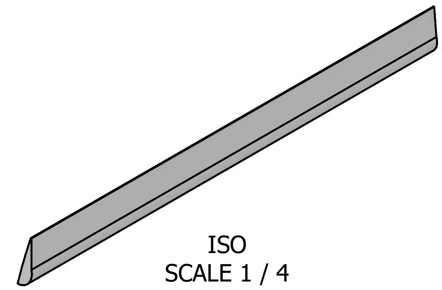

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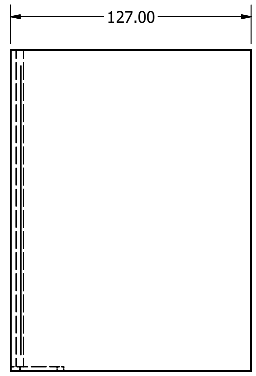

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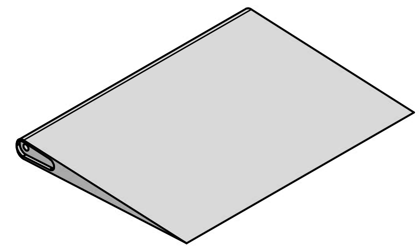

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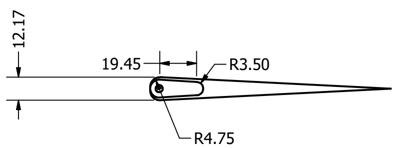

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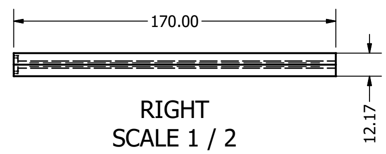

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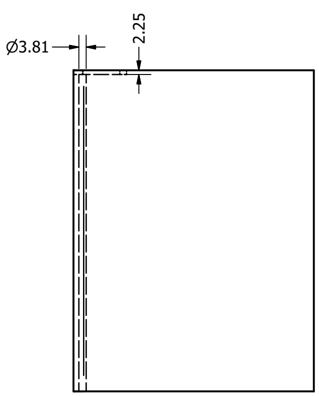

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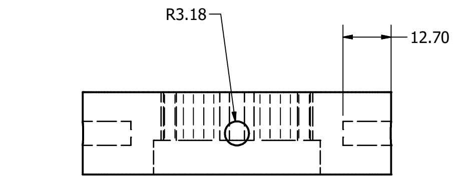

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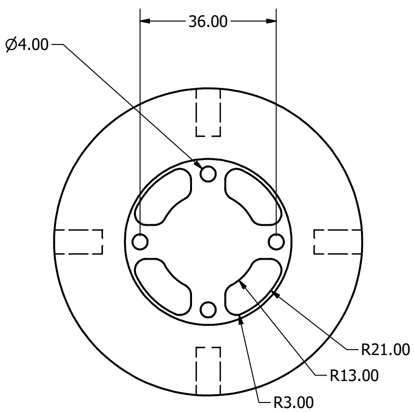

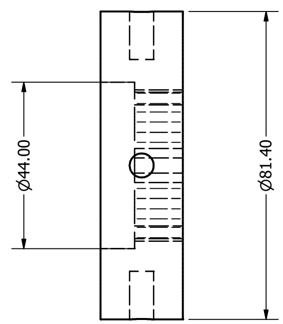

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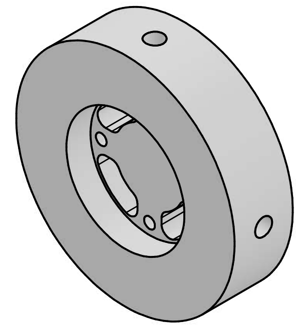

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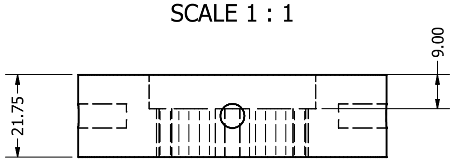

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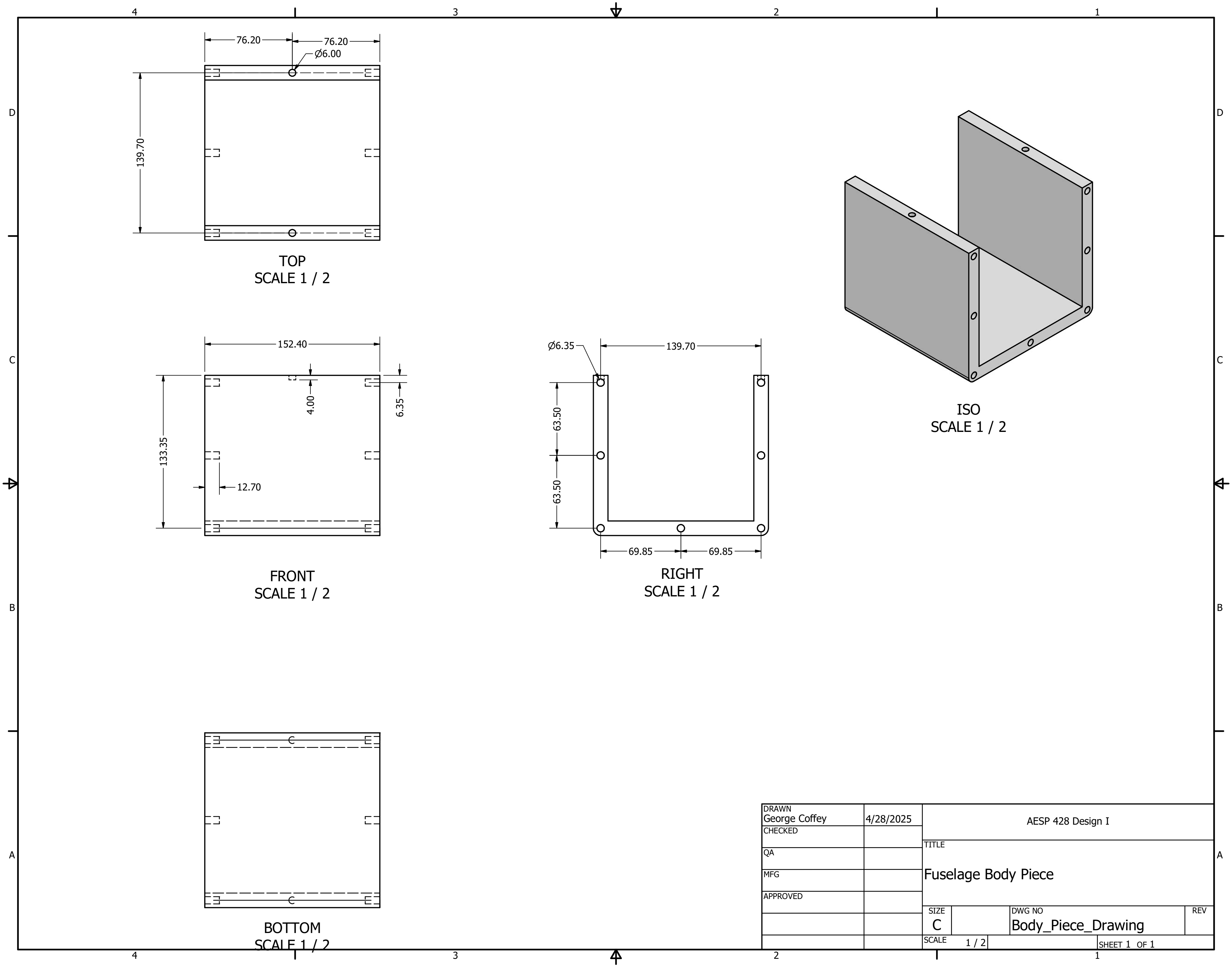

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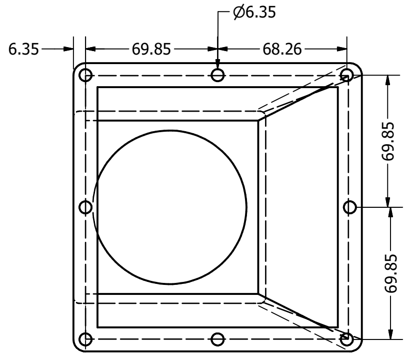

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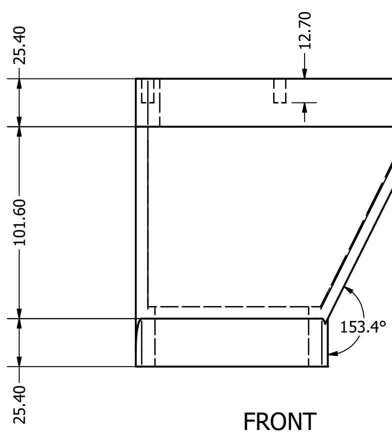

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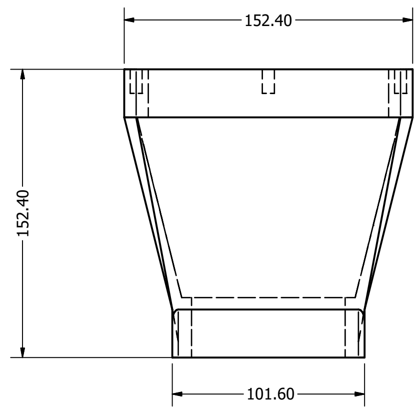

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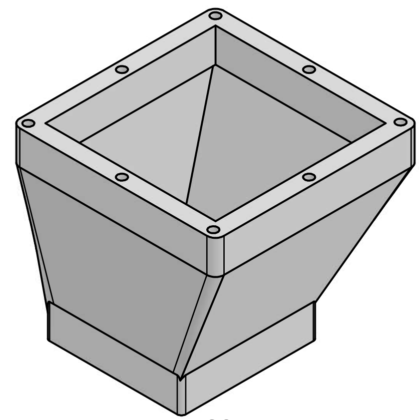

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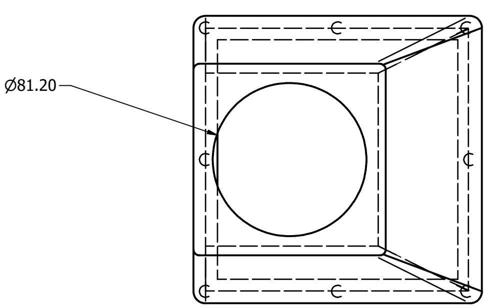

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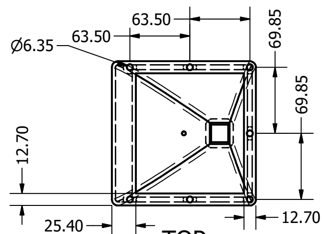

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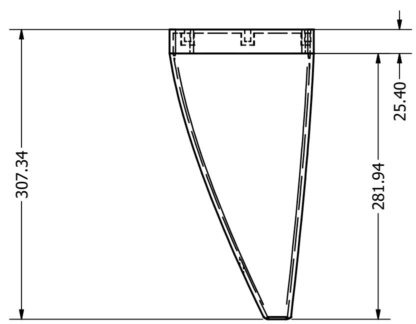

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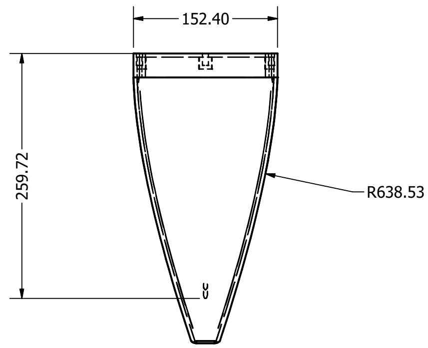

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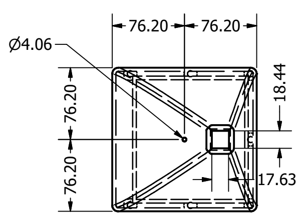

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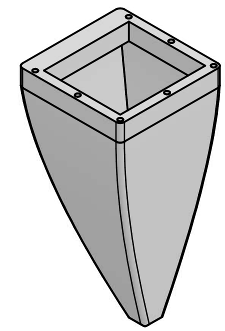

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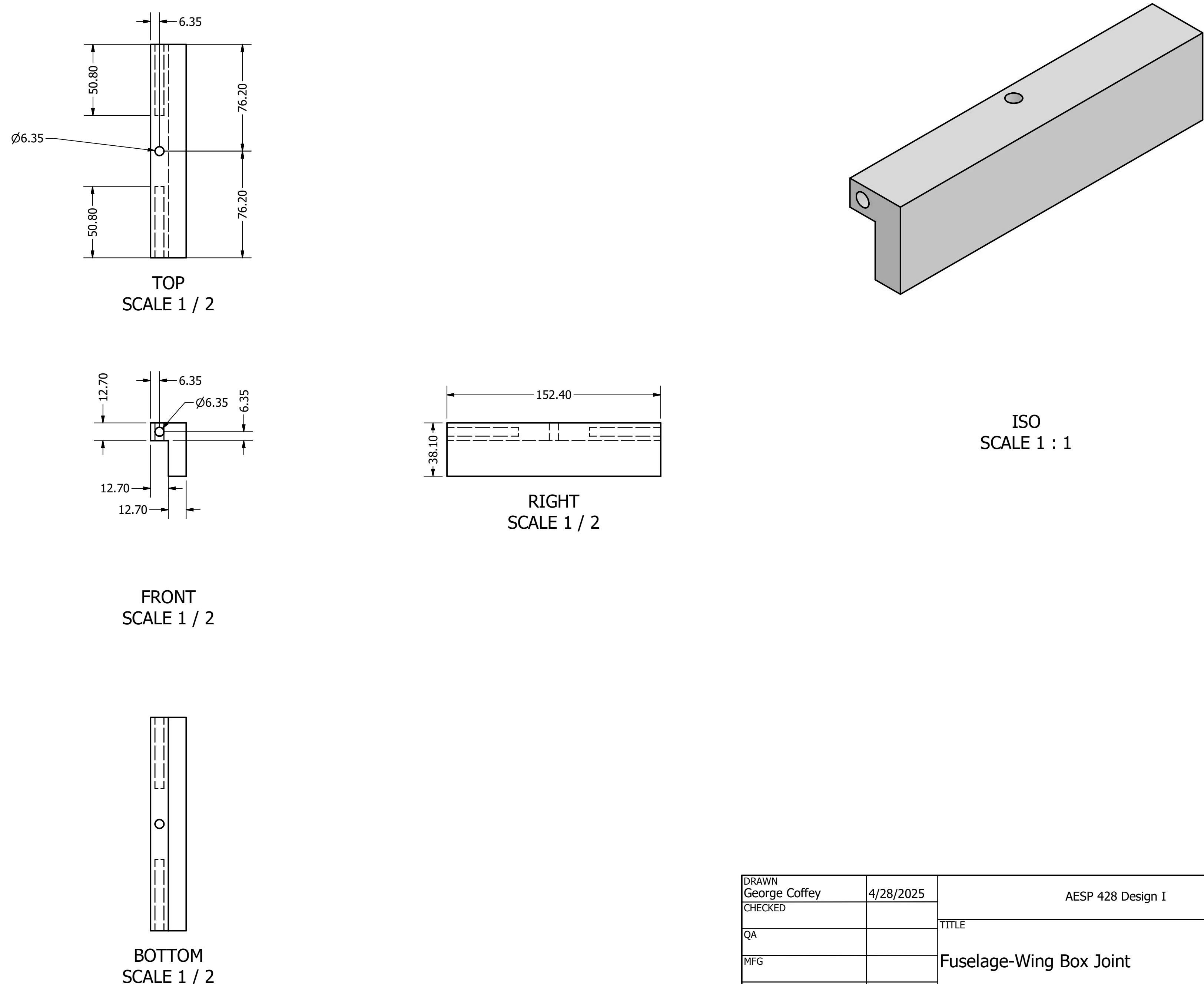

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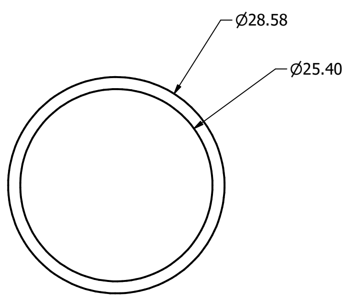

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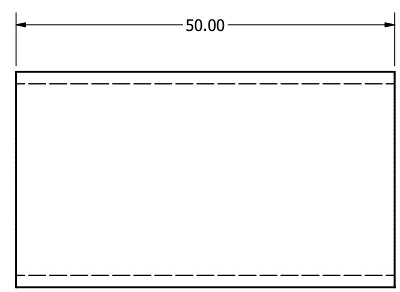

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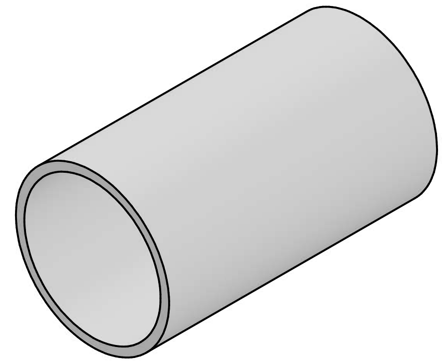

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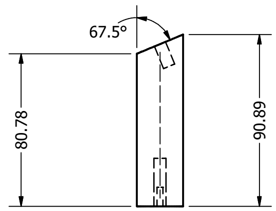
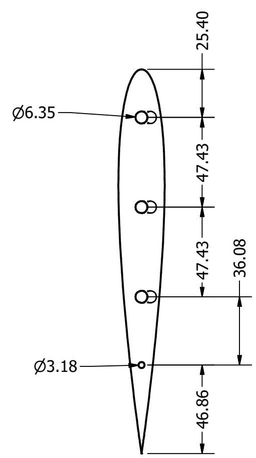
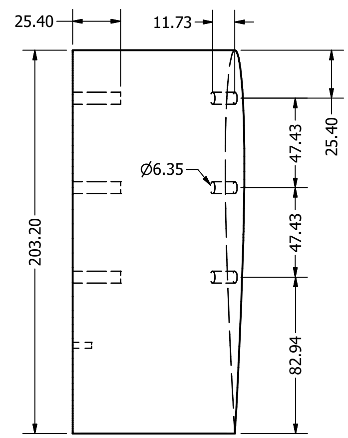
DRAWN George Coffey	4/28/2025	AESP 428 Deisgn I
CHECKED		TITLE Tail Boom Reinforcement
QA		
MFG		
APPROVED		SIZE C / DWG NO Tail_Boom_Reinforcement / REV
		SCALE 2 : 1 / SHEET 1 OF 1



TOP
SCALE 1 / 2



FRONT
SCALE 1 / 2



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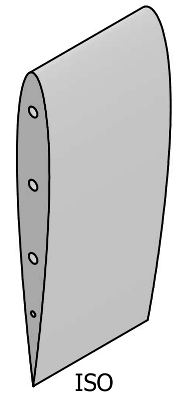
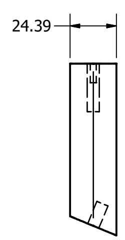
SCALE 1 / 2

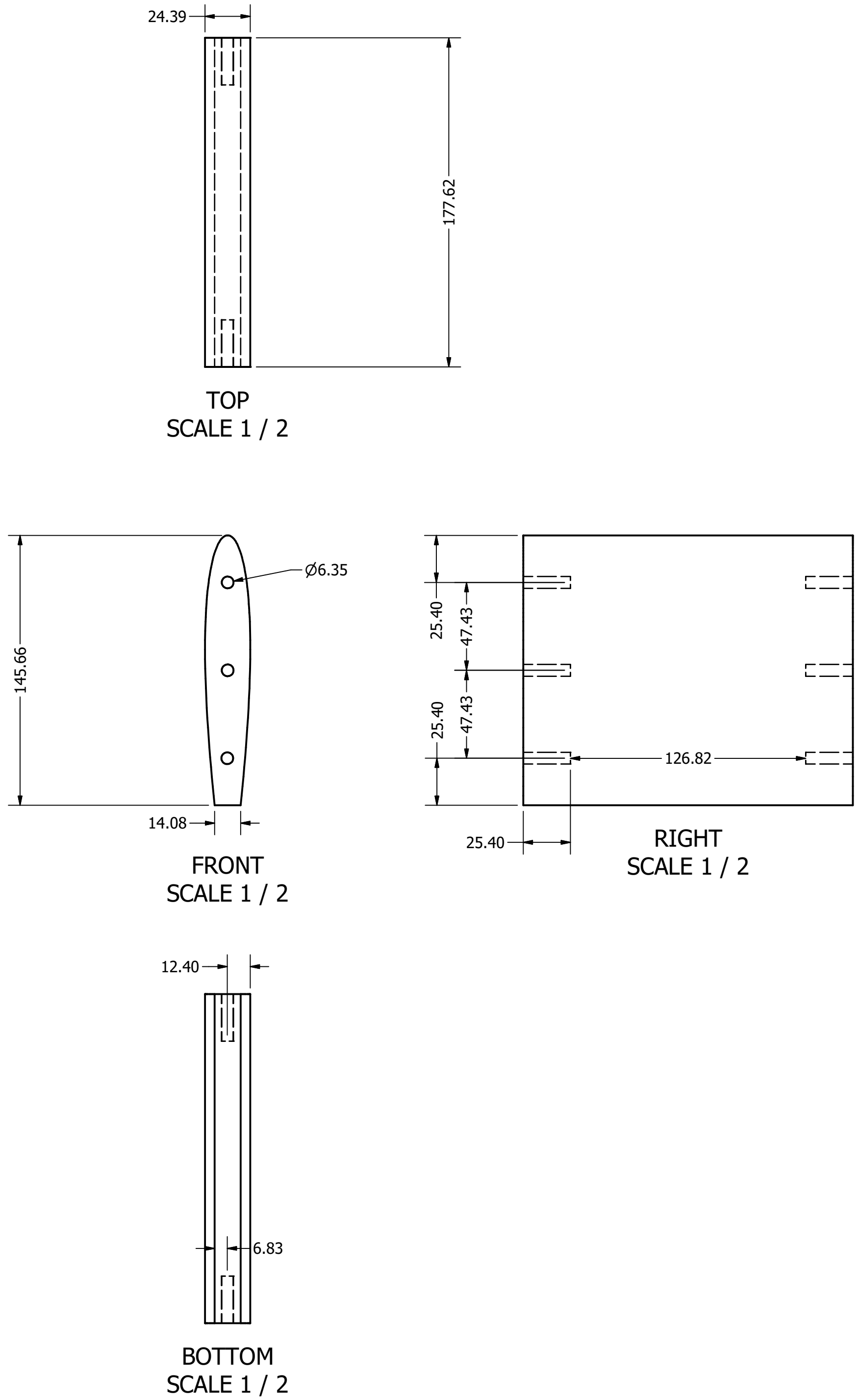


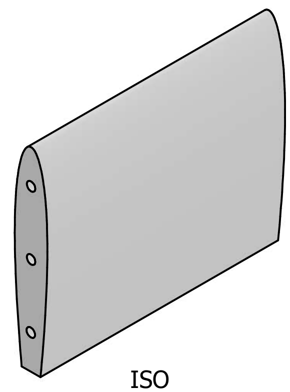
ISO
SCALE 1 / 2



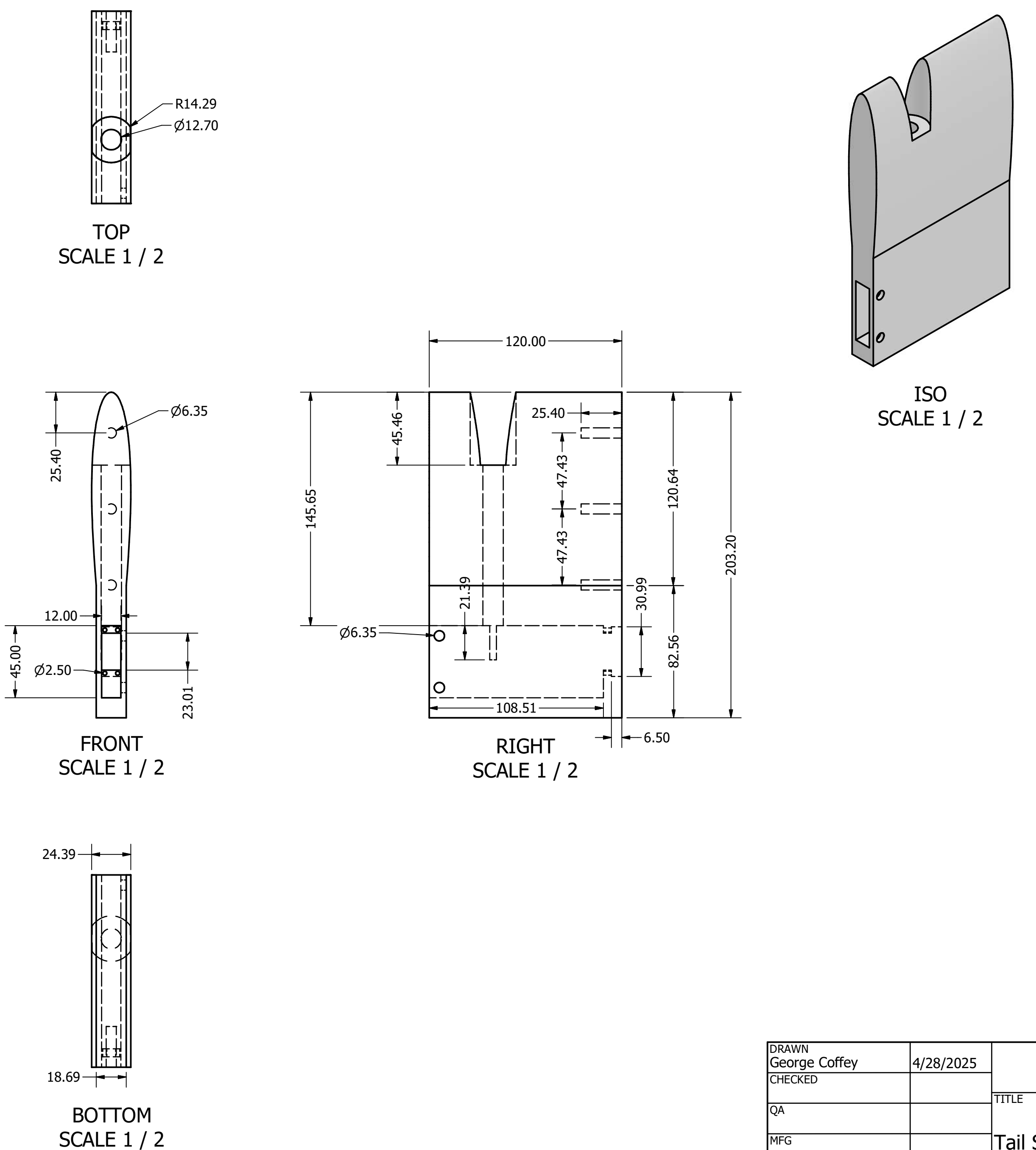
BOTTOM
SCALE 1 / 2

DRAWN George Coffey	4/28/2025	AESP 428 Design I
CHECKED		TITLE Tail Section I
QA		
MFG		
APPROVED		
		SIZE C · DWG NO Tail_SectionI_Drawing · REV
		SCALE 1 / 2 · SHEET 1 OF 1





DRAWN George Coffey	4/28/2025	AESP 428 Design I
CHECKED		TITLE
QA		Tail Section II
MFG		
APPROVED		
		SIZE C · DWG NO Tail_SectionII_Drawing · REV
		SCALE 1 / 2 · SHEET 1 OF 1



DRAWN George Coffey	4/28/2025	AESP 428 Design I
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QA		Tail Section III
MFG		
APPROVED		
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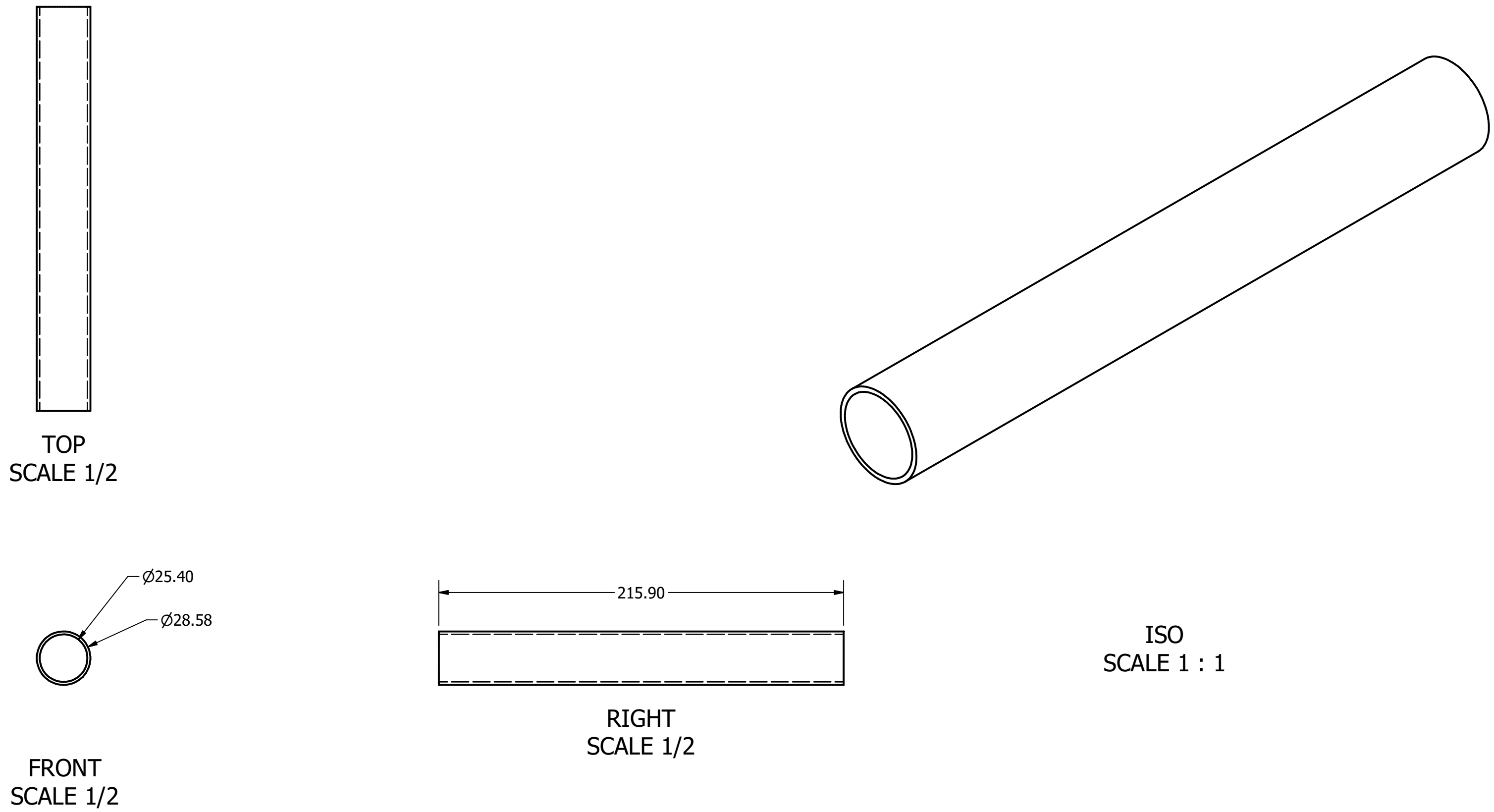
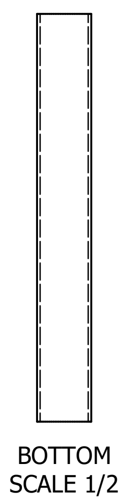
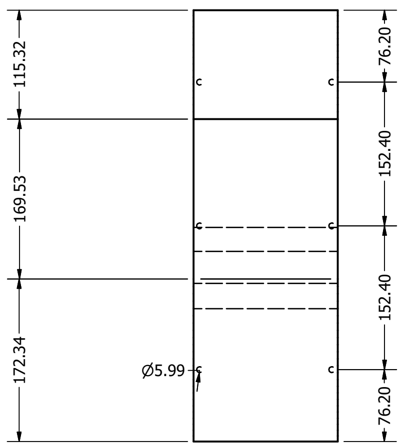
		SCALE 1 / 2 — SHEET 1 OF 1





DRAWN George Coffey	4/28/2025	AESP 428 Design I		
CHECKED		TITLE Wing Boom Reinforcement		
QA				
MFG				
APPROVED				
		SIZE C	DWG NO Wing_Boom_Reinforcement	REV
		SCALE 1/2	SHEET 1 OF 1	



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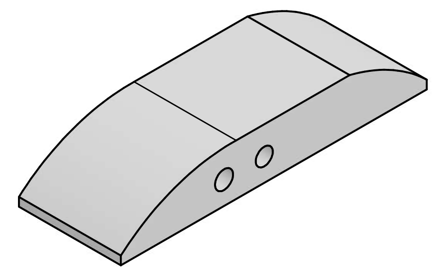
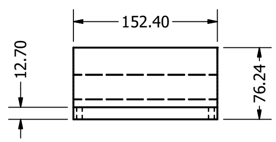
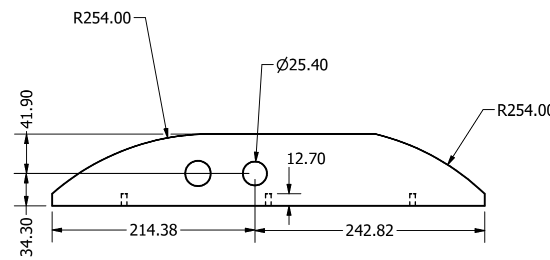


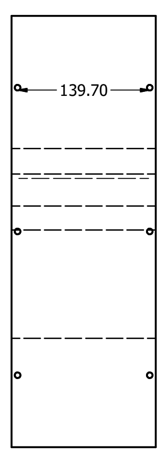
ISO
SCALE 1 / 4



FRONT
SCALE 1 / 4

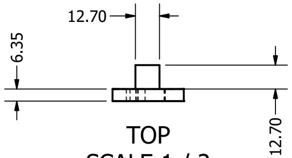


RIGHT
SCALE 1 / 4

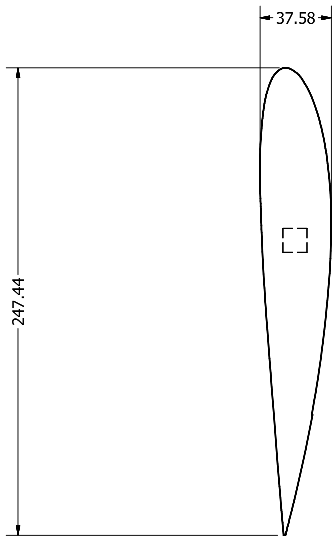


BOTTOM
SCALE 1 / 4

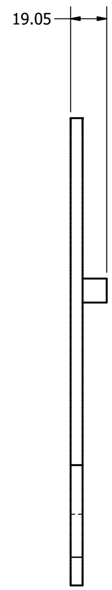
DRAWN George Coffey	4/28/2025	AESP 428 Design I
CHECKED		TITLE
QA		Wing Box
MFG		
APPROVED		
		SIZE C — DWG NO Wing_Box_Drawing — REV
		SCALE 1 / 4 — SHEET 1 OF 1



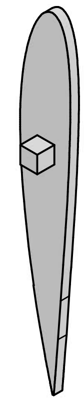
TOP
SCALE 1 / 2



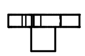
FRONT
SCALE 1 / 2



RIGHT
SCALE 1 / 2

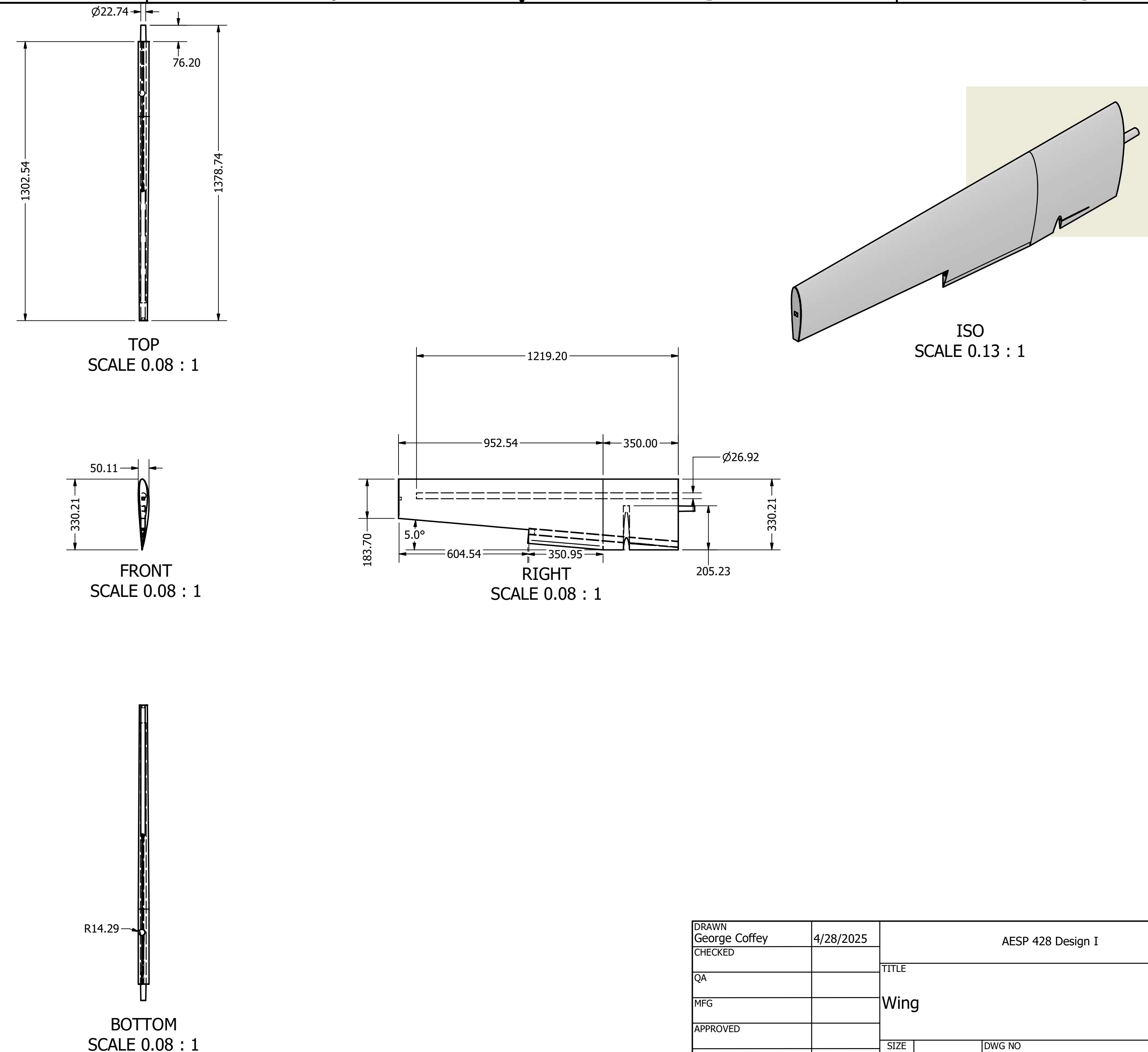


ISO
SCALE 1 / 2

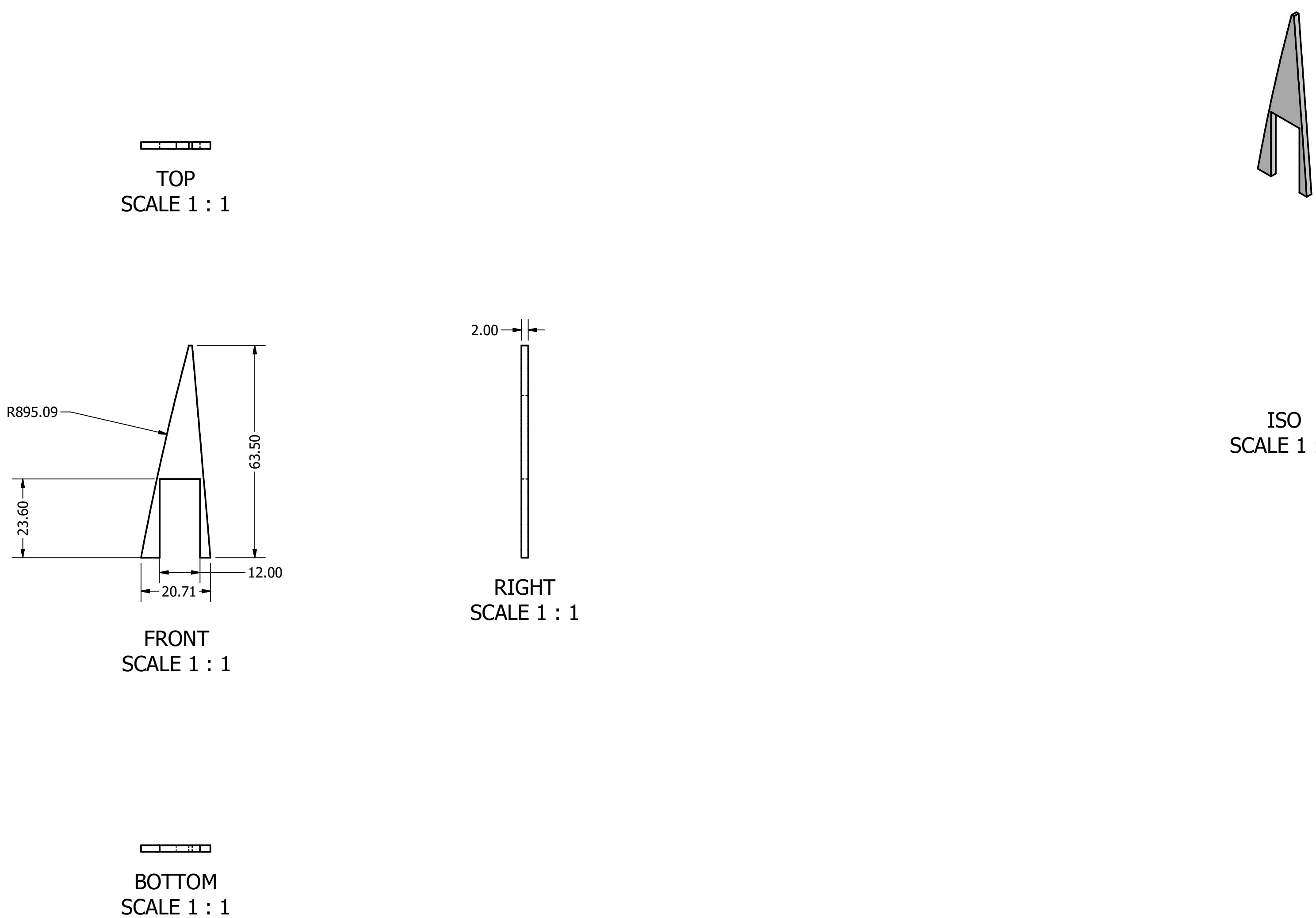


BOTTOM
SCALE 1 / 2

DRAWN George Coffey	4/28/2025	AESP 428 Design I
CHECKED		TITLE Wing Cap
QA		
MFG		
APPROVED		SIZE C / DWG NO Wing_Cap_Drawing / REV
		SCALE 1 / 2 / SHEET 1 OF 1



DRAWN George Coffey	4/28/2025	AESP 428 Design I
CHECKED		TITLE
QA		Wing
MFG		
APPROVED		SIZE C · DWG NO Wing_Drawing · REV
		SCALE 0.08 : 1 · SHEET 1 OF 1



DRAWN George Coffey	4/28/2025	AESP 428 Design I
CHECKED		TITLE Wing Servo Plate
QA		
MFG		
APPROVED		SIZE C, DWG NO Wing_Servo_Plate, REV
		SCALE 1 : 1, SHEET 1 OF 1