University of
Waterloo

Faculty of Engineering

H2DRONES
Dual Environment Vehicle

ME482
Prof. J. Baleshta

Faculty Advisors:
Prof. A. Trivett
Prof. J.P Hickey

Prepared by Group 1:

C. Diffey
E. Fochtberger
S. I. Hussain
K. Strobel
K. Younes

4B Mechanical Engineering

April 3, 2017

Professor J. Baleshta
Department of Mechanical and Mechatronics Engineering
University of Waterloo
200 University Avenue West
Waterloo, Ontario
N2L 3G1

Dear Professor Baleshta,

This report is entitled; *"H2Drones – Dual Environment Vehicle*", was prepared as part of our 4B term for our ME 482 course. This project was completed by; K. Strobel (Design lead), C. Diffey (Validation lead), S. I. Hussain (Team lead), E. Fochtberger (Manufacturing lead), and K. Younes (Analysis lead). The purpose of this report is to summarize the design process, results, manufacturing, testing, and lessons learned whilst creating the *"H2Drone".*

Our group would like to thank both Professor A. Trivett and Professor J.P. Hickey for their time and effort in providing support and input throughout the process. We would further like to thank the student engineering shop staff, the engineering clinic, and the wind tunnel facility for their support in providing guidance and resources to build and validate our final artifact. Lastly, we would like to thank Professor Baleshta and the entire ME 482 teaching staff for spending the time to impart their wisdom to us.

This report was written entirely by the group members above and has not received any previous academic credit at this or any other institution.

We the undersigned take responsibility for this design.

Sincerely,

Claire Diffey

K. Strobel
Design Lead

C. Diffey
Validation Lead

S. I. Hussain
Team Lead

E. Fochtberger
Manufacturing Lead

K. Younes
Analysis Lead

Table of Contents

List of Figures

List of Tables

1.0 Introduction

The work completed in "ME481: H2Drones Final Design Report" [1] helped identify the consumer need for an aerial vehicle that is capable of transitioning and functioning in both air and in water. In addition, it revealed the intention of the team to continue to push the boundaries in aerial vehicle technology and manufacturing. With limited options (range issue or lack of transitioning) available on the market for a dual-environment vehicle that meets the customer demand, the H2Drones team observed a real need to create the amphibious vehicle. The purpose of this report is to outline the procedure and decisions taken in the production of the dual-environment vehicle, carried on from ME481. In addition, it serves as a compass and summary of all the work undertaken to make this unique product come to reality. Finally, a copy of the latest engineering specifications is included in Appendix A of this report.

1.1 Summary of ME481

In ME481, major milestones in the course of the project were completed. Beginning with a detailed market study and benchmarking of existing solutions, the scope definition and engineering specifications were formulated. The minimum viable product, so-called *MVP* herein, and potential customers were also identified. For the sake of clarity, the MVP key highlights are listed in Table 1 below:

Table 1: Minimum Viable Product [1]

Basic Requirements	
Distance of Control	≥ 4km
Flight Time	≥ 35min
Underwater Use	≥ 10min
Cost – $CAD	$500 - $1000
Performance Requirement	
Air Speed	30-40 Km/h
Exciting Factors	
HD Camera/ Lighting System/ Live Camera Feed/ GPS	

The customers were also identified to be aerial photographers and/or hobbyists. With that in mind, the H2Drones team set on the design phase, which commenced with a rough order of magnitude, so-called *ROM*. The ROM phase of the project housed an initial packaging study, which included the basic components for aerial and hydrodynamic functionality, and it resulted in a first order approximation of the sizing (weight, characteristic length, thrust, etc.) of the vehicle. With few guidelines on sizing requirements, a brainstorming session was completed to yield three distinct design iterations. A design decision matrix was then employed to filer the designs and single out one for refinement. The refined design was then altered using aerodynamic knowledge combined with hydrodynamic functionality in mind, and, then, a brief analysis phase was completed for a water-surface takeoff model, which has been identified to be the bottleneck of the design due to the immense drag resulting from the water surface, and water stability model to ensure the feasibility of a stable design. Finally, a proof of concept prototype was purchased to mimic the refined design and demonstrate the team's ability in successfully transforming an aerial vehicle into one that can takeoff from water, giving more confidence in resolving the bottleneck of the design. The aforementioned information can all be found in detail in reference [1].

1.2 Summary of Deviations from ME481

In order to effectively communicate the upcoming design ideas, procedures, and challenges, it is important to first list out deviations from reference [1]. The biggest and by far the most impactful design consideration for ME482 was the scoping down of the project. Initially, ME481 touched upon evaluating several options for transitioning into water from air and in general, water functionality. Going into ME482, the scope definition changed slightly to incorporate more focus into the aerial functionality of the vehicle, with less emphasis on water functionality, which was given secondary priority in the overall design process. As such, the upcoming sections of the report will majorly involve aerial functionality and testing with few, limited scheduled water tests; this may be in direct opposition to what was mentioned in the "Next Steps" section of [1]. However, the decision was taken due to limited time allocation and resource availability for multiple water design iterations.

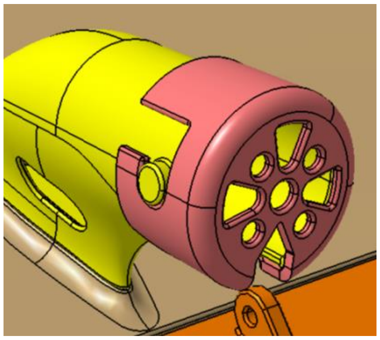
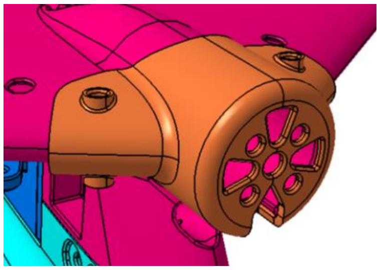
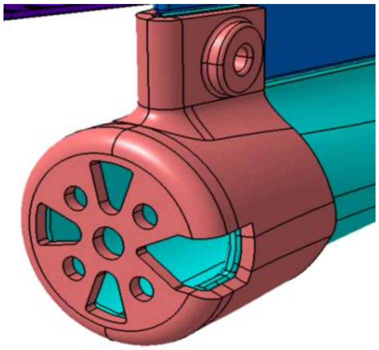
2.0 Design

At the end of ME 481 a good majority of the initial design work had been completed on the vehicle as it pertained to exterior geometry as the design team had converged on a 3-propeller blended body vehicle with a rear packaged water screw. It should be made very clear that the following section focuses on the decisions made during 482 thus if the reader is interested in high-level vehicle characteristics details such as motor location and/or wing surface design they should refer to previous reports [1]. Although changes were made to the vehicle overall sizing during ME 482, the vehicle maintained approximately the same exterior surface just with different proportions. The main focus of ME 482 was on sectioning the vehicle into manufacturable components while ensuring its structural integrity was maintained and also meeting all the design targets. It should be noted that one of the main goals of this was to make the vehicle as modular as possible such that components could easily be swapped out if damaged. The following section gives a high-level overview of the process taken to satisfy these requirements.

2.1 Design for Safety & Sustainability

The safety of people coming in close contact with the vehicle during use was kept in mind throughout the design process. One of the main safety concerns highlighted by the design team was the vehicle propulsion system and how this would interface with the vehicle; namely with the propellers. If for example, these were separated from the vehicle during flight they had the potential to become high speed projectiles. To reduce the probability of this occurrence, custom muzzles were designed and manufactured to provide no less than two independent locking mechanisms to mount the propulsion system to the vehicle. The attachment mechanisms are highlighted in Table 2. Note that this table references a method called compression thrusting which is a characteristic of pusher propellers; these fundamentally cannot become separated during operation as they are always pushing on the vehicle. In addition to designing of safety, sustainability was considered in every aspect of the design. A detailed sustainability study was conducted in ME481, and the results are given in [1].

Table 2: Propulsion System Safety Considerations

Motor Location	**Attachment Mechanism**	**Image**
Wing Propeller (+Y/-Y)	-Glue Bond -Mechanical Lock -Compression Thrusting	
Tail Propeller	-M4 Bolt (+Y) -M4 Bolt (-Y)	
Rear Screw	-M4 Bolt -Compression Thrusting	

2.2 Design Methodology

To take the vehicle from initial conceptualization to its final state the design process was broken into four main stages as outlined below:

1. Initial surfacing – This stage defined the overall exterior surfaces of the vehicle and was primarily completed in ME 481 as shown in Figure 1 (~4 months).
2. Component Break Down – With the overall geometry defined, the vehicle was split up into manageable components with focus on the design of how each section interfaced with adjacent components as shown in Figure 2 (~1.5 months).
3. Interior Design – Each of the major sections was then individually scrutinized to design in its interior structure while staying cognizant of the mass targets as shown in Figure 3 (~3 months).
4. Manufacturing Break Down – With both the exterior and interior geometry of the vehicle defined it was then possible to break down each section into producable components as shown in Figure 4 (~2 months).

2.3 Beta Build Design

To allow sufficient time to manufacture and validate the vehicle its geometry was frozen for build as of January 15th, 2017. All design work done after this date was based on feedback from the manufacturing and assembly process as well as the validation stage. To ensure concise communication the geometry used for manufacture was called 'Beta Build' where as the refined, final product was called Release Candidate 1 (RC1). The following sections give brief descriptions of the design decisions made which resulted in the Beta Build vehicle.

2.4 Wing Tip Design

For assembly purposes the wing tip was designed as a separate component to allow for easy installation of the main wing flap. It was designed to be 3D printed due to the relatively complex geometry required to produce a Hoerner wing tip.

2.5 Nose Cone Design

In order to easily remove the front mounted camera on the vehicle a separate component at the front was added with a custom mount to fit the GoPro Hero 4®. This nose cone also allows for easy access to the battery which was housed at the front of the fuselage.

2.6 Wing Design

The design team took an unconventional approach to the wing structure by relying solely on span wise spars without the use of chord-wise ribs. The driving factor for this decision was based on the fact that, along with the fuselage, the wing interior was required to be used as fill volume to submerge the vehicle thus it was important that the interior of the vehicle be one completely connected chamber. Although these span-wise spars were sufficient to carry the bending loads, they performed poorly in torsion from initial calculations. To make up for this short coming additional material was added to the trailing edge [TE] and leading edge [LE] frame components to increase the wing's torsional stiffness. The spars, along with the TE and LE, were then fixed together with end caps at the fuselage and wingtip with a structural skin lay on top to complete the assembly.

2.7 Main Fuselage Design

Like the wing design the fuselage consists of a frame connected by cylindrical beams; each of which transfer the load directly from the wing spars into the center of the vehicle. The fuselage houses the vehicle dry bay which holds all the electronics except for the battery which sits on its own in the front of the vehicle so that it can be easily accessed to be charged. Note that the dry bay and battery were designed to be at the front of the fuselage to counter the weight of the tail section at the rear of the vehicle. To avoid having to add additional structures to match the high curvature of the body the skin thickness was increased until it could carry the minimal loads on the fuselage.

2.8 Rear Fuselage Design

Due to the length of the vehicle the fuselage was split up into two sections; the rear most of which connected the main fuselage section to the tail section. This configuration additionally granted the user access to the back end of the fuselage for easy access to the wiring going to the propulsion systems. Note that a muzzle was added onto the rear end of the section to attach the water propulsion system to the rear fuselage.

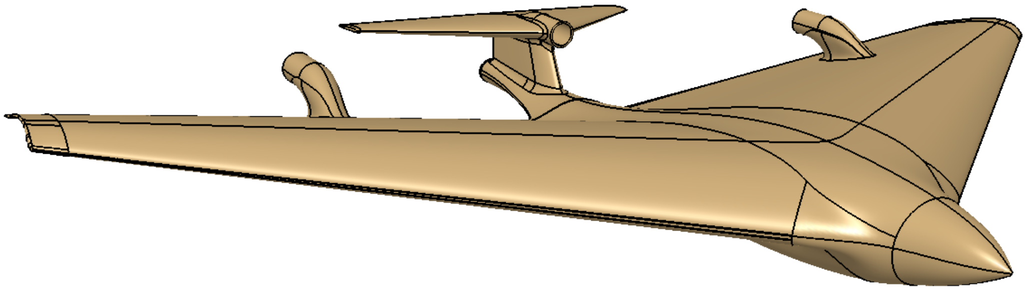


Figure 1: Initial Vehicle Surfacing Geometry

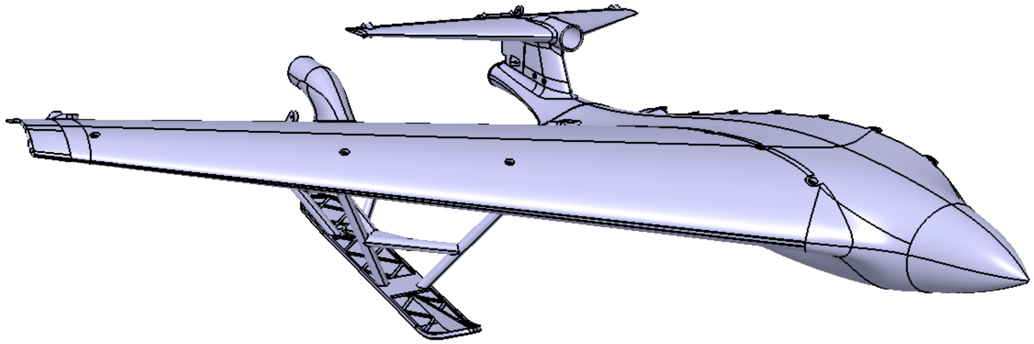


Figure 2: Initial Component Break Down

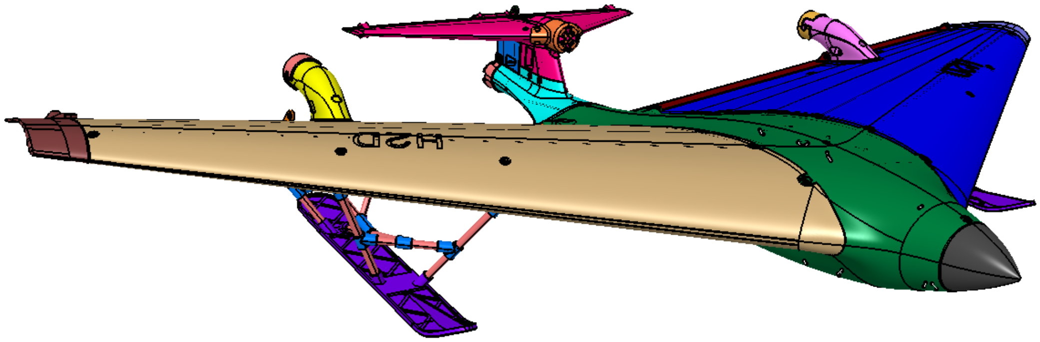


Figure 3: Vehicle Interior and Structural Design

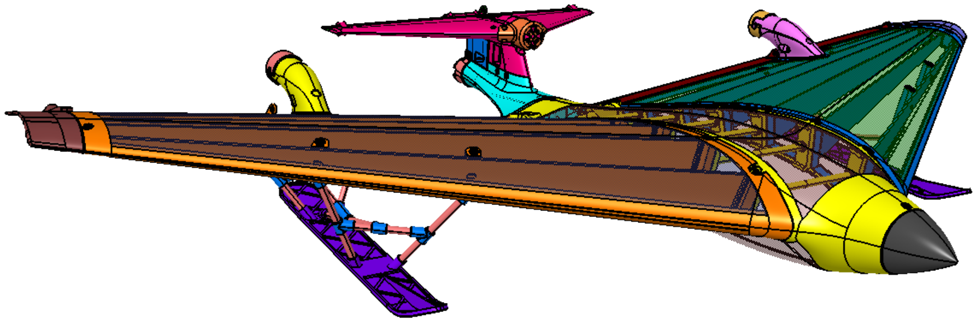


Figure 4: Manufacturing Break Down

2.9 Tail Section Design

One of the main concerns with the tail section was maximizing the rudder control surface area while maintaining the structural integrity of the vertical tail. On top of this, the added complexity provided by the electronics packaged in the rear end, a disproportionate number of additional features were required; because of this for simplicity purposes it was designed as a 3D printed component. One of these features was the mounting system to attach the elevator to the tail section. Since the elevator does not interface with any parts other than the tail section it becomes a rather difficult dynamic component to mechanize, to circumnavigate this detachable journal was added to properly constrain the control surface.

3.0 Analysis

Since aerodynamics is by nature a complex phenomenon of several interrelated variables, and the vehicle is designed to operate in the aerial and hydrodynamic realm, the analysis section of this report helped shape the overall design and strongly influenced key decisions pertaining to the vehicle.

While the project employed several extensive analysis studies, only a handful of those will be presented in this section of the report to maintain brevity. A summary of the analysis studies conducted during ME481 is presented in [1]. Hence, the key studies conducted in ME482 are:

i. Computational Fluid Dynamics (CFD) Static Studies
ii. 2D Ground Effect Simulation
iii. Volume of Fluid (VOF) Model
iv. Finite Element Structural Analysis (FEA)
v. 2D Dynamic Stability Analysis

3.1 CFD Static Studies

The purpose of the static studies is to evaluate the aerodynamic performance of the vehicle at different flight conditions, assess the performance of computational methods in validating the design of the vehicle, and optimize the aerodynamic parameters of the vehicle. For the purpose of this report, a rectangular box enclosed the vehicle and formed the domain. The box was hollowed to take the shape of the vehicle, the surfaces were identified as: walls, inlet, outlet, front, and back, and the free-stream inlet velocity was varied to mimic flight conditions. The flight conditions targeted were takeoff, cruise, and landing at 7, 0, and -5 degree angles of attack respectively. The magnitude of the free-stream velocity was kept constant at 13 m/s, which is in accordance with the thrust levels expected from the three air propellers mounted on the vehicle. A detailed description as well as images of the model setup can be found in B.1. All computations covered in this section were conducted using ANSYS AIM 17.0.

The static studies analyzed three distinct design iterations; the first design iteration yielded poor aerodynamic performance, generating insufficient lift values to maintain the vehicle weight (~3.0 kg) at cruise. The second iteration generated sufficient lift values to maintain cruise, however, it was slightly inefficient, requiring a slanted cruise angle of 3.75 degrees. Finally, the third design iteration was optimized to yield the lift values necessary to meet the performance demands and result in an overall more efficient design. A summary of key variables and parameters employed in the design iterations is given in Table 3 below.

Table 3: Summary of Key Variables in CFD Studies

Iteration#	Wing Planform Area (cm^2)	Aspect Ratio (AR)	Cruise Angle (deg.)	Lift (N) @ cruise	Drag (N) @ cruise
1	2402	2.08	5	15	3.2
2	4053	3.41	3.75	38.6	6
3	4443	3.58	0	36.2	4.0

To ensure the validity of the results obtained, non-dimensional analysis was performed to yield the coefficient of lift and drag values, which were then plotted against well-documented and verified models from airfoiltools.com [2]. The results are highlighted in Figure 5 below.

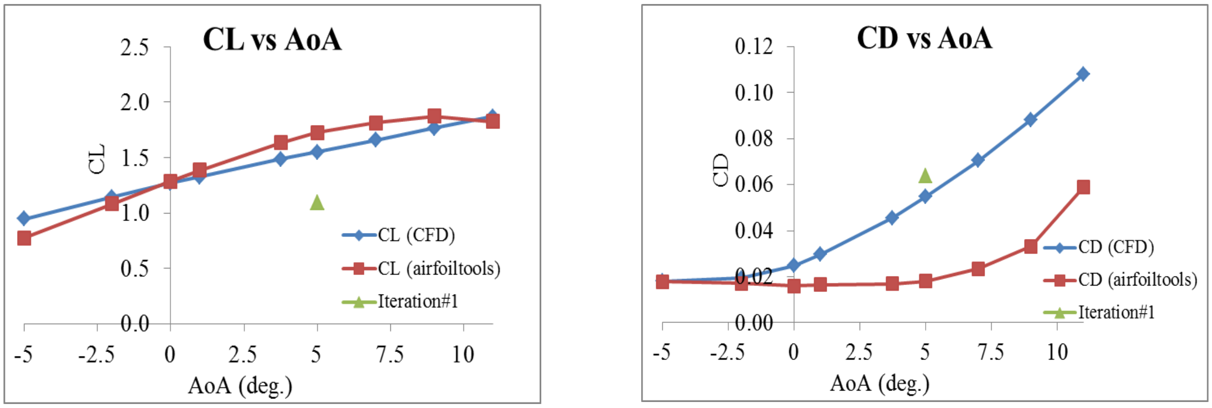


Figure 5: CL, CD plots vs Angle of Attack

As can be seen above, the lift plots match well with literature, however, due to limited computational resources and boundary layer refinement, as well as, contributions to drag from the body of the vehicle, the expected poor performance of the drag plot is not alarming. In order to further confirm, a grid refinement study has been conducted and the results are presented in B.1. The studies also helped quantify and validate the design of the fuselage as a lifting surface, as mentioned in Section 2.0 of this report, and allowed conducting a sensitivity study on the cruise velocity of the vehicle.

3.1.1 Tail Study

Finally, as one complete check of the overall design of the vehicle a flow visualization exercise was completed using streamlines. The exercise pointed an overlooked design issue in the tail section of the vehicle, which normally acts as a stabilizer; it highlighted the fact that the tail section is not functioning as it is supposed to (counteracting the lift generated by the wing), but it has acting to magnify the tendency of a nose up/nose down motion. As a result, the mounting angle of the horizontal tail was changed from 0 degrees to 8.6 degrees. A comparison of the design is shown in Figure 6 below; further details are provided in B.1.6.

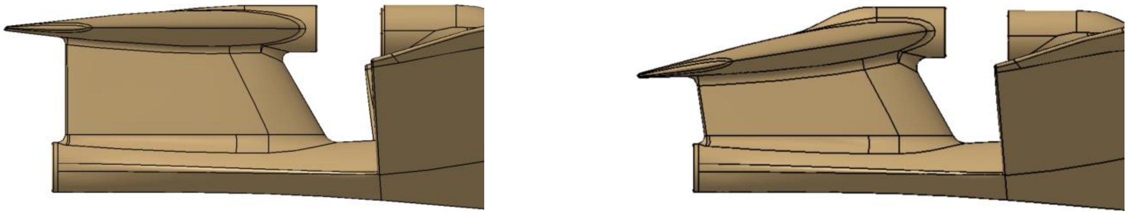


Figure 6: Summary of Old (left) and New (right) Tail Designs

3.2 2D Ground Effect Simulation

Since one of the main functions of the plane is to takeoff from water, it is expected that the dynamics of the flow underneath the wing will be altered due to the high surface tension of the water. As such, ANSYS Fluent was utilized to quantify those effects; the water surface was simulated as a solid boundary wall and the distance between the trailing edge of the airfoil and the wall was varied to obtain a wide range of data. As expected, the lift value increases as the wing approaches the ground; this is due to the energizing of the flow underneath the wing. Further details are provided in B.2.

3.3 Volume of Fluid Model

To accurately assess the structural design of the vehicle, a volume of fluid model employing a multi-phase water-air interface mesh was produced. The vehicle was simulated to dive nose down in the water as a worst-case scenario to estimate the maximum loads experienced on various parts of the wing, fuselage, and tail. The pressure plot obtained was then imported to drive Section 3.4 of this report. Further details are provided in B.3.

3.4 FEA Structural Analysis

Using the results of Section 3.3, areas of concern were identified and load cases were formulated. Namely, three different loading scenarios were analyzed: wing beam loading, wing torsion loading, and tail vertical loading. A summary of the loading conditions studied and the results is given in Table 4 below. Loading conditions with detailed pictures are given in B.3.

Table 4: Summary of FEA Studies

Study	Purpose	Highlight of Results
Wing Beam Loading	Assess the load distribution across the struts of the wing when subject to bending (mimic fall on wing tip)	-Load carried by upper wing struts -Bottleneck at leading edge contact -Rear wing struts unnecessary
Wing Torsion Loading	Assess the load distribution across the struts of the wing when subject to torsion (mimic high wind scenario during cruise)	-Failure at trailing edge fuselage connection -Leading edge bottle neck confirmed
Tail Vertical Loading	Assess the structural integrity of the vertical tail due to loading (mimic a drop on tail)	-Failure at fuselage connections -Increase rudder size

3.5 2D Dynamic Stability Analysis

To better predict the stability of the vehicle and determine the adequacy of the control surfaces in piloting the vehicle a 3 degree-of-freedom model was created to analyze the pitching moment, lift, and drag characteristics. The variables under audit were the thrust location, center of gravity, and control surface sizing. The model simulated the vehicle experiencing a disturbance during cruise in the form of a sudden angular acceleration and evaluated its ability to return to steady state flight by looking at both angle of attack over-shoot and response time.

It should be made clear that this simulation did not model 3D effects such as roll and yaw, however even with these simplifications of the vehicle dynamics significant learnings came out of the model. First off it found that the main wing airfoil used in the beta build vehicle severely limited the range of stable flight positions due to the high pitching moment of the GOE-464 airfoil. Because of this, the main airfoil profile was swapped with the NACA M8 which reduced the pitching moment by 25% at the cost of an 8% reduction in lift. This loss of lift was compensated for by slightly increasing the wing span.

Secondly it was found that the tail section of the vehicle stalls well before the main airfoil; thus, limiting the range of operable angles of attack. To mitigate this the horizontal tail airfoil profile was changed from the GOE 443 to the NACA 0012 which increased the stall angle by 8° at the cost of an additional 0.1N of drag at cruise; a negligible amount in comparison to the rest of the vehicle.

Finally, the vehicle length was stretched by 8% to increase the moment arm of the tail section which reduced the vehicle's sensitivity to the location of the COG. This was found to be the critical point at which the restoring moment provided by the tail overcame the forward pitching moment of the propellers and wing. Detailed plots of the analysis as well as the updated airfoil profiles can be found in B.4.

4.0 Manufacturing

The fabrication of this drone can be separated in two parts. One, the manufacturing method(s) and materials for production and two, the building of the prototype presented at symposium. The focus of this section is on the manufacturing of the beta prototype.

The frame is manufactured via 3D-Printed frame using both ABS and PLA. The frame is stiffened by laser-cut plywood spars, located in the wings and fuselage. The vehicle surface (fuselage and wing) are manufactured out via thermoformed Polyethylene terephthalate glycol-modified (PETG). The critical connections between the wings and fuselage are made using plastic binding posts and metal fasteners with a coat of epoxy for redundancy. Low stress bonds are made using Hot-Melt-Adhesive (HMA); hot-glue. Figure 7 shown below provides an overview of the various manufacturing methods implemented and Figure 8 showcases the 3D printed frame integrated with the wood spar structure.

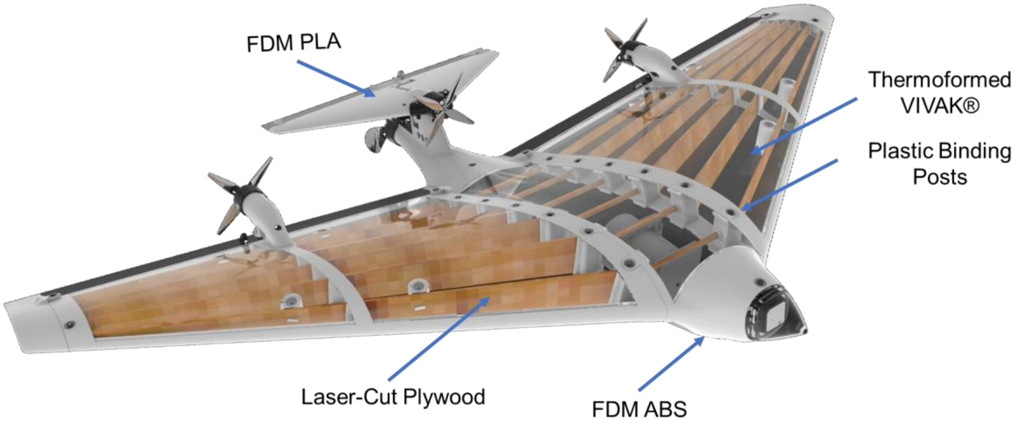


Figure 7: Overview of Manufacturing of the Plane

Figure 8: Prototype Build Photo

4.1 Process and Material Selection

The assembly process and the material selection are interrelated and dependent on one another. A general overview of the main processes taken into consideration and decision making matrix can be seen in the C.3. The criteria for the physical porotype were: light enough to fly but heavy enough for the volume to become neutrally buoyant once filled with water. Non-technical constraints to the prototype build were time and budget. Tests were performed using fiberglass in a vinyl ester matrix. The composite provides good strength and stiffness and was selected for the considerably lower cost compared to Carbon fiber composites this produced a strong, but heavy wing. Due to the complex curing of the polymer matrix a composite layup requires fabrication skills, experience, and time, and a disposable mold. Learning from this experience, it was decided that a composite build would not fulfill the desired requirements, thus manufacturing via thermoforming was implemented. For the forming process a mold is required, this mold can be used multiple times and therefore reduces the risk associated with the damage of parts. Forming material used was PETG which is a modified PETE with a lower melting point; allowing for formability. This material also has the additional benefit of being low cost and readily available [3].

Complex parts such as; motor mounts, the tail section, and the frame (fuselage and wing) were 3D-Printed. This method allows for the creation of complicated geometries with relatively high accuracy. Both ABS and PLA were used. ABS was used in sparing due to high cost thus only implemented for critical members. PLA was implemented for the remaining components. 3D printing also allowed for the creation of interlocking joints fastened using metal bolts and binding posts (root of the wing). This allowed for an accurate structural joint. Thermoformed pieces were located with the 3D-Printed frame using ledges and bonded together using epoxy.

Spars were manufactured using laser cut plywood. This method allows for the rapid creation of 2D profiles of constant thickness thus was optimal for this project. The marginal weight increase from using plywood compared to balsa wood (200 grams), is within reason when compared to the strength improvements achieved. All spars are bonded to the frames and the thermoformed components via epoxy.

4.2 Thermoforming Process Flow

Thermoforming was done on machined molds made of polystyrene. Foam is easily machined, since the mill can run at almost no load speeds. The CNC platform used has a size limit of 305 x 305 mm (1sq.ft) and thus the molds were machined in sections. The sections were then assembled using polyurethane glue. Since the melting temperature of polystyrene is at 240^{o}C, the immediate thermoforming of PETG at

~ 260ºC would result in the destruction of the mold. To counter this, an intermittent layer of 0.5mm (0.020”) thick polystyrene sheets is thermoformed onto the mold first. The layer melts on the top surface of the foam seamlessly, providing a stronger mold that is resistant to higher temperatures. The processed molds are then thermoformed with 1.5 mm PETG sheets. The resulting parts are then cut at the edges for mating to the frame of the drone.

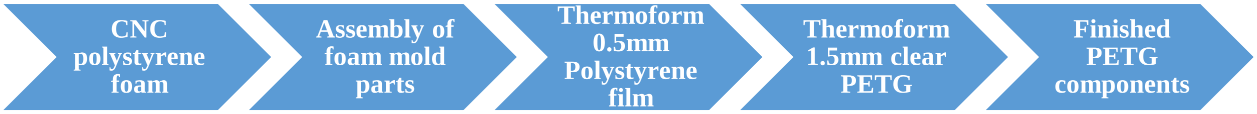


Figure 9: Process Flow for Thermoforming

4.3 Control System and Electronics

The electronics, i.e. the motors, servos, battery and esc’s are off-the-shelf components. These were integrated via nine channels on a conventional 2.4 GHz radio transmitter. The approach is taken in accordance with the scope of the project, which is limited to the mechanical development of the drone. The integration is as follows:

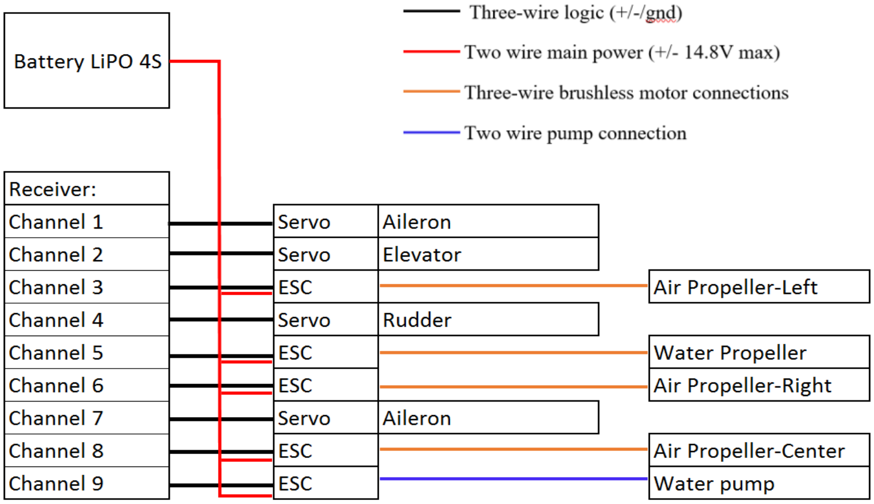


Figure 10: Wiring Schematic of the Electronics

4.4 Water Proofing of Electronics

The main electronics seal is done by a dry-bay inside the fuselage. For the purpose of water testing, the dry-bay was made using watertight plastic bags. The dry-chamber contains the ESC’s, the receiver, and the battery; this allows the battery to be removed, charged, and placed back inside without the risk of water damage. The servos, placed outside the dry-chamber, are sealed using mineral oil, which is filled into the insides of the servo, preventing water from penetrating inside, while maintaining the functionality of the gears. Additionally, the servo is silicon sealed from the outside. The motor windings are factory sealed and no further sealing was necessary for the prototype. Similarly, the water pump did not require sealing as it is designed for operation in water. As a backup safety measure, all electronics placed in the dry-chamber are also subjected to a conformal coating to reduce the risk of a potential leak.

5.0 Design Validation

Due to the amount of computational analysis that went into the design of the vehicle it was important for the design and analysis to be thoroughly validated. Three main areas of validation and testing were focused on during 482; full-scale wind tunnel testing, scale-model wind tunnel testing, and water testing. The following sections outline the results of this validation process.

5.1 Full-Scale Wind Tunnel Testing

Full-scale testing was performed with the vehicle prototype at the University of Waterloo's Large Fire Test Enclosure. Free flight wind tunnel tests were carried out in this facility as opposed to flying the vehicle unconstrained which eliminated the risk of crashing the prototype during testing. The test setup, showing the vehicle support arrangement used and a detailed test plan is given in D.1.

Several things could be observed with this test. Most importantly, it was observed that the vehicle was experiencing dynamic stability issues at certain flight speeds. At 8 m/s, the vehicle experienced Dutch roll, which is a coupling between yaw and roll. As illustrated in Figure 11 there is a large change in both the yaw and roll angle amplitudes, similar to a resonant frequency at 8m/s.

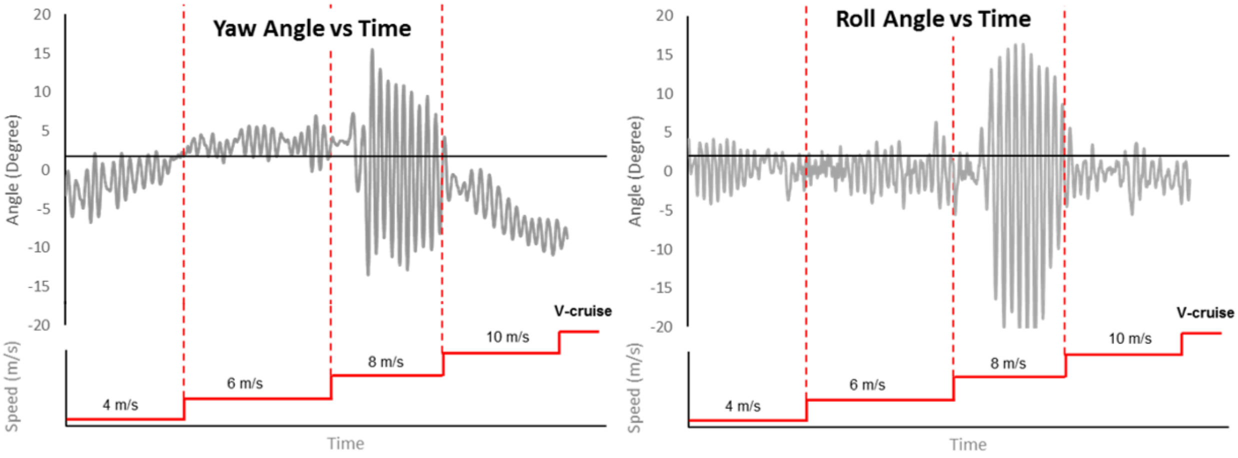


Figure 11: Full-Scale Testing Dynamics

Dutch Roll during flight is a serious issue. However, due to the test setup having strings attached to the wings, it could not be determined if the problem was as severe as the data showed or if the support wires were exacerbating the problem. To investigate this, before any vehicle design changes were made, scaled wind tunnel testing was conducted as outlined in Section 5.2 to determine the yawing moments from different wing designs.

While the dynamic stability showed some issues, the full-scale tests did validate that the propellers provided acceptable/balanced thrust at cruise speed, and that the wing flap sizing could provide reasonable restoring moments to help with dynamic control.

5.2 Yaw Data Collection

Due to the Dutch roll instability issues seen during full scale testing, small scale testing was completed to investigate the effect of altering the main wing attributes to mitigate the resonance experienced during full scale testing. To complete this three different 25% scaled vehicles were rapid prototyped and tested in the University of Waterloo's closed-loop wind tunnel each of which had altered wing dihedral and quarter chord sweep as these were the anticipated culprits causing the instability. A test matrix of the three prototypes is given in Table 5. It should be noted that the Reynolds number obtained during scale testing was approximately 20% that of the full vehicle cruise Reynolds number; this was not a concern however as the purpose of this testing was to evaluate the performance delta between the scale models and not for comparison to the full vehicle.

Table 5: Test Matrix for Yaw Data Collection

Test Sample	Parameters
Aggressive (original design)	Quarter Chord Sweep: 25° Trailing Edge Dihedral: 7°
Moderate	Quarter Chord Sweep: 15° Trailing Edge Dihedral: 2°
Conventional	Quarter Chord Sweep: 5° Trailing Edge Dihedral: 0°

Results from this testing are shown in Figure 12. It should be made clear that this data runs counter intuitive to what is expected and therefore its accuracy is questionable. What was found was maximum yawing moments occurred at 0° yaw angle in all cases which due to symmetry is counter-intuitive. Besides this however, what was clear was the overall response increased with increasing sweep and dihedral which is in agreement with theory.

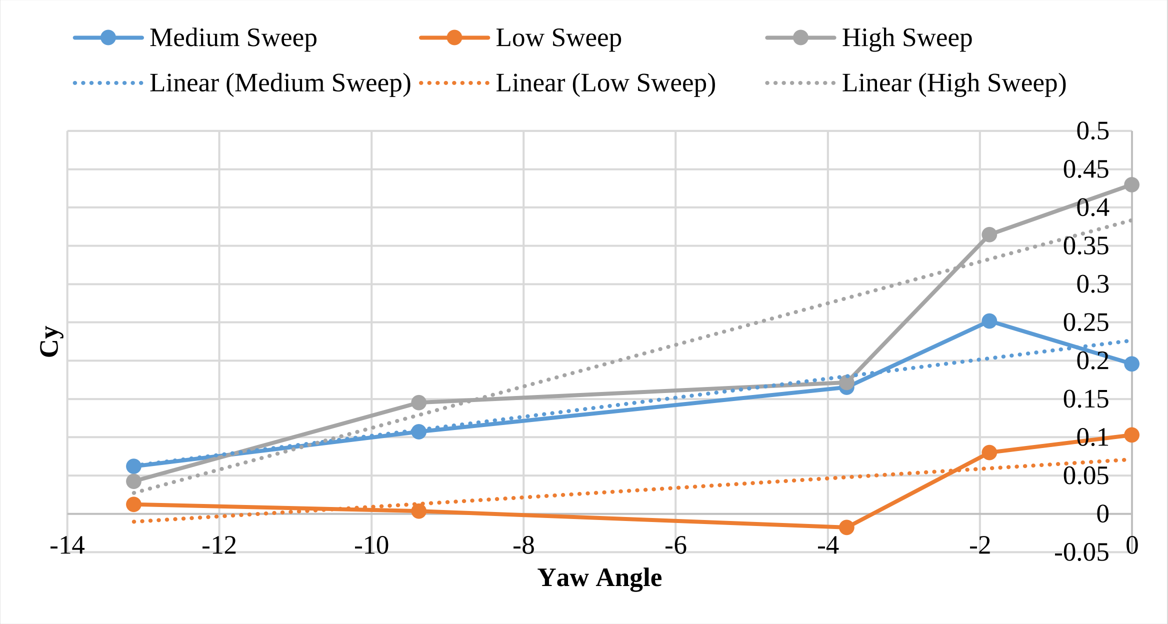


Figure 12: Wing Sweep Design Iteration - Yaw Coefficient vs Angle of Attack

5.3 Scaled Wind Tunnel Testing

Additional scale wind tunnel testing was performed with a 15% scale model in the University of Waterloo’s closed-loop wind tunnel. The scale model was 3D printed and attached to a sting (force balance) shown in D.2 to get lift and drag plots. The sting was calibrated for the range of forces expected for the test. The calibration data can be found in Appendix D.

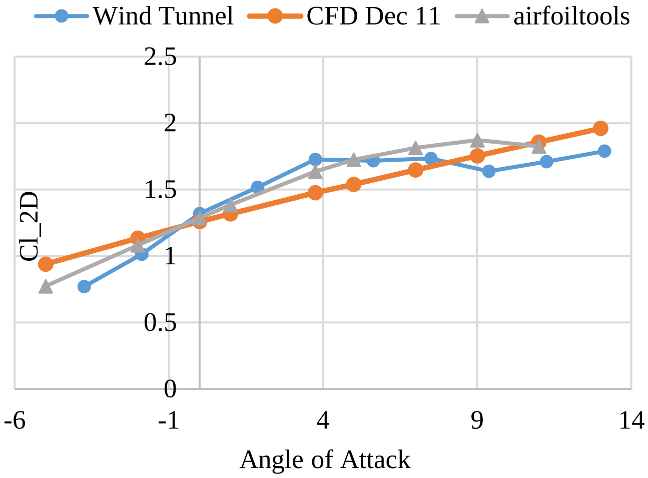


Figure 13: Lift Comparison

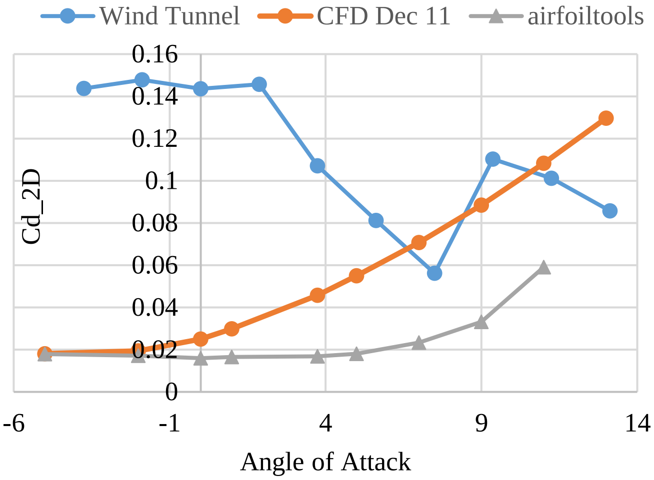


Figure 14: Drag Comparison

Testing the model over a range of angles of attack gave lift and drag plots that were compared with the CFD models from 3.0. The lift plot is shown in Figure 13 and the drag plot can be found in Figure 14. The predicted drag from the wind tunnel tests is significantly larger than that from the CFD. This discrepancy may be attributed to the poor scaling in the wind tunnel (15% used, 25% needed from Re scaling), and that more accurate CFD drag prediction would require far more cells than those used in 3.0. However, the results from the wind tunnel test matched very well with the CFD results for lift, confirming that the CFD models are accurately predicting the vehicle lift and can be used for further design iterations.

5.4 Water Testing

Full water performance system testing (except for water takeoff) was completed in the Physical Activities Complex pool. The water tests included testing of water propulsion, water stability on the surface, submerged and underwater maneuverability. A list of the complete test matrix is found in D.2.3.

From the water testing, several key water operation parameters were optimized. Most importantly, the optimal location of center of gravity for underwater stability was found and the locations for vent holes on the nose were confirmed. The different test locations for the vehicle's center of gravity are shown in Figure 15.

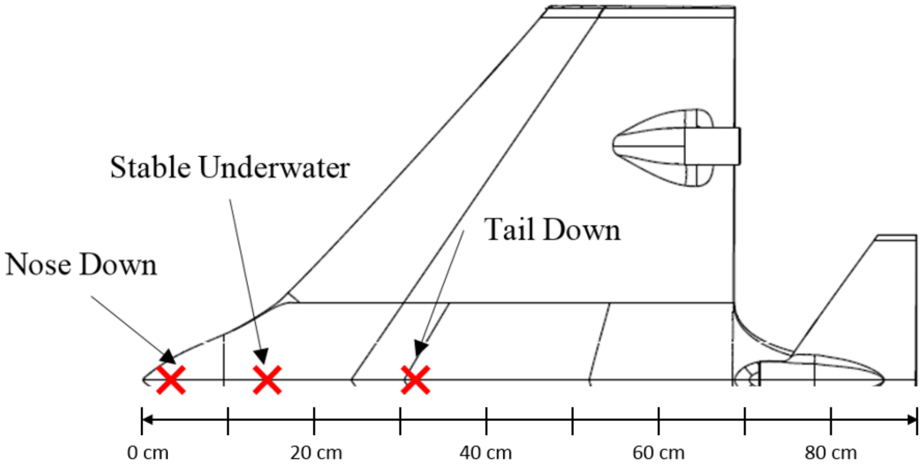


Figure 15: Water Center of Gravity Test Locations

In terms of water performance, the vehicle could travel at speeds of 0.8 m/s on the surface of the water, and 0.3 m/s underwater. However, tests showed that the size of the rudder was insufficient to control the direction of the vehicle while underwater. The rudder size was therefore increased in the next iteration of the vehicle. It was also determined that a fixed dry bay would be needed for the electronics, as the current sealing method failed when the electronics started to heat up underwater. Moreover, it was realized that the component level sealing testing completed in ME481 was found to be not fully representative of actual operation. Component level testing was conducted on servos that did not heat up, however when the full system was tested, the current sealing method (electrical tape) failed as the wiring connections started to heat up underwater.

Finally, to conclude water validation, the vehicle submergence system was tested. Initially the system was design to use a CO_2 canister which would blow water from the ballast tanks. However, as the ballast tanks got larger, the CO_2 system was replaced with a two-way pump, to fill and empty the vehicle. For testing, a one-way windshield washer pump was used to empty the vehicle. The pump could empty the vehicle in ~8 mins, which validates that a pump can remove enough water to allow the vehicle to float on the water surface. While 8 mins is relatively long to empty the vehicle, a faster two-way pump which can pump 8 L/min has been specified. Diagrams of the pump and CO_2 systems can be found in D.2.3.

6.0 Project Management

The ultimate goal of the project was to develop and showcase a RC Plane capable of seamlessly transitioning into water, functioning underwater, surfacing; after which taking off from the surface of the water. Based on limited resource and for the purposes of ME 481/482 the following project deliverables were established; 3D CAD model, robust analytical analysis (CFD and FEA), validated proof of concept (Air and Water), final report detailing the design process (i.e. market analysis, schedule, design, analysis, etc.). These deliverables aligned well with the ultimate project goal; brining the goal one step closer to reality. To effectively manage this and reach project success, various tools were implemented such as; schedules, team organizational/roll charts, budget tracking, and risk registries. This section outlines the implementation of these tools; 0 contains a detailed description of the tools implemented.

6.1 Scheduling

Highlighted below is project milestone, F.2 contains a detailed project schedule. The initial project intention was to produce two prototypes for this reason it was planned to finish the manufacturing of the first prototype by 01 Feb 17 and the verification by 15 Feb 17. This would allow for one month manufacturing of a second prototype before symposium date. This schedule was created with limited experience in manufacturing a prototype of this scale, as such, the project schedule was unrealistic. The project took longer than expected; it was not possible to produce a second prototype.

Table 6: Schedule of Deliverables for ME482

Task	Planned due date	Completion date
1.0 Conceptual Design & ROM	27 May 16	01 Jun 16
2.0 Proof of Concept	24 Jun 16	11 Jul 16
3.0 Analysis	30 Dec 16	15 Jan 17
4.0 Design	30 Dec 16	15 Jan 17
5.0 Manufacturing	01 Feb 17	01 Mar 17
6.0 Verification	15 Feb 17	15 Mar 17

6.2 Budget

Budgets for both cash and work hours were established and tracked separately. Contingency of approximately 20% of total budget was used for both cash and work hours. A rate of $25/hr was used to attach a monetary value to work hours. A cash budget was established for three key phases of the project, which were resource heavy; proof-of-concept (POC), prototype build, and validation. The initial budget of $850 ($750 from the MME department, $100 from team contributions) was divided amongst the project phases, with the largest allotment of capital going to the prototype build. After the completion of the POC it was quickly made apparent that the initial budget of $850 would not be sufficient for this project. To this end the team actively began seeking avenues to generate capital. Crowd sourcing was leveraged allowing the team to generate over $200 in additional capital a 23% increase in the initial budget. At the end of the project a deficit of $700 remained which will be carried by the team members.

A budget of $60,000 (2,400 hours) was created assuming 10-hour work week per team member over the course of 48 weeks. Hours were budgeted for the five core responsibilities of the project; project management, analysis, validation, design, and manufacturing. Based on past project experience the largest number of hours were budgeted for design and manufacturing. Overall the project was within budget for work hours, this was achieved largely in part to the utilization of the risk registry. The risk registry highlighted the gap between the existing knowledge and the required knowledge, this provided team members with perspective when budgeting work hours, even so the team went over budget. This was due in large part to unforeseen challenges in manufacturing and design.

6.3 Risk Mitigation Plan

A risk registry of technical and non-technical risk was established so that countermeasures can be created and implemented (F.4); this tool proved to be valuable to the team in many ways; as mentioned earlier, it helped the team realistically plan the number of hours required for this project. It was identified early on that the project scope posed a risk for this project. Thus, during the design phase the team constantly evaluated the scope, leveraging expertise from instructional and technical staff. Due to this constant evaluation, the initial scope of developing a prototype capable of transitioning into water was modified to not focus on this point, thus this was not incorporated in the scope of ME482.

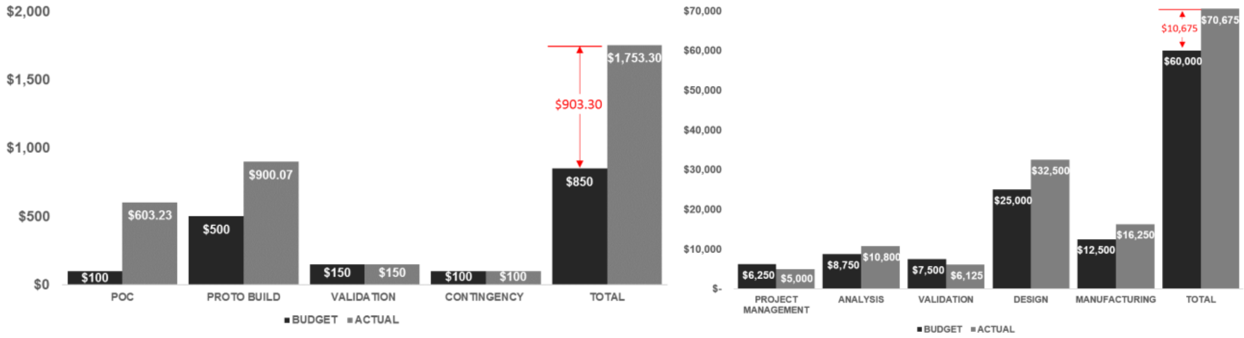


Figure 16: Budget of Liquid Assets (left) and Work Hour Budget (right)

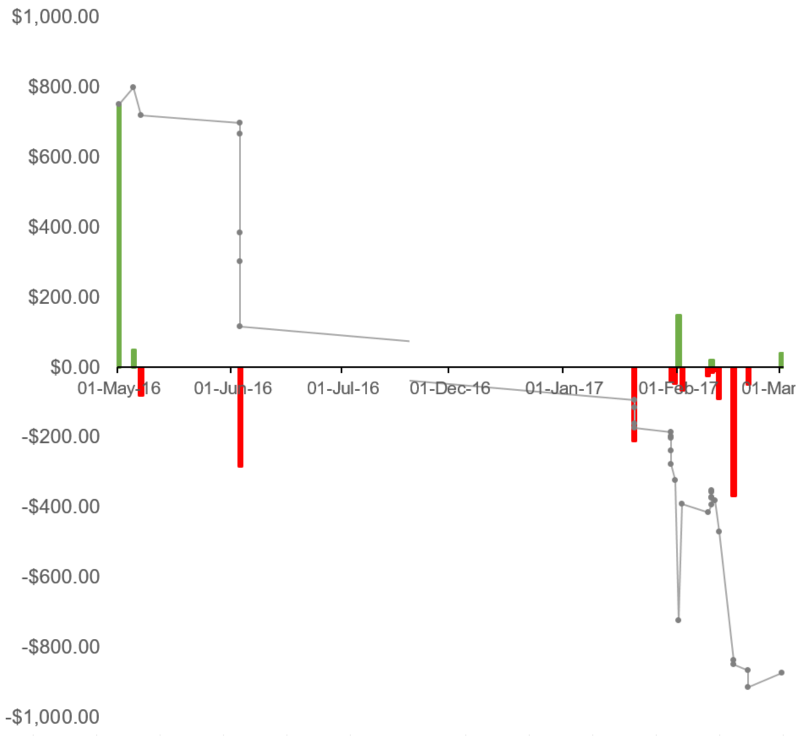


Figure 17: Liquid Assets Cash-flow

7.0 Reflection

7.1 Design

Although the time frame of ME 482 only allowed for one complete build cycle it provided a great deal of learning opportunities for the design team to improve on the vehicle geometry with respect to improving assembly, manufacturing, and functionality. A list of the key learnings from this cycle is provided in Table 7. Along with this detail design, a few major design changes were made as outlined in

Table 8. A reflection from the design section would be reducing the amount of detail provided in the 3D CAD (i.e. simplified wing tip, less parametric design, simplified structures, etc.); this would allow team members to prioritize other activities, further stretching the project deliverables.

7.2 Manufacturing

The method of a 3D-Printed frame and thermoformed skin results in acceptable properties. However, accuracy became an issue, as certain components did not match very well. Although accuracy was not required to the millimeter, it might have affected the overall performance of the vehicle. One solution to more accurate parts is the use of a different material as thermoforming molds and mold features for precise post processing. For example, MDF would increase mold machining, but it would allow a rigid protrusion, hence identifying the exact location of the thermoformed piece to the frame bond. Additional mechanical connections of frame pieces and stiffeners in the form of interlocking lap joints can also ease the assembly and increase the bonding for stronger joints.

Table 7: Design for Functionality/Assembly/Manufacture Improvements

	Description	Rationale
DFF	Control Surface Hooks	Long cantilevered wing-flaps/elevators were under constrained; mid span and end hooks were added.
	Additional Structural Members	Struts were added to reduce flexure in rear fuselage and wingtip.
DFA	Interlocking Joints	Frame butt joints were replaced with interlocking features to improve locating tolerances.
	Fuselage Strut Recessions	Embossments were added to the fuselage struts to avoid misalignment.
	Wing-Fuselage Interface Clearance	Clearance was added to the tabs at the wing-frame to fuselage-frame interface to relax the over constrained joint.
	Wing/Fuselage Skin Tabs	Full span contact patches were added for vehicle skin to improve adhesion.
DFM	Main Wing X-Strut	A mid span strut was added to split the skin into sections that could be CNC'ed in a single step with the resources available.
	Flaps out of wood	Wing flaps were modified to be laser cut rather than 3D printed.
	Leading Edge / Trailing Edge, extrusions	The leading edge and trailing edge frame components were modified to be extruded for full scale production.

Table 8: Major Changes between Beta Build and RC1

Design Change	Cause	Improved Metric
Vehicle Proportions	Stability analysis showed improved flight handling with horizontal tail moment arm increased	Vehicle length increased by 8%
GOE 464 to NACA M8 Main Airfoil Profile Swap	Results from 2D dynamics simulation showed vehicle was sensitive to COG location due to high wing profile pitching moment.	Main airfoil pitching moment reduced by 25%
GOE 443 to NACA 0012 Horizontal Tail Airfoil Profile Swap	Audit of aerodynamic performance showed tail section stalled before main wing.	Tail stall angle increased by 8°
Addition of Skis	Ski-less vehicle requires water body to take off from	Convenience (qualitative)
Addition of Dry Bay	Sealing technique on electronics proved to be inadequate	---

7.3 Validation

The method used for the scaled wind tunnel test of lift showed very good prediction of lift with respect to the CFD analysis. However, the uncertainty and reliability in the drag tests showed issues. The scaled model used for drag measurement should have been 25% size rather than 15% so that the Reynolds number could more closely match that of the full-scale vehicle. With respect to full-scale testing, this allowed changes to be made to fix the detected problems. However, the setup of the test, with the strings attached to the wings may have exacerbated the roll and yaw instability, and so it would have been better if the strings had been attached through the center line of the vehicle. In this way, the strings would have no effect on the roll performance of the test. The biggest takeaway from validation was that scaled wind tunnel testing should have been done as soon as possible, so that design changes from the tests could be implemented into the full-scale build. Moreover, when evaluating the utility of liquid electrical tape as a component level sealant, the initial validation testing that was performed in ME481 was not representative of typical operating conditions. Thus, during actual use (underwater), components overheated and seal integrity was compromised. It would have been much more beneficial if the heat released from the components was taken into consideration before full vehicle testing.

7.4 Analysis

While the analysis section outlined in this report was both diverse and extensive by employing several tools and multiple pieces of software, there will always be room for improvement. One particular pathway for improvement would be investigating both 2D and 3D dynamic stability early on in the project. Despite the expensive nature of such tasks, the team believes they would certainly be worth exploring and will be worthwhile contributors to the overall design process. Another improvement could be obtained in evaluating the aerodynamic performance of various designs simultaneously, thus reaching a more refined solution. Overall, the analysis conducted on the plane proved to be a valuable learning experience.

7.5 Project Management

Transferable skill acquired from this project was the application of the engineering method. In its truest form, the engineering method is approaching a challenge in a systematic manner, developing a solution, validating the solution and then improving the solution. Due the capital-intensive nature of this project, one reflection from project management would be to seek to raise excess capital as much as possible. It was both an exciting opportunity and a learning experience to further develop marketing skills by seeking crowd sourcing funds and creating an online brand presence (YouTube, website etc.)

8.0 Conclusions and Recommendations

As was outlined the ultimate goal was to develop a drone capable of functioning in air, seamlessly transitioning into water, working under water and then taking off from the surface of the water. To achieve this goal with the academic constraints a scope was defined which would allow the team to progress in the direction of achieving the ultimate goal. The scope of the project was to; create 3D CAD model, robust analytical analysis (CFD and FEA), validated proof of concept (Air and Water), and final report outlining and detailing the design process (i.e. market analysis, schedule, design, analysis, etc.). To initiate the project a robust market study was preformed to understand the wants of the customer. After this a period of brainstorming and conceptual design was preformed which lead into a phase of analysis. During this phase, detailed CFD and FEA studies were performed to understand the behavior of the plane. Various key metrics such as C_L and C_D were determined. After yielding positive results from the analysis phase, manufacturing of the plane occurred. Various manufacturing techniques were reviewed and tested after which it was decided to employ thermoforming and 3D printing. A robust validation phase occurred; full scale and scaled wind tunnel testing was done to validate flight characteristics. Water testing was done to validate water functionality. Based on the validation process various recommendations have been made and implemented as to create a refined product. These recommendations are summarized in Section 7.1.

9.0 References

[1] K. Younes, C. Diffey, K. Strobel, E. Fochtberger and S. Hussain, "ME 481: H2Drones Final Design Report," University of Waterloo, Waterloo, 2016.

[2] "www.airfoiltools.com," [Online]. Available: www.airfoiltools.com. [Accessed 28 March 2016].

[3] K. Bastian, "Plastics Machining and Fabricating: Feature," Plasticmachining.com, 2017. [Online]. Available: http://www.plasticsmachining.com/magazine/199802/petg.html.

[4] B. Martin, "nautilusdrydocks.com," 2016. [Online]. Available: http://www.rc-submarine.com/#!rc-submarine-technology/cltyp. [Accessed 24 July 2016].

[5] "Balsa | The Wood Database - Lumber Identification (Hardwood)," Wood-database.com, 2017. [Online]. Available: http://www.wood-database.com/balsa/.

[6] "7075 Aluminium Alloy / Aluminum Alloy 7075," Aircraftmaterials.com, 2017. [Online]. Available: https://www.aircraftmaterials.com/data/aluminium/7075.html.

[7] C. DeMerchant, "Carbon Fiber Properties," Christinedemerchant.com, 2017. [Online]. Available: http://www.christinedemerchant.com/carboncharacteristics.html.

[8] "Mechanical Properties of Carbon Fiber Composite Materials," Performance-composites.com, 2017. [Online]. Available: http://www.performance-composites.com/carbonfibre/mechanicalproperties_2.asp.

[9] "Properties of Carbon Fiber," Clearwatercomposites.com, 2017. [Online]. Available: http://www.clearwatercomposites.com/resources/Properties-of-carbon-fiber.

[10] "Fiberglass and Composite Design Guide," Performance Composite Inc., 2017. [Online]. Available: http://www.performancecomposites.com/about-composites-technical-info/122-designing-with-fiberglass.html.

Appendix A Engineering Specifications

Team: H2Drones
Group#: 1
Engineering Design Specification
Originator: **K. Younes**

28.March.17
Revision Level: D
Document Number: 001

Intended Application:
-dual environment vehicle, with focus on aerial functionality

🟩 Compliant
⬜ Not Observed
▨ Not available
🟧 Non-compliant

Requirements Specification:

No.	**Characteristic**	**Relation**	**Value**	**Units**	**Verification Method**	**Comments**	**Compliance**
	Functional Requirements						
1	Characteristic length	≤	1	m	Examination	Length = 0.8 m	Compliant
2	Battery Life – Air Flight Only	≥	35	min	Test	Matches survey responses. Full flight tests to be conducted in RC1	Not observed
3	Battery Life – Water Only	≥	10	min	Test	Some responses wanted around the 10 min mark	Compliant
4	Method of Water Entry					The height at which the drone will be able to dive into the water from. The way the drone enters the water. **N/A Scope Definition change.**	
5	Method of Water Exit					The speed at which the drone can exit the water. **N/A Scope Definition change.**	
6	Time to Transition from Air to Water	≥	10	min	Test	Actual time is 8 minutes.	Compliant
7	Air Speed	≥	15	m/s	Test	All survey responses were ok with speed under 50km/h. Stability concerns arise at 8 m/s. RC 1 design should resolve.	Non-compliant
8	Water Speed	≥	0.5	m/s	Test	Matches survey responses. Water speed achieved = 0.8 m/s.	Compliant
9	Total Weight	≤	6	kg	Examination	Total weight = 3.3 kg	Compliant

10	Time to charge battery	≥		min		Time is dependent on battery size. No specification given in market survey.	Not observed
	Non-Functional Requirements						
11	Full aerial features (Metric for agility – turn radii)	≤	7m			1 m turning radius	Compliant
12	Full aquatic capabilities (Metric for agility – turn radii)	≤	6m			5 m turning radius	Compliant
13	Sustainability **(indicated targeted CO2 footprint)**	≤	50	Kg CO^2	Analysis	Steel used is recyclable. Wood used is approved to be complying with environment standards. Product does not require any power to operate	Compliant
	Constraint Requirements						
11	Safe operation (propeller mounting)	=	Yes		Test		Compliant
12	Prototype cost	≤	200	$CAD	Analysis	Total cost spent on the final product was $150	Compliant
13	Product sales cost	≤	2500	$CAD	Analysis	All people willing to pay between $1000 and 5000. Final product cost = $1600	Compliant
14	RC range	≥	800	m	Test	People wanted full remote control – look into expanding range	Compliant
15	Temperature	≤	-5	°C	Test	Negative temperatures were not observed.	Not observed
16	Temperature	≥	40	°C	Test	Hot temperatures were not observed.	Not observed
17	Flight altitude	≥	150	m	Test	Vehicle stability; flight tests to be conducted in RC1.	Non-compliant
18	Water depth	≥	50	cm	Test		Compliant
19	Environmental effects (wind speed)	≥	5	m/s	Test	Vehicle able to handle loads in wind tunnel at 11 m/s	Compliant

Appendix B Analysis

B.1 CFD Static Studies

B.1.1 Domain and Mesh Parameters

The mesh (grid) in a CFD simulation plays a critical role in computing the forces of interest. Formulating a sufficiently refined mesh is a task of great complexity, often requiring immense computational power and RAM memory. For the purpose of this project, 12 cores (computer processors) were utilized at the ANSYS Headquarters in Waterloo to assist in the computation. The following table provides an overview of the mesh parameters involved in the CFD models mentioned in 3.0 of this report.

Table 9: Global Sizing and Mesh Details

Global Sizing			
Cell Type	Tetra	**Element Size (m)**	0.001213
Size Function	Curvature & Proximity	**Growth Rate**	1.2
Inflation Layers			
# of Layers	13	**Element Size (m)**	0.001
Transition Ratio	0.35	**Growth Rate**	1.05
Total Cell Count		**2.6E06**	

Boundary-Layer Theory:
$\boldsymbol{\delta = 0.0042\ m}$
Inflation Layers:
$\boldsymbol{\delta = 0.013\ m}$

An attempt to fully resolve the boundary layer by employing 13 inflation layers was made. However, due to limitations in computer storage and memory available, it was observed that the cell size was not sufficient for accurate drag computations (drag is highly dependent on the full resolution of the boundary layer).

Figure 19 provides an image of the domain with the boundary conditions implemented (top left) along with a close-up image on the inflation layers at the nose of the plane (top right). The overall cell count of the grid utilized was 2.6 million cells (Figure 19).

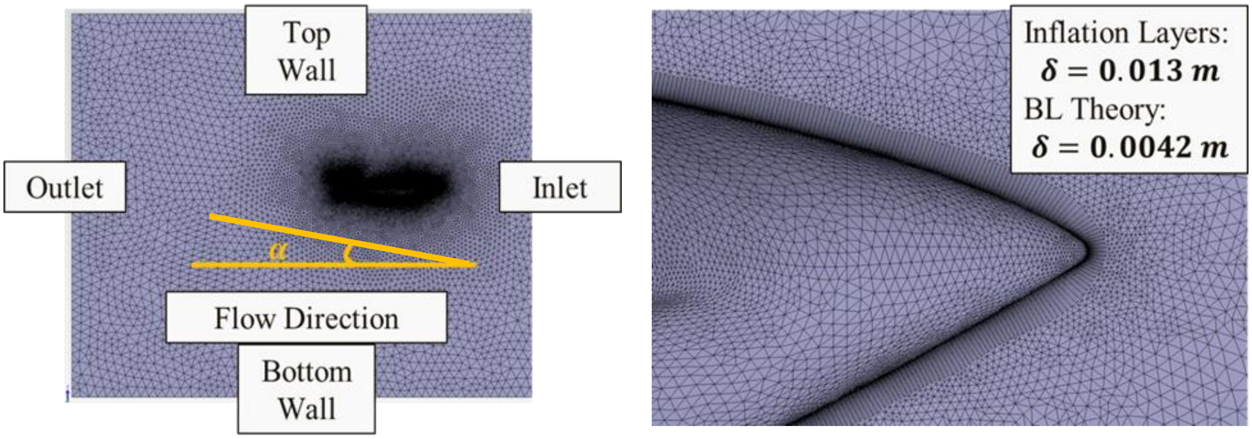


Figure 18: Domain and Boundary Conditions (left) and a Close-up View Around the Nose (right)

The vehicle was employed as a ‘sphere of influence’ whilst creating the mesh, indicating that the grid cells are finest closest to the plane and coarsen moving farther from the plane; this was done in order to increase the refinement in the regions where most changes are expected in the flow (close to the plane) while minimizing the computational power required in resolving the cells where minute changes in the flow are expected (in the far stream).

Figure 19: Snapshot of the Grid Created Around the Vehicle

B.1.2 Detailed Results from Iterations 1-3

Table 10: Raw Data from Iteration 1

Test Matrix – Iteration 1			
Velocity (m/s)	**Vehicle AoA (°)**	**Lift (N)**	**Drag (N)**
10	5	16	3.2
20	10	70	14

Table 11: Raw Data from Iteration 2

Test Matrix – Iteration 2			
Velocity (m/s)	**Vehicle AoA (°)**	**Lift (N)**	**Drag (N)**
13	-5	22.2	3.0
13	3.75	38.6	6.0
13	7	45.6	8.0

Table 12: Raw Data from Iteration 3

Test Matrix – Iteration 3			
Velocity (m/s)	**Vehicle AoA (°)**	**Lift (N)**	**Drag (N)**
13	-5	27.0	2.2
13	0	36.2	4.0
13	7	44.4	6.4

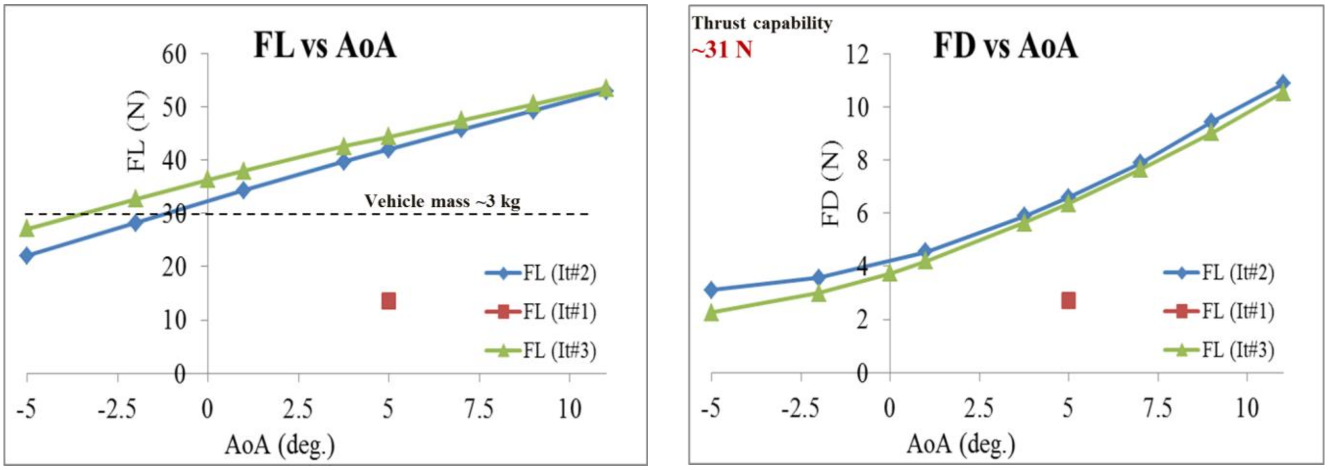


Figure 20: Summary of FL, FD Results from Iterations 1-3

B.1.3 Grid Refinement

A grid refinement exercise was conducted to validate the mesh resolution employed in the CFD analysis and ensure accuracy of the results obtained. Based on advice from the faculty advisor, the mesh size was reduced by an order of magnitude, and the second test case of Table 11 was replicated using the two grids shown in Figure 21.

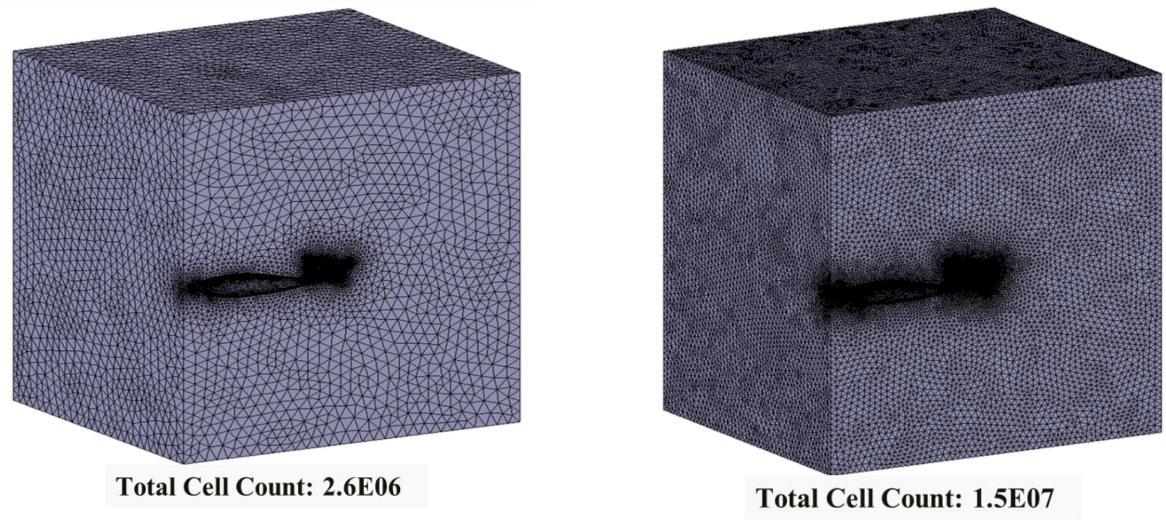


Figure 21: Snapshots of the Overall Domain with Refined Grid (right) and Unrefined Grid (left)

The results obtained from the two test cases showed an average discrepancy of ~5%, which was deemed acceptable by the analysis team based on recommendations from the faculty advisor.

B.1.4 Fuselage as a Lifting Surface

Since the intended design of the vehicle housed a curved, scalloped fuselage, which served to act as an extra lifting surface to alleviate the substantial lift requirements for water takeoff, a separate CFD study was conducted in order to validate that purpose. Using the design in iteration 2, two CFD models were setup – one with solely the wing of the vehicle and the other with the full half-body of the vehicle – to compute the lift and drag forces with and without the influence of the fuselage. The results are summarized in Figure 22.

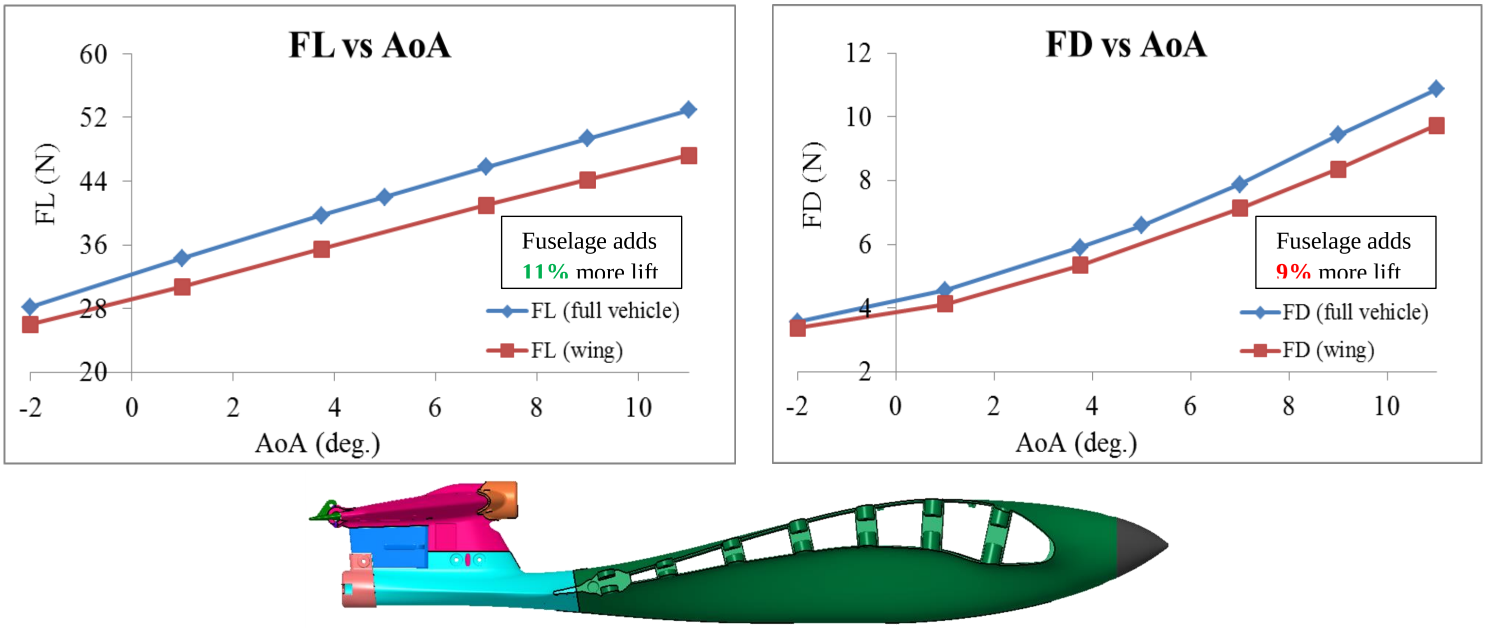


Figure 22: FL, FD Plots with Fuselage Influence

The expected observation that the curvature of the fuselage adds more lift and drag to the overall system parameters was confirmed. On average, the fuselage adds 11% more lift and 9% more drag. While the addition of drag is not a desired feature, the extra lift generated was needed for water surface takeoff and thus, the design was appropriate for the intended application.

B.1.5 Cruise Velocity Sensitivity Study

As an extra sensitivity analysis, the CFD models and results from iteration 3 were used to compute the lift generated by the full vehicle configuration at different cruise velocities. The purposes of this study were to gain a better feel for how sensitive the vehicle is to the initial weight estimate of ~3 kg and to further validate the CFD models using the known quadratic behavior of $F_L \propto V^2$ as a baseline. The results obtained at the estimated cruise angle of 0°are shown in Figure 23 below.

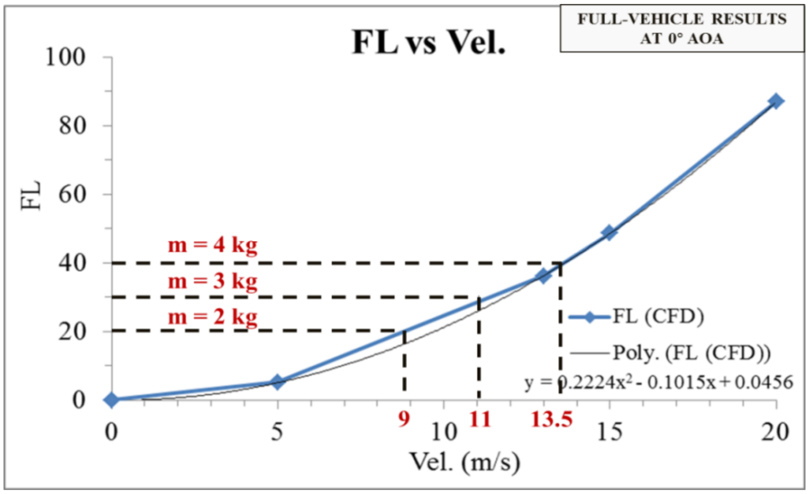


Figure 23: Cruise Velocity-Weight Sensitivity Study

As can be seen, the lift obtained from the CFD models agree well with the theoretical quadratic behavior. In addition, at a cruise of velocity of 13 m/s and with an initial weight estimate of ~3 kg, the factor of safety is 1.2. In other words, even if the weight estimate overshoots by up to 33%, the vehicle is capable of generating sufficient lift to cruise in air.

B.1.6 Tail Study

To fully utilize the powerful tools that common, commercial CFD software offers, a flow visualization study using streamlines was conducted on iteration 3 of the vehicle design. The purpose of this study was to identify any potential room for improvements in terms of aerodynamic performance and vehicle design. Surprisingly, the study helped shed light on a fairly substantial design aspect of the vehicle, the tail section. In general, the tail of an aerodynamic vehicle serves as a stabilizer by counteracting the force of lift generated by the wings and preventing a nose up/nose down tendency. In this particular case however, the tail was generating negative lift values at positive angles of attack, opposite to its intended design; thus, it was not counteracting the lift by the wings, but it was exacerbating the tendency of a nose up/nose down condition. The phenomenon was better visualized and confirmed using streamlines, as shown in Figure 24 below.

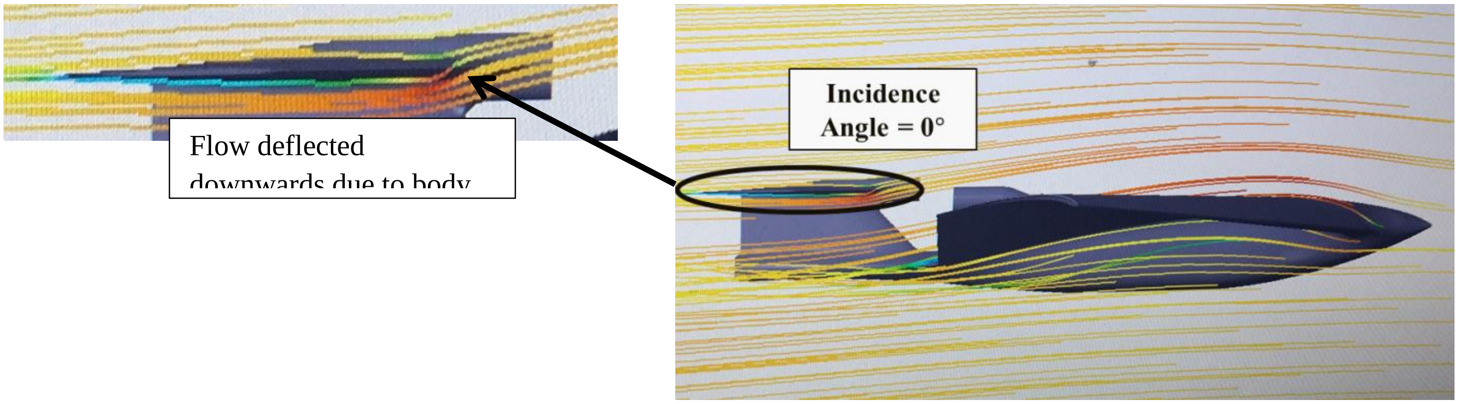


Figure 24: Flow Visualization Study on the Tail Section of the Vehicle

Using the results of the flow visualization study, it was deduced that due to the inherent, intended curvature embedded in the fuselage of the vehicle, the flow reaching the tail section was deflected downwards, resulting in negative forces of lift at positive angles of attack (undesirable). In order to mitigate the problem, three different design changes were considered, and the decision was based on a matrix method, as seen in Table 13.

Table 13: Decision Matrix for Tail Design Change

	Design Change	
	1- Replace the tail airfoil profile to semi-cambered	2- Change the incidence angle of the tail
Time Required	-	+
Risk Involved	-	+
Manufacturability	+	+
Performance	-	+
Sum	**-2**	**+4**

The aspects considered in making the design change of the tail section were time (to make the change in CAD and update the CFD models), risk, manufacturability, and performance. Option 2 proved to be the more attractive candidate mainly due to the simplicity of the design changes in CAD, thus the likelihood of rolling a new design for further CFD testing was higher. Both options are equally manufacturable, while the performance of option 2 outweighs option 1. The reason for this difference is that by employing a half-cambered wing, the incoming flow would still be deflected downwards on the tail however the negative impacts on the lift will be diminished due to the semi-cambered wing design. Option 2 completely cancels the flow deflection since the tail now sees the airflow as oncoming parallel to its orientation. The updated tail design is shown in Figure 25. It was further tested to confirm the hypothesis that the curvature of the body now has no negative impacts on the tail.

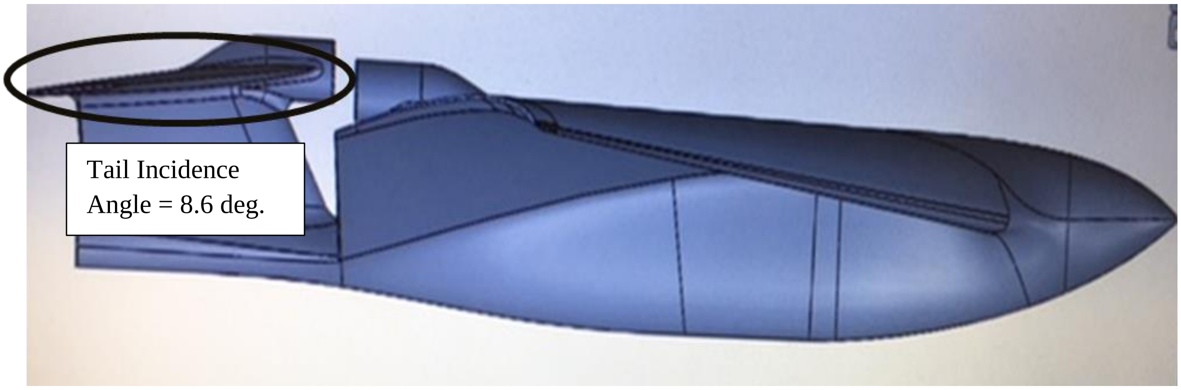


Figure 25: Updated CAD Design with Tail Slanted Upwards at 8.6°

The force of lift generated by the tail was computed over a wide range of angles of attack to longer yield any negative values, indicating that the tail design issue was fully resolved. A plot of the lift values is shown below:

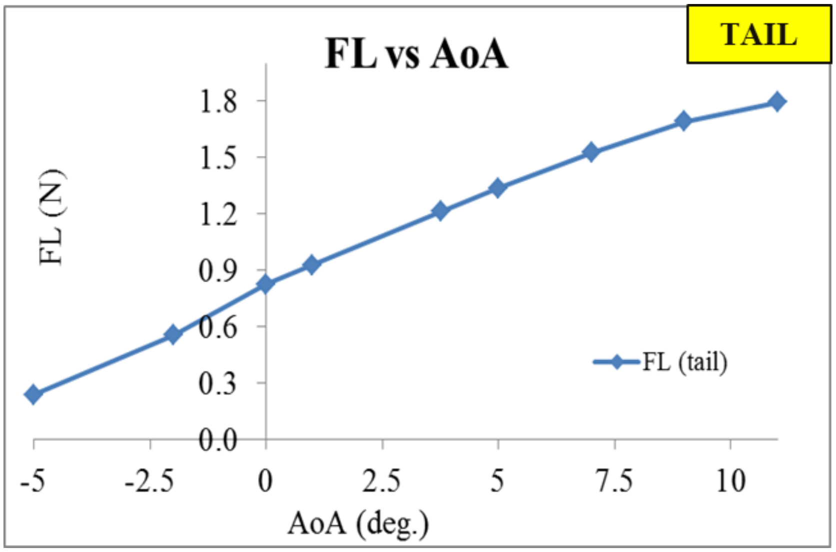
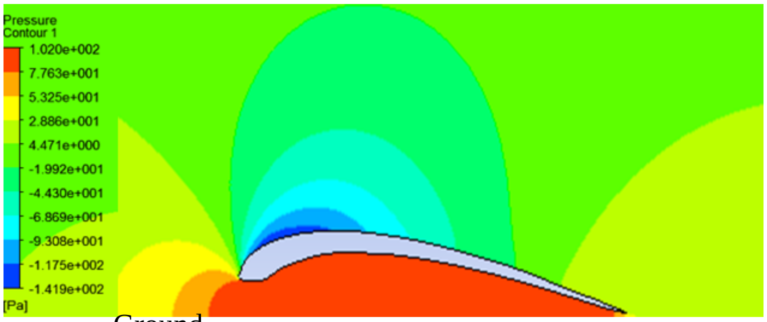


Figure 26: Force of Lift on the Tail at Various Angles of Attack

B.2 2D Ground Effect Data

Since the intended application of the aerial vehicle was water surface takeoff, it was expected that due to the close proximity present between the water line and the lifting surfaces, the fluid dynamics and physics involved underneath the wing would change. As a result, a separate CFD study was conducted on the airfoil profile (GOE 464) in ANSYS Fluent. The purpose of this study was to quantify the effects of the water line on the lift generated by the airfoil. A simple, 2D rectangular domain was created, with the bottom surface modelled as a solid wall (the viscosity of water is high and it essentially acts as a solid under the wing) with a high roughness value. The tests were conducted using a free-stream air velocity of 13 m/s (cruise) and the airfoil was mounted at 4.5 degrees to the horizon, which matches the conceptual design of the vehicle. A parameter sweep of trailing edge distances to the water surface was conducted. The results obtained confirm the finding that the ground effect generates extra lift from the airfoil; this could be attributed to the high pressure build up under the wing, which creates a greater pressure differential and ultimately more lift.



TE Distance (mm)	CL
4000	1.25
57	1.36
7	1.51

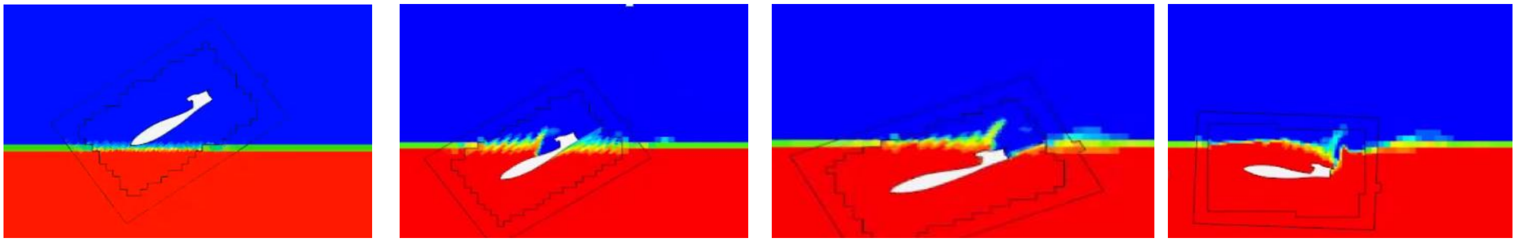
Figure 27: Results of the Ground Effect Analysis

B.3 VOF Model and FEA Data

Since the structural analysis of the vehicle implemented the results from the volume of fluid model, these two sections are combined. First, a quick overview is given on the VOF model and then a deep dive into the detailed FEA analysis is provided.

B.3.1 Volume of Fluid Model

For the volume of fluid model, the plane was dropped at 35 degrees clockwise from the horizontal, at an initial velocity of 13 m/s (cruise). The model involved 3 degrees of freedom and a multi-phase mesh with air (modeled in blue) and water (modeled in red). The purpose of this study was to get an estimate of the loads experienced by the vehicle in the worst case scenario – diving nose down into the water. A timeline of the animation is shown below: A sample of the results obtained from the VOF model is shown in Figure 29 below. The pressure plot was used as a basis to estimate the forces and loads applied in the FEA case studies



Time t = 0s   Time t = 0.5s   Time t = 1s   Time t = 1.5s

Figure 28: Snapshots of the VOF Model during Submersion

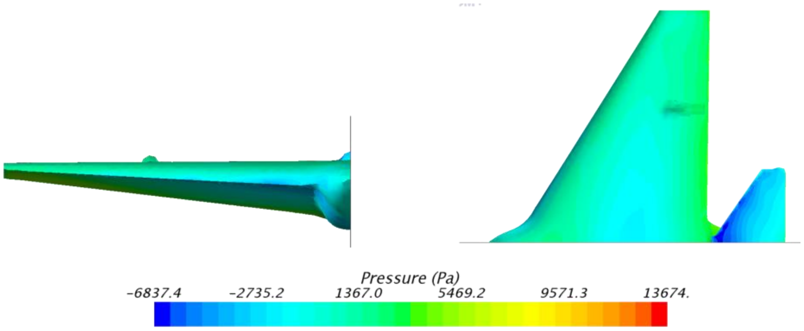


Figure 29: Pressure Plot from VOF Model

B.3.2 FEA Studies

The FEA studies were conducted in order to first and foremost validate the structural design of the vehicle and also to optimize the mass distribution of the supports by looking for areas where the plane was overly-designed or alternatively under-designed.

Case 1 – Landing on Tip (Wing Beam Loading)

The first test case was simulating the plane landing on its tip, and the results are highlighted below. It was deduced that the load moves mainly along the three middle struts in the wing section, indicating that cross bars between those links may help to even out the load distribution. In addition, it was also observed that most the load travels along the front edge of the vehicle, which means that that area of the vehicle may need to be made thicker in order to protect the thermoformed plastic shell.

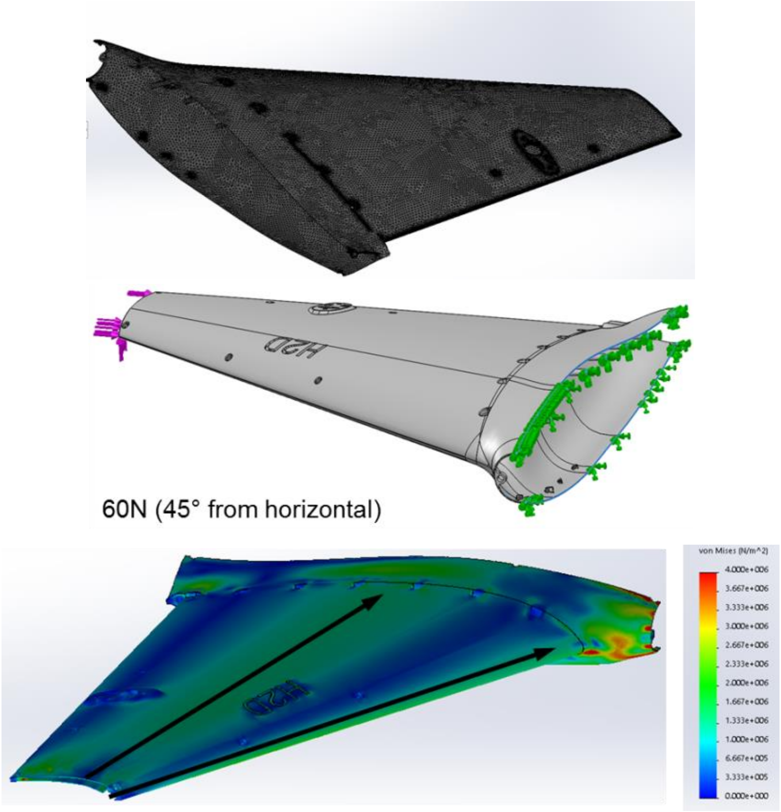


Figure 30: Overview of Mesh (top), Loading Condition (middle), and Results (bottom) for Case 1

Case 2 – High Wind Condition (Wing Torsion Loading)

The second test case was studied in order to mimic high wind conditions on the vehicle whilst on cruise, where lift and wind drag will create a torsion loading on the wing. An overview of the final results, as well as the initial condition of 20Nm at the tip, is shown in Figure 31; it was observed that failure is more likely to occur at the connection of the fuselage at the trailing edge of the wing. In addition, the expected result that the leading edge would be the bottleneck in this particular test scenario was confirmed.

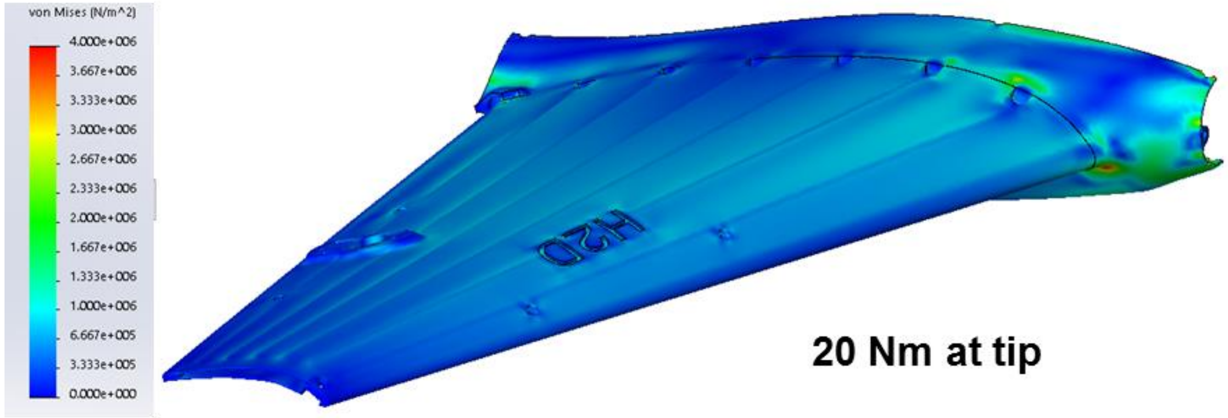


Figure 31: Results from FEA Case 2

Case 3 – Drop on Tail (Vertical Tail Loading)

To round off the failure modes of the vehicle, an additional study was conducted to simulate a sudden drop (or landing) on the tail of the vehicle. Since the rudder area occupied a substantial amount of space in the tail, this test case was necessary in order to validate the tail structural design. The results are given in a succession of images, beginning the mesh (top left) and initial conditions (top right) and ending with a detailed analysis on the fuselage connection (bottom). From Figure 32, it was deduced that more load is carried through the bottom of the fuselage connection to the tail rather than the top; thus, an implementation of a strut between the top and bottom edges of the fuselage would be an ideal scenario to better distribute the load.

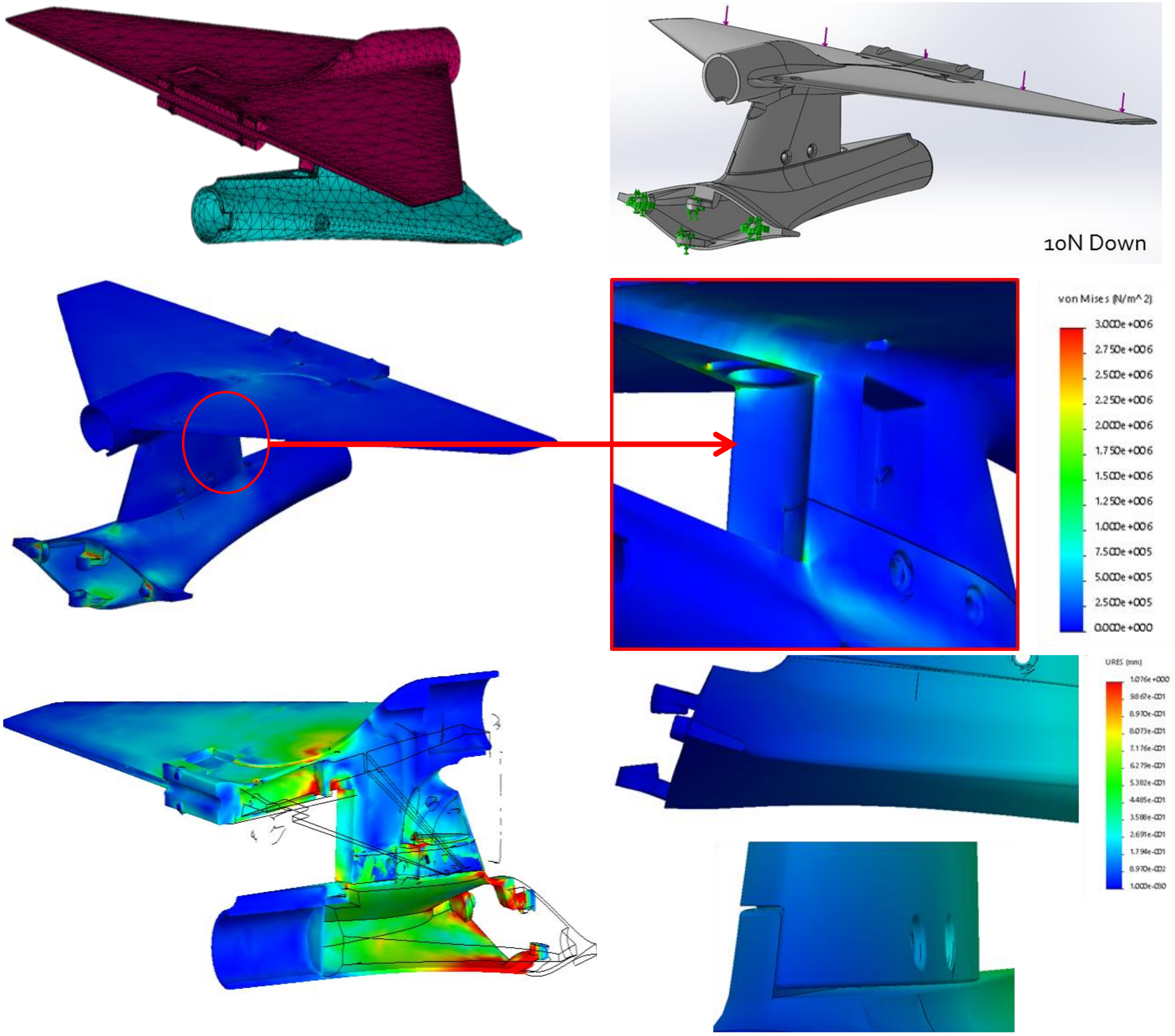


Figure 32: Mesh (top left), Initial Condition (top right), Tail (middle), and Fuselage (bottom)

B.4 2D Dynamics Stability Analysis

The following section outlines supplementary material for the 2D dynamics analysis discussed in 3.5. Please see Figure 33 through Figure 36 for reference to the changes in the airfoil profiles.

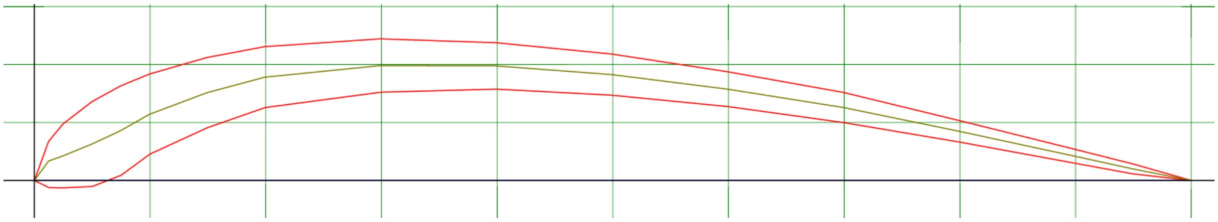


Figure 33: GOE 464; Beta Build Main Airfoil Profile

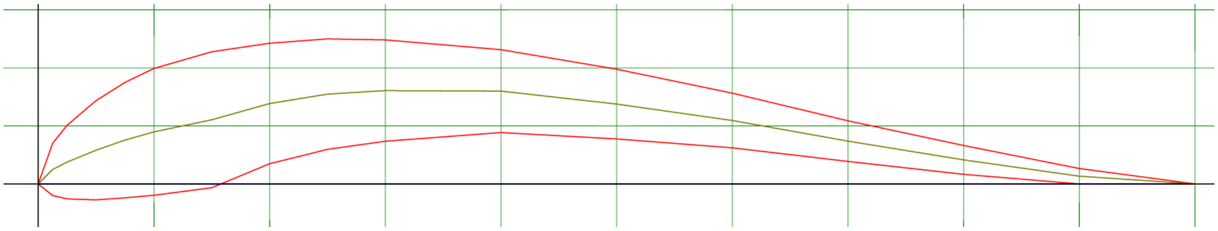


Figure 34: NACA M8; RC1 Main Airfoil Profile

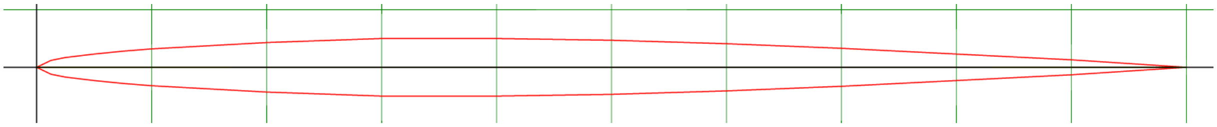


Figure 35: GOE 443; Beta Build Horizontal Tail Profile

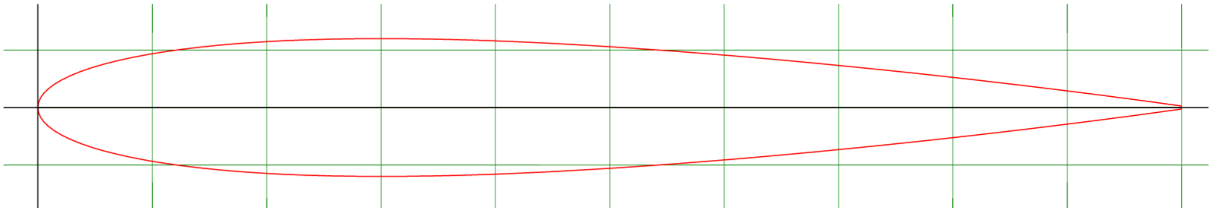


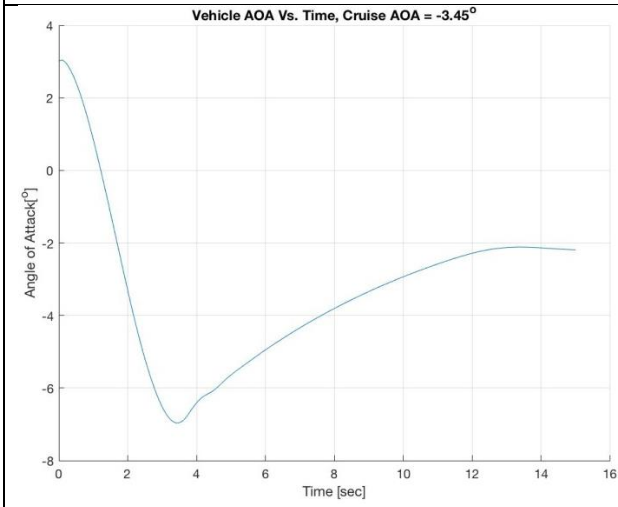
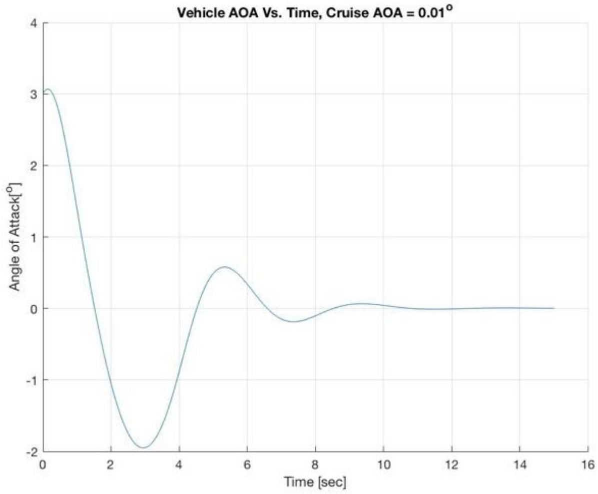
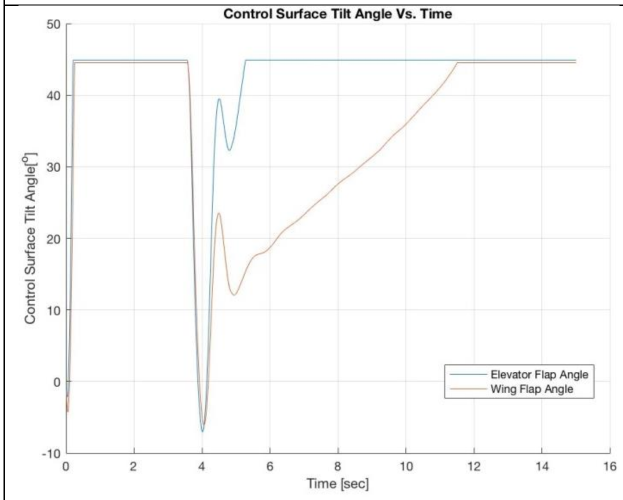
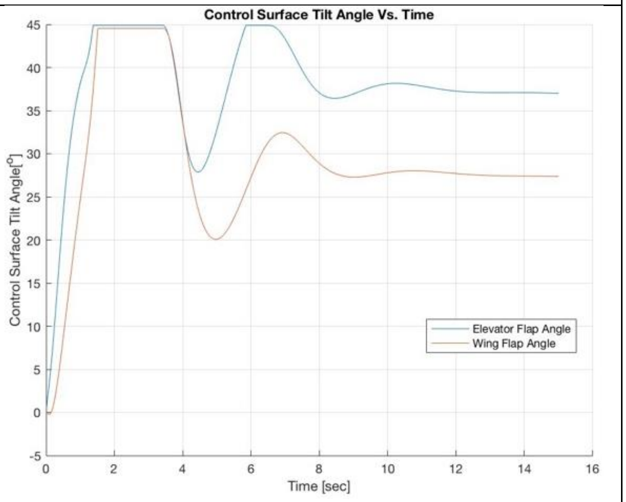
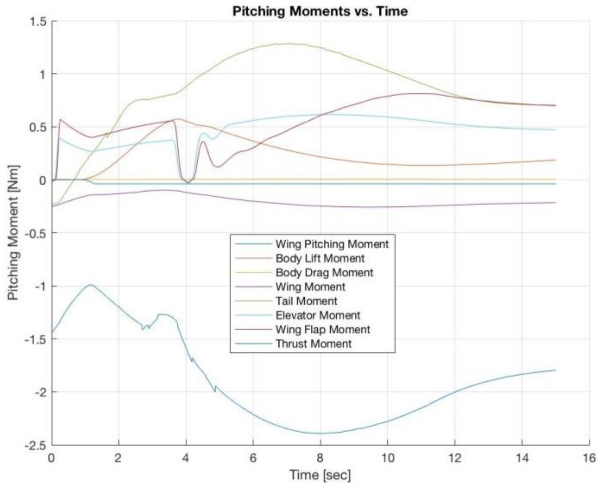
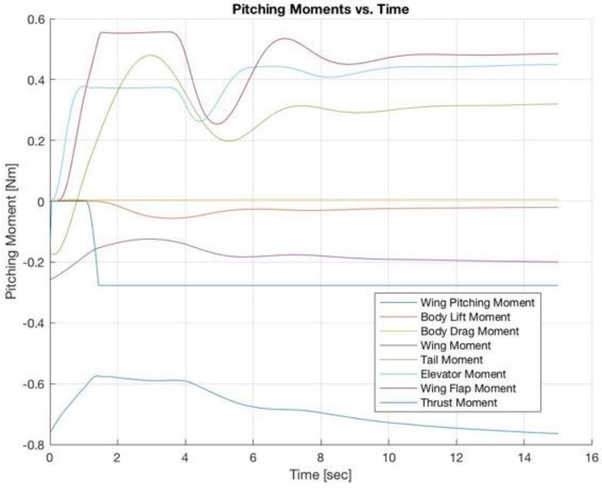
Figure 36: NACA 0012; RC1 Horizontal Tail Profile

The plots below in

Table 14 show the change in behavior between the Beta build design and RC1 design after the changes discussed in 7.1 had been implemented. The main conclusions that can be drawn from this plot are as follows:

- The first row shows the difference in steady state angle of attack of the vehicles. The recommended changes reduced this angle by over 2° resulting in both reduced cruise velocity and reduced drag.
- The second row shows the difference in the required control surface angle to keep the vehicle at its cruise angle of attack. As is clear from the plots the beta build design needed the control surfaces to be at their maximum position to achieve steady state flight leaving very little room for maneuverability and increased drag. The RC1 design reduced this angle by 20%.
- The third row shows the contribution of each pitching moment acting on the body. As is clear from the beta build plot the wing pitching moment over powers all other moments and reaches a maximum at 2.5Nm for this simulation. With the NACA M8 implemented this was reduced to 0.8Nm.

Table 14: Results from the 2D Dynamics Model

Beta Build Design (GOE 464/GOE 443)	**RC1 Design (NACA M8/NACA 0012)**
	
	
	

Appendix C Manufacturing

C.1 Manufacturing Method

A) Machining

Machining is a viable option of manufacturing for almost every product. It has very high precision and accuracy and with current technology, for example 5-Axis CNC, the making of intricate designs is possible. The drawbacks of using a CNC for this specific project are that the wings and fuselage need to be hollow and as light as possible, meaning that the parts would have to be made out of multiple sections and each part would need multiple setups if not made on a 5-Axis CNC. Machining also requires rigid materials to achieve the promised accuracy. Additionally, machining is expansive due to high accuracy.

Wings and the fuselage can also be handmade (i.e. model building) which is a very high labor intensive and high skill operation, but it allows for any material.

B) Casting

Casting is a feasible option for any shape as long as a good mold can be made. The mold, usually female type molds, can be machined or made by other means like cutting 2-D shapes and filling the steps and finishing for a smooth surface. The trouble with casting is that it limits the materials that can be used for the production of the plane.

C) Forming

Many forming types are available, but they also need molds. Again, the molds can be made similar as for castings. The benefit of female molds is the repeatable outside accuracy for many items. Male molds are more economical for quantities under ten [4] but have lower accuracy on the parts outside.

One way of making the wings and fuselage is to use fiber-reinforced materials on a male mold which is a labor-intensive procedure.

Another process is thermoforming. A male mold is required and the part is bound to the thickness of the sheet that is used. It also limits the materials that can be used but produces the finished part rather quickly and efficiently.

C.2 Material

Table 15: Material Properties of Contenders for Plane Build

Material	**Density [Kg/m^3]**	**Yield strength [MPa]**	**Cost [$/Kg]***	**Mfg. method**
Aluminum 6061	2700	250	8.00-20.00	Machining
Graphite - Epoxy	1800	410	20.00-40.00	Layup
Fiberglass -polyester	1520	205	5.00-20.00	Layup
PETG	1270	53	5.00-15.00	Thermoform
ABS	1200-1400	40	20.00-40.00	Thermoform, 3D
PLA	1250	50	20.000-40.00	Thermoform, 3D
Plywood	550	16.5	1.60	Machining [5]
Steel	8300	410	1.00-2.00	Machining

*Cost of materials is very dependent on how the material is purchased. For example, as sheets or profiles etc. PETG and 3D printing materials are chosen due to the accessibility of the manufacturing equipment. They do possess lower mechanical properties, specifically strength, however, enough for the prototype.

Table 16: Decision Making Matric for Vehicle Skin (Fuselage and Wings)

Rank from 1-10 (1 presenting as most desirable) with lowest tally representing optimal solution.

	Composite	**Thermoformed Acrylic**	**Full 3D Printed**
Cost	10 (Cost of composites and epoxy, work hour cost of processing)	4	8 (Cost of material, work hour cost of processing sections; finishing and joining, cost of failed parts)
Availability	7 (Online order ships from the USA)	1 (Available in the maker space, further material can be purchased from regional distributor)	5 (Material readily available however difficult to secure machine time)
Quality	5 (Quality dependent on mold and technician processing)	3 (Quality dependent on mold)	6 (Quality dependent on machine and technician, require post processing to achieve smooth finish)
Strength / Weight	6 (Large increase in weight due to epoxy)	1 (Thin sheets of plastic)	4 (Weight dependent on infill used)
TOTAL	**28**	**9**	**23**

C.3 Manufacturing Process

The initial test of a composite layup has been performed on a plaster mold. Plaster has been used due to low shrinkage and a smooth and dense mold even when poured without a vibration table. It also is readily available in hardware stores and at a low cost compared to silicon molds. The mold is made from a 3D printed component to assure accuracy. However, the plaster needed to be covered in a very strong release agent to ensure proper delamination of the composite afterwards. The mold is made as female section to allow for accurate outside dimensions. The mold has performed well after a coating of spray-tar.

Figure 37: Plaster-mold for Composite Layup

Figure 38: 3D Printed Master (left) and Fiberglass Composite (right)

The removal of the tar is a lengthy and tiring process. Additionally, the fact that a 3D-Printed master mold had to be printed negated the usefulness of this process for the build of only one prototype. Another test has been performed to avoid using a 3D-printed master and the use of foam as a male mold for the layup. However, the sectioning and mold making required much time and very high accuracy. The mold dictates the accuracy of the final build and the use of a male mold, although easier to layup onto, is hard to remove once encapsulated in the composite layup.

Figure 39: Section with Tar Removed from Composite

Figure 40: Sectioned Wing (Y+) of the Plane, in 20mm Increments

Figure 41: Assembled Mold Sections

In Figure 41 is the assembled mold of 20mm foam sections. However, it still requires finishing as all sections are overshooting in size. Once cut and sanded down the mold is ready to be used for layup. The biggest concern with such a mold was the assembly technique. Due to the irregular shape of the wing, the achievement of required tolerances is difficult. It still requires a master profile or many fixtures and jigs to be certain of its correct dimensions. Following with the relatively high cost of composite materials as well as the higher weight this method has also not been pursued further.

Figure 42: Assembled Foam Mold Sections

The process used for the prototype build during the winter 2017 term of ME 482 is a foam mold used for thermoforming the large skin sections and placing on a frame of 3D printed and laser cut parts. Figure 42 shows the CNCed components bonded with a polyurethane adhesive. This mold is then covered with the thin styrene layer (white, seen in Figure 43) to increase its strength and more importantly thermal resistance when used for the final parts. Worth mentioning is also the draft angle of the molds required to form good edges on the parts. The elevation of the mold usually allowed for a more precise contour and folds created, as seen in the front corner of Figure 42 are also less concerning since they do not reach the actual part.

Figure 43: Thermoformed Final Layer (clear) of Fuselage Bottom

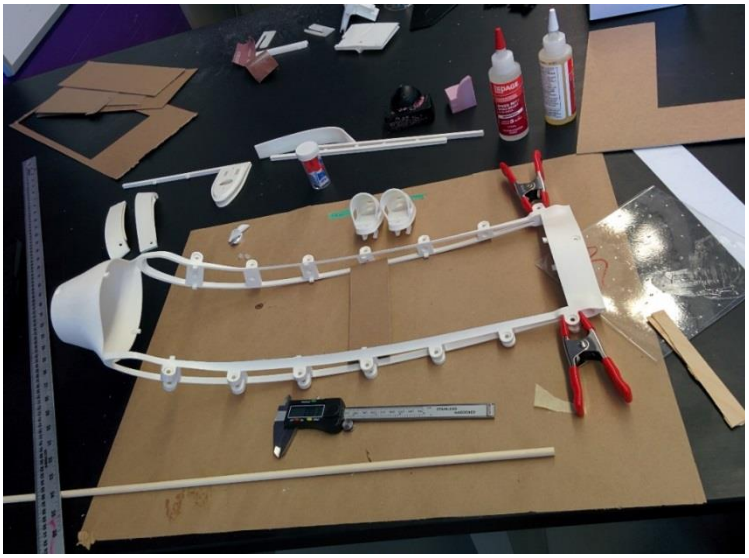


Figure 44: Frame Assembly of 3D-Printed Components

The frame onto which the thermoformed parts are placed is made of 3D-Printed components bonded with epoxy. Once the frame is assembled the addition of the thermoformed pieces adds strength due to much larger bond areas. It must be noted that the frame, although strong enough for its own weight is significantly weaker than anticipated. To further strengthen the joints, critical location has been joined using contacts cement and epoxy reinforcement.

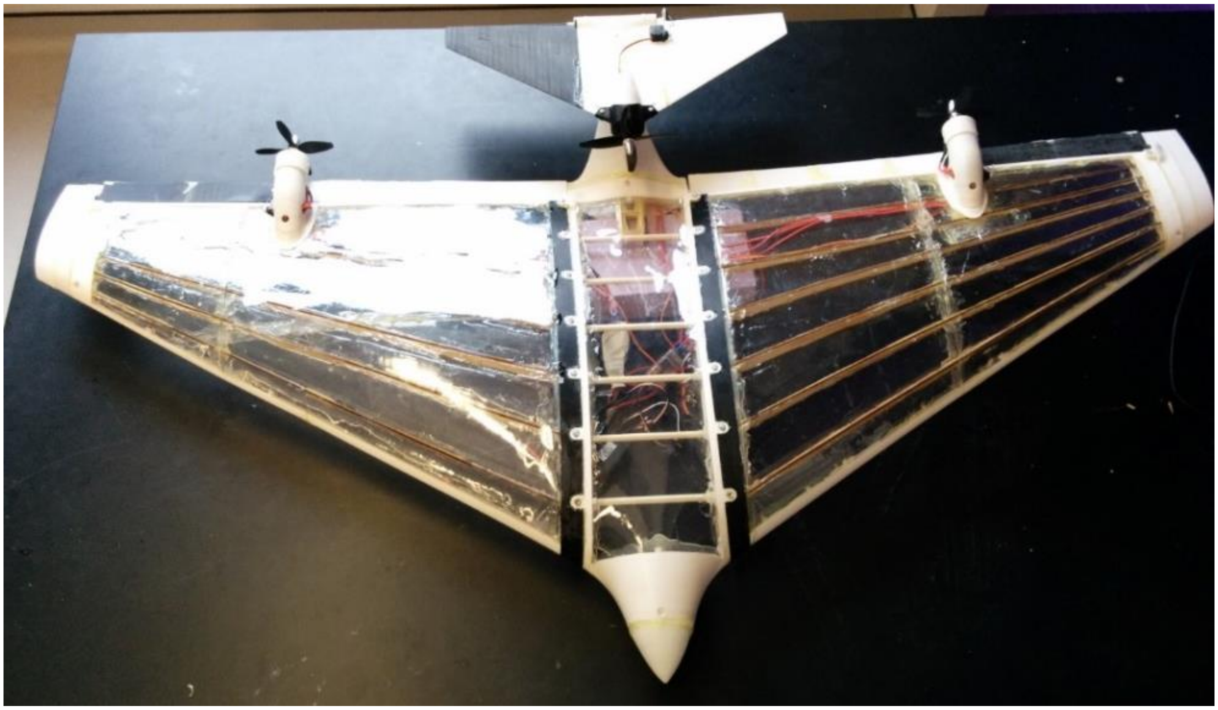


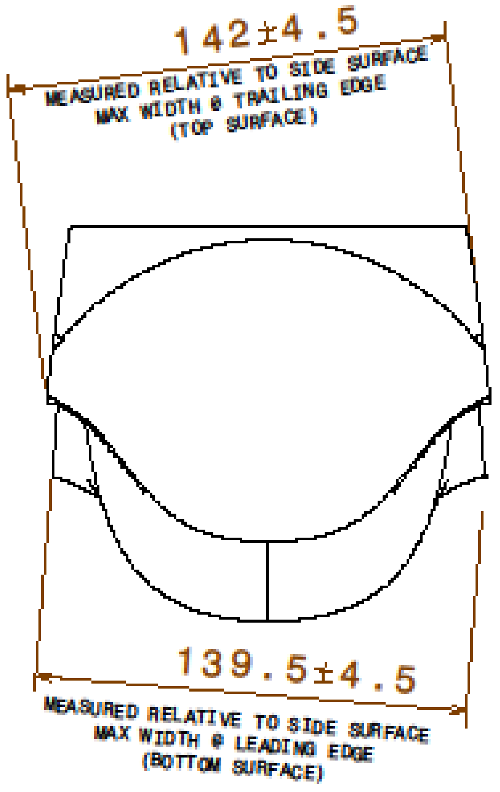
Figure 45: Complete Plane Assembly

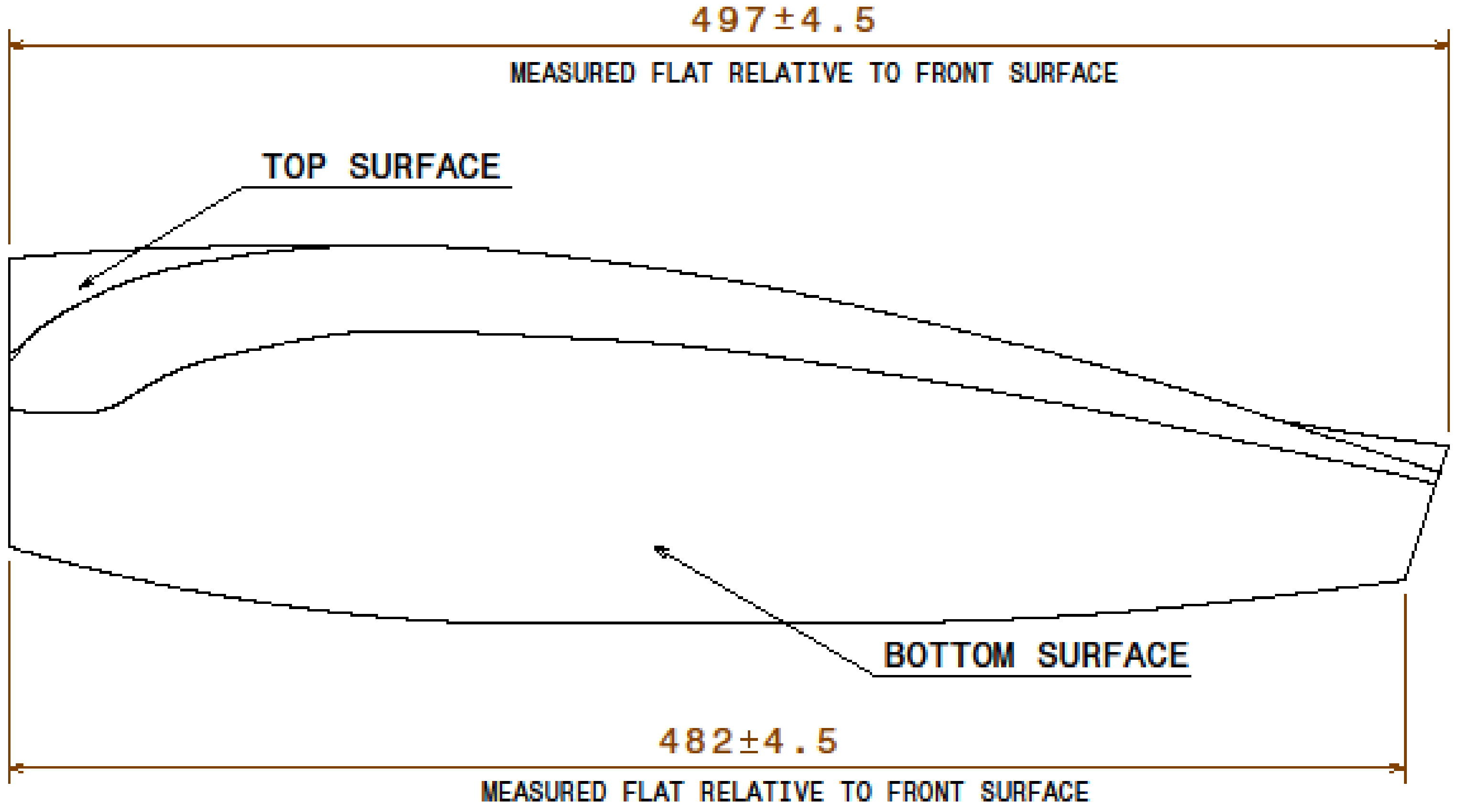
Once the frame and thermoformed pieces are complete, they are assembled and joint using epoxy. This allows for a distinctive look and provides good validation features like the transparency of the large skin components when testing water entry.

C.4 Beta Build Drawings

NOTES:
1. THE FOLLOWING DRAWINGS OUTLINE H2D'S PUFFIN BIRD BETA BUILD COMPONENTS
2. ALL TOOLS TO BE CUT USING OFFICIAL H2D CAD DATA
3. DIMENSIONAL CHANGES MUST BE REVIEWED AND APPROVED BY H2D'S R&D TEAM
4. ALL DIMENSIONS ARE IN DEGREES AND mm UNLESS OTHERWISE SPECIFIED
5. STIFFENER MATERIAL: LASER CUT BALSA WOOD WITH WATERPROOF COATING
6. MOLD MATERIAL: CNCD STYROFOAM

REV	DATE	DESCRIPTION	INIT
A	1/21/2017	INITIAL RELEASE	K.S.





CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

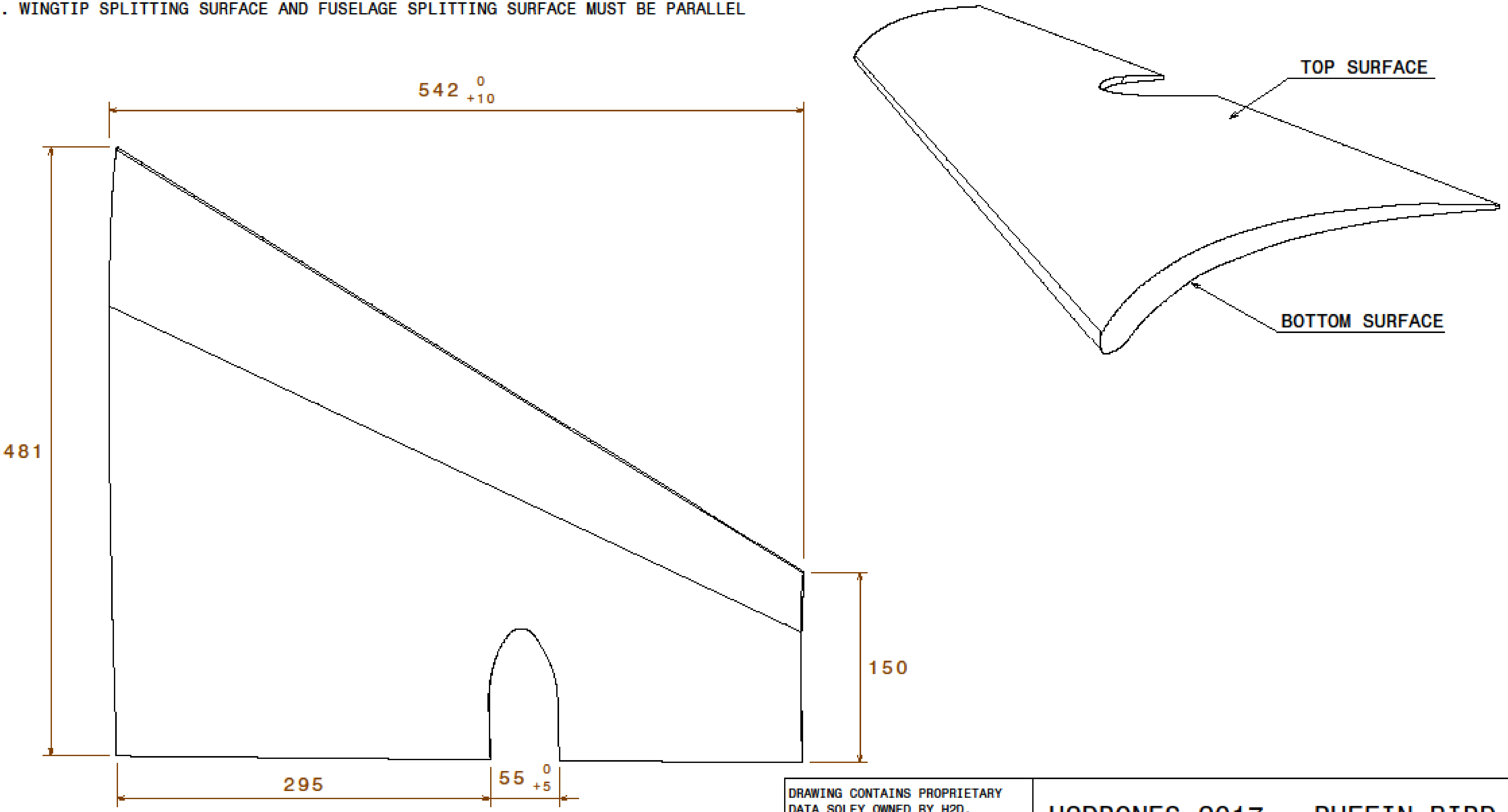
H2DRONES 2017 - PUFFIN BIRD

DRAWING PACKAGE
BETA BUILD NON 3D PRINTED COMPONENTS

DRAWN BY K.S. DATE 1/21/2017
CHECKED BY S.I.H. DATE 1/21/2017
DESIGNED BY H2DRONES DATE 2017

SIZE A3
FUSELAGE MOLD GEOMETRY
REV A
SCALE 2:5
WEIGHT(kg) 3.2
SHEET 1 OF 4

NOTES:
1. +Y MOLG GEOMETRY SHOWN , MOLD IS SYMMETRIC WITH -Y OVER THE ZX PLANE
2. WINGTIP SPLITTING SURFACE AND FUSELAGE SPLITTING SURFACE MUST BE PARALLEL



DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

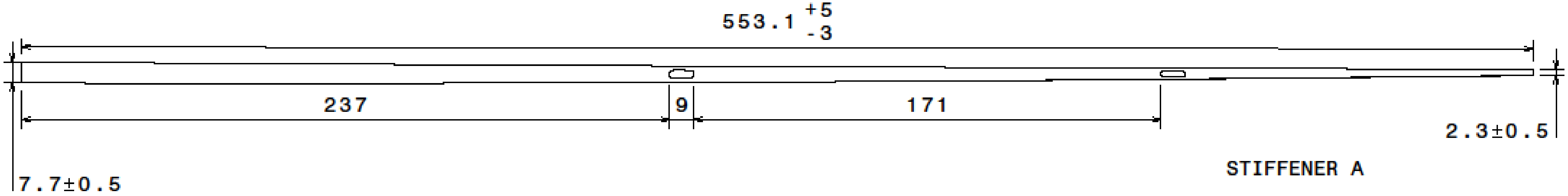
H2DRONES 2017 - PUFFIN BIRD

DRAWING PACKAGE
BETA BUILD NON 3D PRINTED COMPONENTS

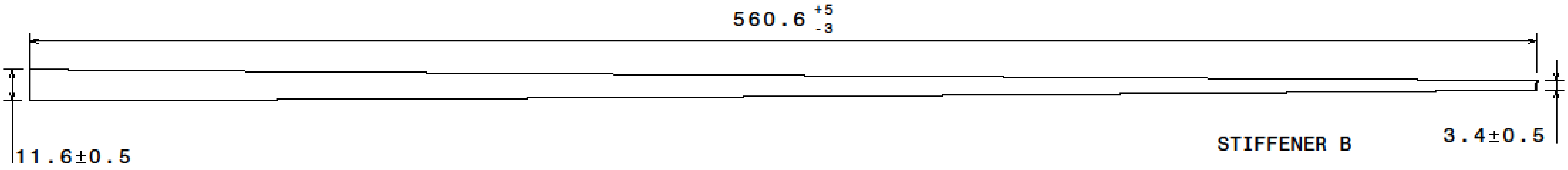
DRAWN BY K.S.	DATE 1/21/2017	SIZE A3	MAIN WING MOLD GEOMETRY
CHECKED BY S.I.H.	DATE 1/21/2017	REV A	
DESIGNED BY H2DRONES	DATE 2017	SCALE 1:3	SHEET 2 OF 4

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED

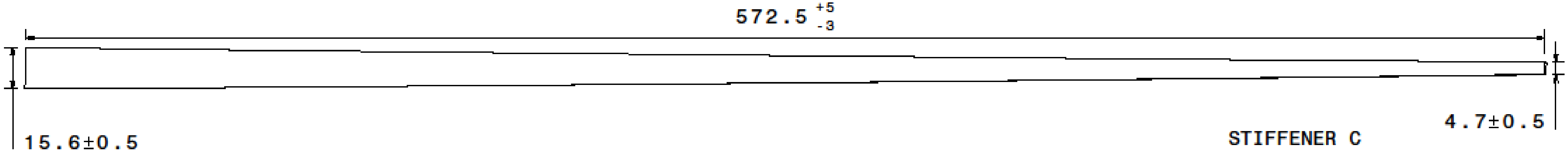
NOTES:
1. DESIGNED THICKNESS: 2.775 ± 0.25
2. THICKNESS IS CRITICAL FOR FIRST AND LAST 4MM OF STIFFENER LENGTH TO ENSURE PROPER INTEGRATION



STIFFENER A



STIFFENER B



STIFFENER C

H2DRONES 2017 - PUFFIN BIRD

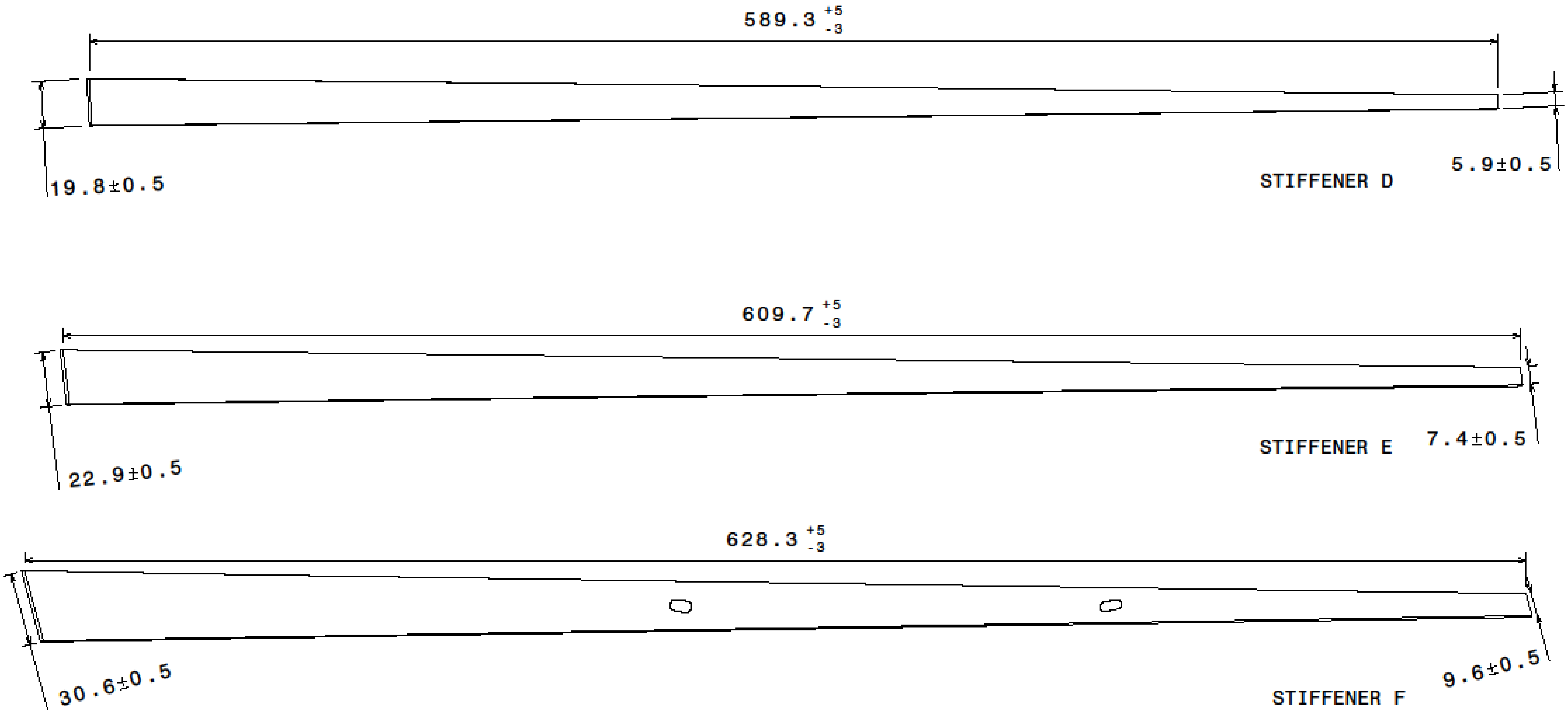
DRAWING PACKAGE
BETA BUILD NON 3D PRINTED COMPONENTS

DRAWN BY	DATE
K.S.	1/21/2017
CHECKED BY	DATE
S.I.H.	1/21/2017
DESIGNED BY	DATE
H2DRONES	2017

SIZE A3
STIFFENER GEOMETRY (A, B , C)
REV A
SCALE 2:3
SHEET 3 OF 4

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED

NOTES:
1. DESIGNED THICKNESS: 2.775 ± 0.25
2. THICKNESS IS CRITICAL FOR FIRST AND LAST 4MM OF STIFFENER LENGTH TO ENSURE PROPER INTEGRATION



CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

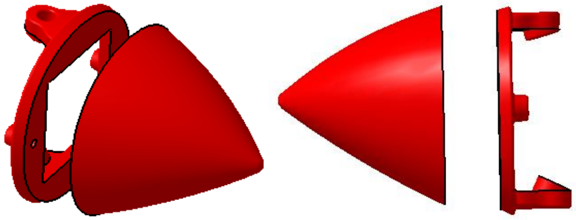
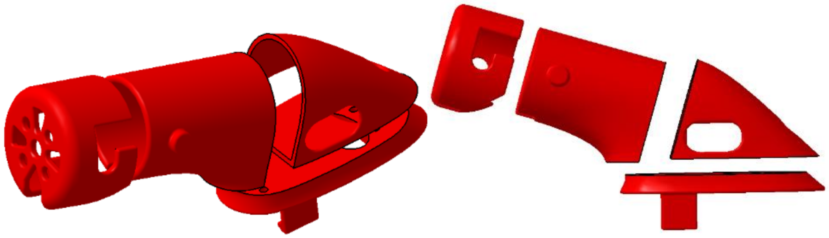
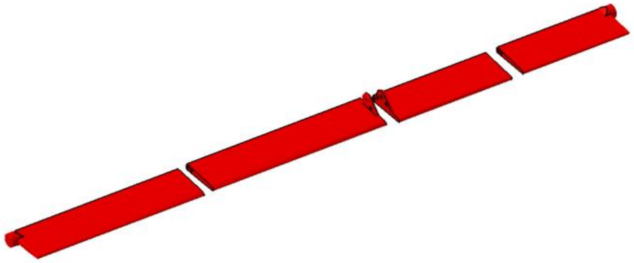
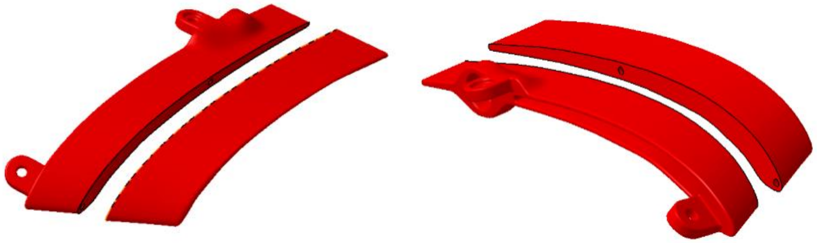
H2DRONES 2017 - PUFFIN BIRD

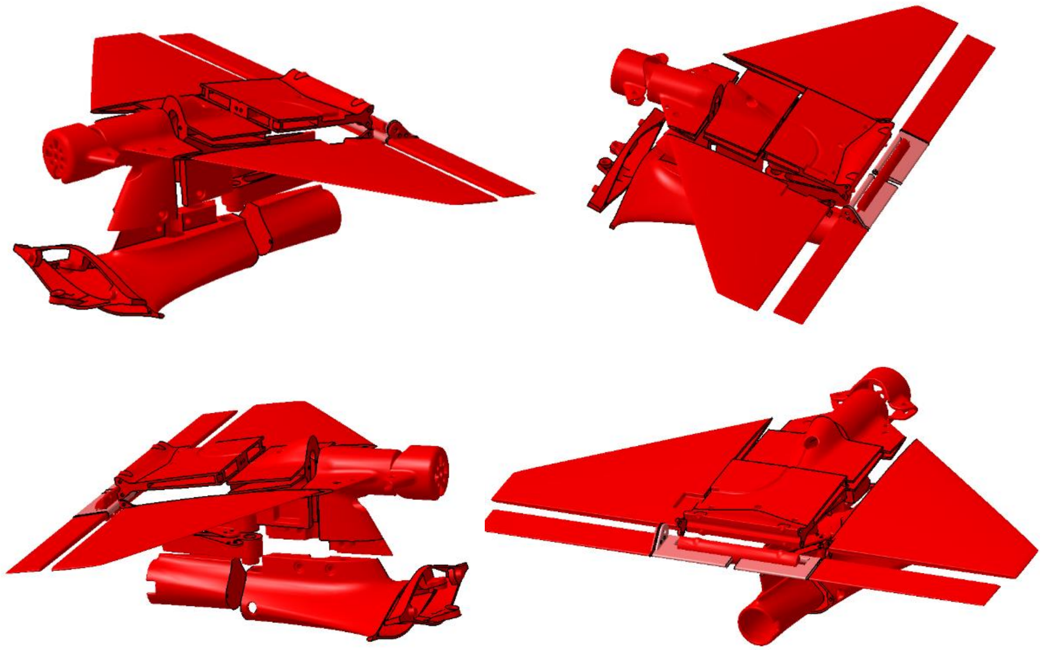
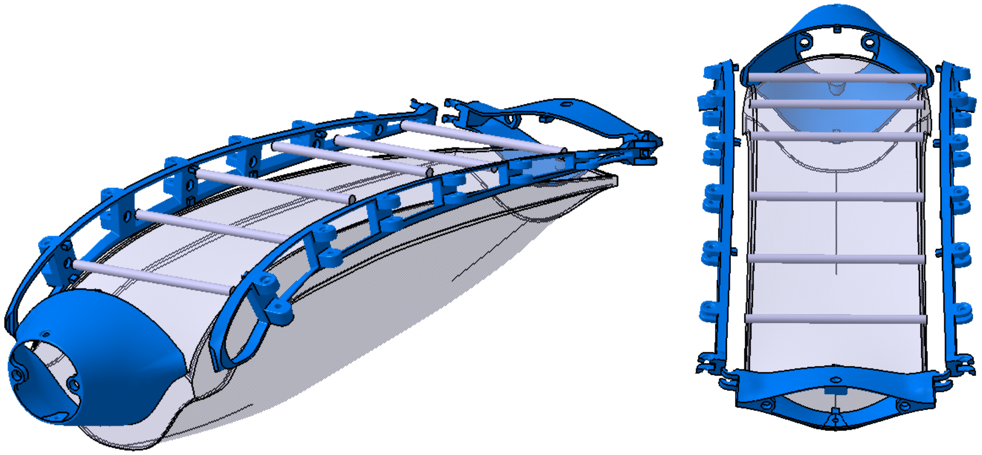
DRAWING PACKAGE
BETA BUILD NON 3D PRINTED COMPONENTS

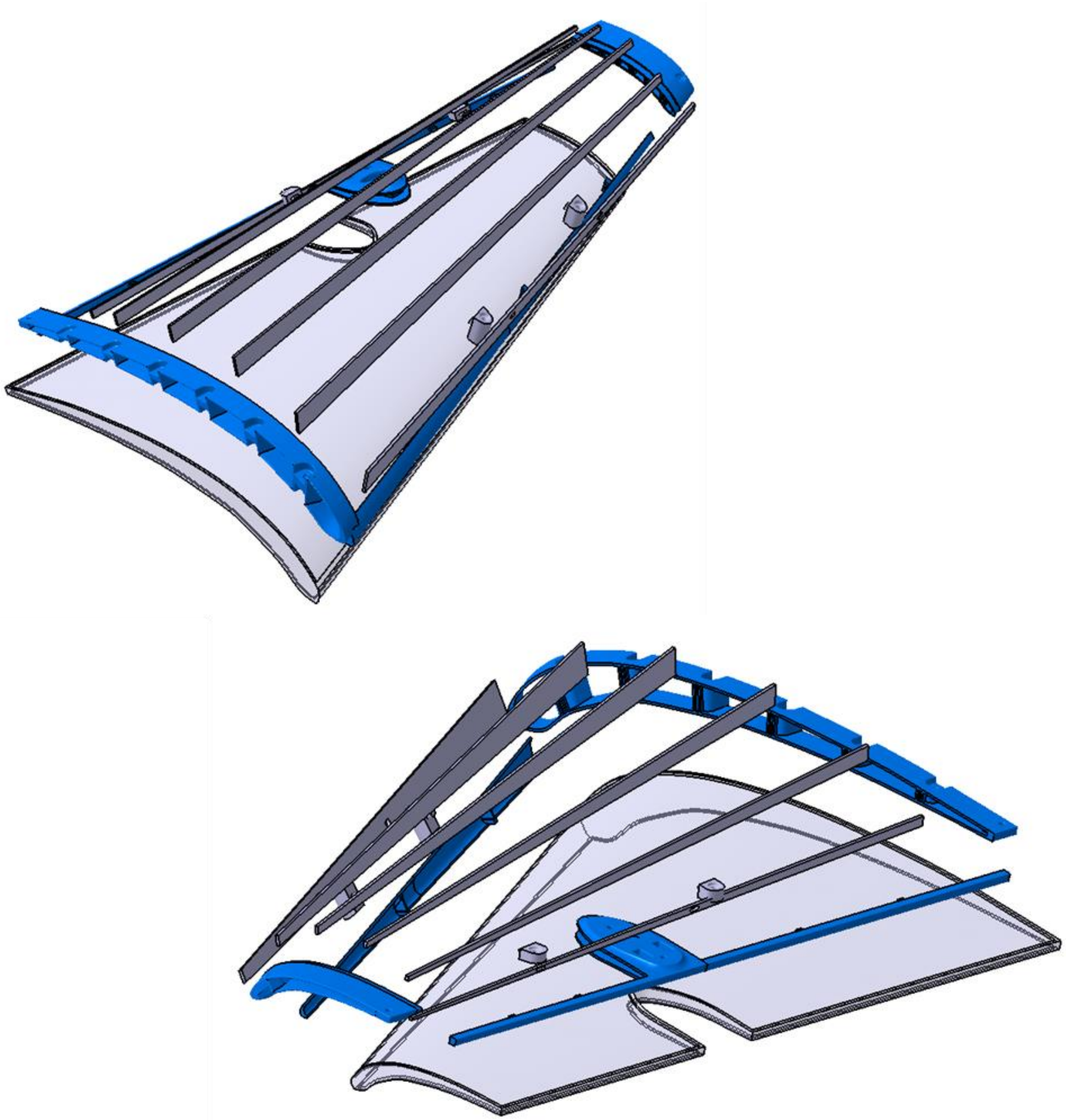
DRAWN BY K.S. DATE 1/21/2017
CHECKED BY S.I.H. DATE 1/21/2017
DESIGNED BY H2DRONES DATE 2017

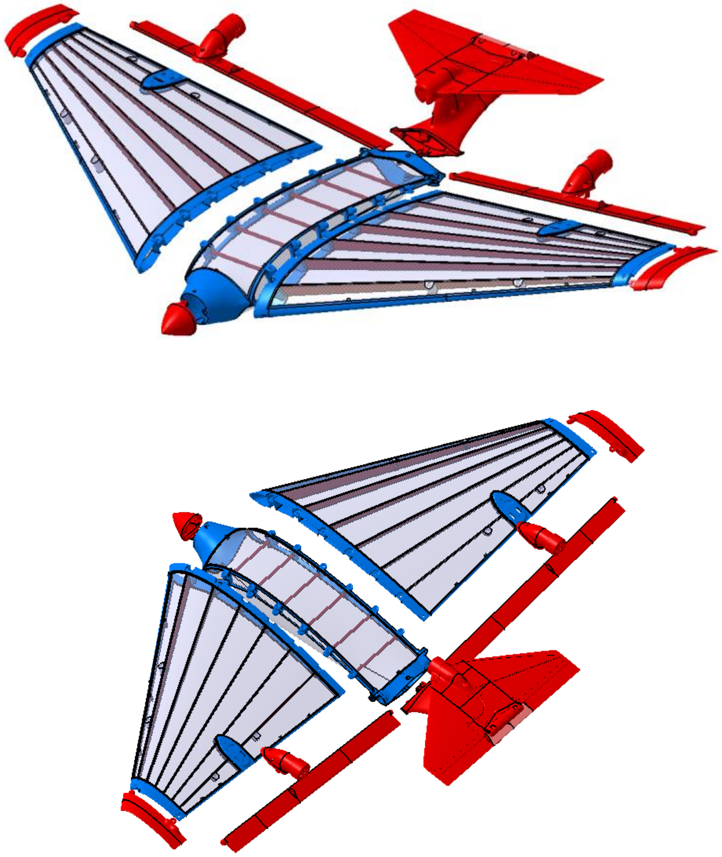
SIZE A3
STIFFENER GEOMETRY (D, E, F)
REV A
SCALE 3:5
SHEET 4 OF 4

C.5 Assembly Instructions

		P/N	Description
Subcomponent Assembly Nose		433-00-A 434-00-A	Camera Housing 1 Camera Housing 2
Subcomponent Assembly Motor Pod		404-00-A 405-00-A 406-00-A 407-00-A 408-00-A 409-00-A 410-00-A 411-00-A	Case 1 Y+ Case 2 Y+ Case 3 Y+ Motor Muzzle Y+ Case 1 Y Case 2 Y- Case 3 Y- Motor Muzzle Y-
Subcomponent Assembly Flaps		435-00-A 436-00-A 437-00-A 438-00-A 439-00-A 440-00-A 441-00-A 442-00-A	Flap 1 Y+ Flap 2 Y+ Flap 3 Y+ Flap 4 Y+ Flap 1 Y- Flap 2 Y- Flap 3 Y- Flap 4 Y-
Subcomponent Assembly Wing Tip		443-00-A 444-00-A 445-00-A 446-00-A	Wing Tip 1 Y- Wing Tip 2 Y- Wing Tip 1 Y- Wing Tip 2 Y-

Subcomponent Assembly Tail		412-00-A 413-00-A 414-00-A 415-00-A 416-00-A 417-00-A 419-00-A 420-00-A 421-00-A 422-00-A 423-00-A 424-00-A 425-00-A 426-00-A 427-00-A 428-00-A 429-00-A 430-00-A 431-00-A 432-00-A	Elevator 1 Elevator 2 Elevator 3 Elevator 4 Elevator 5 Elevator 6 Tail Section 1 Tail Section 2 Tail Section 3 Tail Section 4 Tail Section 5 Tail Section 6 Tail Section 7 Tail Motor Muzzle Rudder 1 Rudder 2 Rear Fuselage 1 Rear Fuselage 2 Rear Fuselage 3 Water Motor Muzzle
Subcomponent Assembly Fuselage		447-00-A 448-00-A 449-00-A 450-00-A 451-01-A 451-02-A 451-03-A 451-04-A 451-05-A 451-06-A 452-00-A 453-00-A	Fuselage Frame Rear Fuselage Frame Y+ Fuselage Frame Y- Fuselage Frame Front Fuselage Strut A Fuselage Strut B Fuselage Strut C Fuselage Strut D Fuselage Strut E Fuselage Strut F Fuselage Upper Skin Fuselage Lower Skin

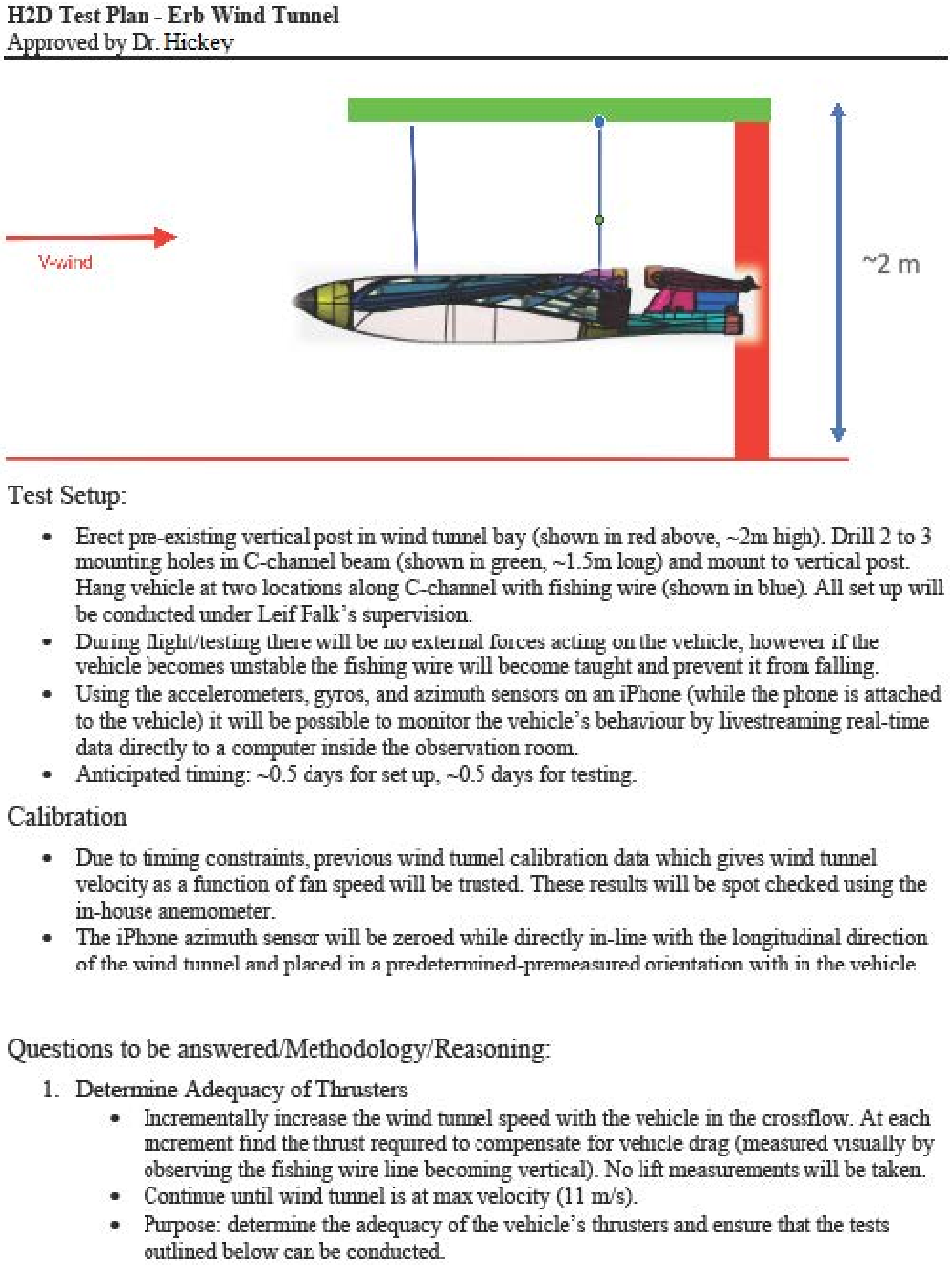
Subcomponent Assembly Wing		454-00-A	Wing Skin I.U Y+
		455-00-A	Wing Skin I.L Y+
		456-00-A	Wing Skin O.U Y+
		457-00-A	Wing Skin O.L Y+
		458-00-A	Wing Frame Inner Y+
		459-00-A	Wing Frame Outer Y+
		460-00-A	Wing Frame TE I Y+
		461-00-A	Wing Frame TE O Y+
		462-00-A	Wing Frame LE I Y+
		463-00-A	Wing Frame LE O Y+
		464-00-A	Wing Frame Center Y+
		465-00-A	Ski Mount I.R Y+
		466-00-A	SKI Mount I.F Y+
		467-00-A	Ski Mount O.R Y+
		468-00-A	Ski Mount O.F Y+
		469-00-A	Spar A Y+
		470-00-A	Spar B Y+
		471-00-A	Spar C Y+
		472-00-A	Spar D Y+
		473-00-A	Spar E Y+
		474-00-A	Spar F Y+
		475-00-A	Wing Skin I.U Y-
		476-00-A	Wing Skin I.L Y-
		477-00-A	Wing Skin O.U Y-
		478-00-A	Wing Skin O.L Y-
		479-00-A	Wing Frame Inner Y-
		480-00-A	Wing Frame Outer Y-
		481-00-A	Wing Frame TE I Y-
		482-00-A	Wing Frame TE O Y-
		483-00-A	Wing Frame LE I Y-
		484-00-A	Wing Frame LE O Y-
		485-00-A	Wing Frame Center Y-
		486-00-A	Ski Mount I.R Y-
		487-00-A	SKI Mount I.F Y-
		488-00-A	Ski Mount O.R Y-
		489-00-A	Ski Mount O.F Y-
		490-00-A	Spar A Y-
		491-00-A	Spar B Y-
		492-00-A	Spar C Y-
		493-00-A	Spar D Y-
		494-00-A	Spar E Y-
		495-00-A	Spar F Y-

Final Assembly		---	Nose Motor Pods Flaps Wing Tip Tail Wing Fuselage

Appendix D Validation

D.1 Full-Scale Wind Tunnel Testing

D.1.1 H2D Test Plan - Erb Wind Tunnel



H2D Test Plan - Erb Wind Tunnel
Approved by Dr. Hickey

Test Setup:

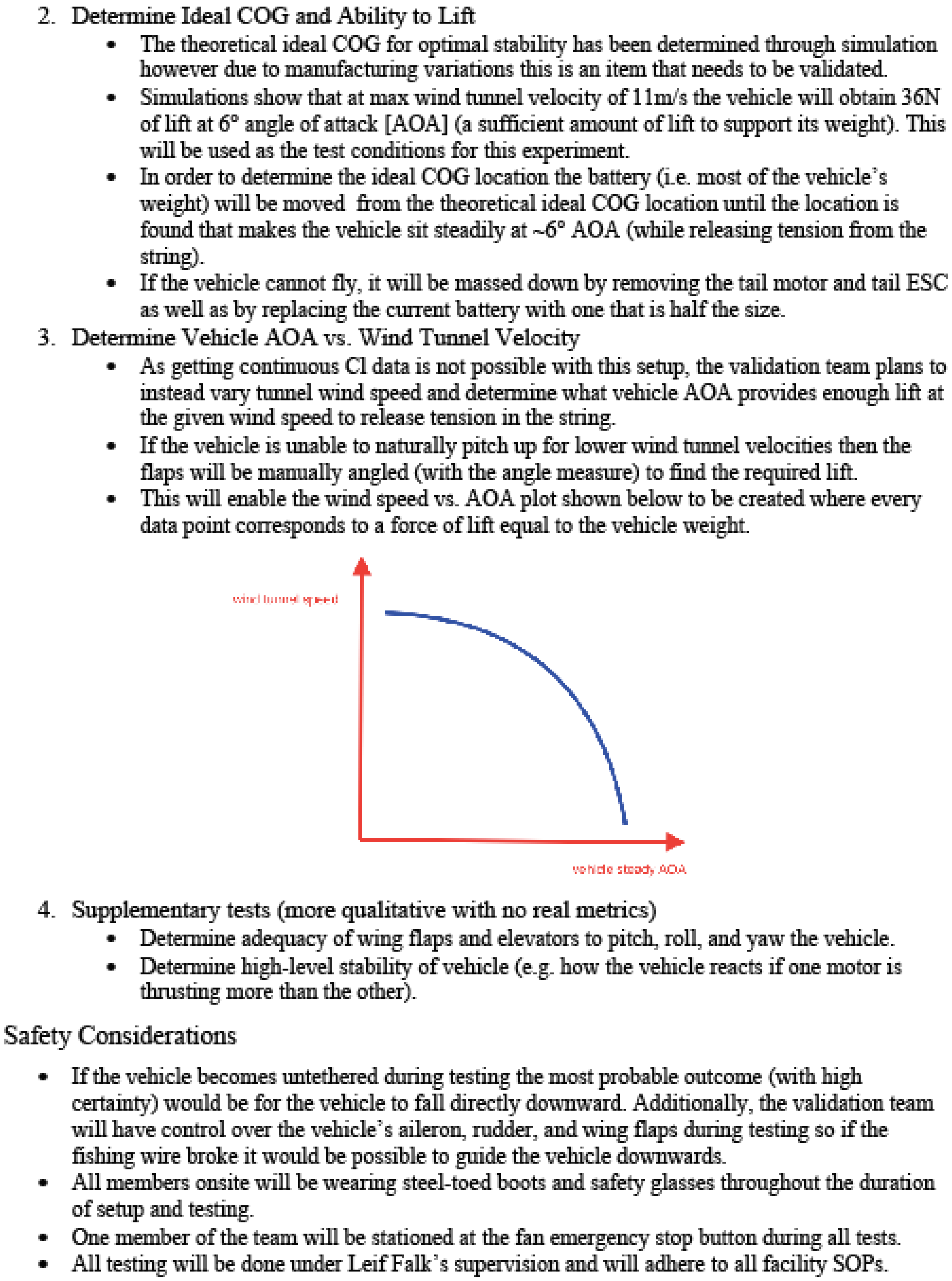
- Erect pre-existing vertical post in wind tunnel bay (shown in red above, ~2m high). Drill 2 to 3 mounting holes in C-channel beam (shown in green, ~1.5m long) and mount to vertical post. Hang vehicle at two locations along C-channel with fishing wire (shown in blue). All set up will be conducted under Leif Falk's supervision.
- During flight/testing there will be no external forces acting on the vehicle, however if the vehicle becomes unstable the fishing wire will become taught and prevent it from falling.
- Using the accelerometers, gyros, and azimuth sensors on an iPhone (while the phone is attached to the vehicle) it will be possible to monitor the vehicle's behaviour by livestreaming real-time data directly to a computer inside the observation room.
- Anticipated timing: ~0.5 days for set up, ~0.5 days for testing.

Calibration

- Due to timing constraints, previous wind tunnel calibration data which gives wind tunnel velocity as a function of fan speed will be trusted. These results will be spot checked using the in-house anemometer.
- The iPhone azimuth sensor will be zeroed while directly in-line with the longitudinal direction of the wind tunnel and placed in a predetermined-premeasured orientation with in the vehicle

Questions to be answered/Methodology/Reasoning:

1. Determine Adequacy of Thrusters
    - Incrementally increase the wind tunnel speed with the vehicle in the crossflow. At each increment find the thrust required to compensate for vehicle drag (measured visually by observing the fishing wire line becoming vertical). No lift measurements will be taken.
    - Continue until wind tunnel is at max velocity (11 m/s).
    - Purpose: determine the adequacy of the vehicle's thrusters and ensure that the tests outlined below can be conducted.



2. Determine Ideal COG and Ability to Lift
    - The theoretical ideal COG for optimal stability has been determined through simulation however due to manufacturing variations this is an item that needs to be validated.
    - Simulations show that at max wind tunnel velocity of 11m/s the vehicle will obtain 36N of lift at 6° angle of attack [AOA] (a sufficient amount of lift to support its weight). This will be used as the test conditions for this experiment.
    - In order to determine the ideal COG location the battery (i.e. most of the vehicle's weight) will be moved from the theoretical ideal COG location until the location is found that makes the vehicle sit steadily at ~6° AOA (while releasing tension from the string).
    - If the vehicle cannot fly, it will be massed down by removing the tail motor and tail ESC as well as by replacing the current battery with one that is half the size.
3. Determine Vehicle AOA vs. Wind Tunnel Velocity
    - As getting continuous Cl data is not possible with this setup, the validation team plans to instead vary tunnel wind speed and determine what vehicle AOA provides enough lift at the given wind speed to release tension in the string.
    - If the vehicle is unable to naturally pitch up for lower wind tunnel velocities then the flaps will be manually angled (with the angle measure) to find the required lift.
    - This will enable the wind speed vs. AOA plot shown below to be created where every data point corresponds to a force of lift equal to the vehicle weight.

4. Supplementary tests (more qualitative with no real metrics)
    - Determine adequacy of wing flaps and elevators to pitch, roll, and yaw the vehicle.
    - Determine high-level stability of vehicle (e.g. how the vehicle reacts if one motor is thrusting more than the other).

Safety Considerations

- If the vehicle becomes untethered during testing the most probable outcome (with high certainty) would be for the vehicle to fall directly downward. Additionally, the validation team will have control over the vehicle's aileron, rudder, and wing flaps during testing so if the fishing wire broke it would be possible to guide the vehicle downwards.
- All members onsite will be wearing steel-toed boots and safety glasses throughout the duration of setup and testing.
- One member of the team will be stationed at the fan emergency stop button during all tests.
- All testing will be done under Leif Falk's supervision and will adhere to all facility SOPs.

Figure 46: H2Drones Test Plan - Erb Facility

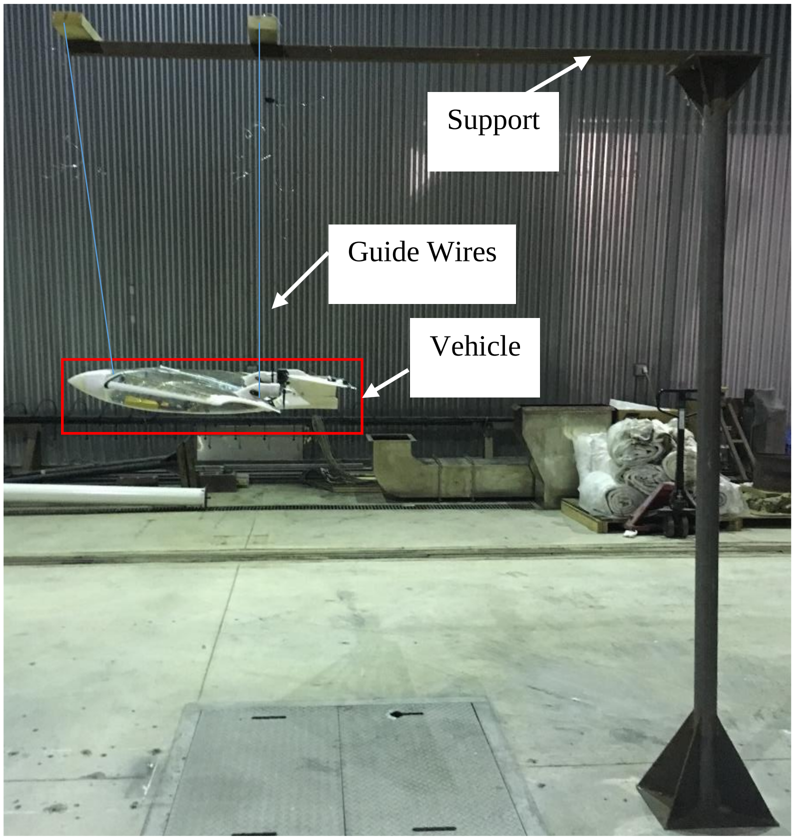


Figure 47: Full-Scale Wind Tunnel Test Setup

D.2 Scaled Wind Tunnel Testing

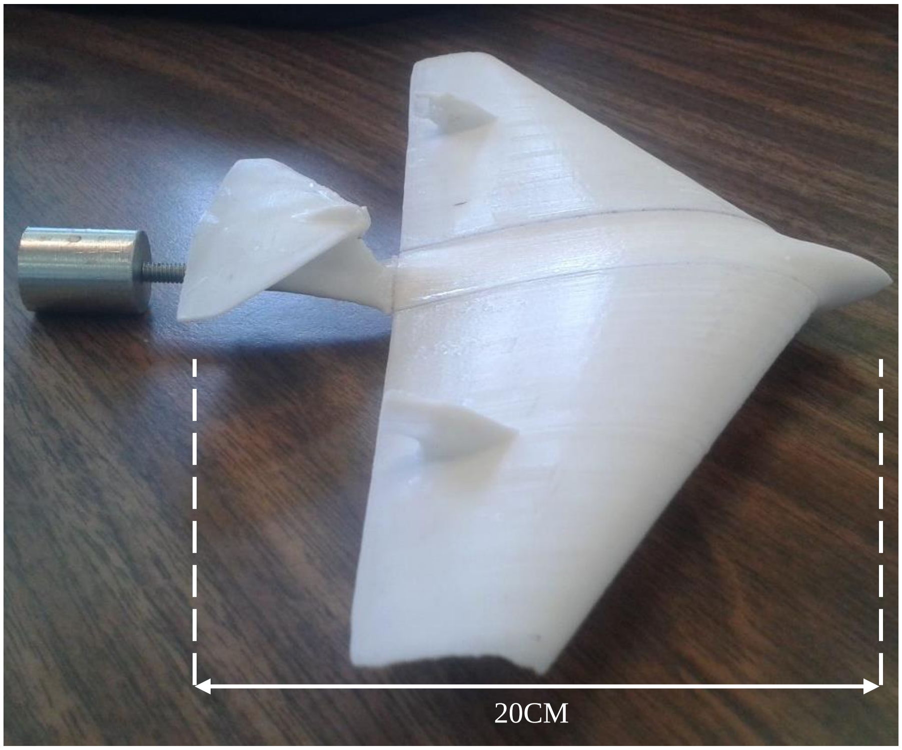


Figure 48: 3D Printed 15% Scale Model

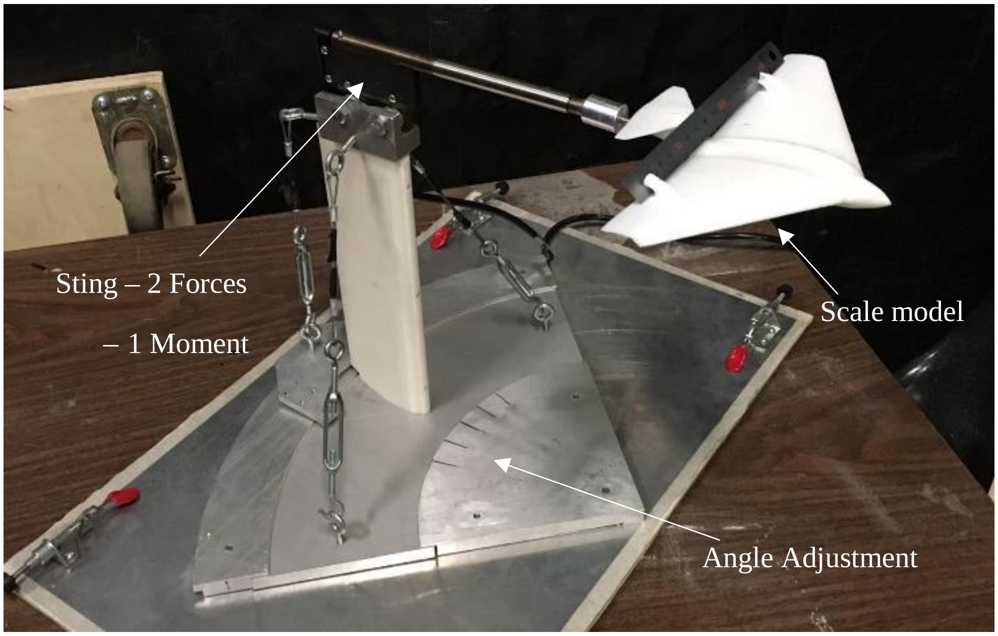


Figure 49: Scaled Model on Sting

D.2.1 Sting Calibration Curves

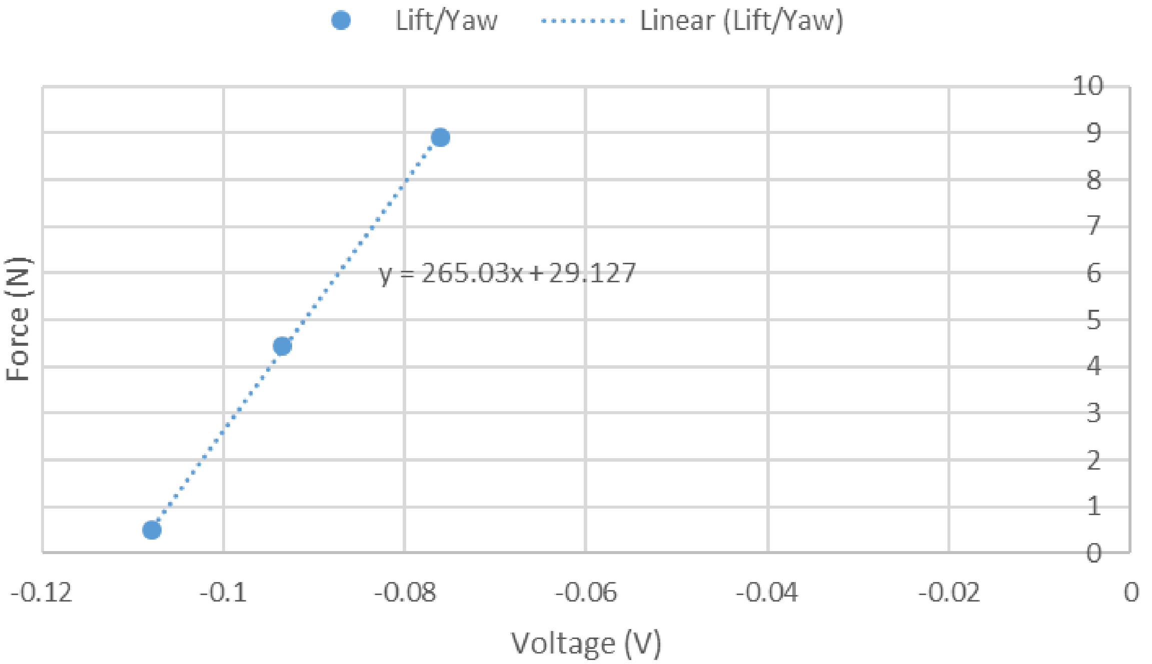


Figure 50: Lift and Yaw Calibration

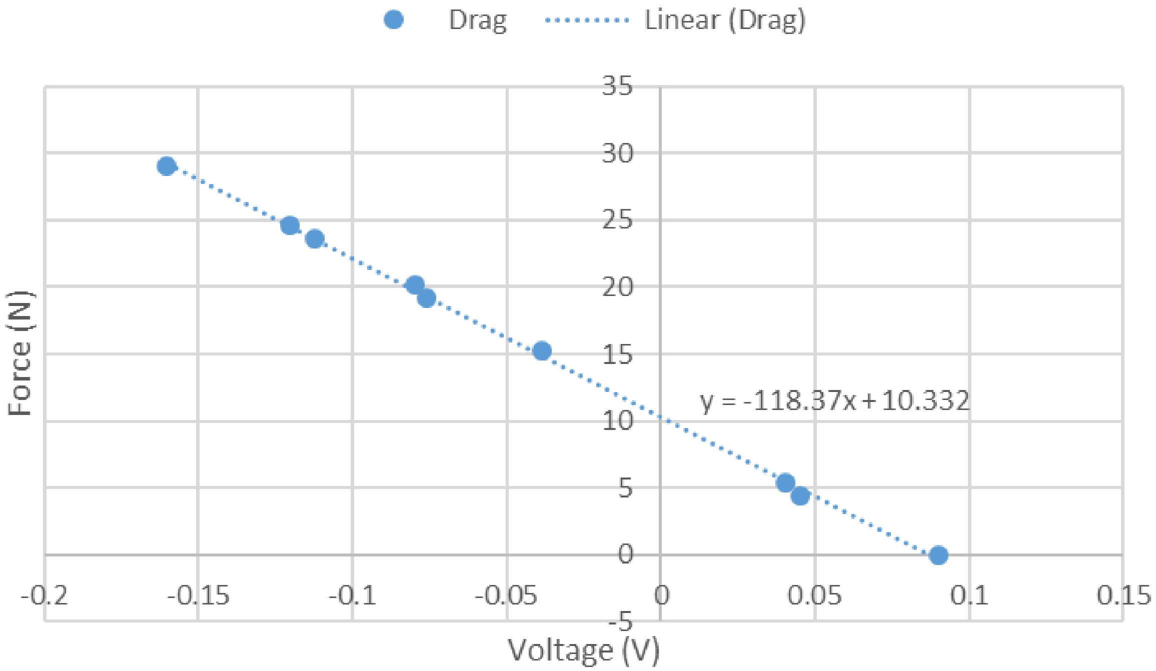


Figure 51: Drag Calibration

D.2.2 Lift and Drag Raw Data

Table 17: Wind Tunnel Raw Data – 100 Hz sampling rate, 500 samples

Angle of Attack (Degrees)	Velocity (m/s)	Drag (V)	Drag RMS (V)	Lift (V)	Lift RMS (V)	Drag (N)	Lift (N)	Cd	Cl
0	11.80	0.0904853	0.0012570	-0.1196030	0.0003076	-0.3231146	0.8158617	-0.1934428	0.4884414
0	15.00	0.0914808	0.0016780	-0.1175470	0.0004109	-0.2052773	1.3915006	-0.0760533	0.5155381
0	20.00	0.0934933	0.0020625	-0.1131240	0.0003630	0.0329424	2.6298521	0.0068652	0.5480640
0	23.24	0.0987482	0.0013169	-0.1118890	0.0031896	0.6549649	2.9756274	0.1010894	0.4592680
1.875	23.21	0.0993100	0.0017535	-0.1103250	0.0035984	0.7214651	3.4135162	0.1116413	0.5282161
3.75	23.25	0.0988948	0.0017084	-0.1086030	0.0027975	0.6723179	3.8956417	0.1036785	0.6007489
5.625	23.22	0.0981492	0.0017094	-0.1087080	0.0027087	0.5840613	3.8662438	0.0903013	0.5977571
7.5	23.19	0.0975071	0.0015387	-0.1086040	0.0025886	0.5080559	3.8953617	0.0787535	0.6038182
9.375	23.15	0.0986624	0.0017375	-0.1094320	0.0036266	0.6448087	3.6635383	0.1002972	0.5698475
11.25	23.12	0.0986176	0.0016978	-0.1088970	0.0026879	0.6395058	3.8133276	0.0997307	0.5946869
13.125	23.06	0.0984263	0.0016974	-0.1083370	0.0027636	0.6168616	3.9701164	0.0967006	0.6223641
-1.875	23.25	0.0982110	0.0013967	-0.1143470	0.0015296	0.5913765	2.2874366	0.0911965	0.3527468
-3.75	23.21	0.0976850	0.0013755	-0.1163350	0.0009381	0.5291139	1.7308364	0.0818764	0.2678340
No Load	0.00	0.0932150	0.0008940	-0.1225170	0.0002069	0.7018596	-3.9553097	-	-

D.2.3 Yaw Raw Data

Table 18: Yaw Raw Data from the Three Tested Models

<table>
<tr><th colspan="6">High Sweep</th></tr>
<tr><td>Angle of Attack</td><td>Velocity</td><td>Yaw</td><td>RMS</td><td>Yaw</td><td>Cy</td></tr>
<tr><td>0</td><td>10.23</td><td>-0.12199</td><td>0.000363</td><td>0.269901</td><td>0.429974</td></tr>
<tr><td>-1.875</td><td>10.27</td><td>-0.12213</td><td>0.000455</td><td>0.230704</td><td>0.364673</td></tr>
<tr><td>-3.75</td><td>10.3</td><td>-0.12256</td><td>0.000503</td><td>0.109192</td><td>0.171596</td></tr>
<tr><td>-9.375</td><td>10.25</td><td>-0.12263</td><td>0.000475</td><td>0.091553</td><td>0.145284</td></tr>
<tr><td>-13.125</td><td>10.25</td><td>-0.12286</td><td>0.000408</td><td>0.026878</td><td>0.042652</td></tr>
<tr><td>NL</td><td>0</td><td>-0.12295</td><td>0.00048</td><td>-4.07766</td><td>-</td></tr>
<tr><th colspan="6">Medium Sweep</th></tr>
<tr><td>0</td><td>10.28</td><td>-0.12141</td><td>0.000333</td><td>0.124031</td><td>0.195675</td></tr>
<tr><td>-1.875</td><td>10.35</td><td>-0.12128</td><td>0.000388</td><td>0.161828</td><td>0.251863</td></tr>
<tr><td>-3.75</td><td>10.364</td><td>-0.12147</td><td>0.000354</td><td>0.106392</td><td>0.165138</td></tr>
<tr><td>-9.375</td><td>10.29</td><td>-0.12161</td><td>0.000342</td><td>0.068035</td><td>0.107125</td></tr>
<tr><td>-13.125</td><td>10.34</td><td>-0.12171</td><td>0.000388</td><td>0.039757</td><td>0.061996</td></tr>
<tr><td>NL</td><td>0</td><td>-0.12185</td><td>0.000234</td><td>-3.76968</td><td>-</td></tr>
<tr><th colspan="6">Low Sweep</th></tr>
<tr><td>0</td><td>10.23</td><td>-0.12204</td><td>0.000351</td><td>0.064675</td><td>0.103033</td></tr>
<tr><td>-1.875</td><td>10.33</td><td>-0.12209</td><td>0.000402</td><td>0.051236</td><td>0.080051</td></tr>
<tr><td>-3.75</td><td>10.27</td><td>-0.12231</td><td>0.000422</td><td>-0.0112</td><td>-0.0177</td></tr>
<tr><td>-9.375</td><td>10.26</td><td>-0.12227</td><td>0.00037</td><td>0.00224</td><td>0.003547</td></tr>
<tr><td>-13.125</td><td>10.29</td><td>-0.12225</td><td>0.000442</td><td>0.007839</td><td>0.012344</td></tr>
<tr><td>NL</td><td>0</td><td>-0.12227</td><td>0.000267</td><td>-3.88699</td><td>-</td></tr>
</table>

Figure 52: Low Sweep Design

Figure 53: Medium Sweep Design

Figure 54: High Sweep Design

D.3 Water System Testing

Water Testing Plan Originator: C. Diffey					17.March.17 PAC Pool 22:00
No.	**Test Description**	**Completed**	**Value**	**Units**	**Comments**
1	Dry weight – before submersion	✓	2920	g	- Weighed without detachable electronics
2	Stability on Surface	✓	N/A	N/A	- Props slightly cut into water, leak in tail
3	Water surface speed	✓	0.8	m/s	
4	Water surface turning	✓	N/A	m	- Rudder too small
5	Fill time	✓	8	min	- Tail submerged first
6	Stability under water	✓	N/A	N/A	- Tail goes down - Weight at front → nose down - Find middle point….
7	Submerged water speed	✓	0.3	m/s	
8	Submerged water turning	✓	N/A	m	- Rudder too small
9	Thrust to Surface	✓	✓	N/A	
10	Wet weight – after submersion				- Need to seal printed parts to stop water entrainment

D.3.1 CO_2 Ballast System

This is the initial ballast system that was chosen for the vehicle. The gas ballast system uses a small canister of liquefied CO2 stored in the vehicle. To submerge the vehicle, the valve at the top of the ballast tank is opened, allowing air to leave the system and water to fill the tank through the open holes at the bottom, and the vehicle to submerge as it increases in weight due to the added water. To surface the vehicle, the vent is closed and the CO2 valve is opened, allowing the gas to fill the ballast tank and expel the water.

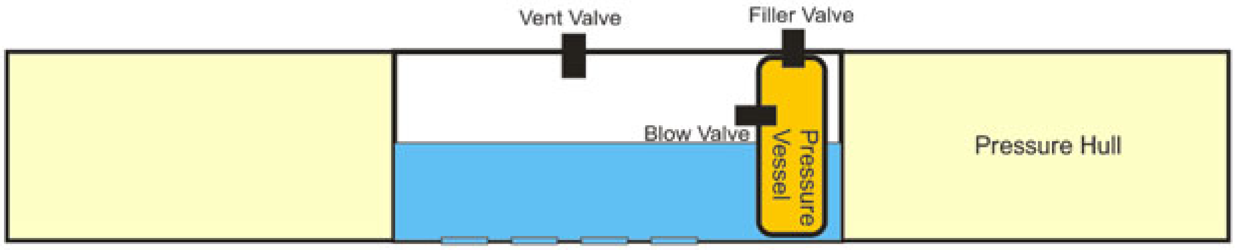


Figure 55: Gas Ballast System Diagram [4]

<u>Ballast System Validation Record</u>

MATERIALS:	
5L gas can	Set of Drills Bits
16g Threaded CO_2 canister 	CO_2 Pump Nozzle 
Duct Tape	Sink
Schrader Valve 	

BRIEF DESCRIPTION OF TEST SETUP (NUMBER OF CYCLES, PHOTOS ETC.)
Test 1: SINK TIME • 5 ½” holes were drilled into the gas can • 2 holes in the top and 3 in the bottom • The gas can was placed in a sink of water and left to submerge 

Test 2: RISE TIME

- Holes in the top were plugged
- A Schrader valve was placed in the top of the gas can
- Gas can was submerged in the sink
- Valve was filled by a CO_2 canister
- Filling stop when the can floated at empty level

RESULTS

Sink Time == 1 minute
Rise Time == 10s

Lessons Learned	
Hole Size	Holes should be made bigger to allow for faster sink time. Also bigger holes will help mitigate pressure buildup seen during emptying of the craft.
Vent Location	Vent should be placed at the highest point of the craft when floating to help lessen air pocket formation
CO_2 Release	Canister head needs to be found to allow for remote operation. Current head requires a pushing force.

D.3.2 Pump Ballast System

This is the final ballast system that was chosen for the vehicle. The vented ballast system consisted of a water pump and a vent to the atmosphere to control the buoyancy of the vehicle. This system is similar to design #1 but with a few modifications. To fully submerge, the pump pumps in water to the ballast tank and the vent goes below the waterline. When the vehicle needs to surface, it thrusts back up to the surface until the vent gets above the waterline. The pump then pumps water out of the ballast tank and the tank is filled with air through the vent.

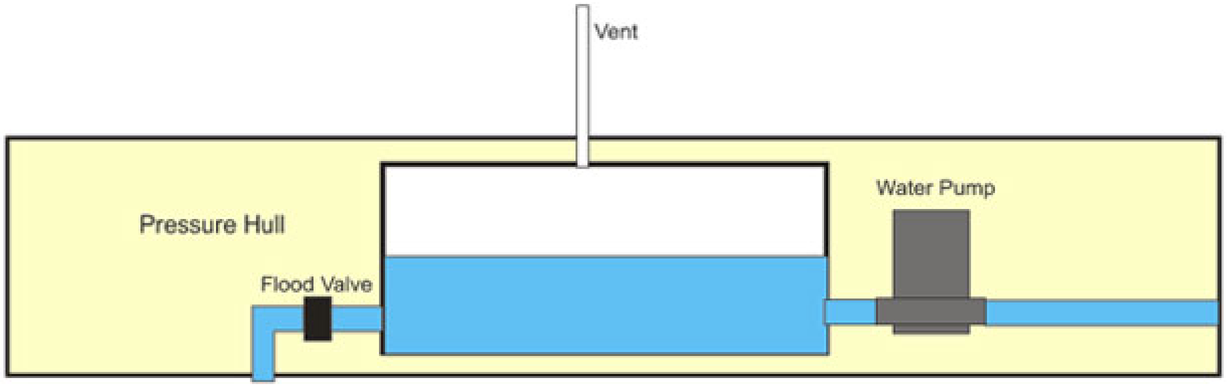


Figure 56: Vented Ballast System Diagram [4]

Pump System Validation Record

SUB SYSTEM: Ballast System

TEAM MEMBER IN CHARGE: CD & EF

BRIEF DESCRIPTION OF TEST SETUP

- Power pump and check volume/time
- Try to reverse pump
- Check no powered flow
- Check running dry

RESULTS

- 900ml in 40 sec = 22.5 mL/sec
    - 490 sec to pump 11L
- Can run dry with no problems
- Not reversible
- Does not act as a valve – not leak safe
- Water can flow through while powered off

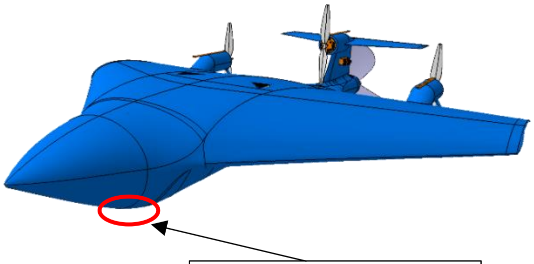
NEXT STEPS

- current draw measurements
- control integration
    - Brushed motor ESC
    - Separated battery (if too high current draw)

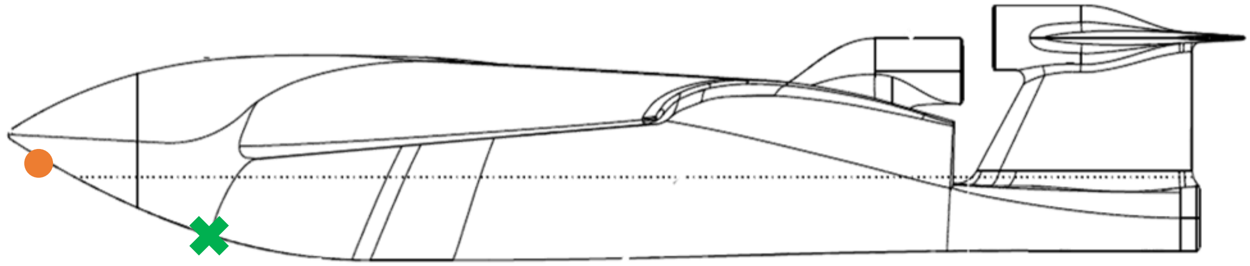
REQUIREMENTS

Mass	121 grams
Battery	12 VDC

SKETCH OF INTEGRATION INTO VEHICLE (WIRE ROUTING, REQUIREMENTS, INTERACTION WITH OTHER SYSTEMS)



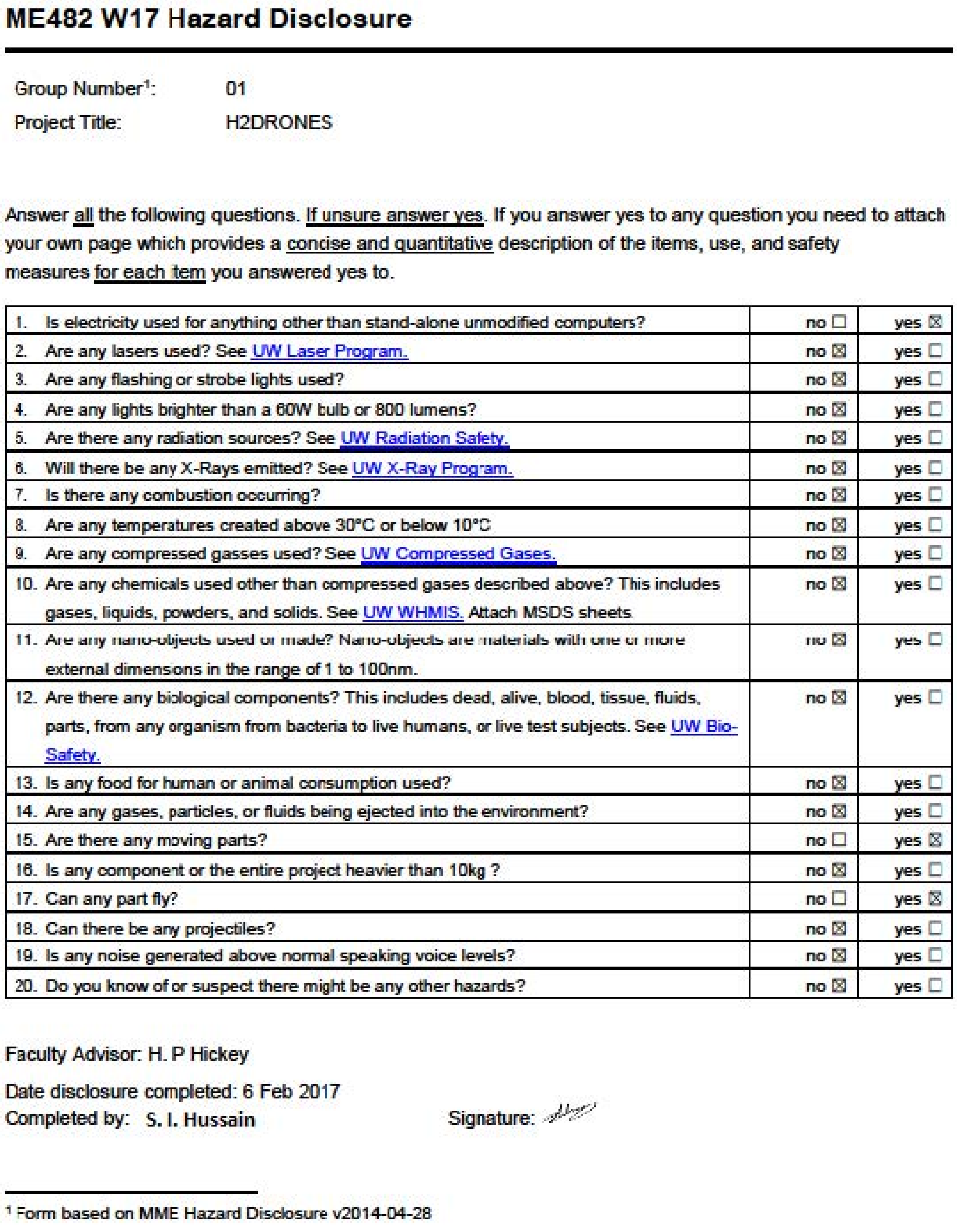
Inlet to pump – lowest point of plane



✖ Optimized Centre of Gravity Location

● Additional Vent Location

Appendix E Hazard Disclosure Form



ME482 W17 Hazard Disclosure

Group Number[1]: 01

Project Title: H2DRONES

Answer all the following questions. If unsure answer yes. If you answer yes to any question you need to attach your own page which provides a concise and quantitative description of the items, use, and safety measures for each item you answered yes to.

1. Is electricity used for anything other than stand-alone unmodified computers?	no ☐	yes ☒
2. Are any lasers used? See UW Laser Program.	no ☒	yes ☐
3. Are any flashing or strobe lights used?	no ☒	yes ☐
4. Are any lights brighter than a 60W bulb or 800 lumens?	no ☒	yes ☐
5. Are there any radiation sources? See UW Radiation Safety.	no ☒	yes ☐
6. Will there be any X-Rays emitted? See UW X-Ray Program.	no ☒	yes ☐
7. Is there any combustion occurring?	no ☒	yes ☐
8. Are any temperatures created above 30°C or below 10°C	no ☒	yes ☐
9. Are any compressed gasses used? See UW Compressed Gases.	no ☒	yes ☐
10. Are any chemicals used other than compressed gases described above? This includes gases, liquids, powders, and solids. See UW WHMIS. Attach MSDS sheets.	no ☒	yes ☐
11. Are any nano-objects used or made? Nano-objects are materials with one or more external dimensions in the range of 1 to 100nm.	no ☒	yes ☐
12. Are there any biological components? This includes dead, alive, blood, tissue, fluids, parts, from any organism from bacteria to live humans, or live test subjects. See UW Bio-Safety.	no ☒	yes ☐
13. Is any food for human or animal consumption used?	no ☒	yes ☐
14. Are any gases, particles, or fluids being ejected into the environment?	no ☒	yes ☐
15. Are there any moving parts?	no ☐	yes ☒
16. Is any component or the entire project heavier than 10kg ?	no ☒	yes ☐
17. Can any part fly?	no ☐	yes ☒
18. Can there be any projectiles?	no ☒	yes ☐
19. Is any noise generated above normal speaking voice levels?	no ☒	yes ☐
20. Do you know of or suspect there might be any other hazards?	no ☒	yes ☐

Faculty Advisor: H. P Hickey

Date disclosure completed: 6 Feb 2017

Completed by: S. I. Hussain

Signature:

---

[1] Form based on MME Hazard Disclosure v2014-04-28

ME482 W17 Hazard Disclosure

---

1) Is electricity used for anything other than stand-alone unmodified computers?
Yes, electricity supplied from a <BAT. VOLTAGE> DC battery outputting <AMP> will be used. The battery is installed securely inside the airplane and sealed from the environment. Due to the low amperage of the battery there should be no safety concerns. Electricity will also be present to charge the DC battery. The battery will be charged from a 110V electrical outlet.

15) Are there any moving parts?
Yes, moving parts are present (propellers and wing flaps). To ensure safe operation the propellers are securely attached to the shaft of the motor, incorporating fail-safe design to hold the propeller in place. Since the propellers are made out of plastic no cut hazards are present. The pressure present at the pinch point of the flaps is so low no major safety concerns are present. The vehicle will only be operated by trained individuals.

17) Can any part fly?
The vehicle will only be operated by trained individuals in an open environment away from property and individuals. Appropriate PPE (glasses) will be used and a safety zone made.

Appendix F Project Management

F.1 Team Organization Chart

Team Member	Role	Primary Function	Secondary Function
C. Diffey	Validation Lead	• Subcomponent validation • Verification of prototype • Finite element analysis	• Support manufacturing
E. Fochtberger	Manufacturing Lead	• Manufacturing of Prototype • Material and manufacturing method selection	• Design for manufacturing • Support validation
S. I. Hussain	Team Lead	• Project management (budgeting, scheduling, team leadership) • Procurement	• Support manufacturing • Support validation
K. Strobel	Design Lead	• CAD • Design for manufacturing	• Support validation • Support analysis (CFD & FEA)
K. Younes	Analysis Lead	• Computational fluid dynamics analysis	• Support validation

F.2 Project Schedule

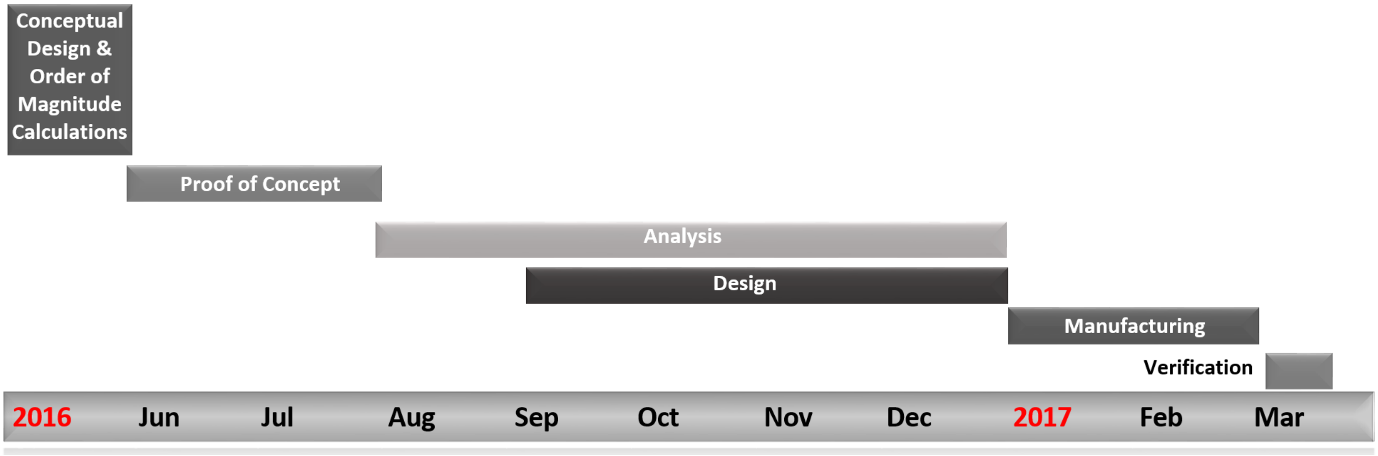


Figure 57: ME481& ME482 H2Drones Schedule

F.3 Budget

Table 19: H2Drones Team Balance Sheet

	Debit	Credit
CAPStone Engineering Fund	$750.00	
Osama Bakht	$50.00	
Tariq	$20.00	
Shehab	$20.00	
Tilt	$150.00	
Professor Baleshta	$40.00	
FliteCraft - Servo		-$21.98
FliteCraft - Servo		-$30.51
FliteCraft - RC Plane		-$282.44
FliteCraft - Charger		-$83.56
HobbyKing - Parts		-$184.74
Website Hosting		-$79.77
HobbyKing - Parts		-$209.12
Home Hardware-Plaster		-$12.58
Home Hardware-Plaster		-$12.58
SkyCraft Hobbies-Connectors		-$23.68
Pieriks Cycle - CO2 Pump		-$46.10
SkyCraft Hobbies-Prop mount		-$10.16
HomeDepot - Plywood 1/8		-$3.50
HomeDepot - Foam & Adhesive		-$36.47
HomeDepot - Epoxy		-$39.82
FliteCraft - Rod, extension, wire		-$46.22
FliteCraft - ESC, XT60		-$66.12
HomeDepot - Plastidip		$22.60
FliteCraft - Msc		-$6.22

FliteCraft - Msc		-$13.99
Sayal - 3D Print		-$23.67
Ferrel - White Foam		-$9.12
Plastic World - Styrene, Acrylic		-$89.27
3D Printing ABS - E5		-$366.73
Spaenuar - Plastic Binding Post		-$12.02
Princess Auto		-$16.94
Plastic World – Vivak®		-$48.59
	$1,030.00	-1753.3
TOTAL		**-$723.30**

F.4 Risk Registry

Table 20: Risk Registry Plan

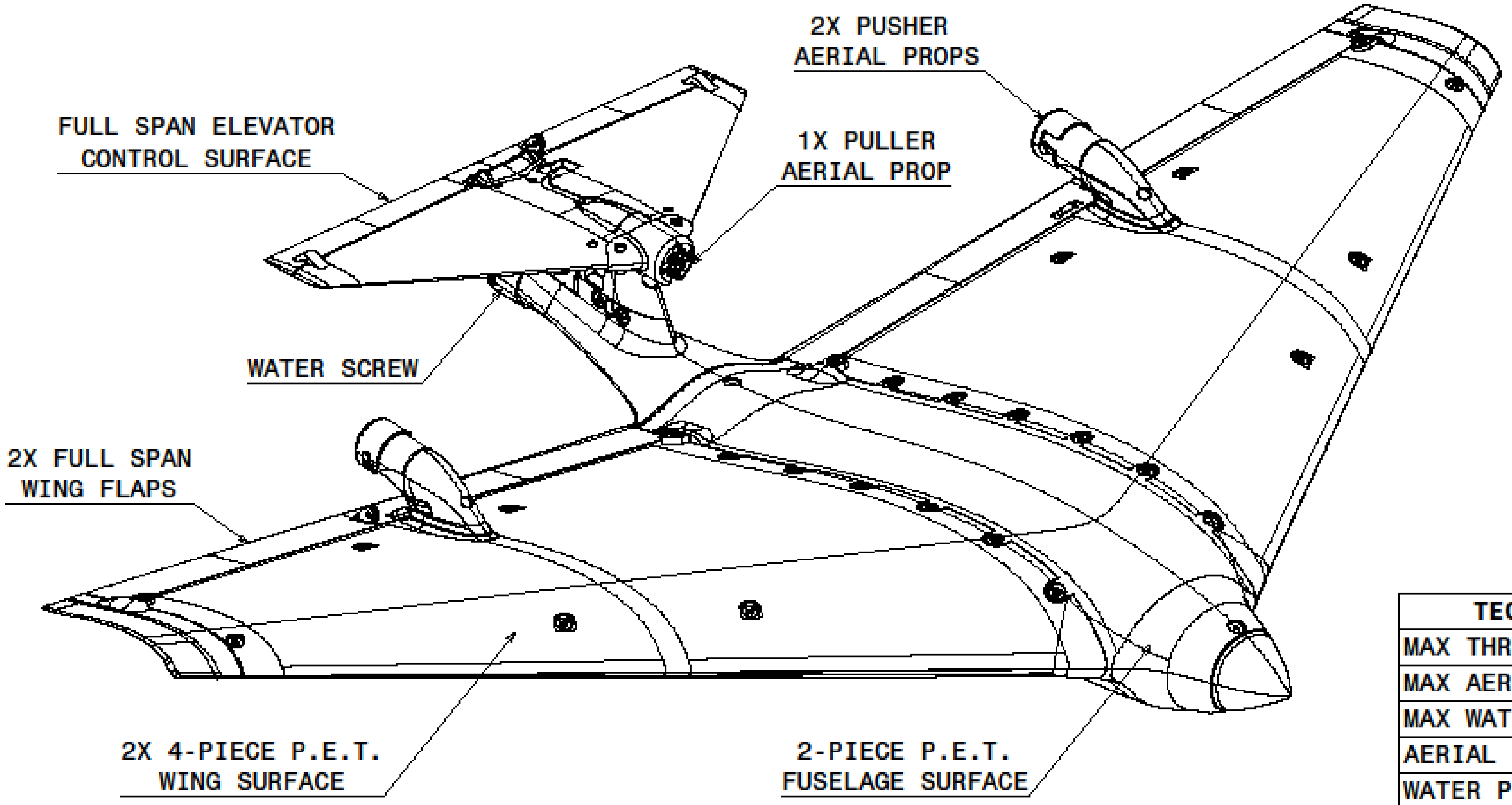
#	Risk	Description	Type	Prob.	Sever.	Mitigation plan
1	Scope	Design solution implementation is too extensive and needs more time than expected	Non-Technical	L	H	Simplification of design and regular feedback instructional staff. Reduce scope as appropriate.
2	Budget	Labor and material estimates are unreasonable	Non-Technical	M	M	Careful resource sourcing and time tracking.
3	Waterproofing Components	Components not capable of surviving water ingress	Technical	H	M	Purchase (or have ready to purchase critical components). Preform subsystem testing prior to integration into vehicle.
4	Prototype cannot fly	Due to aerodynamic parameters selected the airplane is not capable of flight	Technical	H	M	Preform CFD analysis to optimize design. Seek consult of experienced professors. Utilize manufacturing method which enables modification (i.e. modular build to allow modification to aero profile)

5	Schedule	Utilizing time efficiently to fulfill outlined scope	Non-Technical	M	M	Careful scheduling of task. Gaining stakeholder involvement to develop effect schedule and share ownership of responsibilities.
6	No prior experience in designing airplanes, or water vessels	Difficulties in accurately assessing the challenges faced and timeline required. High learning curve	Technical	H	H	Seeking guidance from experienced professors and instructional staff. Preforming effective research to understand challenges and learn from experience.

Appendix G Full Vehicle Drawings

NOTES:
1. THE FOLLOWING DRAWINGS OUTLINE H2DRONE'S PUFFIN BIRD VEHICLE GEOMETRY
2. ALL TOOLS TO BE CUT USING OFFICIAL H2D CAD DATA
3. DIMENSIONAL CHANGES MUST BE REVIEWED AND APPROVED BY H2D'S R&D TEAM
4. MINIMUM PLA PRINTING THICKNESS - 1.8mm
5. DIMENSIONS FOR REFERENCE ONLY, REFER TO CAD DATA FOR RECREATION

REV	DATE	DESCRIPTION	INIT
A	3/27/2017	INITIAL RELEASE	K.S.



TECHNICAL SPECIFICATIONS	
MAX THRUST/WEIGHT	1.2
MAX AERIAL THRUST	39N
MAX WATER THRUST	20N
AERIAL PROPULSION	3X BLDC MOTORS
WATER PROPULSION	1X BLDC MOTOR
SPEED CONTROL	3X 60A ESC
ENERGY STORAGE	3Ah @ 14.8V
MAX L/D	7.8

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

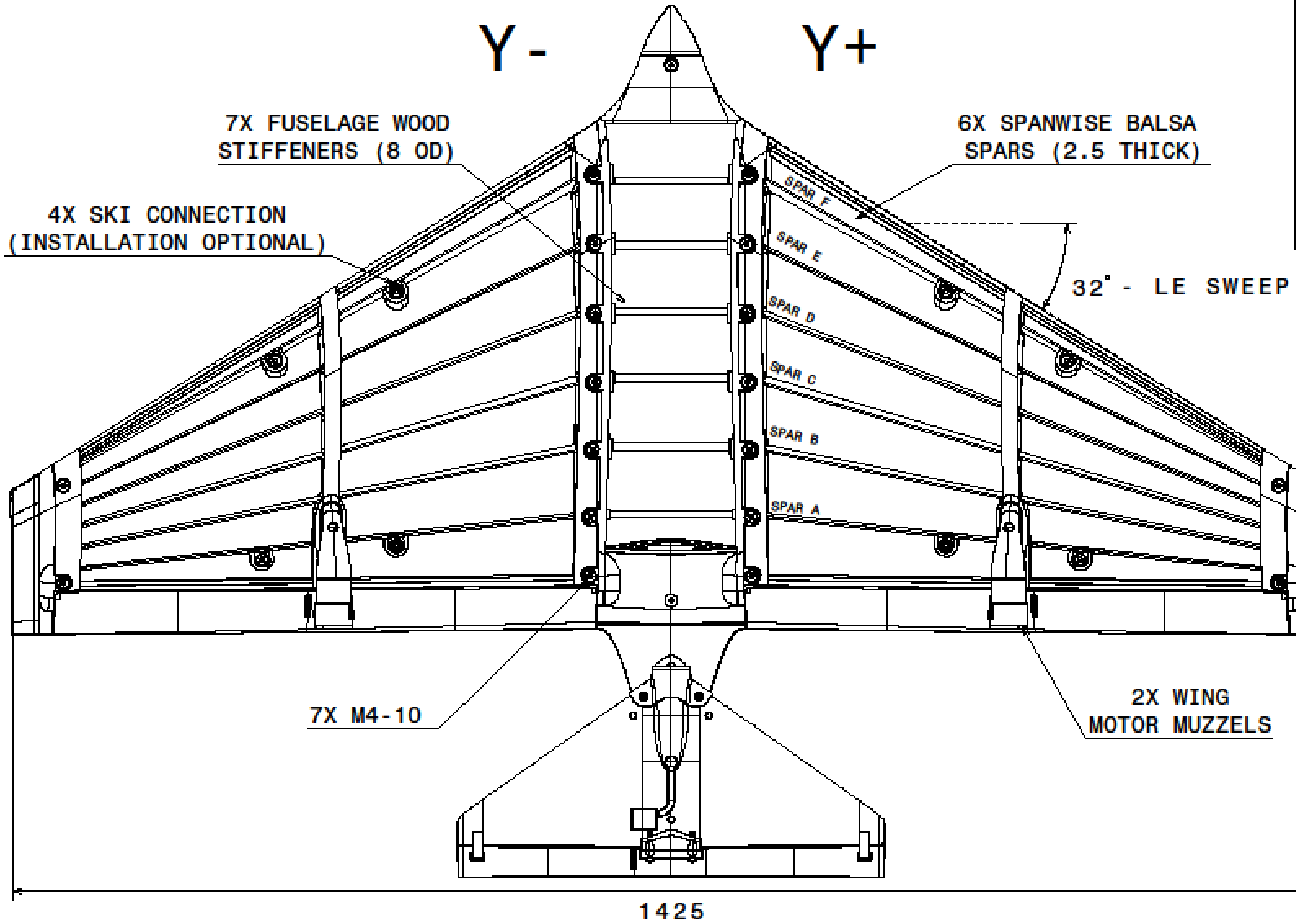
H2DRONES - PUFFIN BIRD

DRAWING TITLE
GENERAL VEHICLE DETAILS - 1

DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/28/2017
DESIGNED BY H2D DATE 2017

SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 1:4
WEIGHT(kg) 3.3
SHEET 1

NOTES:
1. FUSELAGE/WING SKIN NOT SHOWN



MAIN WING TECHNICAL SPECIFCATIONS	
PLANFORM AREA	0.446 m2
ANGLE OF INCIDENCE	4.5°
Q. CHORD SWEEP ANGLE	25°
WING TWIST	0°
TRAILING EDGE DIHEDRAL	7°
ASPECT RATIO	3.59
TAPER RATIO	0.21
AIRFOIL PROFILE	NACA - M8
WING FLAP DIMENSIONS	44 X 600

AERIAL MOTOR SPECIFICATIONS	
RATED THRUST	3X 13N
RATED VOLTAGE	14.8V
MANUFACTURER	TURNIGY
kV RATING	3000 RPM/V
WEIGHT	3X 79g
MAX POWER	3X 375W
PROPELLER OD	WING: 100mm TAIL: 127mm

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

DRAWING TITLE
GENERAL VEHICLE DETAILS - 2

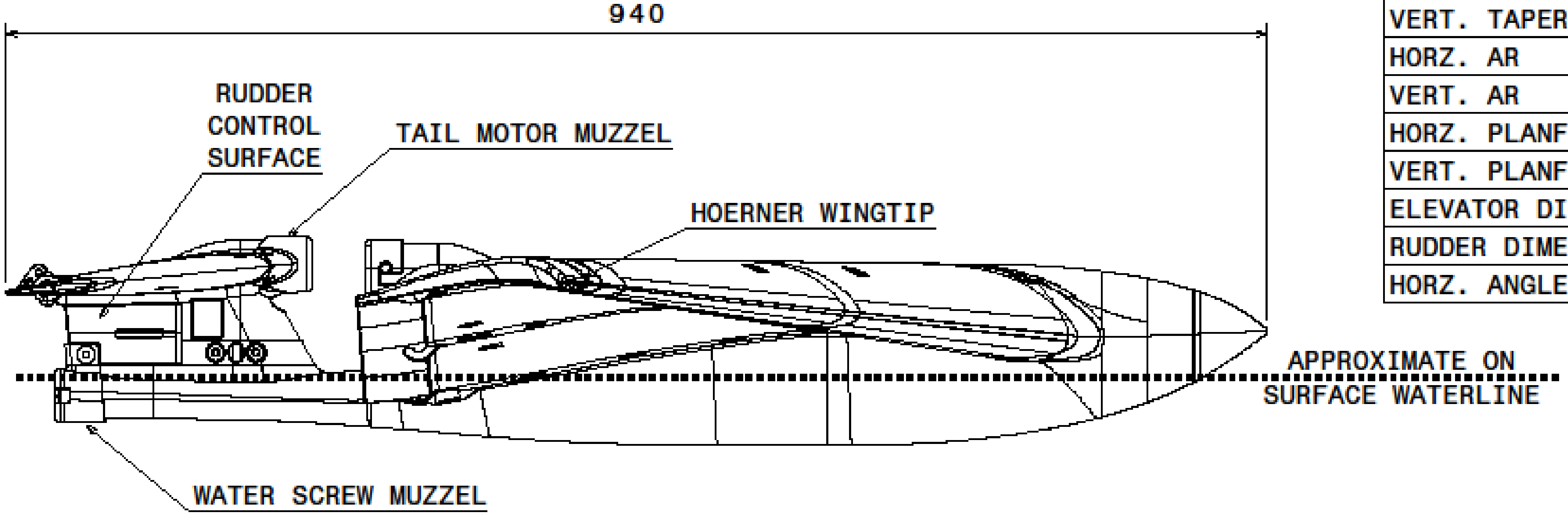
DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/29/2017
DESIGNED BY H2D DATE 2017
SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 1:5
WEIGHT(kg) 3.3
SHEET 2

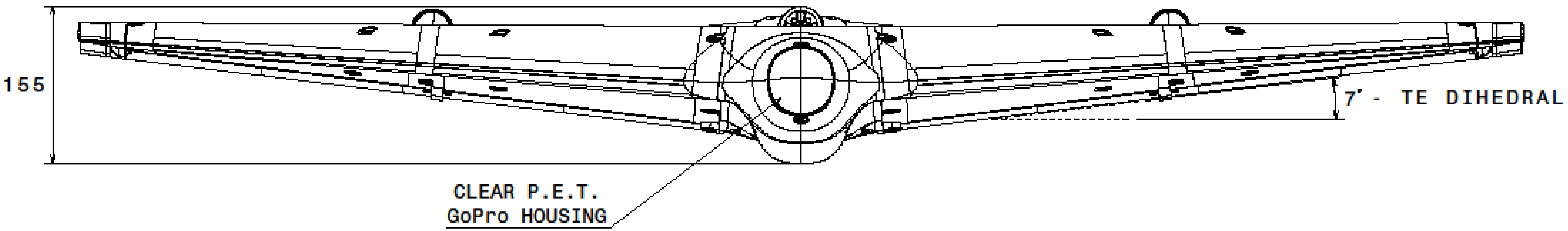
CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

NOTES:
1. VEHICLE VOLUME: 19.8L

TAIL SECTION GEOMETRY DETAILS

HORZ. AIRFOIL	NACA - 0012
VERT. AIRFOIL	EPPLER - 473
HORZ. TAPER RATIO	0.28
VERT. TAPER RATIO	0.65
HORZ. AR	3.04
VERT. AR	1.05
HORZ. PLANFORM AREA	666 cm^2
VERT. PLANFORM AREA	107 cm^2
ELEVATOR DIMENSIONS	35 X 450
RUDDER DIMENSIONS	46 X 83
HORZ. ANGLE OF INCIDENCE	5.8°





DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

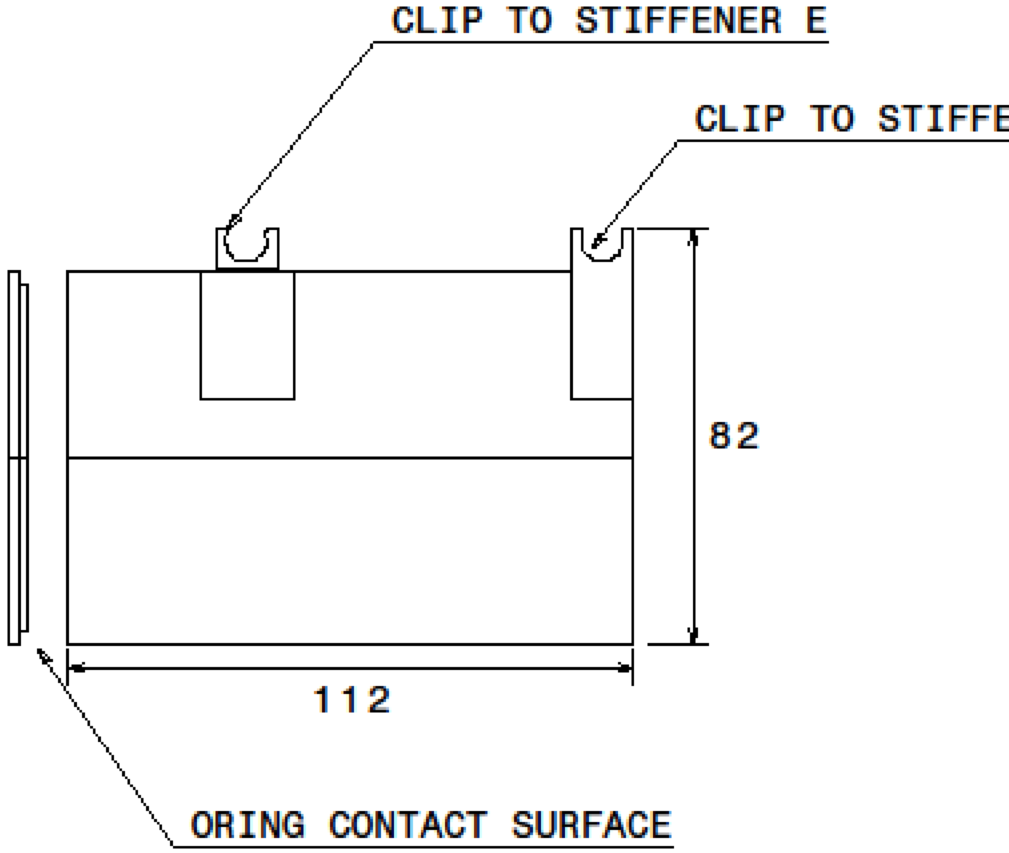
DRAWING TITLE
GENERAL VEHICLE DETAILS - 3

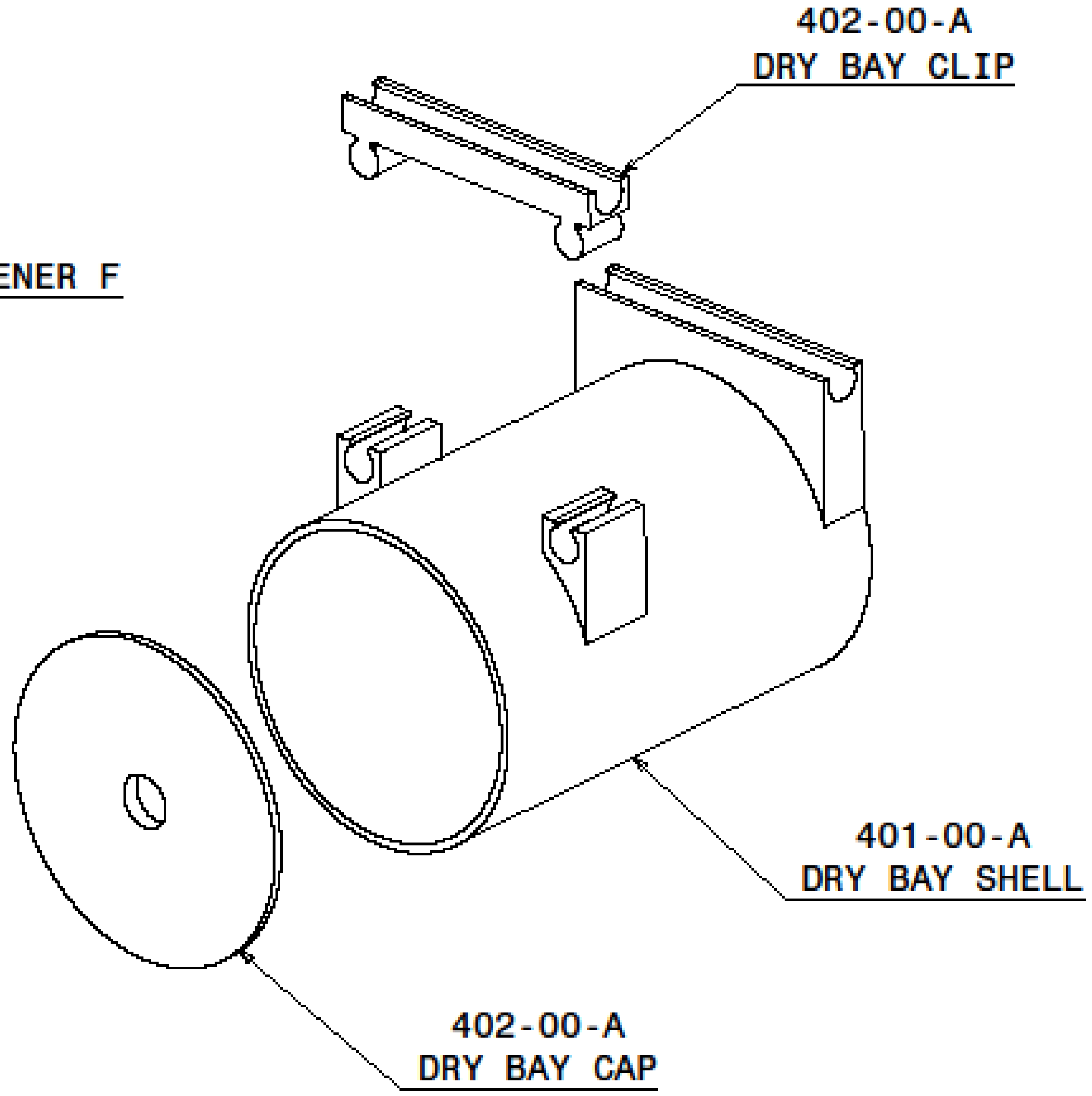
DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/28/2017
DESIGNED BY H2D DATE 2017

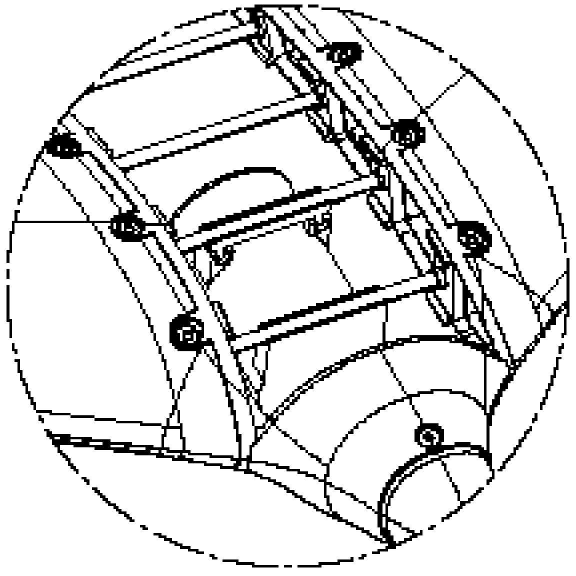
SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 1:4
WEIGHT(kg) 3.3
SHEET 3

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

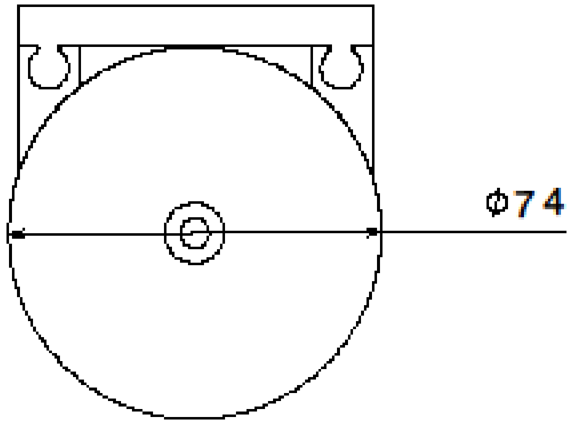
NOTES:
1. PLUG WIRE OPENINGS WITH RTV WHEN INSTALLED
2. ORING GEOMETRY NOT SPECIFIED







DRY BAY LOCATION



BILL OF MATERIALS

P/N	DESCRIPTION	MATERIAL
401-00-A	DRY BAY SHELL	PLA
402-00-A	DRY BAY CAP	PLA
403-00-A	DRY BAY CLIP	PLA

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

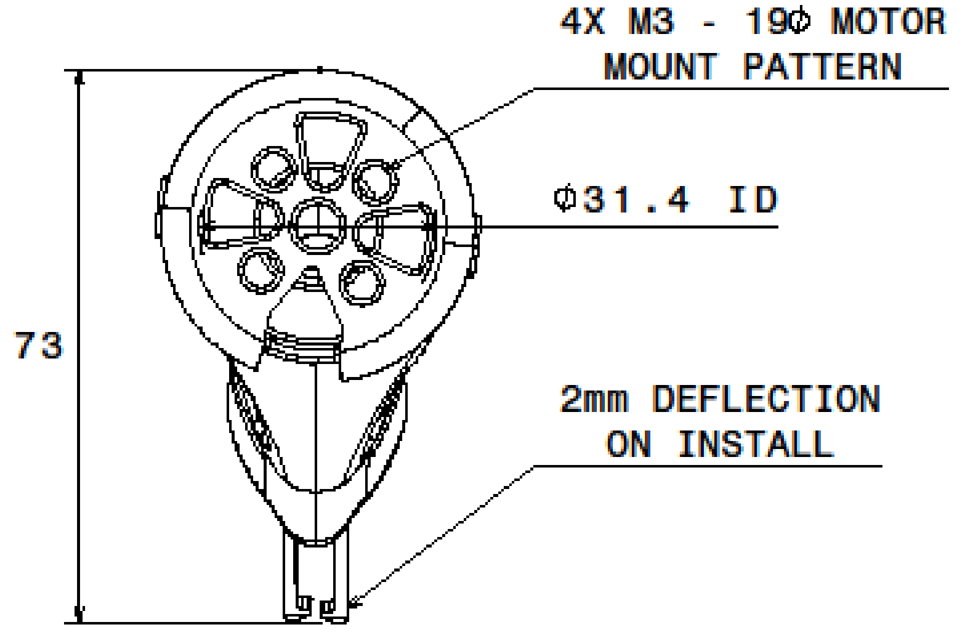
DRAWN BY K.S.	DATE 3/27/2017
CHECKED BY S.H.	DATE 3/28/2017
DESIGNED BY H2D	DATE 2017

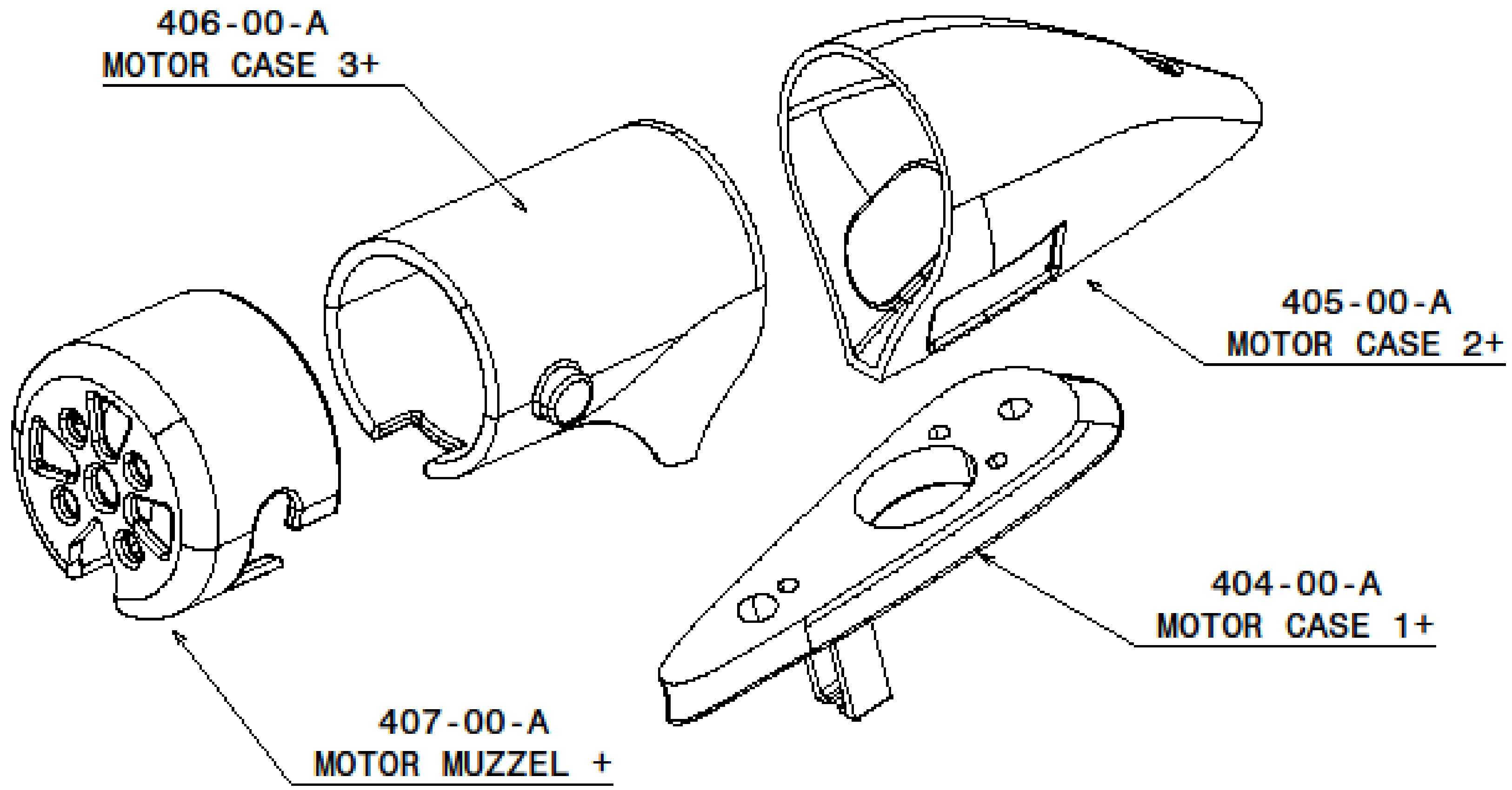
DRAWING TITLE
DRY BAY ASSEMBLY

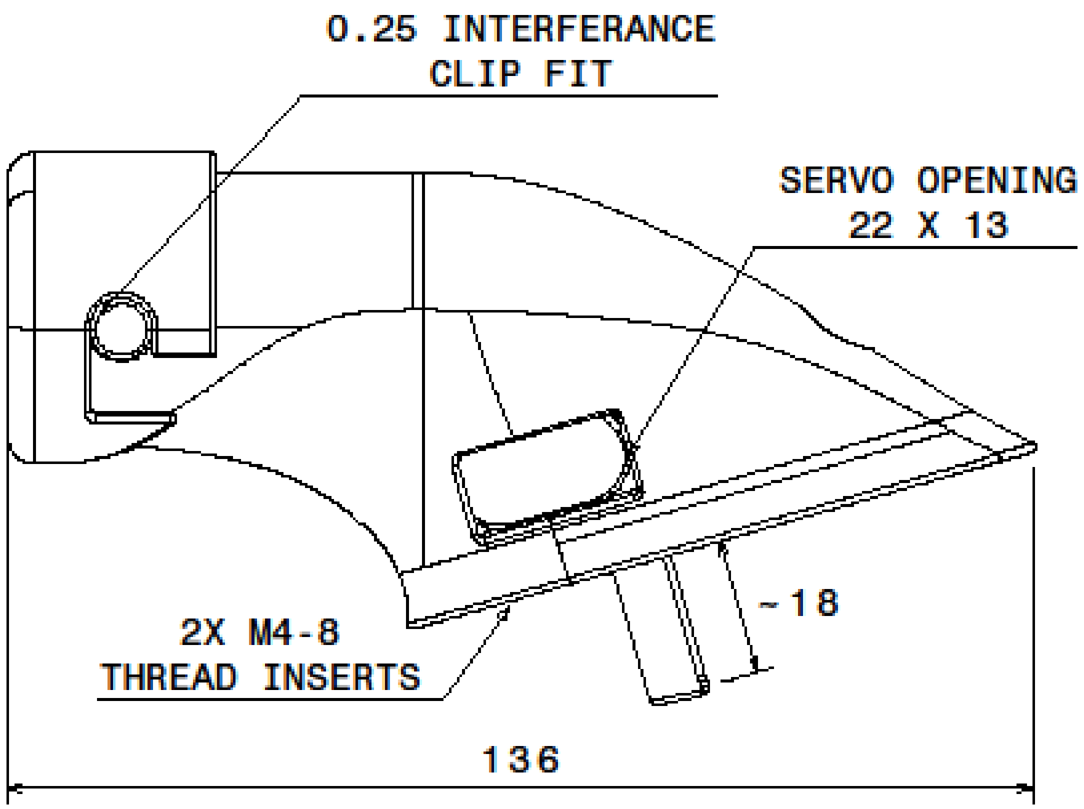
SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 2:3
WEIGHT(g) 97
SHEET 4

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

NOTES:
1. SEE 'GENERAL VEHICLE DETAILS - 2' FOR Y+ VS Y- DESIGNATION
2. JOIN MOTOR CASE 1-2-3 WITH EPOXY BOND







BILL OF MATERIALS

P/N	DESCRIPTION	MATERIAL
	Y+	
404-00-A	MOTOR CASE 1+	PLA
405-00-A	MOTOR CASE 2+	PLA
406-00-A	MOTOR CASE 3+	PLA
407-00-A	MOTOR MUZZEL +	PLA
	Y-	
408-00-A	MOTOR CASE 1-	PLA
409-00-A	MOTOR CASE 2-	PLA
410-00-A	MOTOR CASE 3-	PLA
411-00-A	MOTOR MUZZEL -	PLA

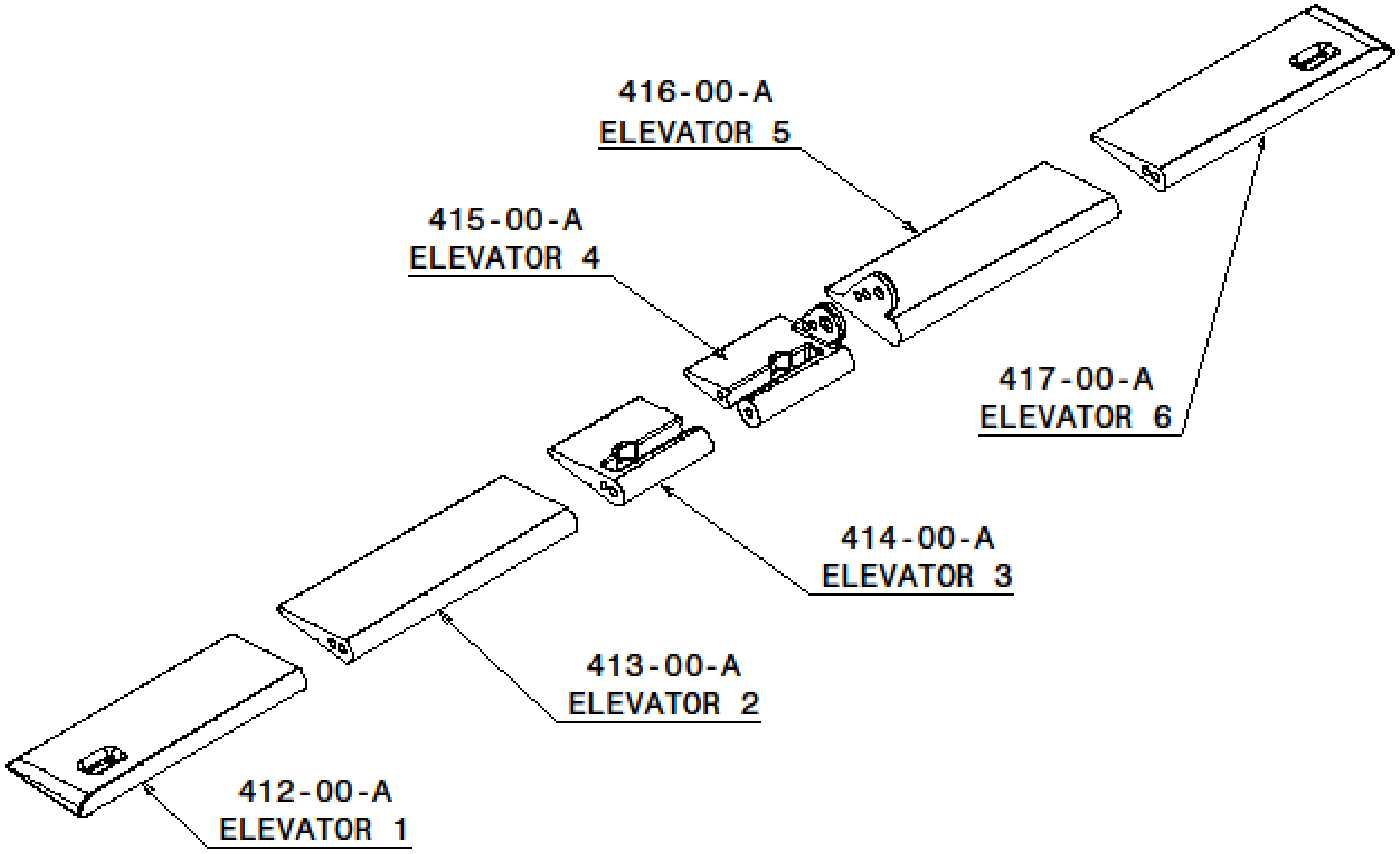
H2DRONES - PUFFIN BIRD

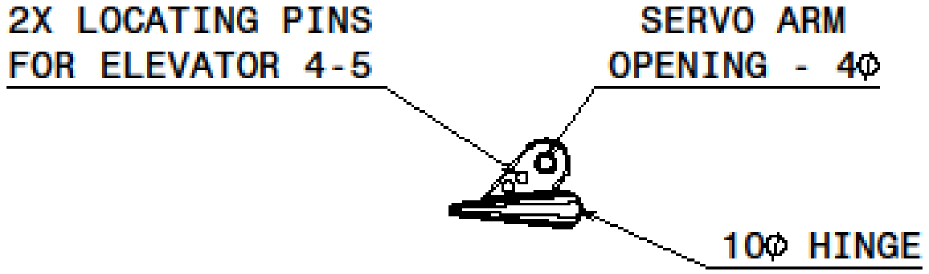
DRAWING TITLE
WING MOTOR CASE ASSEMBLY

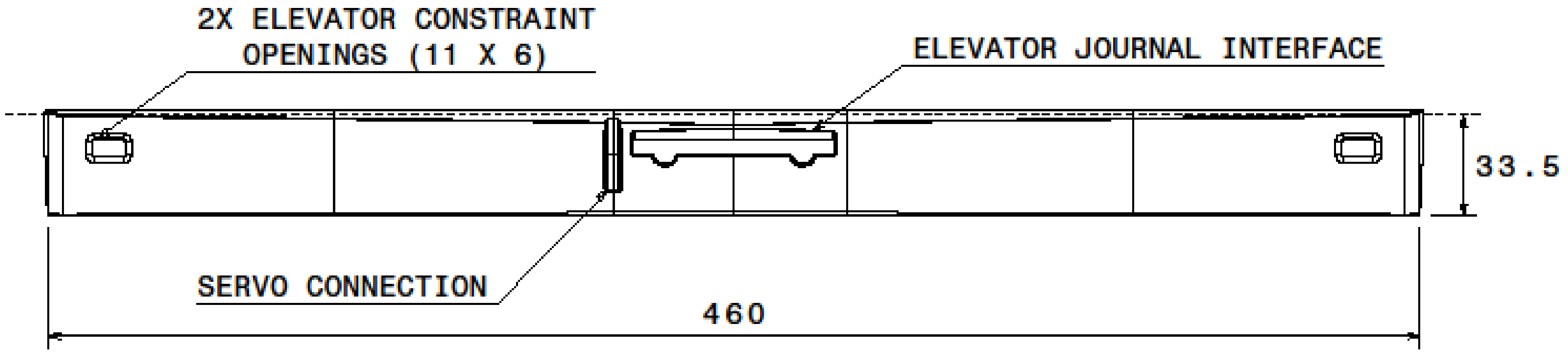
DRAWN BY K.S.	DATE 3/27/2017	SIZE A3	DRAWING NUMBER 101-00-A		REV A
CHECKED BY S.H.	DATE 3/28/2017	SCALE 1:1	WEIGHT(g) 46		SHEET 5
DESIGNED BY H2D	DATE 2017				

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

NOTES:
1. JOIN ELEVATOR 1-2-3-4-5-6 WITH EPOXY BOND







BILL OF MATERIALS		
P/N	DESCRIPTION	MATERIAL
412-00-A	ELEVATOR 1	ABS
413-00-A	ELEVATOR 2	ABS
414-00-A	ELEVATOR 3	ABS
415-00-A	ELEVATOR 4	ABS
416-00-A	ELEVATOR 5	ABS
417-00-A	ELEVATOR 6	ABS

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

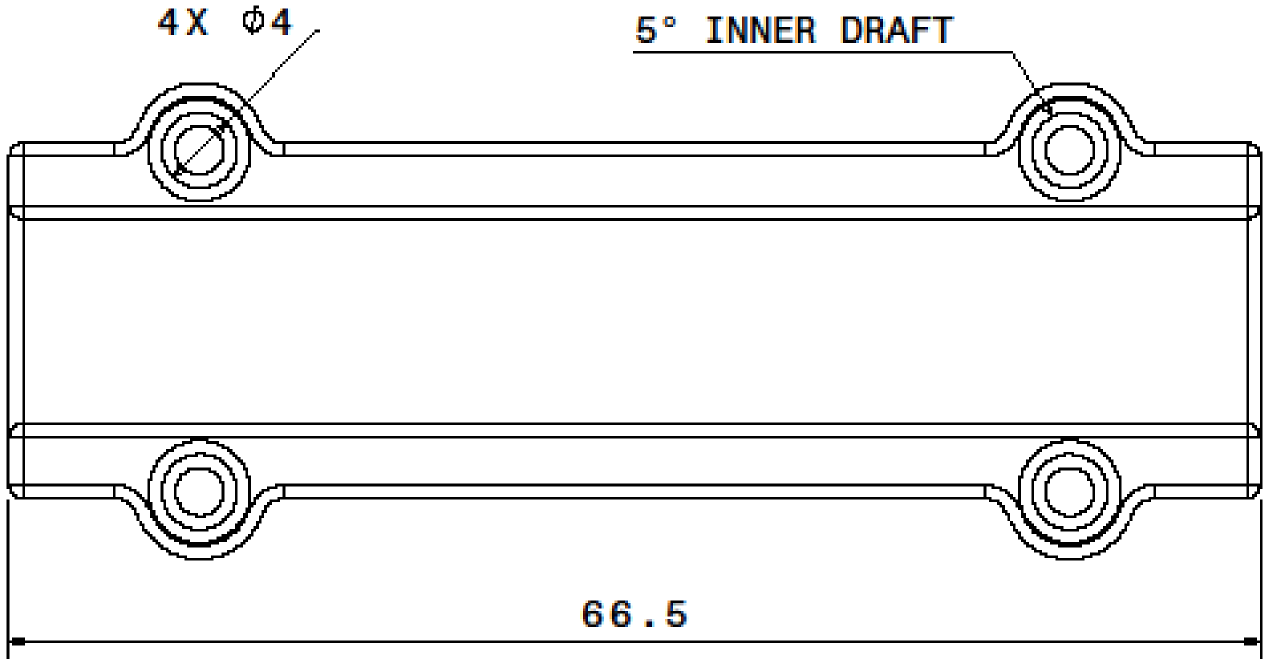
H2DRONES - PUFFIN BIRD

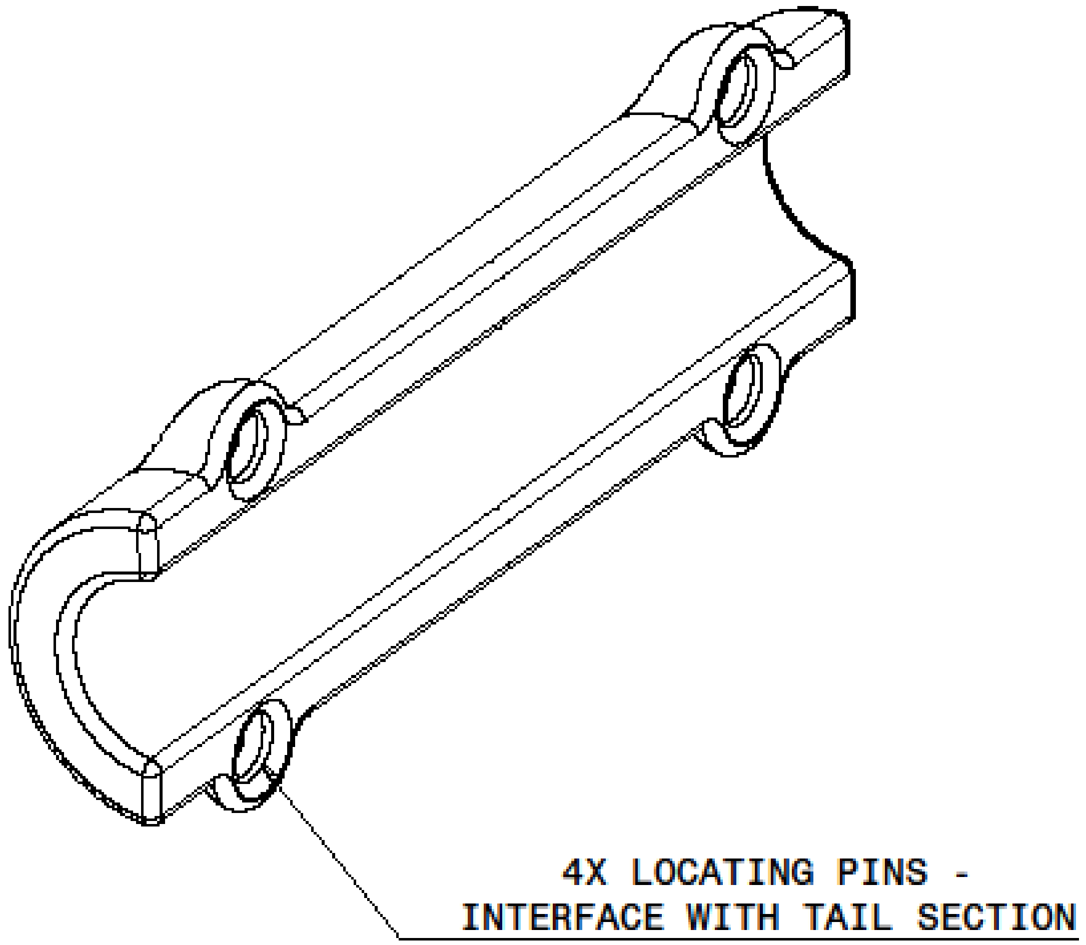
DRAWING TITLE
ELEVATOR CONTROL SURFACE ASSEMBLY

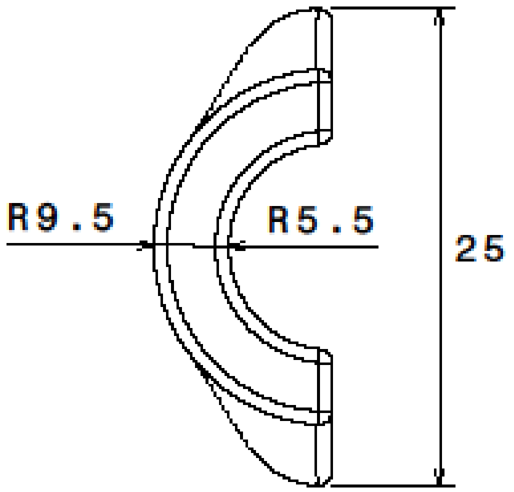
DRAWN BY K.S.	DATE 3/27/2017	SIZE A3	DRAWING NUMBER 101-00-A
CHECKED BY S.H.	DATE 3/28/2017	REV A	
DESIGNED BY H2D	DATE 2017	SCALE 1:2	WEIGHT(g) 91
		SHEET 6	

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

NOTES:
1. ATTACHMENT STRATEGY TO TAIL SECTION - 2X ZIP TIES
2. MATERIAL - PLA







CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

H2DRONES - PUFFIN BIRD

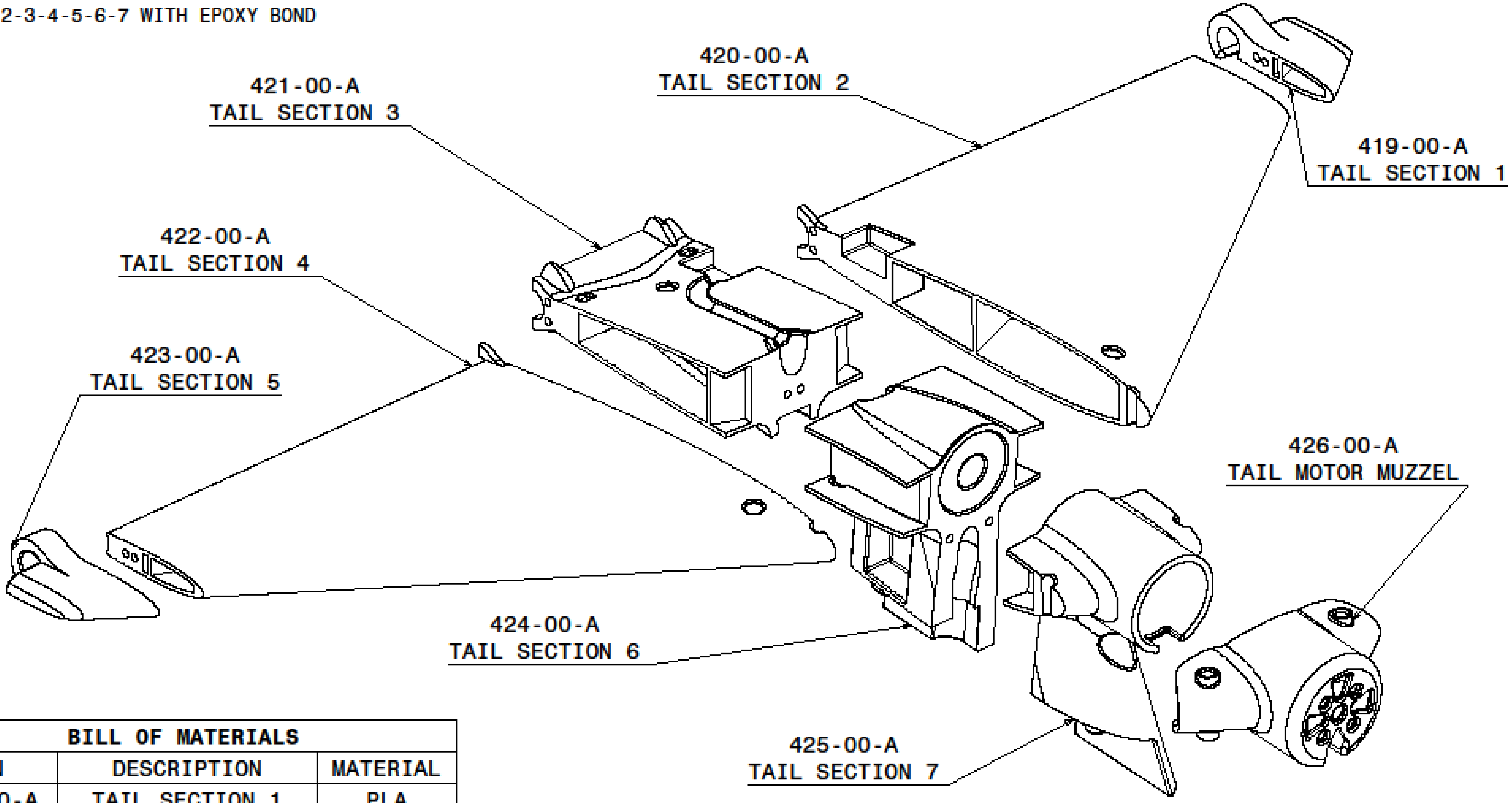
DRAWING TITLE
ELEVATOR JOURNAL - 418-00-A

DRAWN BY K.S.	DATE 3/27/2017
CHECKED BY S.H.	DATE 3/28/2017
DESIGNED BY H2D	DATE 2017

SIZE A3	DRAWING NUMBER 101-00-A	REV A

SCALE 5:2
WEIGHT(g) 7
SHEET 7

NOTES:
1. JOIN TAIL SECTION 1-2-3-4-5-6-7 WITH EPOXY BOND



BILL OF MATERIALS		
P/N	DESCRIPTION	MATERIAL
419-00-A	TAIL SECTION 1	PLA
420-00-A	TAIL SECTION 2	PLA
421-00-A	TAIL SECTION 3	PLA
422-00-A	TAIL SECTION 4	PLA
423-00-A	TAIL SECTION 5	PLA
424-00-A	TAIL SECTION 6	PLA
425-00-A	TAIL SECTION 7	PLA
426-00-A	TAIL MOTOR MUZZEL	PLA

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

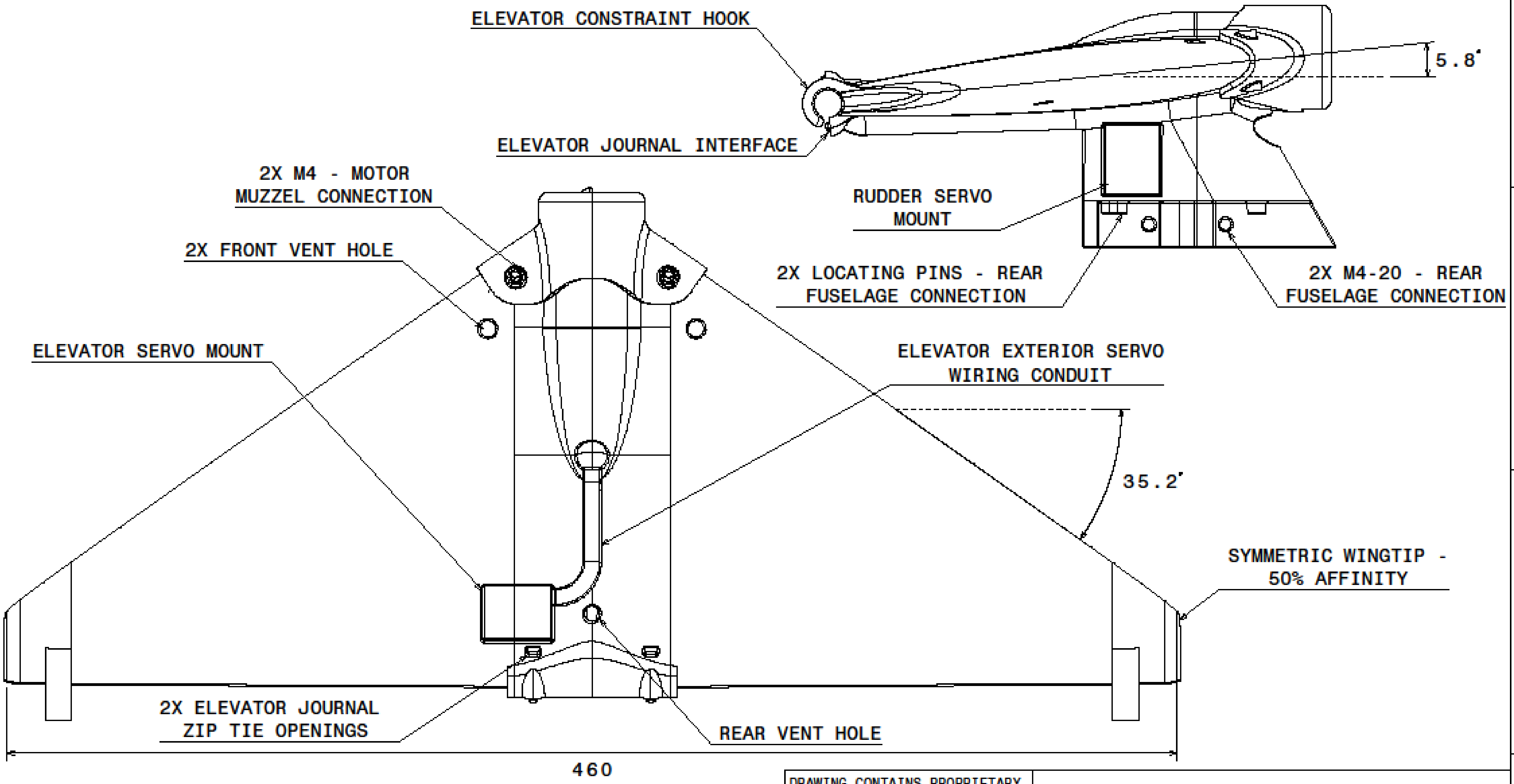
H2DRONES - PUFFIN BIRD

DRAWING TITLE
TAIL SECTION ASSEMBLY - 1

DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/28/2017
DESIGNED BY H2D DATE 2017

SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 2:3
WEIGHT(g) 392
SHEET 8

NOTES:
1. ASSEMBLY TO BE MODIFIED TO INCLUDE P.E.T. SKIN



CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

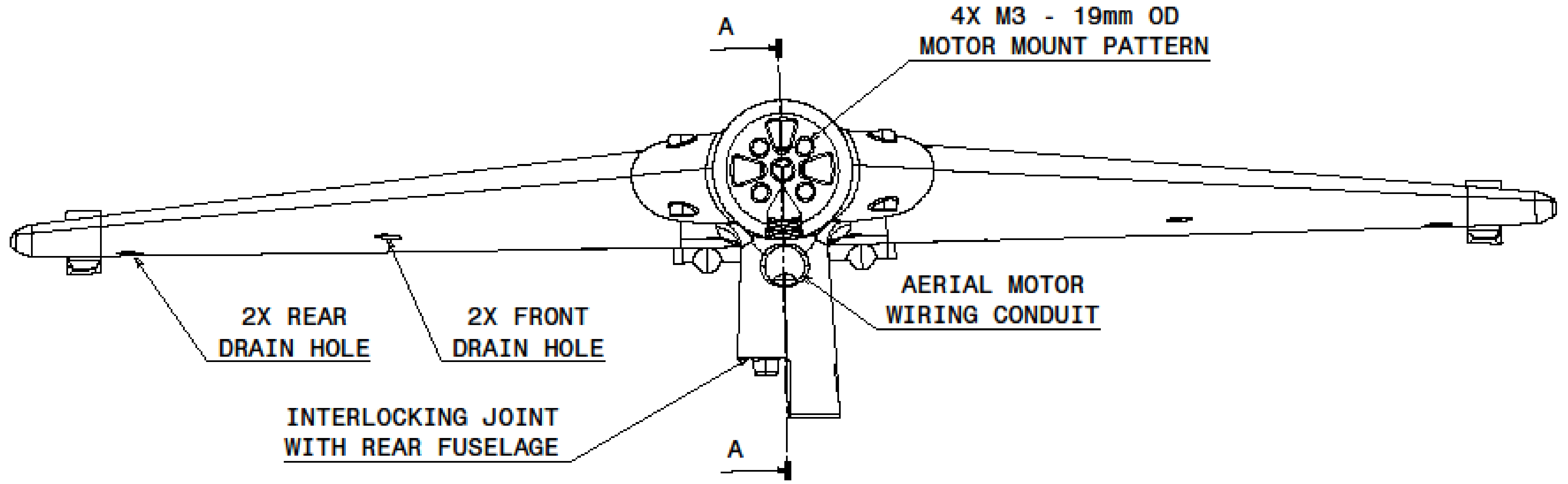
H2DRONES - PUFFIN BIRD

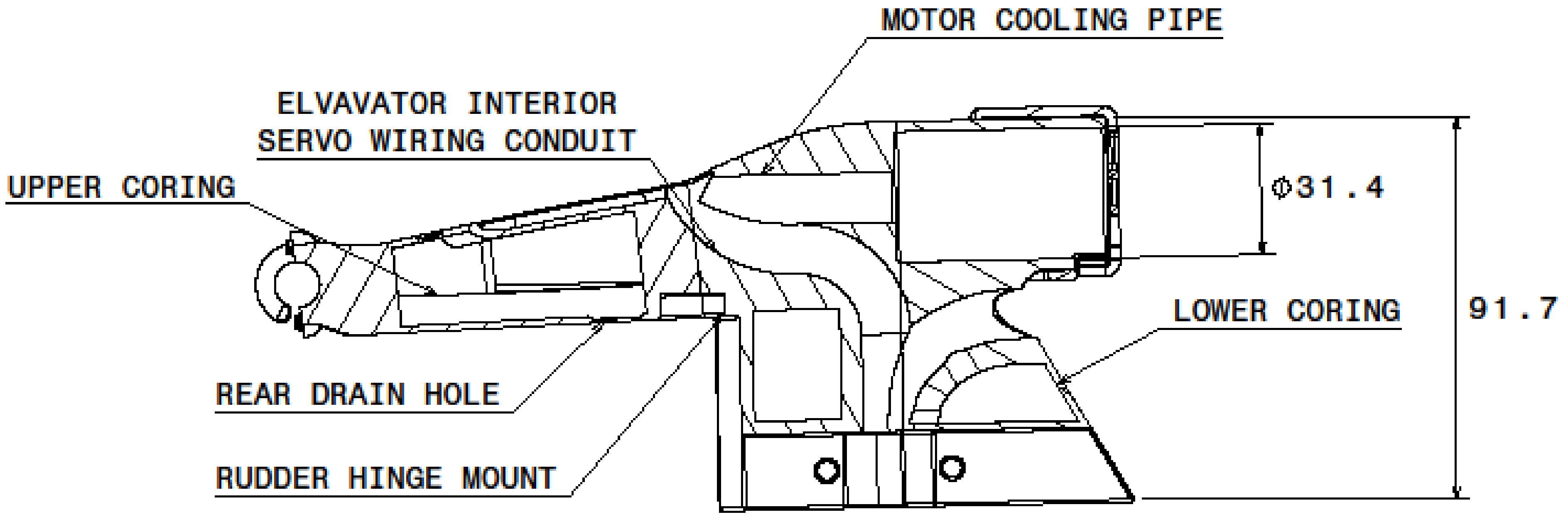
DRAWING TITLE
TAIL SECTION ASSEMBLY - 2

DRAWN BY K.S. DATE 9/27/2017
CHECKED BY S.H. DATE 9/28/2017
DESIGNED BY H2D DATE 2017

SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 2:3
WEIGHT(g) 392
SHEET 9

NOTES:
1. N/A





Section view A-A

DRAWING CONTAINS PROPRIETARY
DATA SOLEY OWNED BY H2D.
REDISTRIBUTION IN ANY FORM
IS NOT ALLOWED WITHOUT
WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

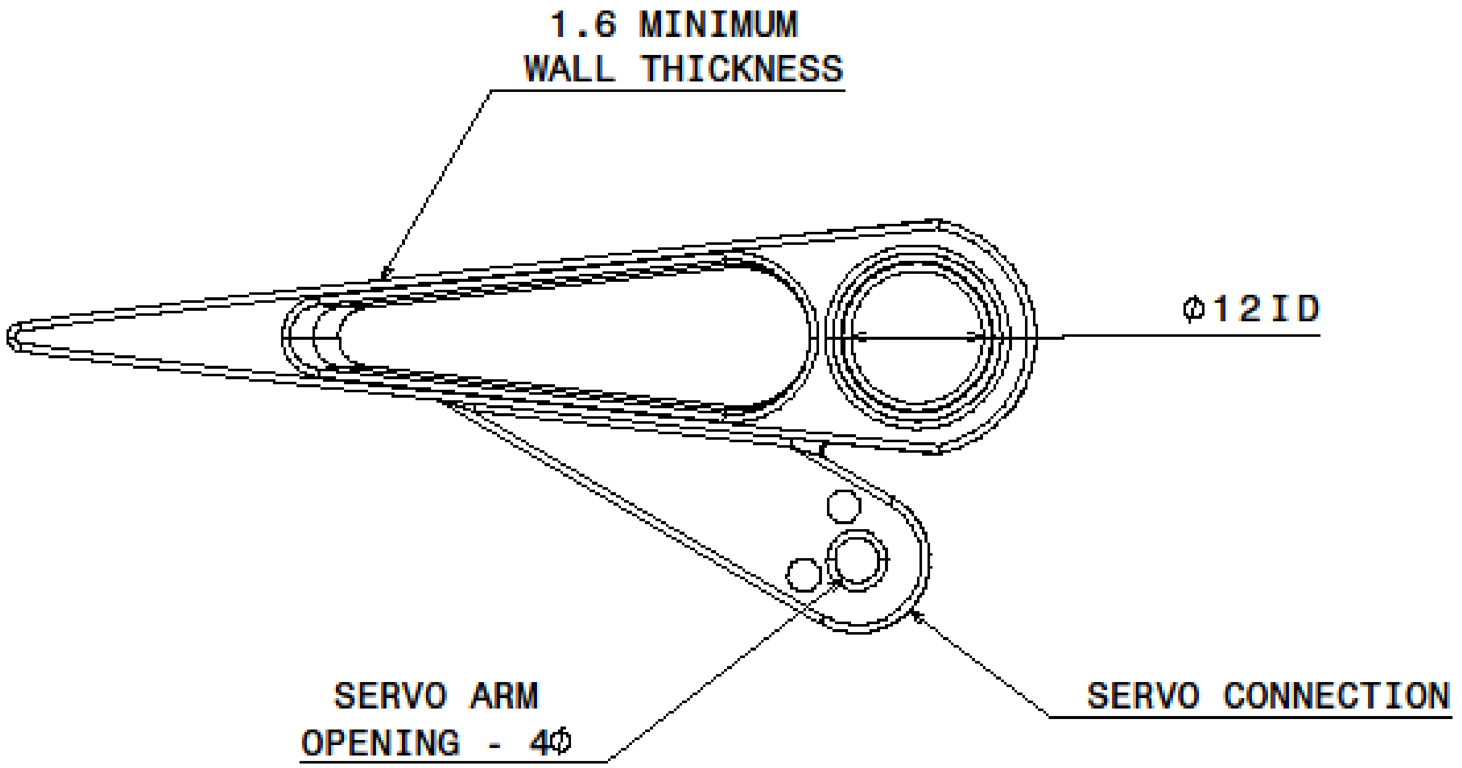
DRAWING TITLE
TAIL SECTION ASSEMBLY - 3

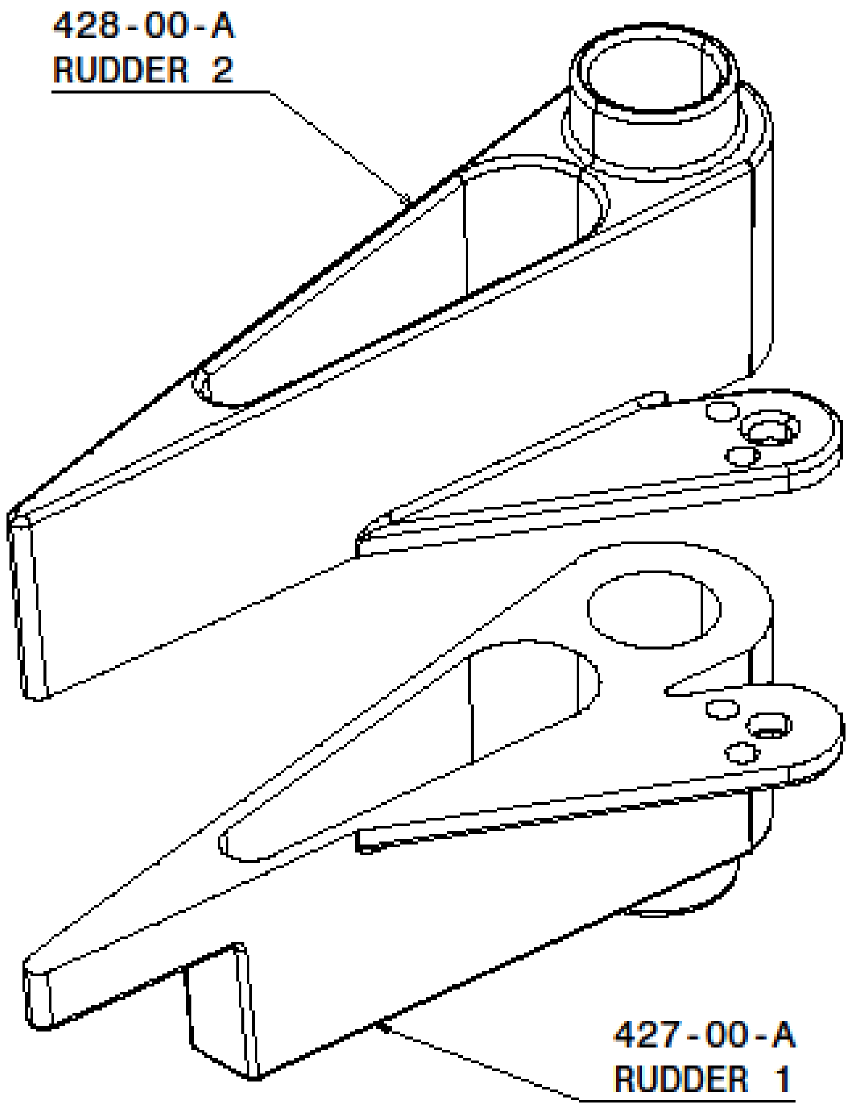
DRAWN BY K.S. DATE 9/27/2017
CHECKED BY S.H. DATE 9/28/2017
DESIGNED BY H2D DATE 2017

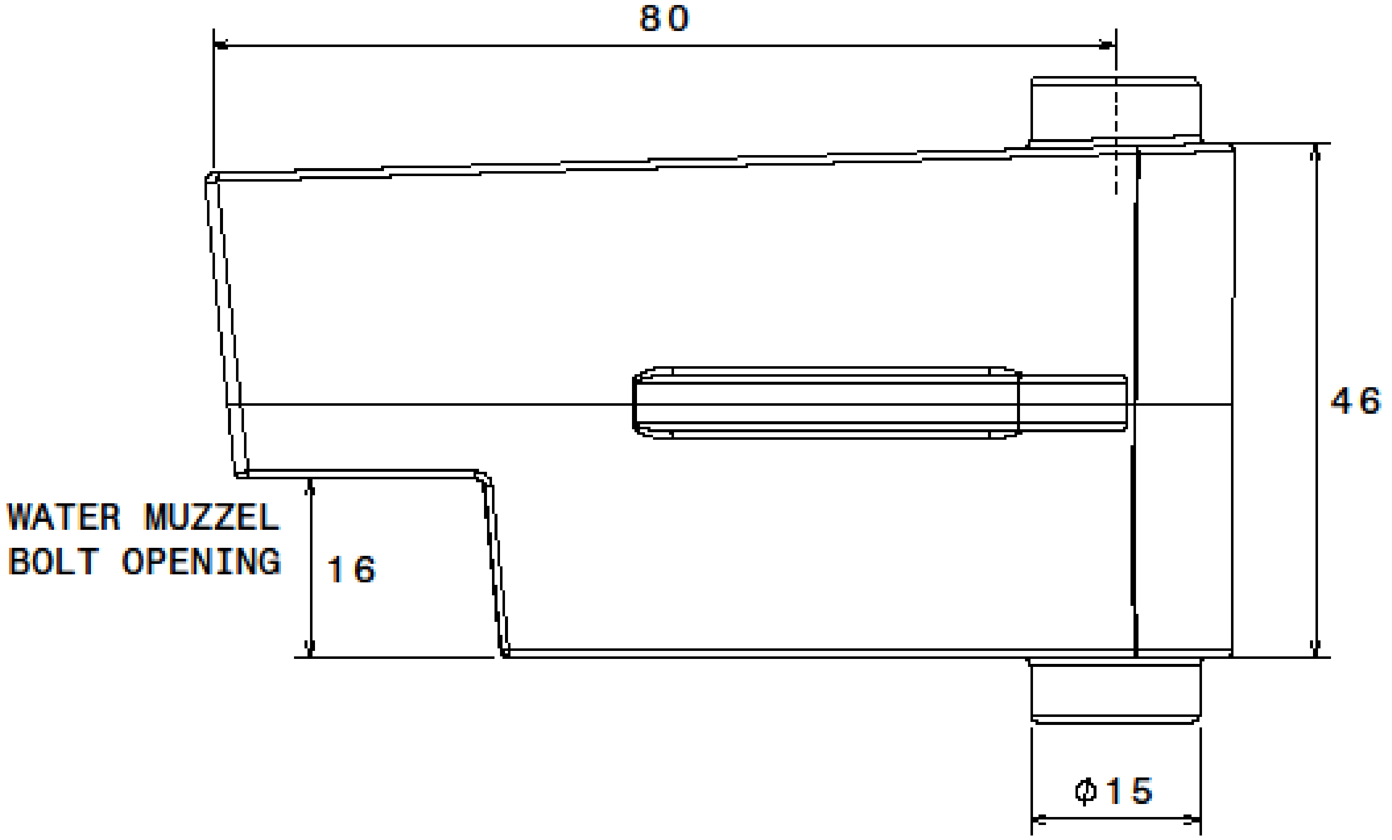
SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 2:3
WEIGHT(g) 392
SHEET 10

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

NOTES:
1. JOIN RUDDER 1-2 WITH EPOXY BOND







BILL OF MATERIALS

P/N	DESCRIPTION	MATERIAL
427-00-A	RUDDER 1	PLA
428-00-A	RUDDER 2	PLA

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

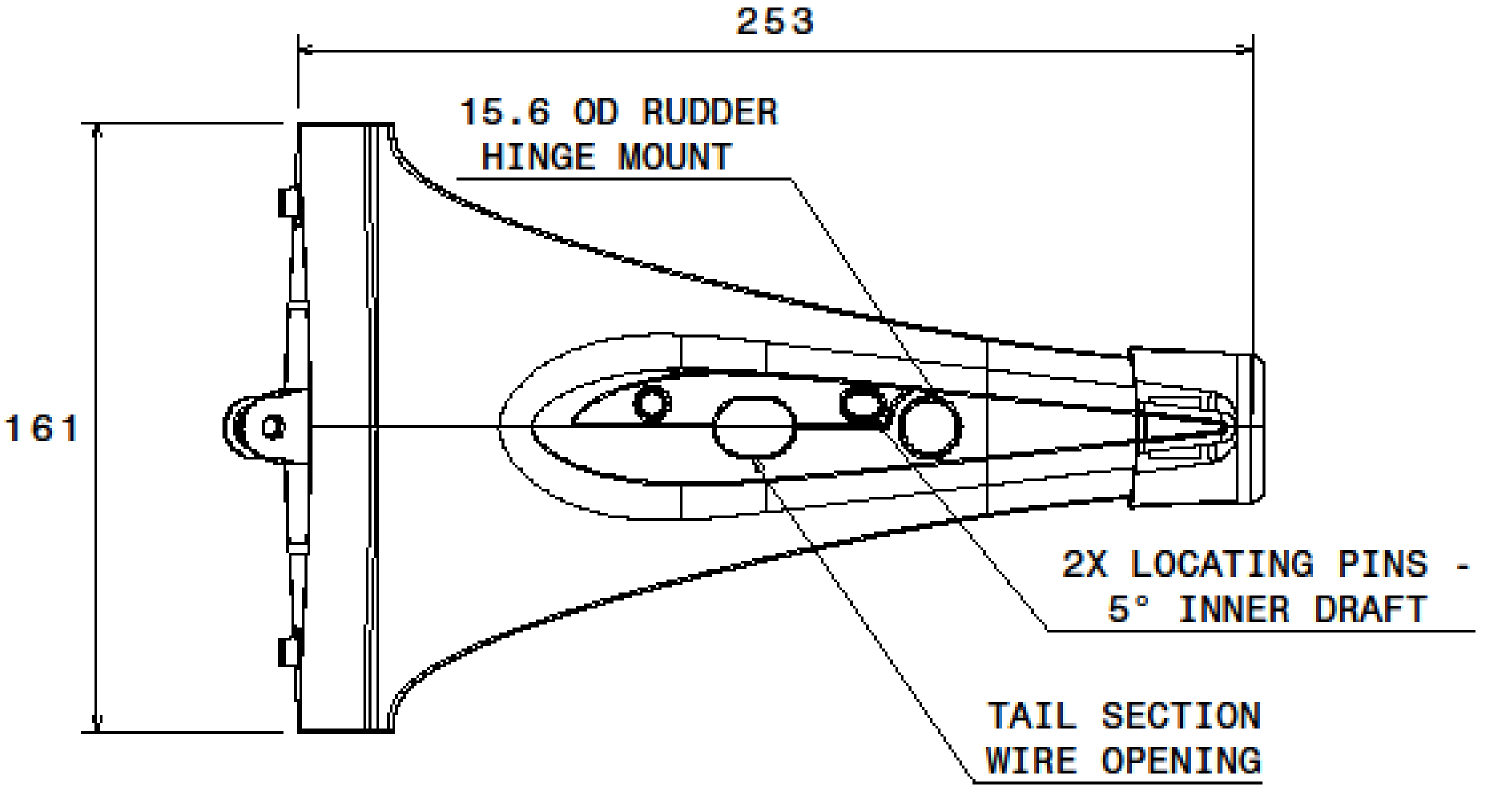
DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

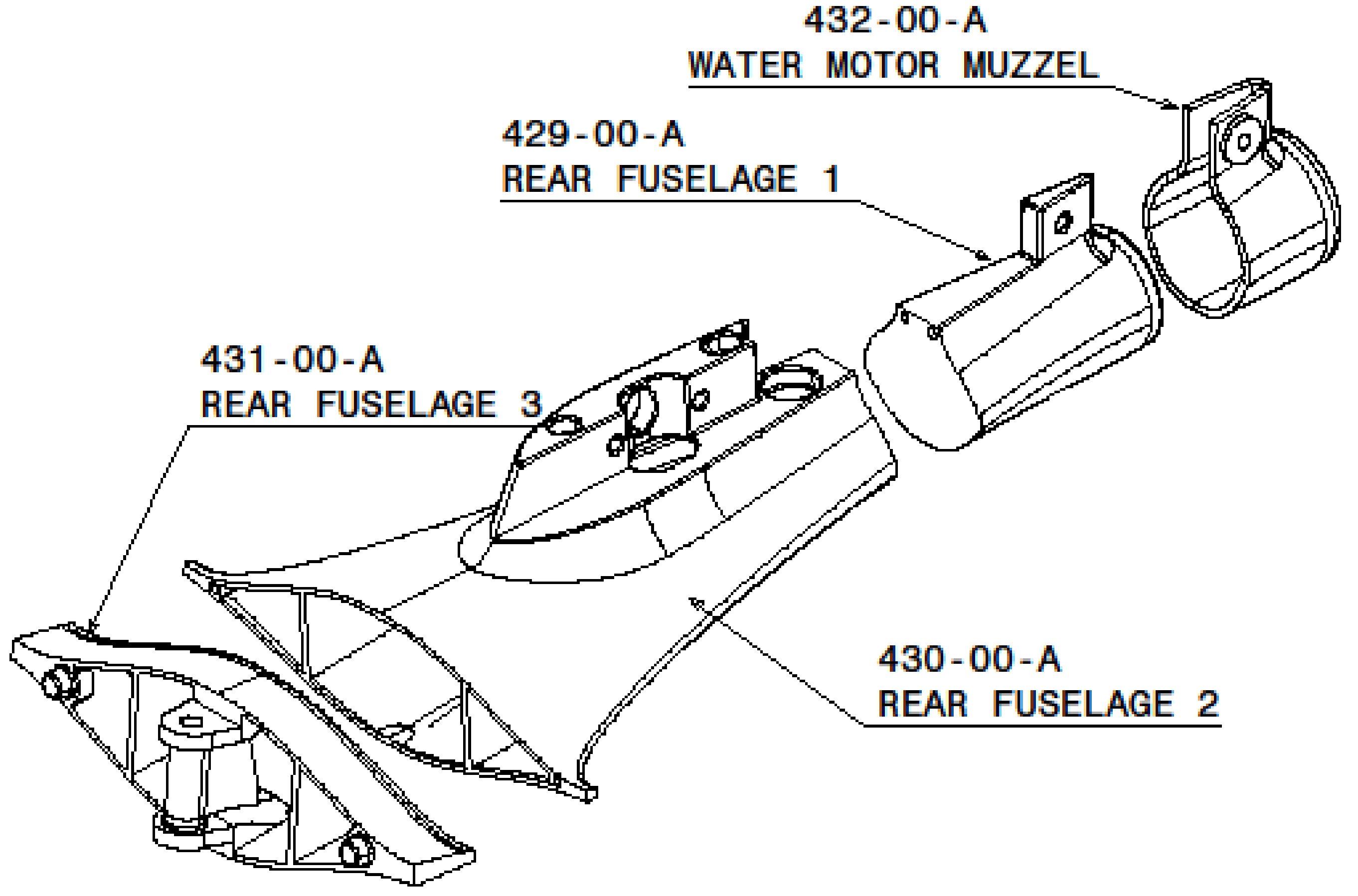
H2DRONES - PUFFIN BIRD

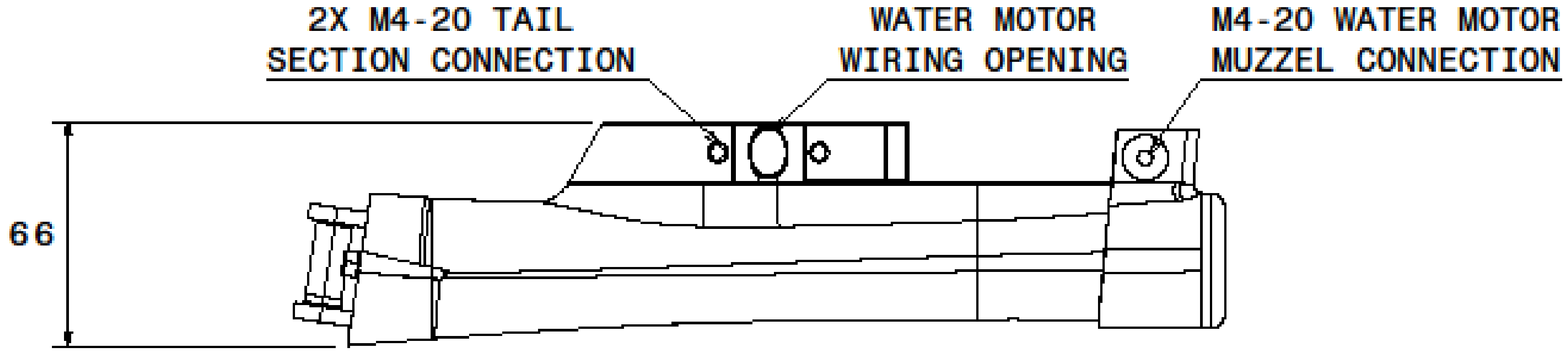
DRAWING TITLE
RUDDER ASSEMBLY

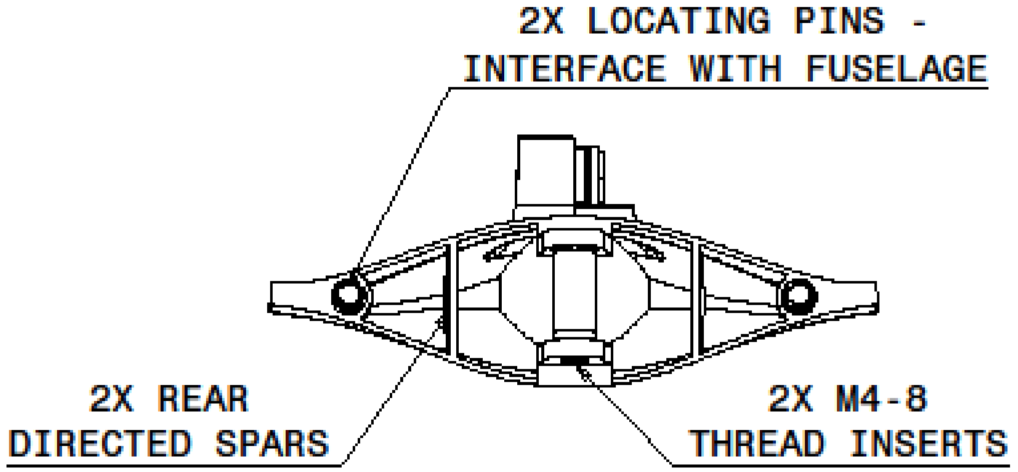
DRAWN BY K.S.	DATE 3/27/2017	SIZE A3	DRAWING NUMBER 101-00-A
CHECKED BY S.H.	DATE 3/29/2017	REV A	
DESIGNED BY H2D	DATE 2017	SCALE 3:2	WEIGHT(g) 30
		SHEET 11	

NOTES:
1. JOIN REAR FUSELAGE 1-2-3 WITH EPOXY BOND









BILL OF MATERIALS		
P/N	DESCRIPTION	MATERIAL
429-00-A	REAR FUSELAGE 1	PLA
430-00-A	REAR FUSELAGE 2	PLA
431-00-A	REAR FUSELAGE 3	PLA
432-00-A	WATER MOTOR MUZZEL	PLA

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

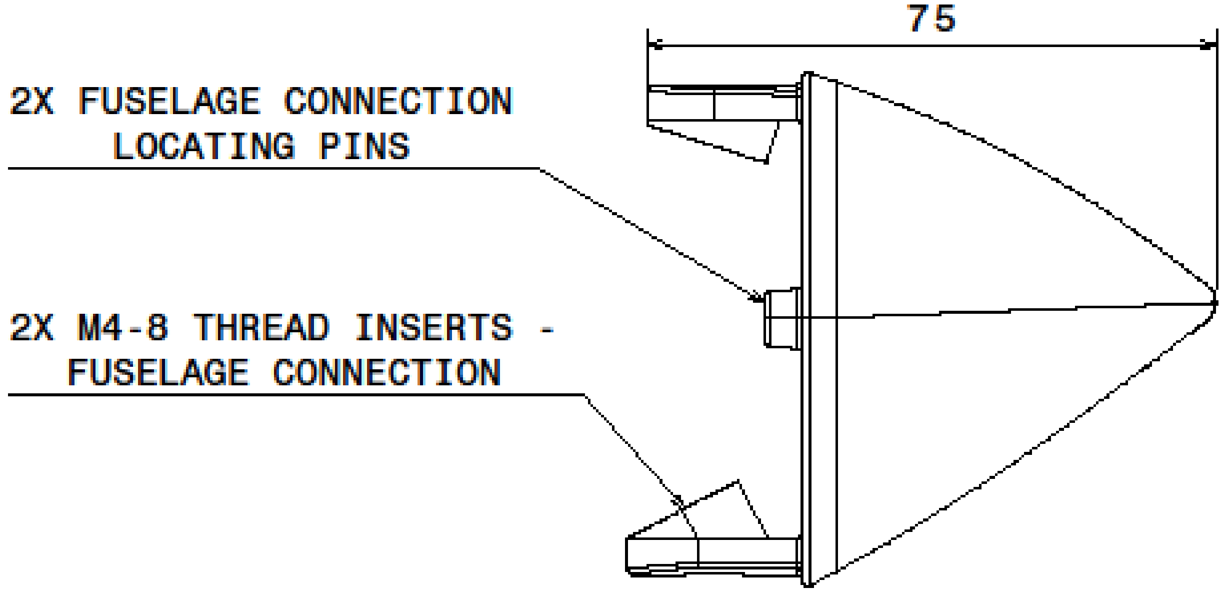
DRAWING TITLE
REAR FUSELAGE ASSEMBLY

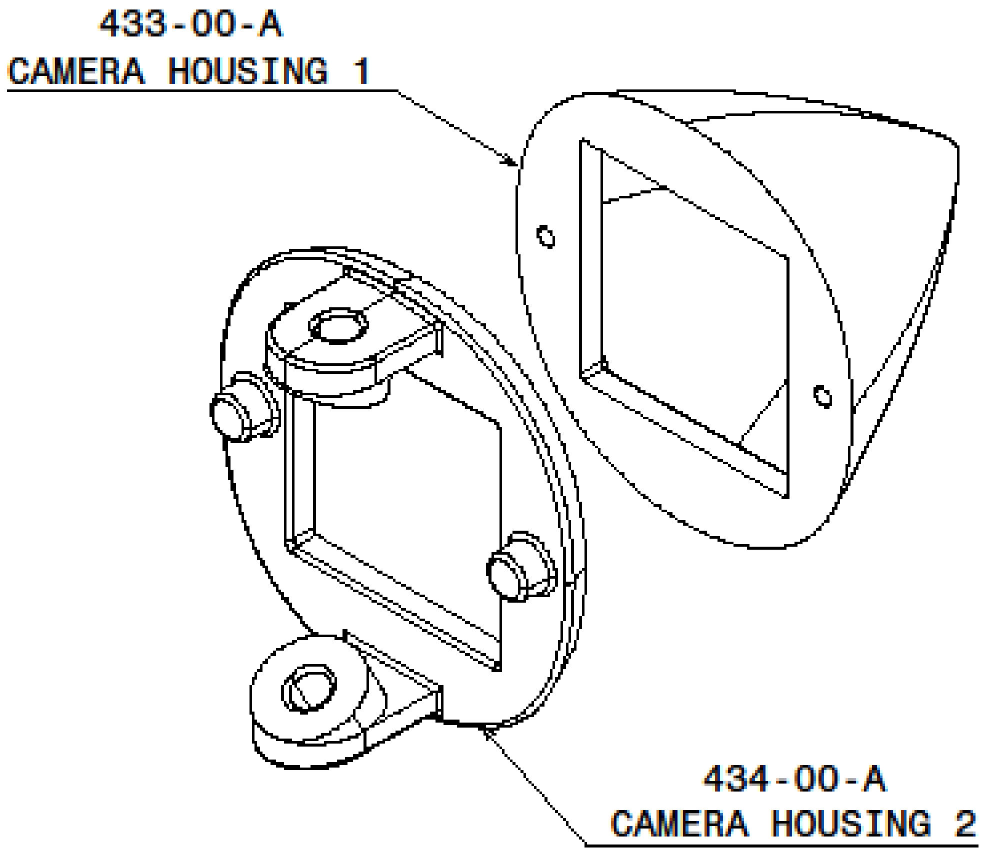
DRAWN BY	K.S.	DATE	3/27/2017
CHECKED BY	S.H.	DATE	3/28/2017
DESIGNED BY	H2D	DATE	2017

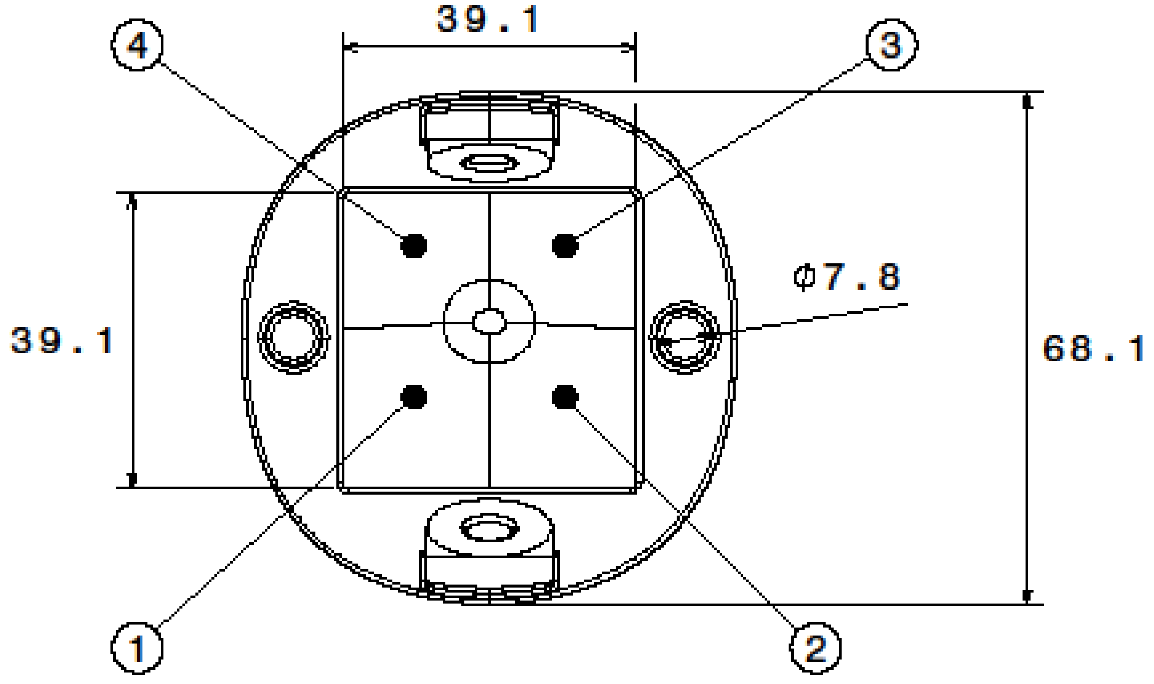
SIZE	DRAWING NUMBER	REV
A3	101-00-A	A

SCALE 1:2 WEIGHT(g) 154 SHEET 12

NOTES:
1. JOIN CAMERA HOUSING 1-2 WITH EPOXY BOND
2. ABSORBANCE PLUS REFLECTION MUST NOT EXCEED 15% AS MEASSURED IN LOCATIONS 1 THROUGH 4







BILL OF MATERIALS		
P/N	DESCRIPTION	MATERIAL
433-00-A	CAMERA HOUSING 1	CLEAR P.E.T.
434-00-A	CAMERA HOUSING 2	CLEAR P.E.T.

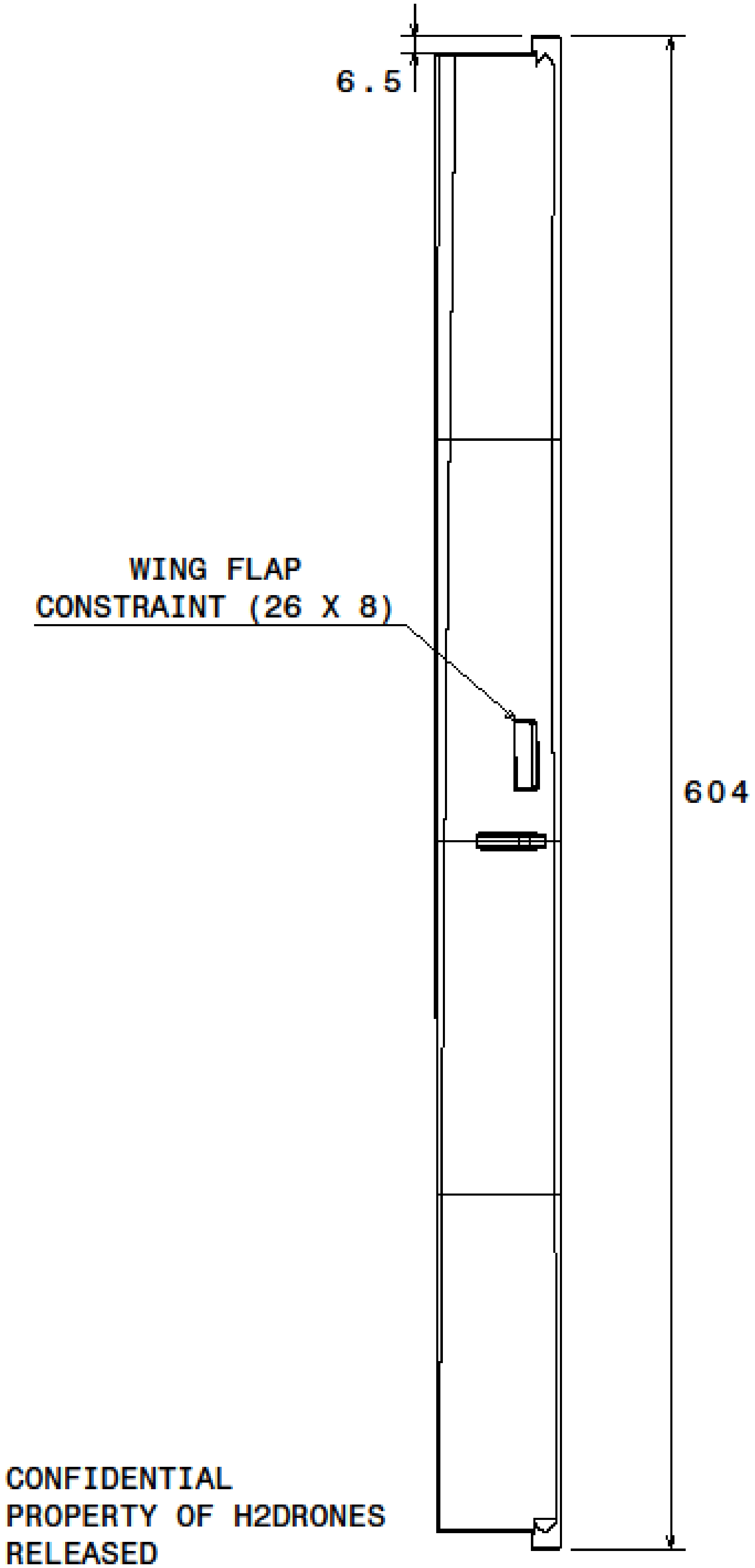
DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

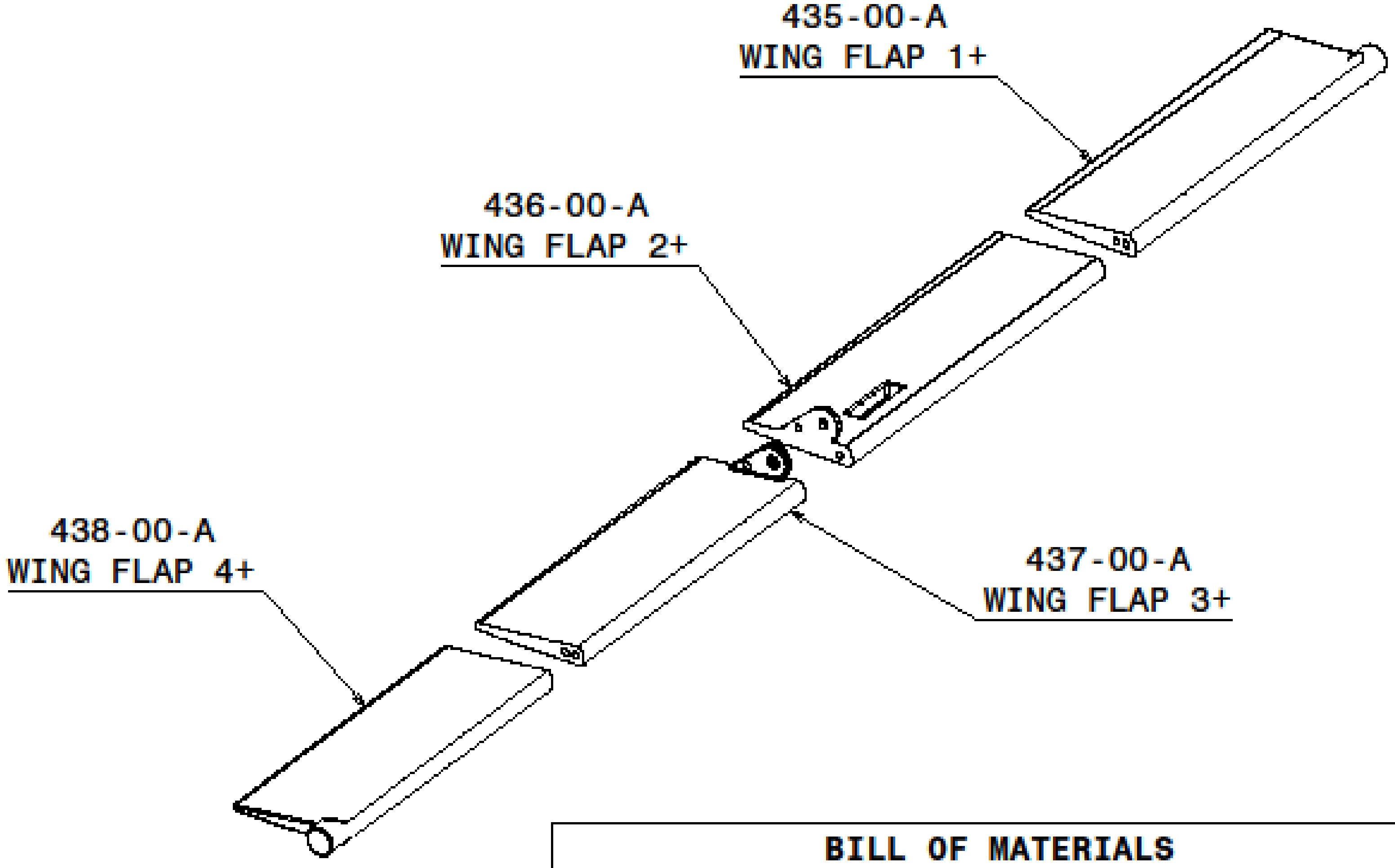
H2DRONES - PUFFIN BIRD

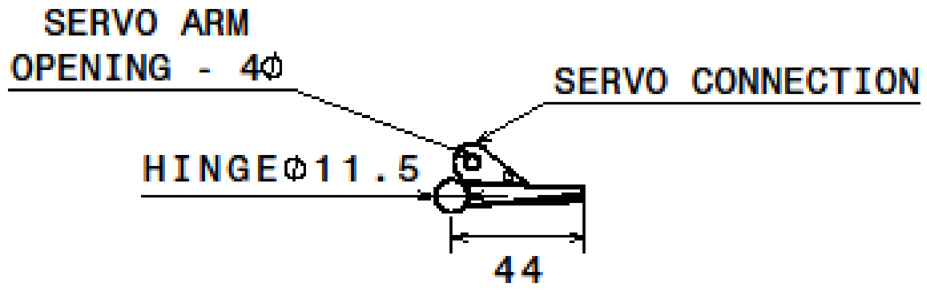
DRAWN BY K.S.	DATE 3/27/2017	DRAWING TITLE CAMERA HOUSING ASSEMBLY	
CHECKED BY S.H.	DATE 3/28/2017	SIZE A3	DRAWING NUMBER 101-00-A — REV A
DESIGNED BY H2D	DATE 2017	SCALE 1:1	WEIGHT(g) 31 — SHEET 13

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

NOTES:
1. JOIN WING FLAP 1-2-3-4 WITH EPOXY BOND
2. WING FLAP Y+ SHOWN, SYMMETRIC WITH WING FLAP Y-







BILL OF MATERIALS

P/N	DESCRIPTION	MATERIAL
	Y+	
435-00-A	WING FLAP 1+	ABS
436-00-A	WING FLAP 2+	ABS
437-00-A	WING FLAP 3+	ABS
438-00-A	WING FLAP 4+	ABS
	Y-	
439-00-A	WING FLAP 1-	ABS
440-00-B	WING FLAP 2-	ABS
441-00-A	WING FLAP 3-	ABS
442-00-A	WING FLAP 4-	ABS

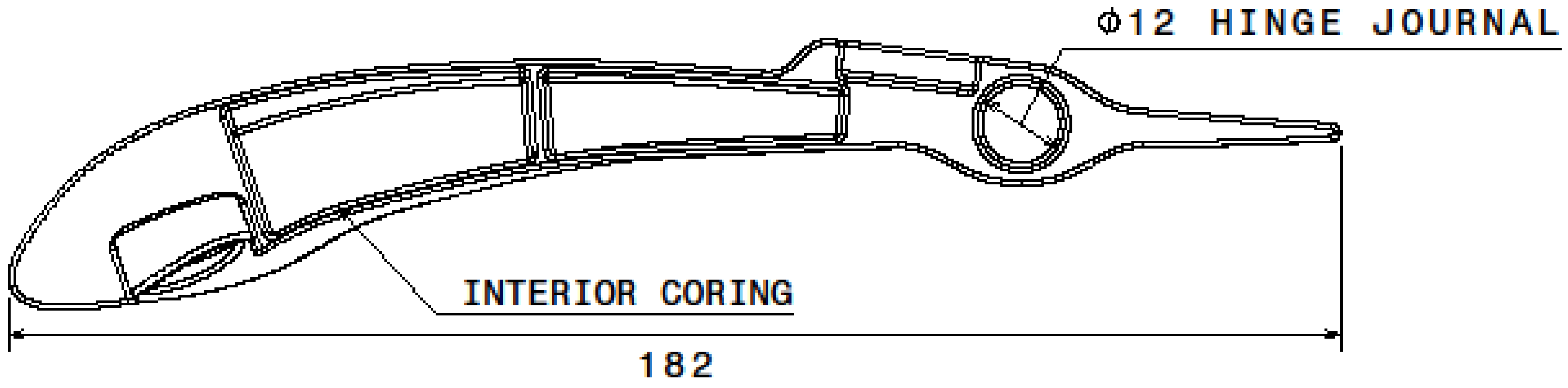
CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

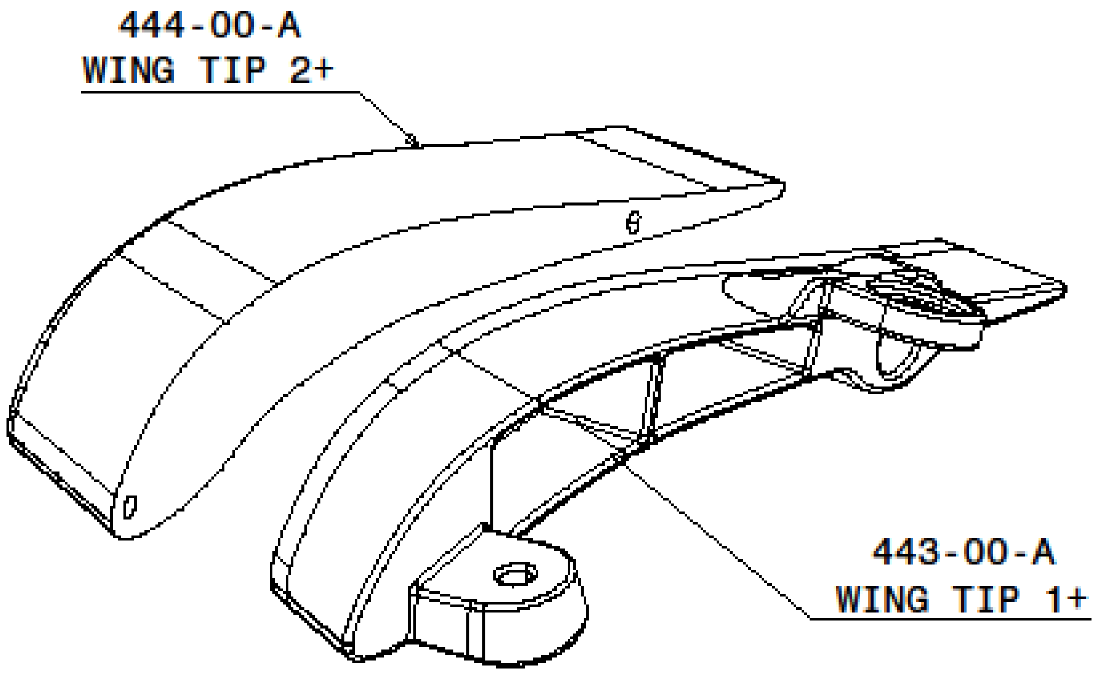
H2DRONES - PUFFIN BIRD

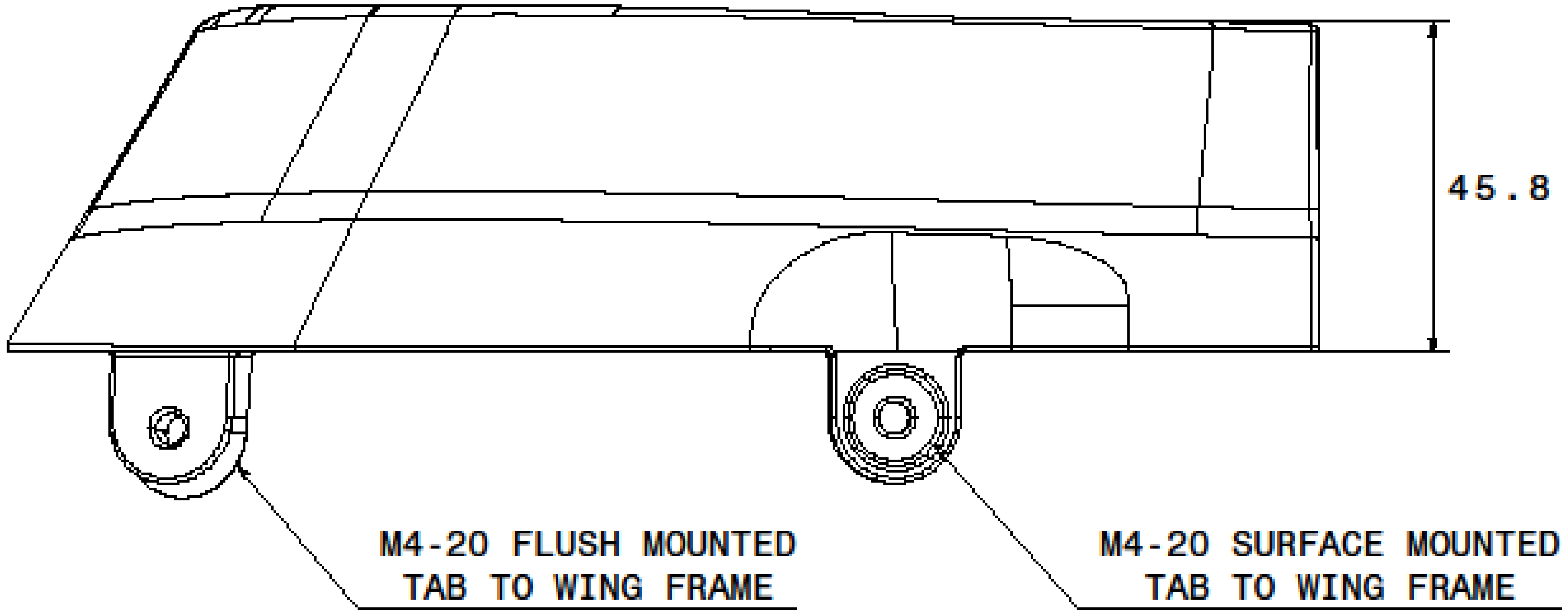
DRAWING TITLE
WING FLAP ASSEMBLY

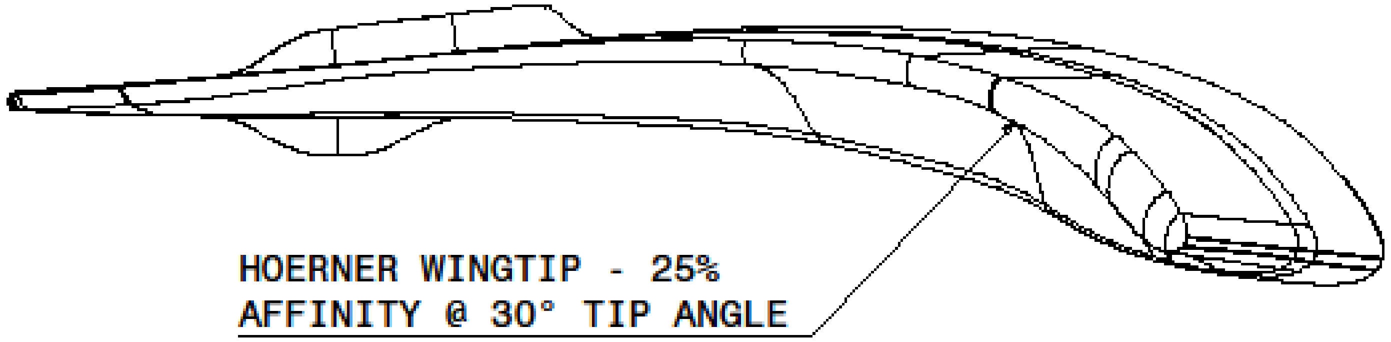
DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/28/2017
DESIGNED BY H2D DATE 2017
SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 2:5
WEIGHT(g) 179
SHEET 14

NOTES:
1. JOIN WING TIP 1-2 WITH EPOXY BOND
2. WING TIP Y+ SHOWN, SYMMETRIC WITH WING TIP Y-









BILL OF MATERIALS		
P/N	DESCRIPTION	MATERIAL
	Y+	
443-00-A	WING TIP 1+	PLA
444-00-A	WING TIP 2+	PLA
	Y-	
445-00-A	WING TIP 1-	PLA
446-00-A	WING TIP 2-	PLA

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

DRAWING CONTAINS PROPRIETARY
DATA SOLEY OWNED BY H2D.
REDISTRIBUTION IN ANY FORM
IS NOT ALLOWED WITHOUT
WRITTEN CONSENT FROM H2D.

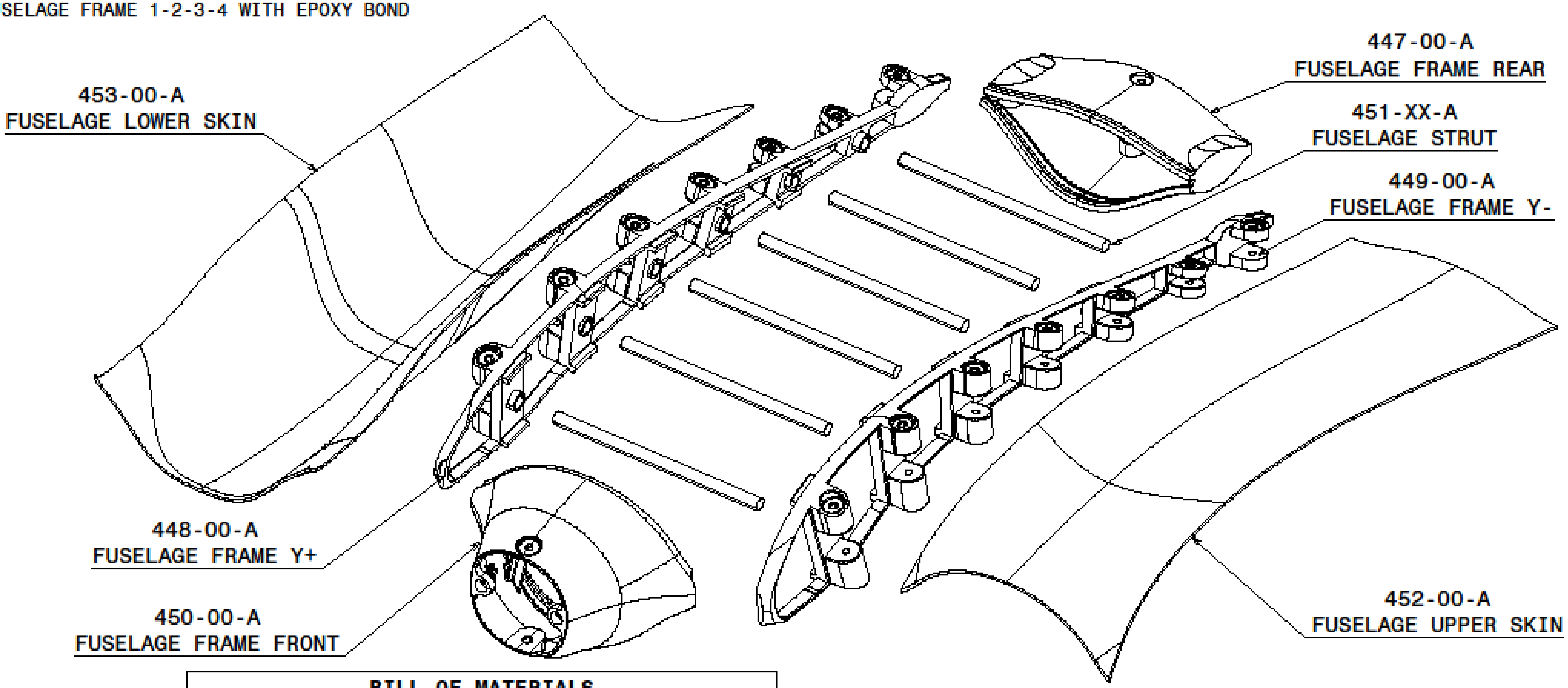
H2DRONES - PUFFIN BIRD

DRAWING TITLE
WING TIP ASSEMBLY

DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/28/2017
DESIGNED BY H2D DATE 2017

SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 1:1
WEIGHT(g) 64
SHEET 15

NOTES:
1. JOIN FUSELAGE STRUTS TO FUSELAGE FRAME Y+/Y- WITH QUICK SET LOCKTITE
2. JOIN FUSELAGE FRAME 1-2-3-4 WITH EPOXY BOND



BILL OF MATERIALS

P/N	DESCRIPTION	MATERIAL
447-00-A	FUSELAGE FRAME REAR	PLA
448-00-A	FUSELAGE FRAME Y+	PLA
449-00-A	FUSELAGE FRAME Y-	PLA
450-00-A	FUSELAGE FRAME FRONT	PLA
451-01-A	FUSELAGE STRUT A	BALSA
451-02-A	FUSELAGE STRUT B	BALSA
451-03-A	FUSELAGE STRUT C	BALSA
451-04-A	FUSELAGE STRUT D	BALSA
451-05-A	FUSELAGE STRUT E	BALSA
451-06-A	FUSELAGE STRUT F	BALSA
452-00-A	FUSELAGE UPPER SKIN	P.E.T.
453-00-A	FUSELAGE LOWER SKIN	P.E.T.

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

DRAWING CONTAINS PROPRIETARY
DATA SOLEY OWNED BY H2D.
REDISTRIBUTION IN ANY FORM
IS NOT ALLOWED WITHOUT
WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

DRAWING TITLE
FUSELAGE ASSEMBLY - 1

DRAWN BY
K.S.
DATE
3/27/2017

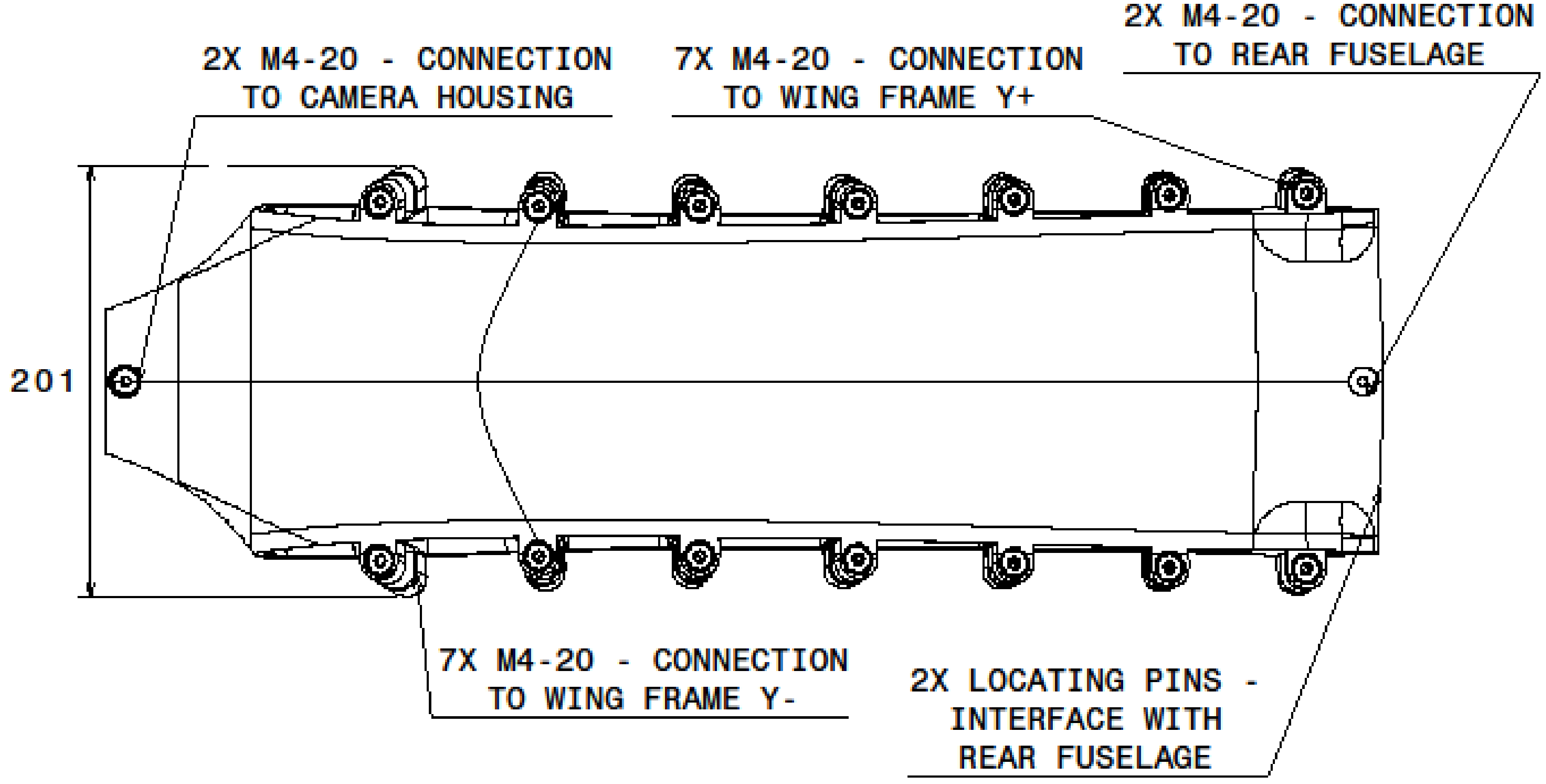
CHECKED BY
S.H.
DATE
3/28/2017

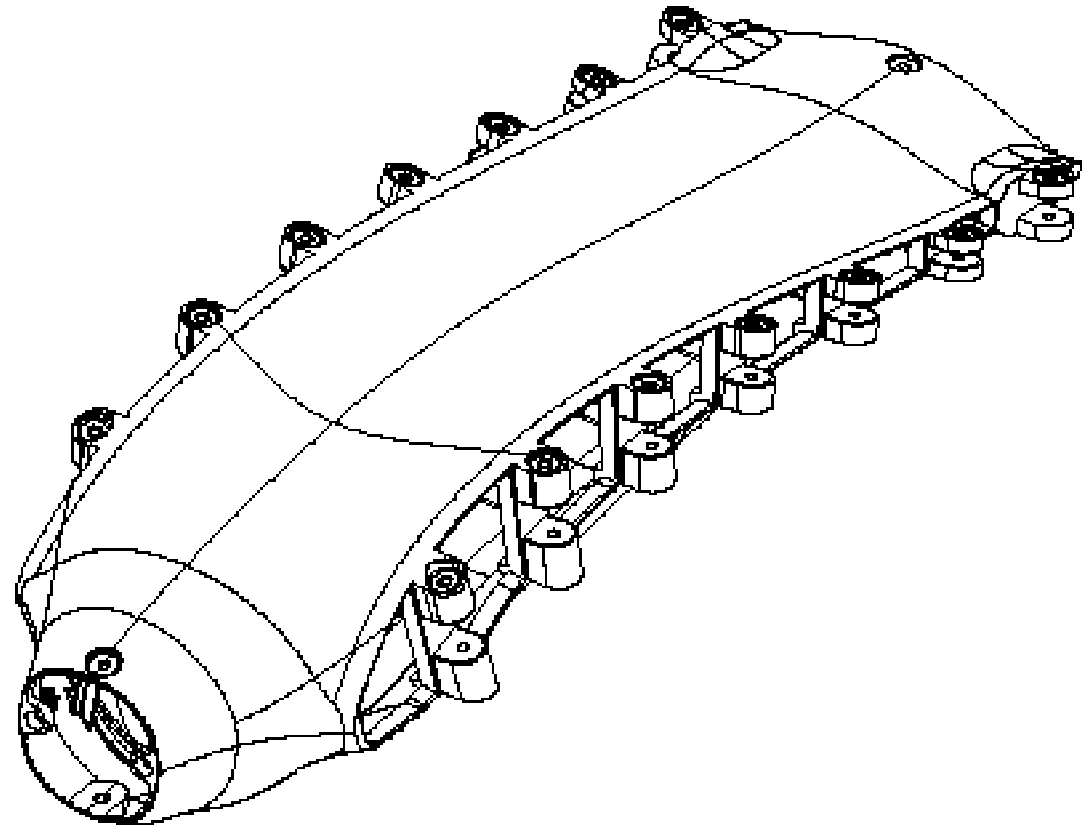
DESIGNED BY
H2D
DATE
2017

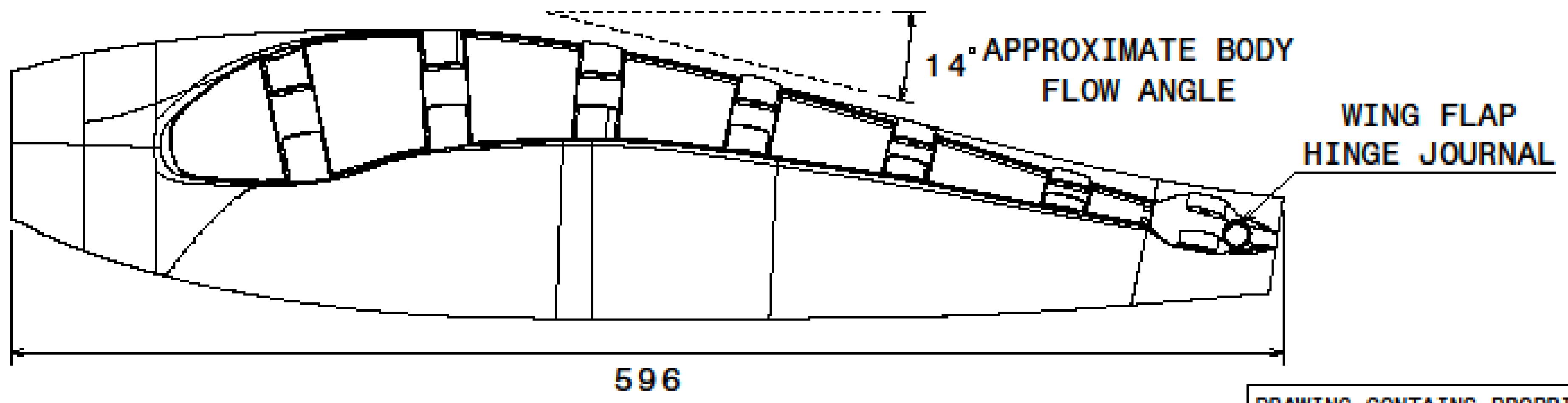
SIZE
A3
DRAWING NUMBER
101-00-A
REV
A

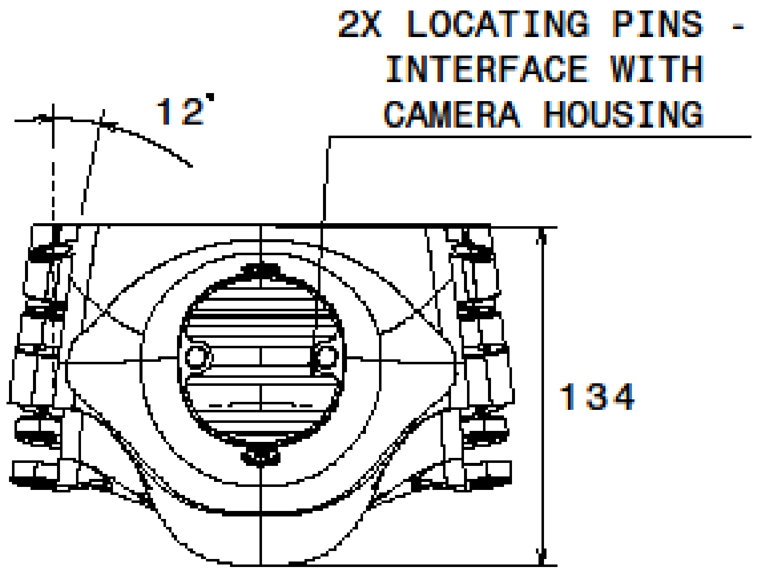
SCALE 3:5
WEIGHT(g) 616
SHEET 16

NOTES:
1. SKIN MUST NOT SIT MORE THAN 0.25 PROUD OF FRAME









CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

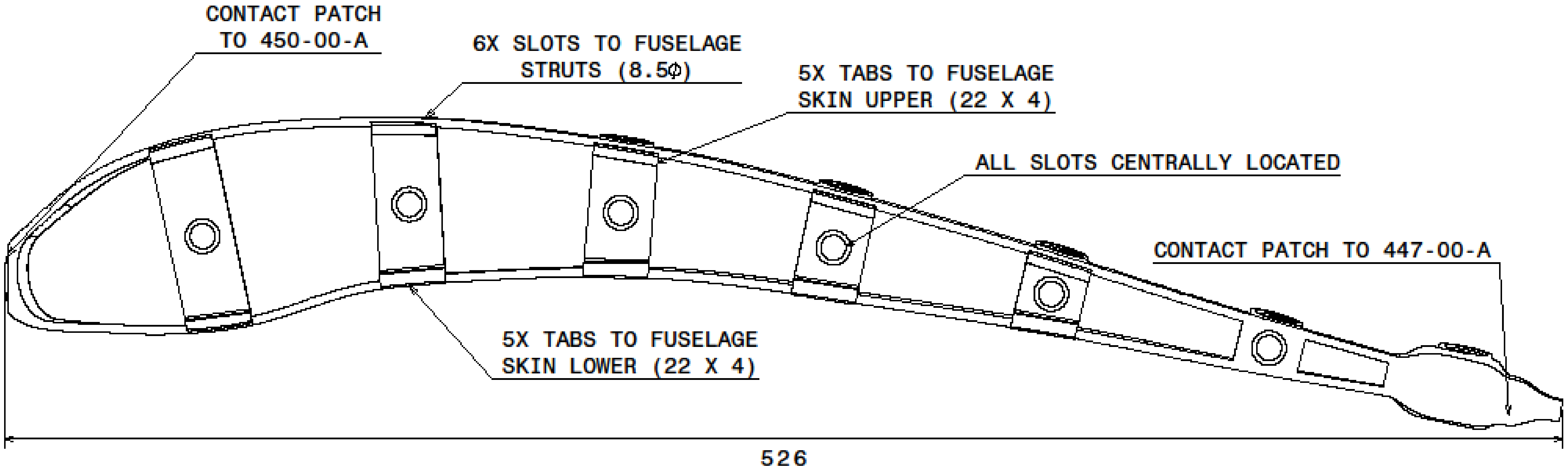
H2DRONES - PUFFIN BIRD

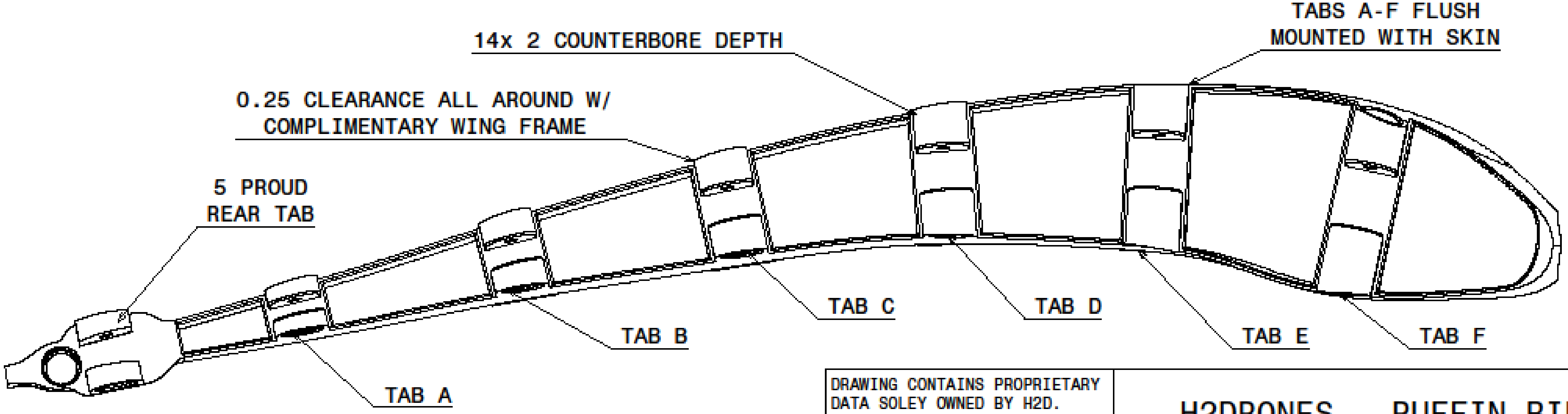
DRAWING TITLE
FUSELAGE ASSEMBLY - 2

DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/28/2017
DESIGNED BY H2D DATE 2017

SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 1:3
WEIGHT(g) 616
SHEET 17

NOTES:
1. 448-00-A FUSELAGE FRAME Y+ SHOWN, SYMMETRIC WITH 449-00-A FUSELAGE FRAME Y-





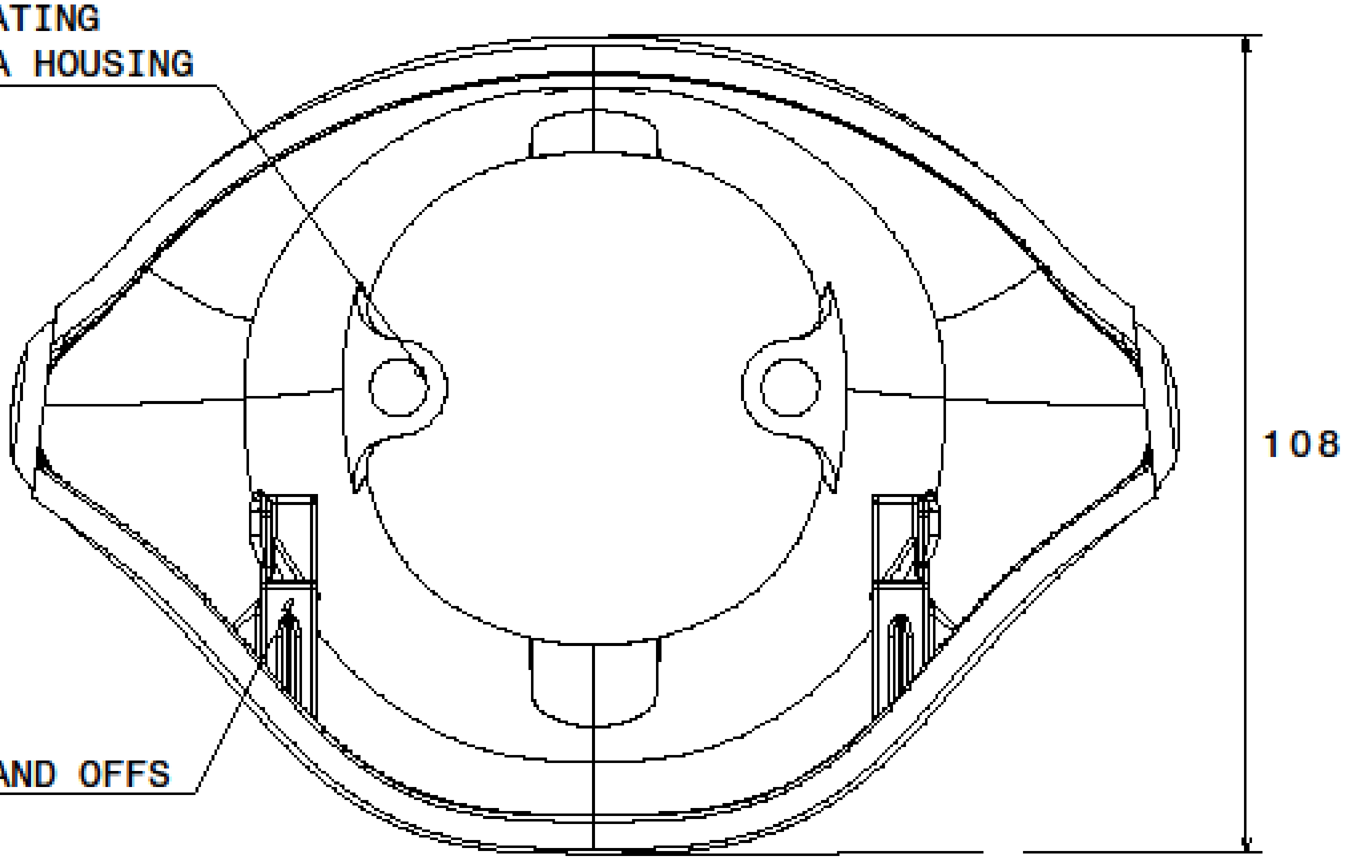
H2DRONES - PUFFIN BIRD

DRAWING TITLE
FUSELAGE ASSEMBLY - 3

DRAWN BY K.S.	DATE 3/27/2017	SIZE A3	DRAWING NUMBER 101-00-A
CHECKED BY S.H.	DATE 3/28/2017	REV A	
DESIGNED BY H2D	DATE 2017	SCALE 1:2	WEIGHT(g) 118
		SHEET 18	

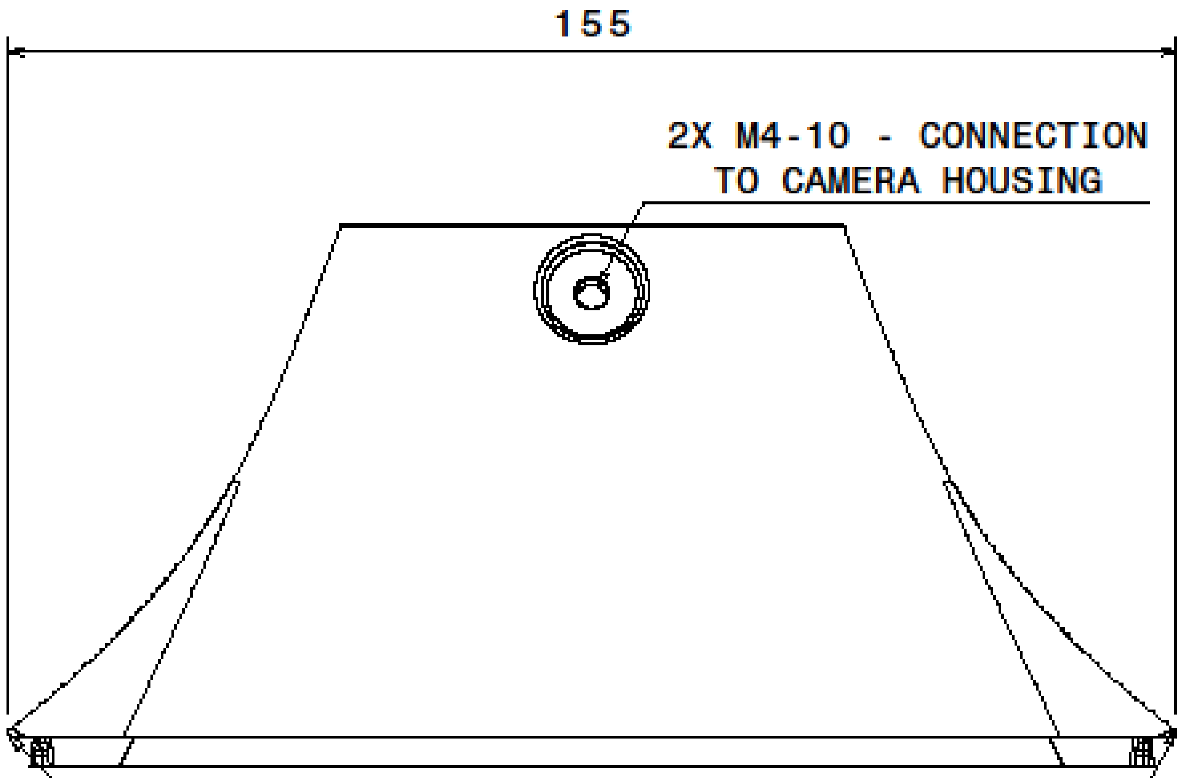
CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

NOTES:
1. 450-00-A FUSELAGE FRAME FRONT SHOWN



2X 9ϕ LOCATING PINS TO CAMERA HOUSING

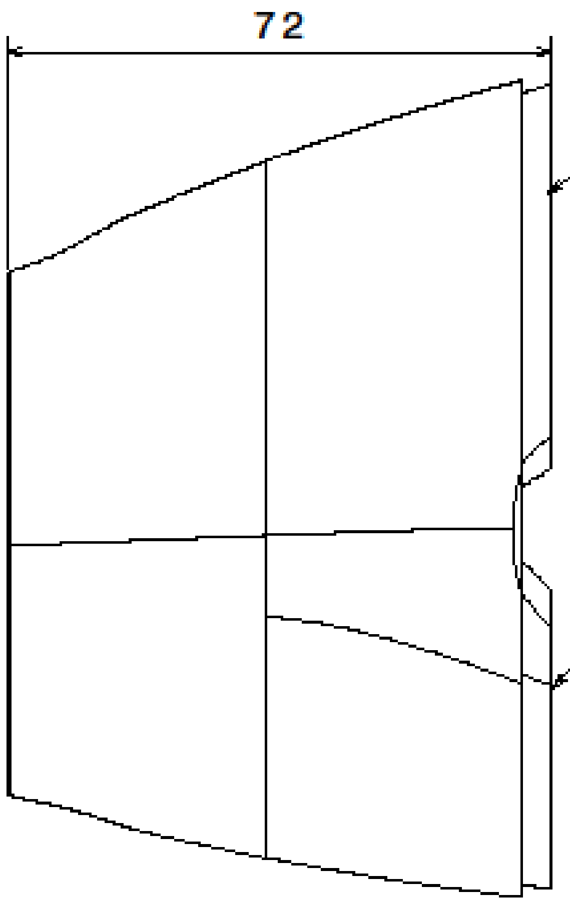
4X BATTERY STAND OFFS



2X M4-10 - CONNECTION TO CAMERA HOUSING

CONTACT PATCH WITH 449-00-A

CONTACT PATCH WITH 448-00-A



FULL SPAN TAB - CONTACT PATCH W/ UPPER SKIN

FULL SPAN TAB - CONTACT PATCH W/ LOWER SKIN

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

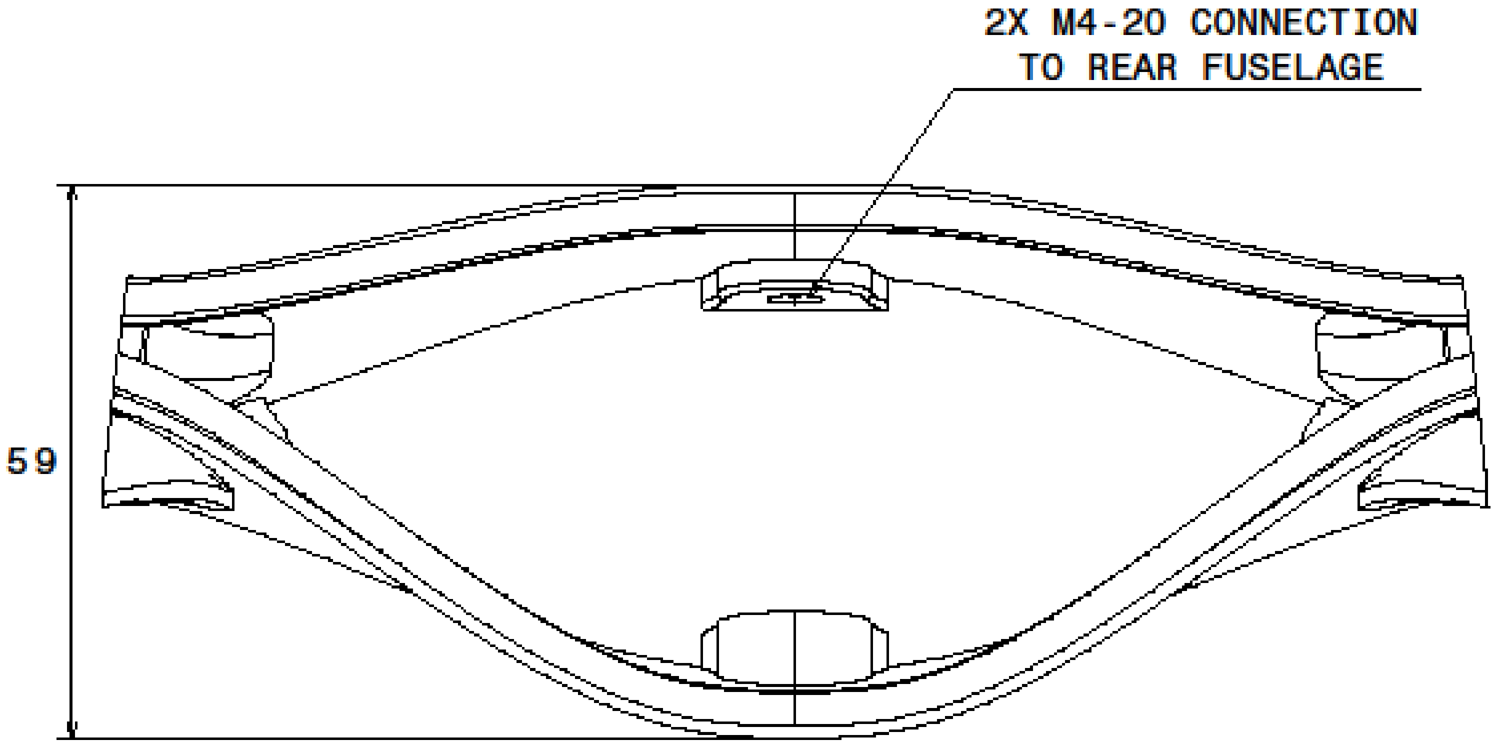
H2DRONES - PUFFIN BIRD

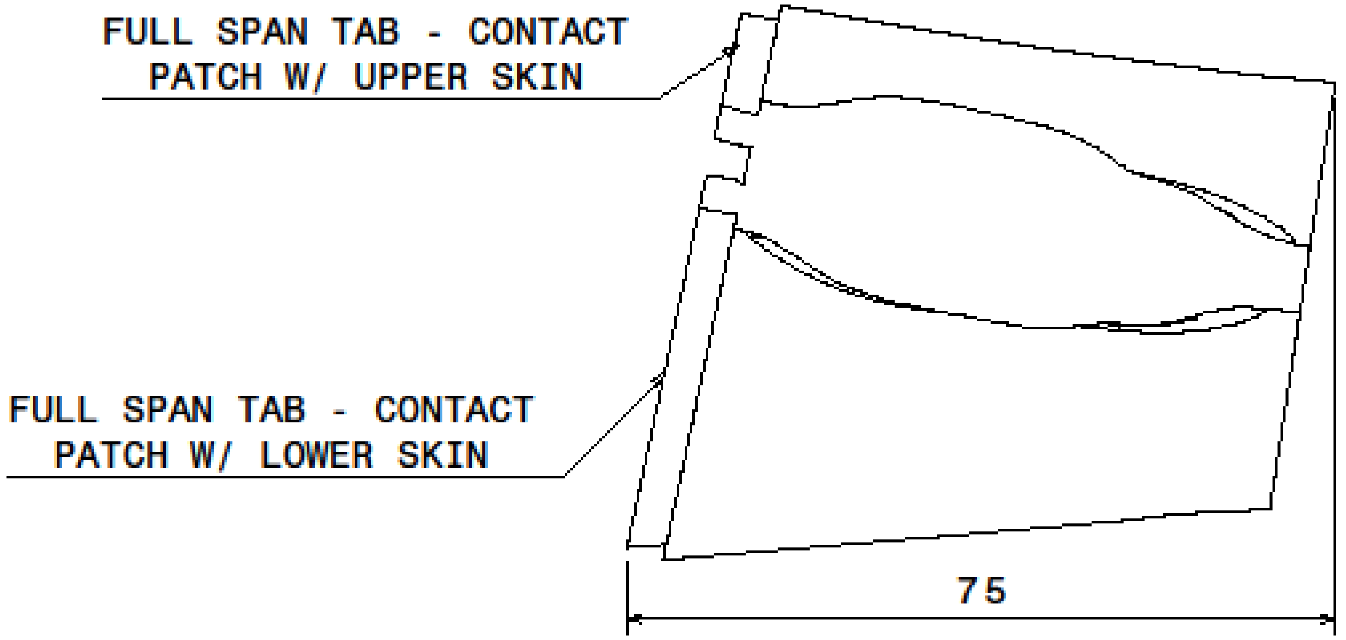
DRAWING TITLE
FUSELAGE ASSEMBLY - 4

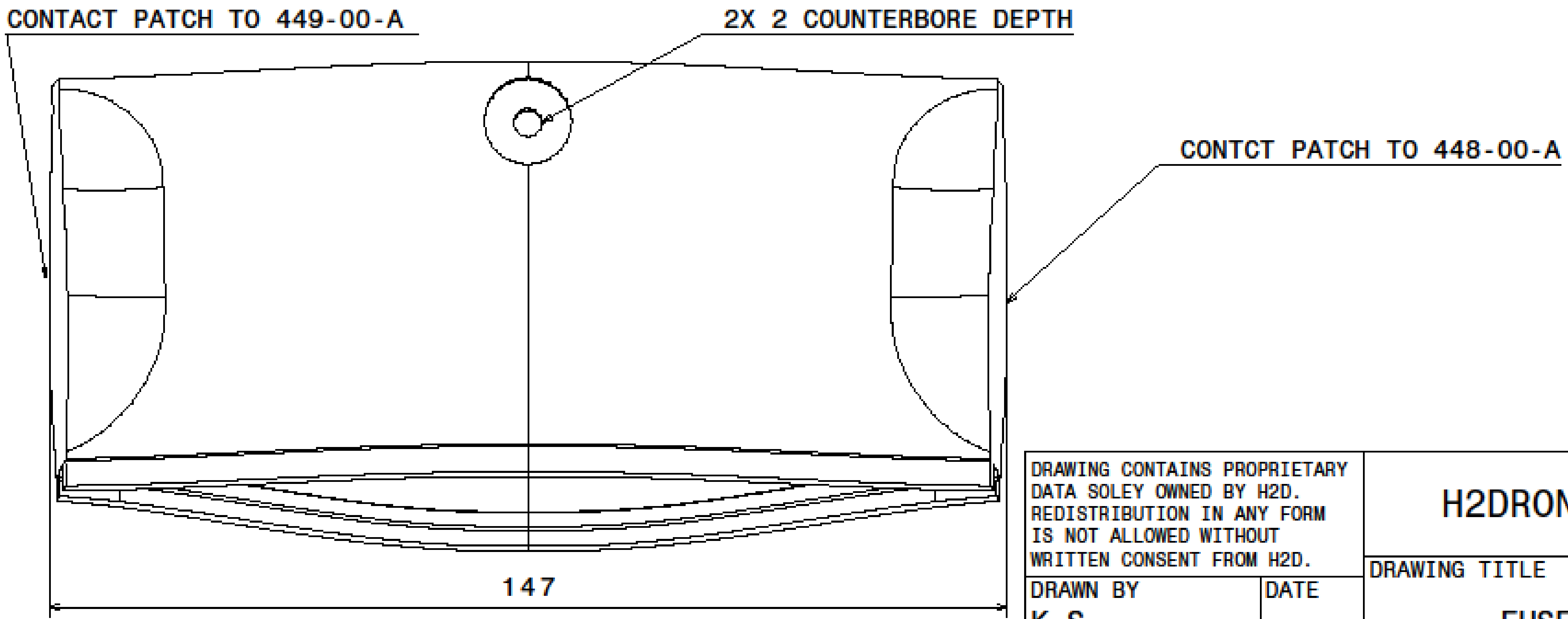
DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/28/2017
DESIGNED BY H2D DATE 2017

SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 1:1
WEIGHT(g) 49
SHEET 19

NOTES:
1. 447-00-A FUSELAGE FRAME REAR SHOWN







CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

DRAWING CONTAINS PROPRIETARY
DATA SOLEY OWNED BY H2D.
REDISTRIBUTION IN ANY FORM
IS NOT ALLOWED WITHOUT
WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

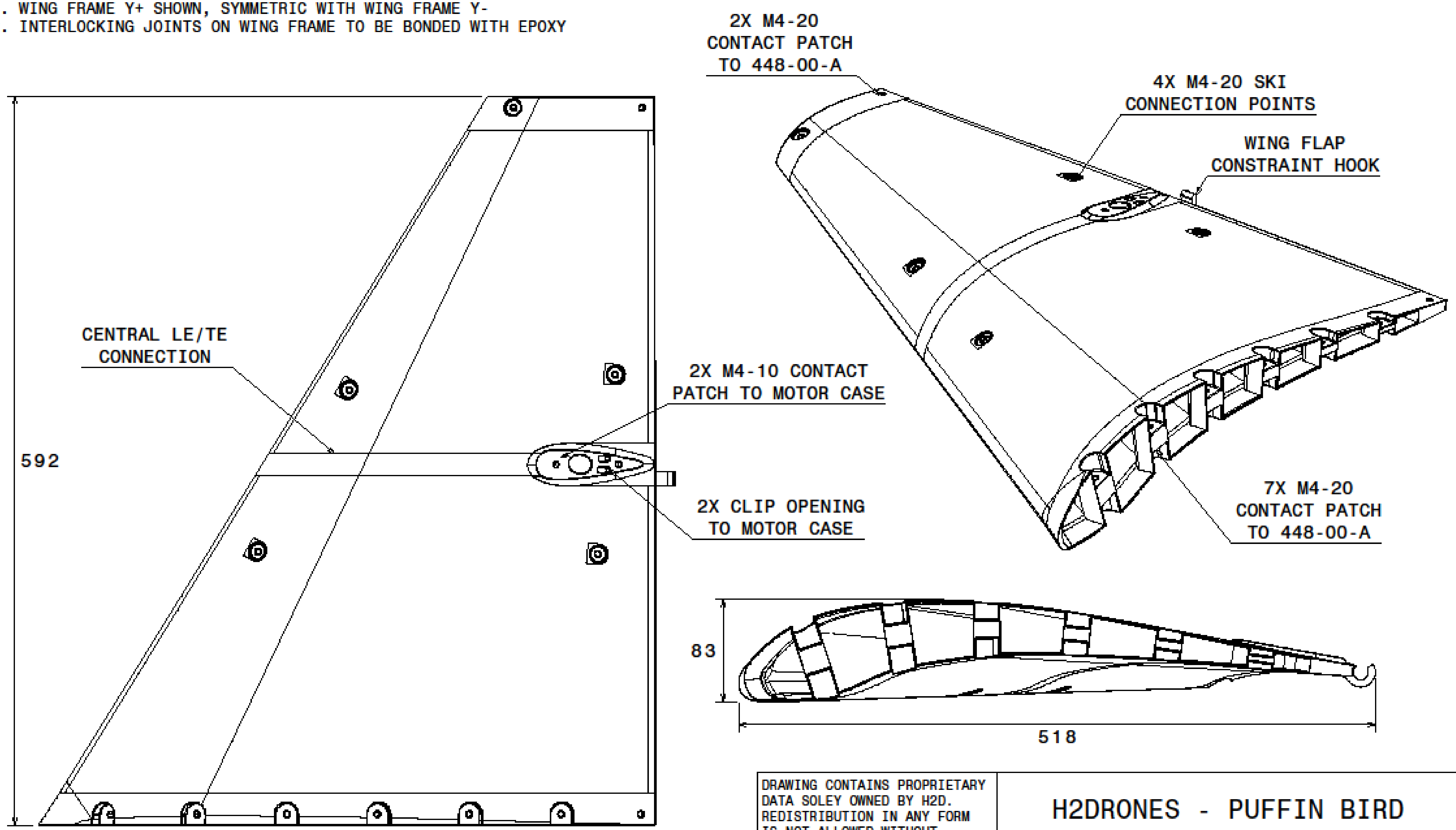
DRAWING TITLE
FUSELAGE ASSEMBLY - 5

DRAWN BY K.S.	DATE 3/27/2017
CHECKED BY S.H.	DATE 3/28/2017
DESIGNED BY H2D	DATE 2017

SIZE	DRAWING NUMBER	REV
A3	101-00-A	A

SCALE 5:4
WEIGHT(g) 47
SHEET 20

NOTES:
1. WING FRAME Y+ SHOWN, SYMMETRIC WITH WING FRAME Y-
2. INTERLOCKING JOINTS ON WING FRAME TO BE BONDED WITH EPOXY



DRAWING CONTAINS PROPRIETARY
DATA SOLEY OWNED BY H2D.
REDISTRIBUTION IN ANY FORM
IS NOT ALLOWED WITHOUT
WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

DRAWING TITLE
WING ASSEMBLY - 1

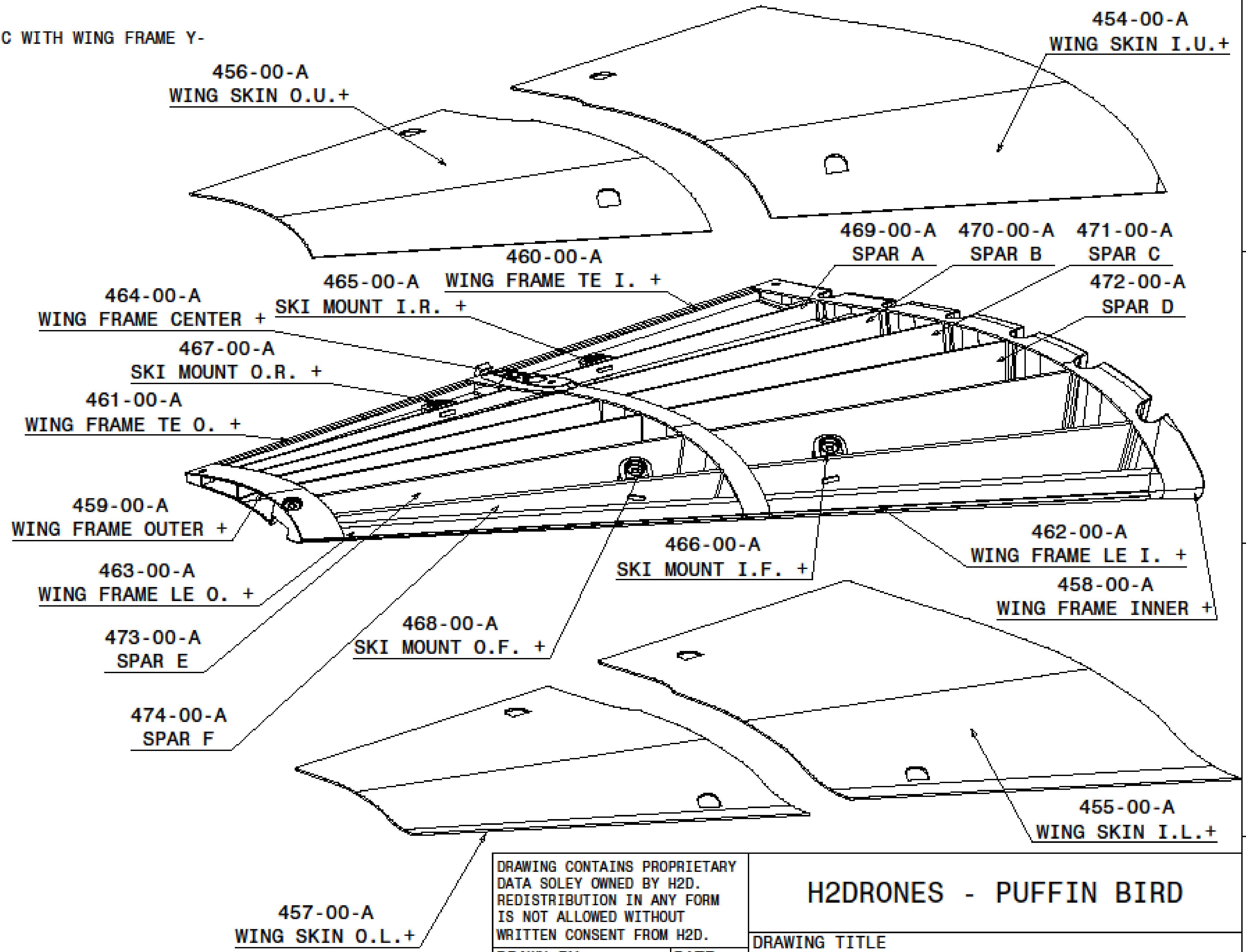
DRAWN BY K.S. DATE 3/27/2017
CHECKED BY S.H. DATE 3/28/2017
DESIGNED BY H2D DATE 2017

SIZE A3
DRAWING NUMBER 101-00-A
REV A
SCALE 1:3
WEIGHT(g) 941
SHEET 21

CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

NOTES:
1. WING FRAME Y+ SHOWN, SYMMETRIC WITH WING FRAME Y-

BILL OF MATERIALS		
P/N	DESCRIPTION	MATERIAL
	Y+	
454-00-A	WING SKIN I.U.+	P.E.T.
455-00-A	WING SKIN I.L.+	P.E.T.
456-00-A	WING SKIN O.U.+	P.E.T.
457-00-A	WING SKIN O.L.+	P.E.T.
458-00-A	WING FRAME INNER +	PLA
459-00-A	WING FRAME OUTER +	PLA
460-00-A	WING FRAME TE I. +	PLA
461-00-A	WING FRAME TE O. +	PLA
462-00-A	WING FRAME LE I. +	PLA
463-00-A	WING FRAME LE O. +	PLA
464-00-A	WING FRAME CENTER +	PLA
465-00-A	SKI MOUNT I.R. +	PLA
466-00-A	SKI MOUNT I.F. +	PLA
467-00-A	SKI MOUNT O.R. +	PLA
468-00-A	SKI MOUNT O.F. +	PLA
469-00-A	SPAR A +	BALSA
470-00-A	SPAR B +	BALSA
471-00-A	SPAR C +	BALSA
472-00-A	SPAR D +	BALSA
473-00-A	SPAR E +	BALSA
474-00-A	SPAR F +	BALSA
	Y-	
475-00-A	WING SKIN I.U. -	P.E.T.
476-00-A	WING SKIN I.L. -	P.E.T.
477-00-A	WING SKIN O.U. -	P.E.T.
478-00-A	WING SKIN O.L. -	P.E.T.
479-00-A	WING FRAME INNER -	PLA
480-00-A	WING FRAME OUTER -	PLA
481-00-A	WING FRAME TE I. -	PLA
482-00-A	WING FRAME TE O. -	PLA
483-00-A	WING FRAME LE I. -	PLA
484-00-A	WING FRAME LE O. -	PLA
485-00-A	WING FRAME CENTER -	PLA
486-00-A	SKI MOUNT I.R. -	PLA
487-00-A	SKI MOUNT I.F. -	PLA
488-00-A	SKI MOUNT O.R. -	PLA
489-00-A	SKI MOUNT O.F. -	PLA
490-00-A	SPAR A -	BALSA
491-00-A	SPAR B -	BALSA
492-00-A	SPAR C -	BALSA
493-00-A	SPAR D -	BALSA
494-00-A	SPAR E -	BALSA
495-00-A	SPAR F -	BALSA



CONFIDENTIAL
PROPERTY OF H2DRONES
RELEASED
DIMENSIONS IN mm AND DEGREES

DRAWING CONTAINS PROPRIETARY DATA SOLEY OWNED BY H2D. REDISTRIBUTION IN ANY FORM IS NOT ALLOWED WITHOUT WRITTEN CONSENT FROM H2D.

H2DRONES - PUFFIN BIRD

DRAWING TITLE
WING ASSEMBLY - 2

DRAWN BY K.S.	DATE 3/27/2017	SIZE A3	DRAWING NUMBER 101-00-A		REV A
CHECKED BY S.H.	DATE 3/28/2017				
DESIGNED BY H2D	DATE 2017	SCALE 1:3	WEIGHT(g) 941		SHEET 22

Appendix H Individual Lessons Learned

H.1 K. Younes

Design

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments, engineering specification, CAD Model, Analyses etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications	-Conduct market research and benchmark existing solutions -Research aerodynamic parameters and learn from expertise	-Lack of available resources in the aerospace market (most of the work is confidential) -Widely varying and interrelated aerodynamic parameters and conflicting nature of the project (light for flight, heavy for submersion)	-It is important to research existing solutions in order to ensure the creation and development of a novel idea
Identify a solution that satisfies the needs analysis	-Brainstorm design concepts and perform preliminary aero calculations -Set up CFD models and ensure performance is as expected	-Generating enough realistic, feasible design concepts without going into too much detail	-The value of having more than one solution/alternative will help in the long run if things go bad (Plan B)
Consider safety, society and sustainability issues in selecting a solution	-Design concepts to package the propellers and electronics away from any hazards -Ensure flight altitude is limited to within acceptable range by Canadian Aviation -Set up symposium and comply to safety	-None, everyone at the engineering department helped tremendously in meeting safety standards	-Failure to meet safety will cost you dearly, ensure this is in consideration early on in the project
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	-Update and create engineering specifications	-Engineering specifications in particular is very sensitive to the time of the project and progress. Keeping track of all the documents and various changes is tough. Prefer to have one eng spec only	-None, it was not a very useful document and drawings are on the verge of going extinct due to the design & mfg. in 3D
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	-Perform prototype testing -Participate in validation of design (air & water) -Consult faculty and course advisors constantly and implement feedback	-Finding locations suitable for testing! Whether in air or water, which was way tougher to test due to the lack of a controlled water body environment	-Having a well-thought and rigorous validation plan is critical to ensure design functionality -More than one validation exercise on the go (small scale/large scale) will give much more insight into the project success than just one

Project Management

Performance Indicator	**List the specific deliverables you produced that demonstrated your performance** (i.e. Reports, assignments etc.)	**What challenges were presented to you in achieving this learning outcome?**	**What is the value of this learning outcome for a future design project task?**
Decompose a project into a manageable set of objectives and/or tasks	-Divide tasks of the project into different areas and subdivide those into areas of expertise in the team	-Lack of time to learn new skills and perform unexplored tasks	-Able to simplify a grand task such as designing an airplane into smaller, simpler and manageable tasks (this is important)
Develop and track a schedule with milestones	-Meet internal and external deadlines (symposium, design reviews)	-Workload often made it difficult to meet deadlines and dates had to be pushed	-That deadlines are meant to be met otherwise you risk running out of time
Manage financial, human and/or physical resources	-Meet a tight budget and gather resources to perform tasks	-Insufficient funding to perform another build cycle and better refine the design	-Important to scope down to avoid having high expenses at the end of the project -Better keep track and consult everyone before spending
Identify and manage risks	-Scope down the project to meet symposium deadline	-Convincing team members that certain risks are worth exploring/considering	-It is extremely useful once utilized! The risks are very important!
Apply change management	-Shift priorities promptly to deliver tasks on time and support team members	-Gathering and shifting resources can be a struggle, especially with the busy schedules	-Flexibility in team members and realizing the fact that changes are expected is important. -Having team members with a wide variety of skills helps simplify tasks greatly and allows individuals to shift priorities without a steep learning curve.

Communication

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Write effective reports and design documentation	-Write analysis sections and intro of reports -Proofread and ensure coherent report structure	-Finding the motivation to write after long hours of work -Lack of communication on a standard set of formatting numerics	-Improve and develop effective communication and writing skills
Make effective presentations	-Participate in all design reviews -Prepare separate analysis presentation and participate in analysis comptetion	-Convincing everyone about certain slides/content -Dividing the slides equally	-Gain confidence in public speaking -Improve oral communication skills and present a simplified engineering idea

Other Lessons-Learned

The project provided a great learning experience for me personally. Having only been exposed to CFD in an academic setting, I got a chance to enrich my knowledge and analyze complicated aerodynamic phenomena whilst developing the plane. I learned a lot about the great deal of complexity associated with designing a functional airplane and the tremendous amount of effort needed to ensure all aspects of the design are fully resolved and well analyzed. I also learned that while things look overly simplified in CAD and on paper, in reality however, systems behave much differently and anything that could possibly go wrong – from stability to insufficient lift – will go wrong. I learned that a strong team needs to be well prepared for failure and react promptly to come up with alternative solutions; this was demonstrated by our team numerous times and it is the reason why we made it as far as we have. Moreover, I learned that time is very precious and allocating resources effectively is a key to project success while maintaining a healthy, positive team relationship.

Lastly, I learned that the lack of computational power and resources can significantly impact the analysis of any project; seeking power and utilizing different sources for this specific task was very challenging.

Be very prepared to take no for an answer and come up with a better, uncontested answer next time – don’t give up.

H.2 K. Strobel

Design

Performance Indicator	List the specific deliverables you produced that demonstrated your performance	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications	Developing the technical specifications for the plane (not the engineering specs but rather the aerodynamic specs)	Had to learn everything about aerodynamics, all I knew at the beginning of the project was that lift had to equal the weight.	I want to go into the aerospace industry, there are clear direct benefits for my future
Identify a solution that satisfies the needs analysis	Developing about 15 different concepts for the vehicle geometry and plugged them into a decision matrix to figure out what was best	It is tough to figure out qualitative values for a decision matrix without introducing biases, especially to things that are so unknown to me like aircraft design	I want to develop vehicles from cradle to grave, this was a perfect activity for that and gave me great experience
Consider safety, society and sustainability issues in selecting a solution	Our propellers were a concern of the faculty to safety, I designed a custom mount to attach them to our plane that had redundancy caked into it	Getting approval from our advisor that he actually thought my design for it would be good enough	Design for safety is important. Design for safety is important. Design for safety is important.
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	I did the CAD work and all of the DWGs for our vehicle. This was my biggest contribution to the project	Designing a plane is hard. It is really tough to balance factor of safety with weight. It always needs to be lighter, which is very tough to make happen	There was a lot of iterations between FEA and design to figure out where we needed material and where we didn't, this was a valuable lesson for future projects.
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	I led the efforts on full scale wind tunnel testing.	It is hard to get data that you can trust, this was definitely a problem with our set up and was something we had to scrutinize	It doesn't matter how pretty your CAD is, if it doesn't work in validation then it's not a good design

Project Management

Performance Indicator	**List the specific deliverables you produced that demonstrated your performance** (i.e. Reports, assignments etc.)	**What challenges were presented to you in achieving this learning outcome?**	**What is the value of this learning outcome for a future design project task?**
Decompose a project into a manageable set of objectives and/or tasks	I did not do a good job of this, I cast our net wide when we were scoping the project and got us down some alleys that I should not have	It is hard to fight between what you really WANT to do and what is actually practical, if I could have I would have tried to take this project to the moon and back	Scope your project accordingly; this is a really important skill to have and really drives the success of your project.
Develop and track a schedule with milestones	I did not lead the PM efforts but I was more of an engineering lead, thus I was continuously in contact with the project PM about deliverables and deadlines.	It is hard to communicate technical details to someone without the technical background in the area you are concerned with.	The business people are essentially the ones that drive the company you are working for, being able to communicate with them is probably the most important skill you can have
Manage financial, human and/or physical resources	I worked with the PM to help divvy up our engineering resources.	Being able to get someone to do something for you without ordering them to do it is a work of art.	As someone who would like to be in more of a managerial position rather than a technical position in the future this is a very important skill to have
Identify and manage risks	We had a major risk of going over budget. Working with the PM we put together a crowd fund sourcing forum to get money for the project	Taking off my engineering hat and putting on my business hat to convince people to donate to the project	It is very important to be able to sell your product, this is something I learnt from this
Apply change management	When we found out our plane was unstable I worked through the night to find a technical solution to the problem and implemented it into design immediately	Getting an accurate model the vehicle flying is very hard and unreliable; there are so many unknowns	I learnt how to both design and manage a problem under an incredibly tight deadline.

Communication

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Write effective reports and design documentation	Like everyone else, I did a lot of writing for the report.	It is hard to go back to remember everything you've done over the last 4-8 months on the project and be able to gather all that information together into one report	I learnt the value of keeping a good record of what you did throughout the term by using a diary
Make effective presentations	I took a large role in the presentation preparation as I am stickler for how they look.	It is hard to convince someone that the little details in your PowerPoint slides really matter	I found a happy balance between working on the fine details and making sure the presentation was appropriate

Other Lessons-Learned

- Don't spend so much time on the fine details in CAD, focus on the big picture. This is the biggest lesson I learnt by far.
- Take advice from elders, there is a reason why people say wisdom comes with age.
- Ask why three times on everything. If you can't give good answers for all three of them then you should really reconsider what you are doing. Scope your project accordingly, keep in mind what you know and what is practical.

H.3 S. Hussain

Design

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments, engineering specification, CAD Model, Analyses etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications	- Performing detailed market analysis to understand what the market wants - Survey design and website creation - Brainstorming solutions based on engineering intuition	- First time developing a website - Understanding how best to assess the customer and establish a minimal viable product (MVP)	- The importance of designing to the customer was highlighted - The value of bounded creativity was emphases (brainstorming creative, yet implementable solutions)
Identify a solution that satisfies the needs analysis	- Based on brainstorming and initial design direction performing proof of concept testing - Deciding on make or break parameter (water take-off) and developing solution for parameter	- Difficulties in creating a POC which could take off from water - Creating a representative yet controlled environment	- The value of accurate POC testing - How performing POC testing early in the design phase can positively impact the design (helping avoid challenges)
Consider safety, society and sustainability issues in selecting a solution	- Ensuring all POC and validation testing was performed in a safe environment - Ensuring safety of all when manufacturing	- Getting approval from all stakeholders (Life guards at PAC pool, technicians in the maker space)	- Understanding the importance of safe testing procedure and safe manufacturing - Improved quality is achieved when work is performed safety
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	- Creating tool paths for CNCing foam molds - Creating GCODE for 3D printing components	- Impact of technical variables on quality and time when 3D printing and CNCing	- Acquired skills in CNCing and 3D printing
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	- While manufacturing the beta prototype, recording design change points required for producing a more DFM revision.	- Due to the many constraints in the design (weight limitations, defined airfoil, etc) my past conventions of DFM were challenged. For example, not all joints could be made into interlocking joints due to the thin geometry.	- I could understand how to DFM a highly sensitive design such as an airplane.

Project Management

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Decompose a project into a manageable set of objectives and/or tasks	- Developing project schedules - Understanding the interdependency of project tasks and how decisions made in design can impact manufacturing, how manufacturing can impact validation etc. - Making decisions on project direction	- Having enough bandwidth to process all the information - Having the foresight to prioritize tasks	- More confident in making technical decisions
Develop and track a schedule with milestones	- Making project schedule	- Limited time - How to motivate people to do work? - Other stresses / priorities	- It is hard to motivate people - You can’t please everyone
Manage financial, human and/or physical resources	- Seeking additional capital (crowd sourcing) - Conflict resolution	- Working in a team with strong personalities	- Understanding how difficult it is to manage a team - Understanding the impact of having responsibility with no power - Implement group contract
Identify and manage risks	- Creating risk registry - Implementing risk registry	- Even though risk were identified and countermeasures implemented challenges were still faced - Risk registry did prove helpful in appropriately scoping project	- Importance of planning and spending a investing time early in the design phase will save time later on
Apply change management	- Establishing and updating project priorities - Allocating resources to facilitate change; time, capital and work hours	- Motivating individuals to keep working even after shifts in priorities - Having to be the “bad guy” can make it difficult to drive necessary change	- Sometimes it is better to lose the battle than win the war, select battles wisely

Communication

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Write effective reports and design documentation	- Report writing - Symposium poster creating	- Explaining complicated processes effectively - The importance of understanding who the audience is; our symposium poster has less technical detail than any of our presentations	- Writing concisely and to the point about technical matters - Remembering to get to the point not focus on background if you don't have to
Make effective presentations	- Making IDR, MDR, FDR presentations	- Making professional concise presentations - Developing presentations on sections where I was not the one to do the work; i.e. making the CFD slides	- Professional presentation skills, I used these in my recent interviews

Other Lessons-Learned

A team of five working over the course of approximately one year served as a perfect platform for developing and acquiring project management skills. Initially due to a lack of understanding of the challenges involved it was difficult to establish accurate timelines. As the project progressed and team members became to gain expertise in their role establishing more accurate timelines became possible. Another challenge faced during the project was maintaining motivation. Due to the length and the challenge of the project there were many times when morals were low which significantly impacted the quality of work. To overcome this challenge, successes were celebrated vocally. A critical lesson learned regarding project management was the importance of building team spirit, the lack of team bonding activities not related to work greatly impacted the working dynamic. Assuming past academic relationships were sufficient to facilitate positive group, dynamics was wrong. In the future, more emphasis will be put into maintaining and developing intrapersonal skills. This project also served as a medium for me to acquire skills in manufacturing and validation. Having to construct a full scale aerial vehicle was an exciting challenge. This challenge introduced me to new prototyping techniques such as thermoforming, resin printing, and desktop CNC milling. It was truly exciting to make educated decisions on process and material based on sound engineering knowledge. Points of failure became opportunities for growth, and points of achievements were a pat on the back. Validation was another point of technical growth, having to systematically analyse the vehicle, develop test procedures and creating test setups allowed me to acquire skills in validation. Furthermore, being able to make educated recommendations to design based on findings, and then observing the impact of these changes was an ideal way to observe the relationship between the two. Acting as the project lead was a wonderful way for me to keep my finger on the pulse, this allowed me to effectively make executive decision, it also allowed me to gain a breath of knowledge, assisting in all areas of the project.

H.4 C. Diffey

Design

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments, engineering specification, CAD Model, Analyses etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications	- Need Statement - Benchmarking - Asking stakeholders questions about problem - Engineering design specifications -	- It was challenging to find a short need statement that fully defined the problem. - Finding stakeholders to ask questions of was also a challenge, since at this stage I have a relatively small network to reach out to.	- The value of this learning outcome is that in future design projects I will be better able to analysis needs so that the problem which is trying to be solved will be better defined. -
Identify a solution that satisfies the needs analysis	- Decision matrix - Group consensus on final design	- Coming to a consensus is not always easy with groups that don’t usually work together - Trying not to subconsciously sway the results of a decision matrix	- Learned to consider out-of-the-box ideas during the conceptual design phase, as these ideas can often morph into very good, feasible designs later on.
Consider safety, society and sustainability issues in selecting a solution	- Review of aerial vehicle law - Review of underwater vehicle law -	- It was difficult to determine which laws and safety regulations applied to our design. - Regulations apply to characteristics of a device and our design was still morphing	- Will keep safety, society and sustainability issues in mind during the entire design process instead of an after thought
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	- Importing of supplier parts into CAD - Simulated component loading prior to construction	- Supplier drawings are not always exactly as the real part is. This caused some problems with manufacturing - There was not time to perform some of the simulations fully in the allotted time of the course	- Having your own tolerances that account for supplier part deviations makes manufacturing easier
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	- Stability Testing - Scaled wind tunnel testing - Water testing - Component level testing	- When time is tight, getting accurate results is hard - Testing was done at a late stage in the course -	- Whenever possible things should be validated testing or trying to implement the idea instead of only running computer simulations -

Project Management

Performance Indicator	**List the specific deliverables you produced that demonstrated your performance** (i.e. Reports, assignments etc.)	**What challenges were presented to you in achieving this learning outcome?**	**What is the value of this learning outcome for a future design project task?**
Decompose a project into a manageable set of objectives and/or tasks	- Report section breakdown - Was responsible for specific tasks and accomplished them	- For the report, some of the sections were dependent on the completion of others which complicated the decomposition of sections	- Completing small sub-tasks helps to lessen the load of the entire task - A good project breakdown highlights areas of high workloads allowing for adjustments
Develop and track a schedule with milestones	- Helped manage my own schedule to get tasks done in time with others task timelines	- It was hard to predict all the aspects of the schedule that would need contingency - Meetings had to be rescheduled as people got more and more busy	- Showed that the better you track your progress to the planned milestones the better prepared you are for last minute changes
Manage financial, human and/or physical resources	- Acquired materials and parts to be used in testing/validation and final artifact - Worked on my own sections and was accountable for them	- Estimating work hours was difficult -	- Better understanding of contingency which helps with allocating work hours -
Identify and manage risks	- Identification of facility use schedule time lines and blackout periods - Came up with solutions to problems encountered when testing prototype	- Did not account for the fact that student projects would be the first to get pump if there were schedule changes -	- Importance of identifying risks at the beginning of a project - Continual identification of risks and progress of mitigation efforts
Apply change management	- FEA findings used to make design changes for vehicle structural integrity - Scope changes - Kept updated copies of documents and incorporated changes	- Changes often take more time to implement than expected -	- You should always include contingency when allotting time to tasks - No matter what how well you plan a project change is inevitable

Communication

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Write effective reports and design documentation	- Term review presentations - Symposium and conference posters - Grant applications - Final report	- It is sometimes difficult to express the ideas in your head through written communication	- All engineering work needs to be documented not only to explain current designs but to aid in the creation of future ones.
Make effective presentations	- Design reviews with classmates and external reviewers -	- There has to be a balance between providing enough information while not keeping slides tidy	- It helped be to improve my presentation and public speaking skills when are essential to engineering communication

Other Lessons-Learned

First and most importantly, I learned a lot about the complete design process in creating a product. I had never had the opportunity of taking a project from the initial conceptual design stages all the way to a working prototype. I did some other design projects before but not as big and demanding as this one. It forced me to pay better attention to details as they would matter a lot when physically applied. I also experienced the importance of milestones and due dates. Sometimes these dates get pushed back, but having set deadlines that must be met helps with minimizing any pushback.

From this project, I have also gained skills in giving presentations and communicating ideas. I have in the past shied away from doing presentations, but having to do presentations and communicate with external reviewers has made me better at public speaking. The symposium and term reviews has also given me more practice for giving technical presentations to both technical and non-technical audiences.

From the completion of this project with such a large group I learned that it is not always possible to for everyone plans or ideas to be met. With five people on board, much work can be achieved but it demands a lot of management and communication. Sometimes for a decision to be made a vote so that the project can progress. Realization of when useful dialog and discussion has stalled is important and through this project I have become better at recognize and dealing with these situations in a way that benefits the progress of the project.

H.5 E. Fochtberger

Design

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments, engineering specification, CAD Model, Analyses etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications	The definition of the project is a team decision and dependent on concrete member inputs based on rational arguments. Engineering criteria/constraints are formulated (translated from public input) by the engineer	After an engineering education and by default engineering inclinations the need must be defined for the general population. Something “cool” for an engineer might be impractical and not useful.	Although a need is required for an engineering design to become a successful product, engineers should look beyond the “Could this be sold in a Supermarket” approach and develop novel ideas.
Identify a solution that satisfies the needs analysis	Search in things that exist and design by analogy	The harder the engineering principles the harder it is to find good examples	Looking at nature can provide much highly sophisticated engineering input.
Consider safety, society and sustainability issues in selecting a solution	Material selection and manufacturing methods	Many methods exist and some are less sustainable than others, with an additional constraint of time and resources.	Manufacturing and materials for a project should be discussed i9n parallel when designing a product.
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	Production of a product based on 3D designs and 2D drawings.	“Hard to build” components require special attention, in many different forms. Time, but also skill, or jigs and fixtures	It is important to layout a thorough plan of building of a novel prototype. Preparation pays off.
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	Testing of vehicle in a wind tunnel	Wind tunnel testing requires a thorough setup and results are not textbook simple.	Validation of real life products is open ended but the value is also much greater than theoretical analysis. It is important to know where and how to get the results properly interpreted.

Project Management

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Decompose a project into a manageable set of objectives and/or tasks	Report section writing and revising and manufacturing scheduling	Scheduling of tasks that are woven into a bigger picture with multiple parties involved.	Careful planning and early birds have an edge when it comes down to executing a plan.
Develop and track a schedule with milestones	Revising a schedule into manageable time frames (personal) to achieve bigger milestones and deadlines	Utopian deadlines (self-set or group decision)	A contingency plan is important and planning should be done on concrete values not on thin air judgment calls
Manage financial, human and/or physical resources	Material management of build	Limited budget can pose a tight place.	A team needs to be aware of all expenses and also included in decision making when it involves everyone.
Identify and manage risks	Time management and missing deadlines which affect project outcome	Certain tasks can put an entire project into jeopardy	Task should be identified throughout the project as high risk and carried trough as such
Apply change management	Flexible timelines or revisions	Missed timelines need to be adjusted and reasons incorporated immediately	Contingency needs to be monitored consistently and if issues arise they need to be solve d immediately.

Communication

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Write effective reports and design documentation	Report section writing, team communication via all media used	Not all things can be communicated in the same way	The team needs to set rules on how certain things are communicated. It simplifies and accelerates communication (Real time messenger does not communicate drawings well for example)
Make effective presentations	Present and prepare parts of presentation	Presentations need to have a "flow" while communicating the actual content precisely	Each team member should be able to give the complete high-level presentation, while each task champion jump in when specific questions are asked.

Other Lessons Learned

Motivation is key in a project. It is helpful to reflect in shorter episodes to keep the motivation up and be agile enough to correct mistakes done along the way. From a manufacturing lead role: It pays off to have a good research done before hand on materials, manufacturing methods, suppliers access to tools etc. Reflecting back, one cannot over prepare for a project so when there seems to be time it should be used to identify the things that could go wrong in the near future of the project both as the product itself as well as the team relations.