BYU

BRIGHAM YOUNG UNIVERSITY

AIAA Design/Build/Fly Competition 2020-2021 Aircraft Design Report

Contents

I Executive Summary

The Brigham Young University (BYU) American Institute of Aeronautics and Astronautics (AIAA) Design, Build, Fly (DBF) team entered the national competition this year for the first time. The competition this year is to build and fly a payload-carrying airplane that deploys and retrieves a towed sensor pod carrying lights that are visible from the ground. This year requires that the team record video footage of each aspect of the competition and submit it by April 18, 2021.

This competition is carried out over the course of several different missions. The first mission is a flight carrying no payload and the airplane must fly three laps around the course within 5 minutes. The second mission must be flown with the maximum payload on board, and again three laps must be completed in 5 minutes. The third mission requires the airplane to fly as many laps as possible while carrying the towed sensor pod within a 10-minute window. In addition to these flight requirements, the team must also complete a ground mission where they demonstrate the ability to deploy and recover the payload and test the strength of the payload shipping container.

The scoring sensitivity analysis indicated that speed and sensor pod weight were the most influential parameters in the overall score. Accordingly, the team decided upon a design that focuses on lifting a few, heavy, sensor pods. Each sensor pod is designed to weigh approximately 2 lbs, and the airplane is designed to carry a maximum of three sensor pods for flight mission 2. The sensor pod was also designed to be approximately 12 inches long because a longer sensor pod receives more points. The overall configuration of the airplane is a monoplane with a conventional T-tail empennage design. The main wing is tapered at the tips to improve overall lift-to-drag and the lifting surfaces are designed to be capable of carrying at least 10 pounds.

The team is currently working on its first full-scale prototype, having completed preliminary testing with a half-scale prototype in early January. This prototype will help the team understand the structural soundness of the current design as well as determine what changes need to be made to the sensor pod in order to ensure proper deployment and recovery. This prototype, along with a prototype of the sensor pod, are expected to begin flight testing within two weeks of the design report submission.

II Management Summary

II.A Team Organization

Figure 1 depicts the overall organization of the team structure. Each of the teams is lead by an individual who answers to the Engineering Lead. The skills required for each position/team are as follows.

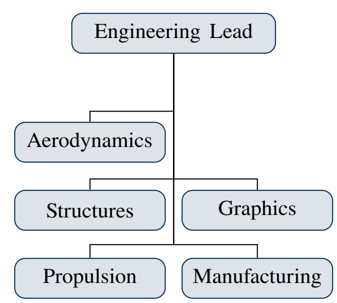


Figure 1 Here we show the structure of, and assignment areas within, our team organization.

Engineering Lead The Engineering Lead must be able to coordinate the efforts between all of the teams and be in charge of setting milestones and communicating with the advisor.

Aerodynamics The Aerodynamics team members have expertise in aerodynamic analysis, including knowledge of theory and computational models.

Structures The Structures team members focus on skills in structural analysis and testing. This year's Structures team lead had to leave the team for personal reasons in December and the responsibilities of the Structures team became absorbed into the other teams.

Propulsion The Propulsion team focuses on analyzing and testing the propulsion system effectiveness and efficiency, but also has skills in electronics related to the propulsion system.

Manufacturing The Manufacturing team oversees the manufacturing of all prototypes and testing apparatus.

Graphics The Graphics team has skills in CAD design as well as graphical marketing for the team.

In addition to the nominal skill sets for the team they lead, the sub-team leads also demonstrate leadership, communication, and organizational skills befitting those in decision making positions.

II.B Schedule

Figure 2 depicts the team's planned vs. actual timeline for the year up to the point of submission for this report. The takeaway from this figure is that the team fell short of maintaining the initial planned schedule for most aspects of the designing and building. However, the team has been putting in extra time over the first few months in the year 2021 to ensure that the airplane is ready to fly for the virtual competition.

Once this design report is submitted, all attention will be on constructing a full-scale prototype and building the final airplane. Progress is shown up to the current date. It is anticipated that the team will spend at least two more weeks finishing and flying the detailed prototypes before proceeding to the final build.

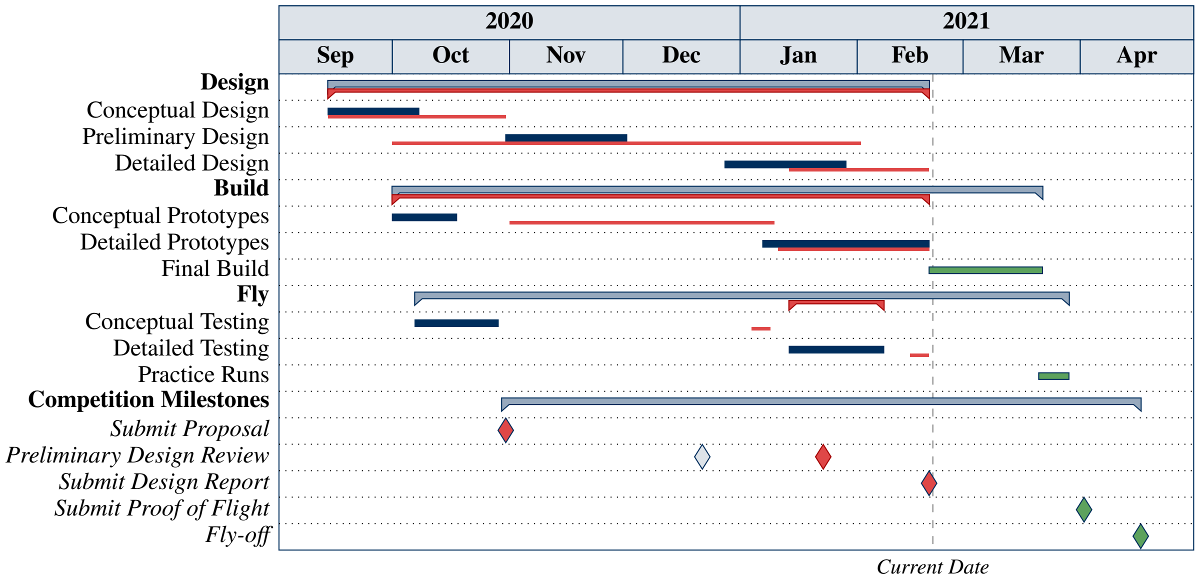


Figure 2 This milestone chart reveals the team's original plan for major elements of the team's design process compared to the actual timing of these events. Note that the team submitted the proposal on time, as well as this report. The team anticipates remaining on schedule for much of the future elements of this chart.

III Conceptual Design

III.A Mission Requirements

The objective for the 2020-2021 DBF competition is to design, build, and test a UAV with a towed sensor. The UAV must be able to carry a payload and deploy, operate, and recover an aerodynamically stable towed sensor pod. The success of the UAV will be determined in 3 flight missions and one ground mission.

III.A.1 Flight Mission Scoring:

The flight missions will be flown on a course as shown in figure 3. Turns will occur when signaled by the turn judge. The aircraft must remain in line of sight of the pilot at all times.

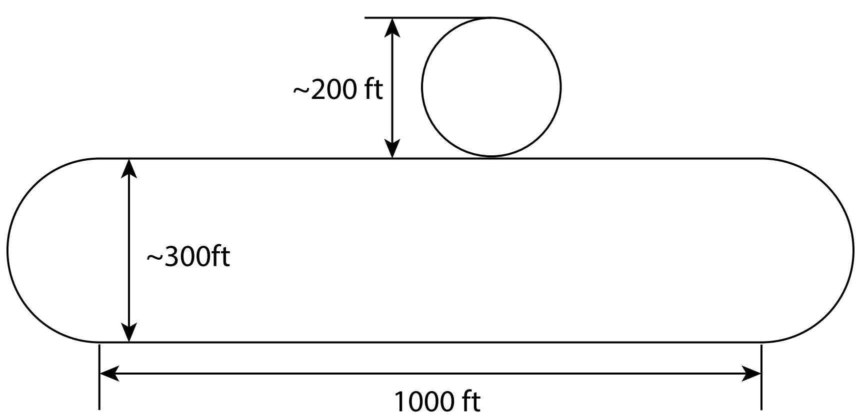


Figure 3 This plot breaks down the estimated lengths of the course based on the scale drawing from the mission requirements.

Flight Mission 1: The UAV must fly 3 laps of the flight course in a 5-minute flight window. There is no payload for the staging flight. Time starts when the throttle is advanced for the first take-off attempt and ends when the aircraft completes three laps. The aircraft does not need to land within the 5 minute window. Scoring for mission one is binary and defined as:

$$M_1 = \begin{cases} 1 & \text{if successful completion} \\ 0 & \text{if failure to complete} \end{cases}$$

Flight Mission 2: The aircraft will carry its maximum payload (sensor in shipping container, shipping container simulators, and deployment/recovery mechanism) as determined in the technical inspection. The aircraft must fly 3 laps within a 5-minute flight window. Points are awarded according to the equation:

$$M_2 = 1 + \frac{\text{\#containers/time}}{max(\text{\#containers/time})}$$

where the numerator is the individual team score and $max()$ indicates the maximum values of all competitors.

Flight Mission 3: The aircraft will carry the sensor and the deployment/recovery mechanism. The aircraft must deploy the sensor before the first 360 degree turn of the first lap, then fly as many laps as possible within a 10-minute flight window. After the 10-minute window, the sensor pod must be recovered and the aircraft must land successfully. Points are awarded according to the equation:

$$M_3 = 2 + \frac{\text{\#laps } \times \text{sensor length } \times \text{sensor weight}}{max(\text{\#laps } \times \text{sensor length } \times \text{sensor weight})}$$

where the numerator is the individual team score and $max()$ indicates the maximum values of all competitors.

III.A.2 Ground Mission:

The ground mission is a ground demonstration of missions 2 and 3. The mission is broken into 4 parts, two of which are timed. First, the assembly crew member must demonstrate that the sensor shipping container protects the sensor pod from a 10-inch drop. Second, the assembly crew member loads the full payload for mission 2, and the pilot will demonstrate that controls are active. Third, the assembly crew member will prepare the aircraft in configuration for mission 3 and the pilot will demonstrate that controls are active. Fourth, the assembly crew member will hold the aircraft and the pilot will demonstrate functionality of the deployment recovery mechanism. Parts 1 and 4 are scored on completion. Parts 2 and 3 are timed. The mission score is based on the time as follows:

$$GM = \frac{min(\text{time})}{\text{time}}$$

where the denominator is the individual team score and $min()$ indicates the minimum values of all competitors.

III.A.3 Total Score Summary:

The total score for a given team is:

$$TS = M_1 + M_2 + M_3 + GM + DR$$

where TS is total score, M_i is the score associated with the mission number subscript, GM is the ground mission score, and DR is the design report score.

III.A.4 Design Requirements

The competition rules define design constraints that all aircraft must follow.

Sizing The aircraft must have a wingspan less than 5 feet. AMA regulations dictate that the UAV must weigh less than 55 pounds.

Electronics/Propulsion The aircraft must be propeller driven and electric powered with an unmodified commercially available electric motor. LiPo battery packs must be un-altered and commercially procured. There is a limit of 100 watt-hours per battery pack. There is no limit to total battery weight.

Sensor The deployed sensor must have a minimum of 3 external lights, viewable in flight, operating one at a time and controlled by a physical connection to the aircraft. When not deployed, the sensor must be carried internally to the airplane. The sensor must be deployed at distance of at least ten times the length of the sensor and must be aerodynamically stable.

Payload and Shipping Container A sensor shipping container must be designed that fully encloses the sensor and protects it from drops. The sensor shipping container will be tested during drop tests in the Ground Mission. Shipping container simulators carried on mission 2 must be the same size and weight as the shipping container with sensor.

III.B Sub-system Design Requirements

The team has organized the sub-system requirements into aerodynamics, structure, propulsion, and specialty requirements explained below.

III.B.1 Aerodynamics Requirements

The aircraft must have a wingspan less than 5 feet. The wing must be designed to create enough lift to carry a large payload to score well on mission 2, but also minimize drag and increase speed to complete mission 1 and increase the score on missions 2 and 3. The wing and tail must be designed to ensure airplane stability even when towing the sensor pod.

III.B.2 Structural Requirements

Materials must be selected to maximize simplicity of manufacturing and strength while minimizing weight. The wing must be reinforced to handle at least 2.5 g with the full payload. Landing gear must be able to support take-off and landing forces. The fuselage must be able to house as many shipping containers as possible as well as the deployment and recovery mechanism.

III.B.3 Propulsion Requirements

A power system must be selected that can produce enough thrust to overcome drag and fly fast enough to complete and score well on each mission. Enough battery is necessary to fly for at least 10 minutes on mission 3. The maximum weight of the aircraft is projected to be 10 pounds when fully loaded on mission 2. The propulsion system must be sufficiently powerful to fly with this load, while remaining efficient at lower weight loading in order to achieve a 10 minute flight on mission 3.

III.B.4 Payload

A sensor pod must be designed that is aerodynamically stable and compact. It must be as long as possible and be at least 1 inch in diameter. A mechanism must be designed to deploy and recover the sensor pod, and shipping containers will be needed to protect the pod.

III.C Scoring Sensitivity Analysis

The team analyzed the sensitivity of the total mission score to design parameters. To simplify the analysis, the team considered the scoring factors of Time from Mission 2 and Number of Laps from Mission 3 into a single design outcome: Speed. The team discussed the collateral effects of the remaining scoring factors on the others and decided to conduct the sensitivity analysis as if they were independent factors.

Because speed factors into two missions, it has a larger impact on total score. According to the results of the sensitivity analysis, the most important factors are the airplane speed and the time required to complete the Ground Mission. Therefore, the design will prioritize speed and easy access to the airplane cargo bay. Additionally, the team decided to increase the sensor weight and decrease the number of packages to increase the score on the second mission. This also results in a faster load/unload time for the Ground Mission.

III.D Concept Review, Weighting, and Selection Process

III.D.1 Wing Configuration Selection

Multiple different wing configurations would be capable of completing the missions. Due to the team's goal of maximizing payload weight, the team considered using a biplane configuration to increase the lift. This design wasn't chosen because of its increased complexity over a monoplane, which didn't yield improvements that made the design worthwhile. Additionally, the team considered different wing placements on the fuselage, and quickly decided to use a high-mounted wing design so that the center of gravity is below the wing and improves roll stability. In order to increase the lift generated by the wing and therefore increase the maximum payload capacity the wing chord was designed to be 12" to increase the total lifting surface area.

III.D.2 Wing Placement Selection

For the wing placement, the team decided to mount the wing on top of the fuselage primarily for stability reasons. Keeping the center of gravity below the wing improves the roll stability by enabling the airplane to return to equilibrium similar to a damped pendulum when a force causes it to tilt to one side.

III.D.3 Empennage Configuration Selection

Initially, the team planned to release the payload out of the back of the fuselage, which would pose a threat to a standard boom and tail configuration by risking a collision. Therefore, the initial design included a twin-boom configuration that provided enough space for the payload to deploy out the back of the fuselage with a much smaller risk of collision with the booms. The twin boom design led to the design of a U-tail configuration, with the horizontal stabilizer having a width equal to the separation distance between the two booms and with the two vertical stabilizers positioned on the top of either side of the horizontal stabilizer.

Ultimately the team decided to drop the payload out of the bottom of the fuselage, negating the need for a twin-boom configuration. However, the team continued to pursue a twin-boom configuration due to structural and financial constraints. In order to use a single boom, the team would need to procure a thicker carbon fiber rod than was readily available, and consequently decided to use two booms with smaller diameters.

After discussing the required structural support for wing-mounted tail booms, the tail design was adjusted to move the booms from the wings to the sides of the fuselage to simplify the wing structure and decrease weight. The airplane will still have torsional rigidity of a twin boom, and the booms will still be mounted at wing level, so they will not interfere with payload deployment or recovery.

III.D.4 Propulsion Configuration Selection

The configuration of the propulsion system is primarily dependent on the mission requirements. For various missions, the aircraft will be required to either tow a sensor pod out of the rear or bottom of the aircraft or will be required to carry a significantly heavy load, approximately double the weight of other missions. While a pusher configuration could theoretically be set up such that it would not interfere with the tow line, in practice there are many variables that exist which could allow the tow line to interfere with the propeller during flight. Additionally, a pusher configuration must propel air which has additional aerodynamic interference from the fuselage. Because the aim is to maximize both power and efficiency in two different flight modes, the additional interferences of a pusher configuration increases the difficulty of optimizing a system adequate for both modes of flight. In order to reduce the possibility of interference from the towing control line and ease the motor optimization process, a tractor configuration was selected.

III.D.5 Payload

The team discussed various ideas for a sensor pod, but ultimately decided upon a 1x12 inch cylinder with four stabilizing fins at the rear. A pointed nose cone would be placed at the front of the pod to increase stability. Previous versions included an expandable wing concept, which was discarded because it acted like a miniature plane and there was not enough space to incorporate stabilizers. After analyzing the point matrix, the team decided to focus on making a long and heavy sensor. The pod was not heavy enough after assembling and adding electronics, so the team added lead shot as ballast weight; up to a target of 2 pounds. This ballast can be shifted to change the balance.

Additionally, the team wanted to carry as many shipping containers as possible, but discarded that notion in favor of fewer but heavier sensor pods. The fuselage of the plane was designed to hold three shipping containers. The winch mechanism will be mounted upside down within the aircraft directly under the center of gravity. The mechanism will allow the sensor to feed out of the bottom of the plane.

III.D.6 Final Concept

IV Preliminary Design

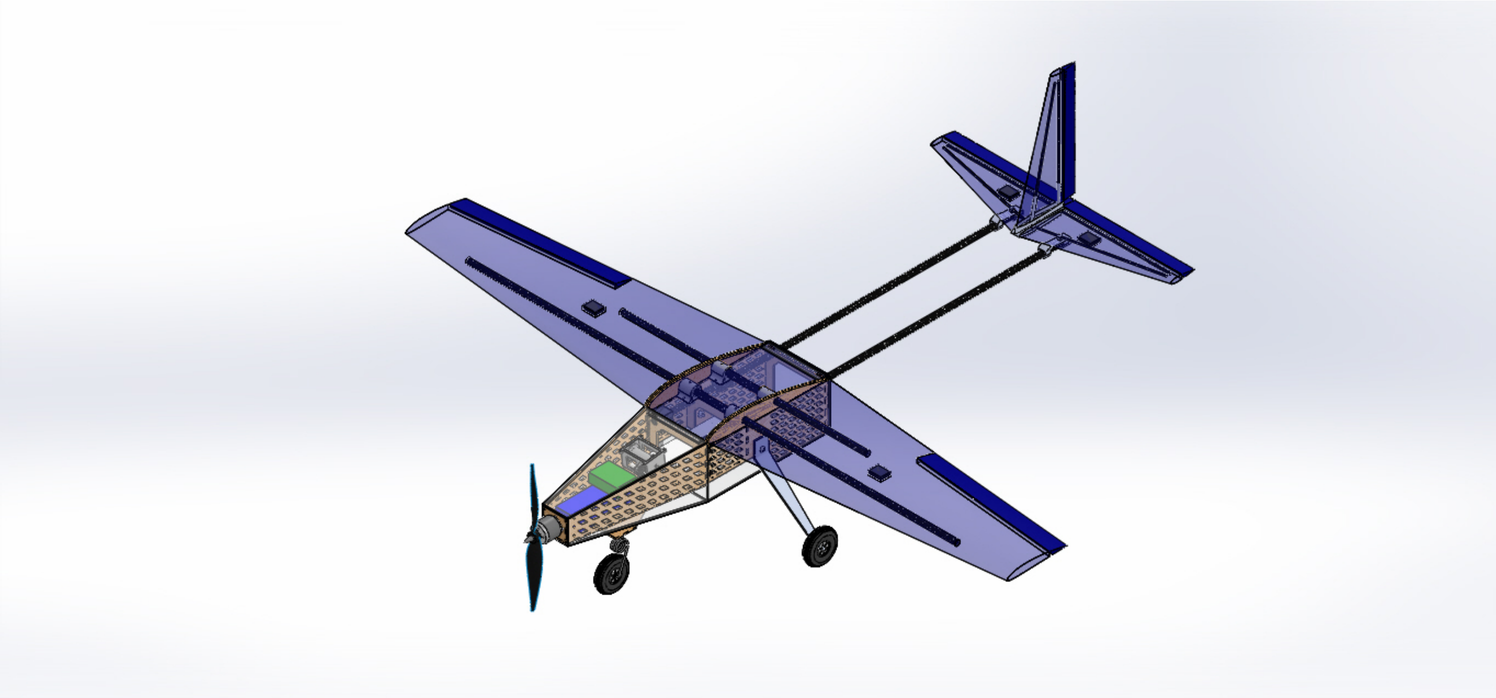


Figure 4 Rendering of the team's conceptual aircraft design.

IV.A Methodology

The team worked primarily in teams to design the airplane and systems involved. Due to a limited number of students, many tasks were carried out by individuals rather than groups. The design process involved communication of design changes to other sub-teams to ensure that changes in one system or design aspect did not negatively impact the work of another sub-team. Weekly meetings were held to discuss progress and communicate plans between the team members.

IV.A.1 Wing/Tail Design

Airfoil(s) The team considered several different airfoil shapes, namely

- NACA 4412
- NACA 6412
- Eppler 420
- Eppler 423
- Clark-Y

The initial design choice was the NACA 6412 because it provided lots of lift at low speeds, while also showing low lift-to-drag. Upon further analysis the team decided to use an Eppler 420 airfoil because it provided slightly more lift than the NACA 6412 while still maintaining a gentle stall (ie. CL did not drop off steeply with angle of attack). After reviewing reports from other teams during previous competitions, the team realized that the design speed was much too slow to be competitive, with the design speed being around 40 mph, and other teams having previously competed at 60+ mph. As a result, the team decided to seek out a wing that had less camber and thus would be able to fly at higher speeds while producing the same amount of lift as the previous design. Drawing on the experience of other winning teams, the team decided to study the Clark-Y. The flat bottom of the Clark-Y airfoil enables easier mounting of the wing to the fuselage. After simulating the design in XLFR5 using the Clark-Y airfoil on the main wing, the design speed increased. Thus, the Clark-Y airfoil became the airfoil of choice for the design.

Wing Sizing The wing was designed primarily to lift 10 lbs for the heaviest flight mission. The wing was decided to have a chord of 12 inches to increase the surface area and the total amount of lift. Due to the design requirement to have a wingspan of less than 5 feet, the wingspan is designed to be exactly 5 feet, and the team will adjust the manufactured wing accordingly to ensure compliance with the competition rules. To decrease the likelihood of tip stall, the wing tips have a three-degree washout relative to the root. To improve the amount of lift generated at an overall angle of attack of zero degrees, the whole wing is mounted at an angle of attack of three degrees relative to the fuselage. The first iteration had a three-degree dihedral to improve roll stability, but this was ultimately removed from the design because it increased the manufacturing complexity at the attachment point between the fuselage and the main wing. Instead, the wing was designed to have zero dihedral and to have a taper ratio of zero to improve manufacturability and design simplicity.

As the team continued to refine the wing design in XFLR5, the team tried changing the taper ratio. The team tried three different values, and chose the best of those three.

Table 1 The results of studying different taper ratios. These velocities correspond to the then current design.

Taper Ratio	Efficiency at AoA = 0°	Velocity at mass = 4945.9 grams
1.00	1.18	57.8 mph
0.75	1.18	59.3 mph
0.50	1.18	61.2 mph

Table 1 shows that they are all similarly efficient in level flight, and that the smaller taper ratio requires a slightly faster velocity, as expected due to the smaller surface area. Furthermore, analysis of the lift-to-drag ratio (see figure 5 shows that as the taper ratio is decreased, the lift-to-drag ratio is also increased and the peak moves to higher velocities.

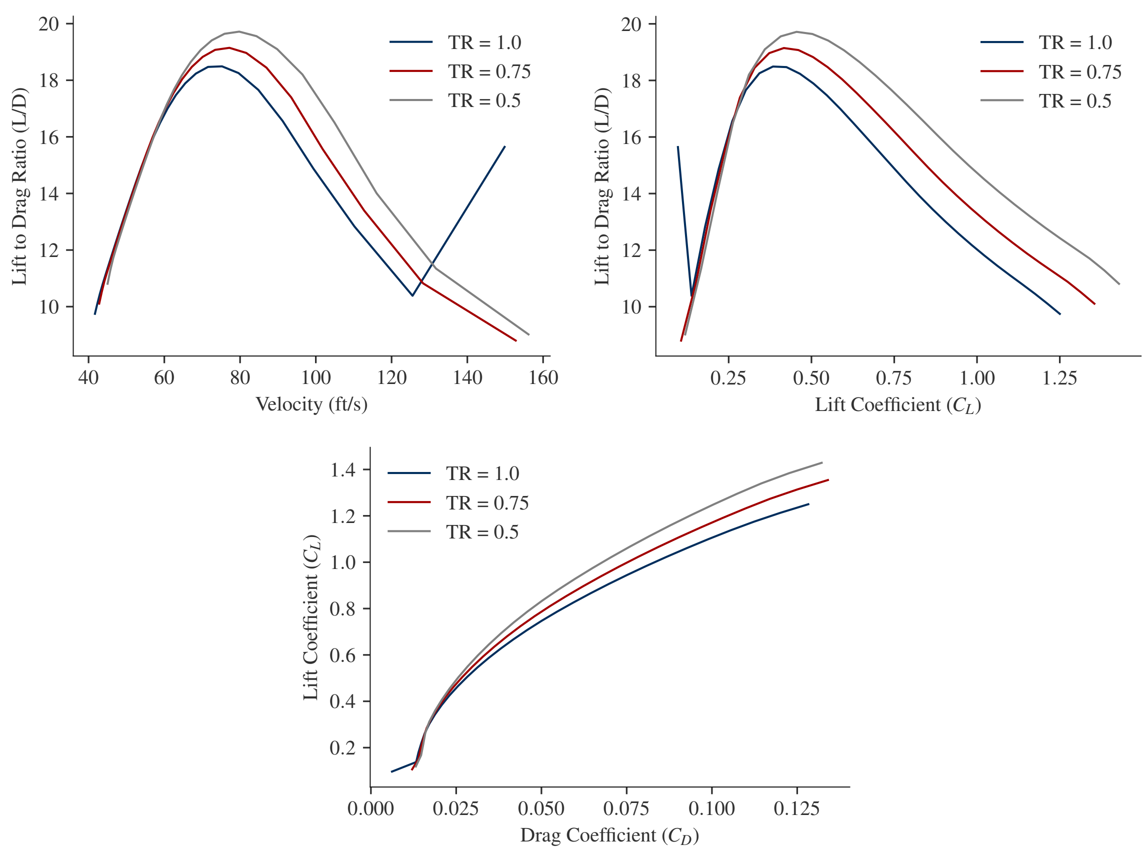


Figure 5 The effects of using different taper ratios for the main wing.

Tail The original choice of tail was a U-tail configuration, which initially seemed to follow naturally from the initial twin-boom design. After further discussion, this was deemed not necessary, and the team decided to use a conventional tail design.

As the team continued to refine the design in XFLR5, the team considered different tail sizes. Ultimately the team decided to use a conventional tail composed of three identical parts, two for the horizontal stabilizer and one for the vertical stabilizer. This increases the simplicity of the design. Three different sizes of this shape were considered, being named here as small, medium, and large. The following analyses were completed using a fixed distance between the leading edges of the wing and horizontal stabilizer of 1.00 meters. Each component had a taper ratio of 0.4, with a straight trailing edge. In table 2, the chord and span refers to the horizontal stabilizer. The vertical stabilizer has the same root chord and half the span because it is single-sided. Stability analyses ignored drag due to the fuselage and propeller.

After analyzing the results of this analysis, the large tail is undoubtedly the most stable for the airplane, but it also puts a lot of weight on the back of the airplane, necessitating some additional pushing forward of the other heavy components. The medium size also performs well, and combined with its smaller size it is deemed a more suitable tail for the current purposes. Therefore, of these three possibilities the team chose the medium tail.

Table 2

Tail Size	Root Chord (in)	Span (in)	Horizontal Tail Volume	Vertical Tail Volume
Small	3.94	15.75	0.28	0.04
Medium	5.91	23.62	0.57	0.06
Large	7.87	31.50	1.15	0.12

Table 3 shows the final sizing for the Wing and Tail of the preliminary design.

Table 3 Preliminary wing and tail sizes.

Parameter	Wing	Vertical Tail	Horizontal Tail
Span (ft)	5.00	2.00	2.00
Root Chord (ft)	1.00	0.50	0.50
Tip Chord (ft)	0.50	0.20	0.20
Wing Area (ft^2)	3.75	0.35	0.70
Aspect Ratio	6.67	5.71	5.71

IV.A.2 Propulsion

The propulsion system was designed upon a lithium-polymer battery with six cells in series. In order to fulfill the mission requirements effectively, the aircraft must cruise at a high airspeed and carry its maximum load during mission 2 and carry a significantly lighter load for missions 1 and 3. The team found that it was easier to implement an optimal motor-propeller combination to fulfill both of these missions using lithium-polymer setup with four cells in series. The team was able to decide upon a Turnigy 4240-470kv motor for the powerplant, and a different combination of propellers and batteries for each mission.

IV.A.3 Fuselage

The aircraft is subjected to specific mission requirements which depend on the fuselage of the aircraft to be able to be filled with a large quantity of shipping containers and be able to deploy a sensor pod out of the bottom of the aircraft. The team aims to carry less shipping containers, but have a large, heavy sensor pod. Because this requires a large payload area, the team developed and adopted the “box and bay” construction method, which has a designated, reinforced box which holds all the essential electronics towards the nose, and a large, open-bottom payload bay to hold the shipping containers behind it. Additionally, the payload bay is situated so that the center of gravity of installed shipping containers aligns with the center of gravity of the aircraft. The supporting structures, wings, landing gear, and tail booms are built around the box and bay which allows the aircraft to efficiently complete the three missions, while remaining strong and lightweight.

IV.A.4 Payload

Stability and Balance The pod body needs to be aerodynamically stable. This is achieved by balancing the sensor pod just like a typical aircraft. The pod electronics are fixed in place to prevent shifting, which would change the center of gravity mid-flight. The release/recovery portions of the mission are where the balance is critical, since any misalignment will alter the placement while recovering the pod.

The sensor pod needs to be towed from the center of gravity. Because it needs to be aerodynamically stable, the tow line must be aligned between the centers of gravity within the aircraft and towed sensor. If not, unwanted forces will be introduced to the system. Additionally, during testing, it was found that by towing the sensor pod via the nose caused it to "hang" or drag. It would become unstable at low velocities and completely uncontrollable at target velocity. As for the aircraft, unwanted forces would affect the aircraft during turning and other maneuvers.

The pod is kept stable aerodynamically by first balancing it as one would a typical aircraft. The other key feature is the four stabilizing fins located at the rear of the pod. They stick out from the pod body and are used to keep the pod straight in the air. They also are critical for helping the pod track straight and remain stable while in the recovery phase.

Winch Design The mission requirements state that the sensor must be fully deployed by the first 360° turn and needs to be recovered by the landing. As such, the winch mechanism needs to be strong and quick. This presents an interesting challenge, as speed and torque are usually mutually exclusive in light-weight designs. Most motor/servo setups considered were either high in speed or torque, but not both. The setup chosen was a compromise of the two. A 130-sized motor paired with a 250:1 gear reduction gave a middle range RPM of 220 and a stall torque of 3.2kg-cm. This will be more than enough torque to recover the sensor pod.

The motor will be paired to a reversible speed controller, controlled via the transmitter. A switch will determine when to stop and when to start, and the tow line marker gives a visible signal that the tow line is nearing the end. The tow housing is bolted to the underside of the top plate in the fuselage directly under the center of gravity. As explained previously, this is the optimum position to tow from, as it reduces the effect of unwanted forces. The housing is 3D printed and the tow line reel is held within. Being mounted upside-down, the sensor pod will release down through the bottom of the fuselage. There is a cradle that the pod will rest in during flight. In order to prevent the sensor becoming unstable due to twists in the wire, the tow line will pass through a swivel prior to entering the sensor pod. The tow line consists of 2 wires sheathed in silicone, allowing a true ground while still maintaining flexibility. The wire spool is hollow, allowing the wire to pass through it.

IV.B Estimated Aircraft Performance

IV.B.1 Performance Prediction Methodologies and Uncertainties

The aerodynamic performance of the lifting surfaces for the airplane was evaluated using XFLR5, which uses a vortex lattice model coupled with airfoil data generated using XFOIL to evaluate the performance of a design. The airfoil data include viscous effects. Due to the nature of XFLR5, and its sub-components, there is some moderate uncertainty in the analyses, mostly uncertainty in 3D coupled aerodynamics. Only flight testing will give us a complete picture, but history shows that the analysis tools used in XFLR5 are sufficiently accurate for preliminary analysis at this level.

IV.B.2 Lift and Drag

Table 4 shows the estimated lift and drag characteristics of the aircraft for the various flight missions.

Table 4 Estimated total lift and drag values.

Parameter	Mission 1	Mission 2	Mission 3
$C_{L_{\text{max}}}$	1.31	1.35	1.31
$C_{L_{\text{avg}}}$	0.38	0.38	0.38
C_{D_0}	0.021	0.018	0.019
L/D_{cruise}	17.9	21.4	19.4
Efficiency Factor (e)	0.994	0.994	0.994

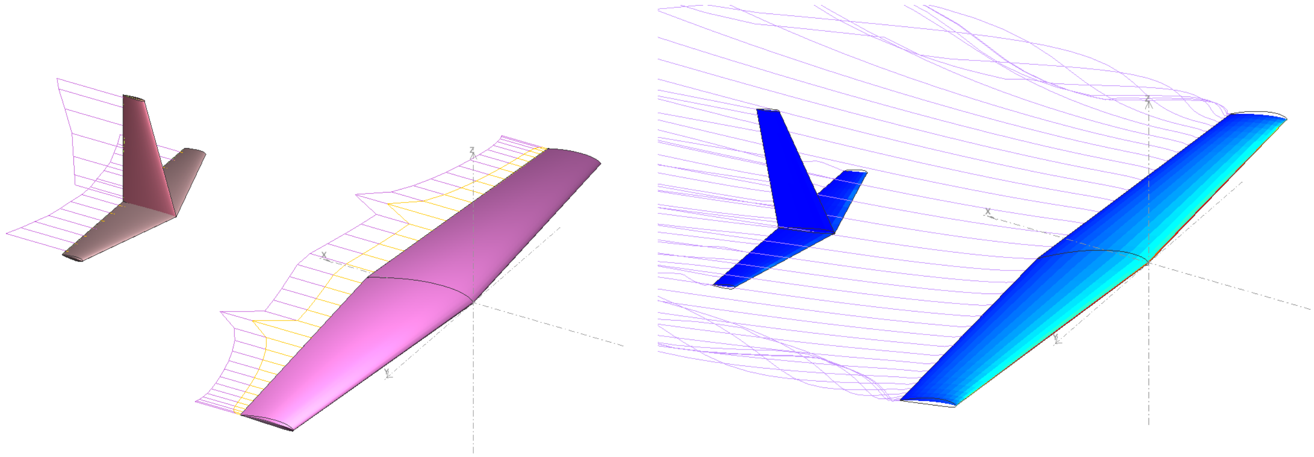


Figure 6 Views of the design in XFLR5. *Left:* Showing both induced and viscous drag components. *Right:* Showing the pressure distribution and streamlines at an angle of attack of 11°.

IV.B.3 Stability

Table 5 shows the stability derivatives output by XFLR5 for the nominal design, and table 6 and figure 7 show the eigenvalues for the various stability modes for each mission. These stability analyses were performed using a viscous analysis with the atmosphere properties set to values more similar to those in northern Utah, where the temperature is lower and altitude is greater than the original competition location in Tuscon, Arizona. For these analyses, only the drag due to the lifting surfaces was considered, omitting the drag due to the fuselage, landing gear, and deployed payload. Additionally, the mass of the landing gear was also ignored.

Table 5 XFLR5 Stability Derivatives

	Angle of Attack	V_C	Side Slip Angle	V_C	Roll Rate	V_C	Pitch Rate	V_C	Yaw rate	V_C
Lift Force	C_{L_α}	5.013	C_{L_β}	—	C_{L_p}	—	C_{L_q}	12.028	C_{L_r}	—
Drag Force	C_{D_α}	0.2011	C_{D_β}	—	C_{D_p}	—	C_{D_q}	—	C_{D_r}	—
Lateral Force	C_{Y_α}	—	C_{Y_β}	-0.379	C_{Y_p}	-0.034	C_{Y_q}	—	C_{Y_r}	0.4564
Rolling Moment	C_{ℓ_α}	—	C_{ℓ_β}	-0.035	C_{ℓ_p}	-0.462	C_{ℓ_q}	—	C_{ℓ_r}	0.1251
Pitching Moment	C_{m_α}	-2.60	C_{m_β}	—	C_{m_p}	—	C_{m_q}	-23.5	C_{m_r}	—
Yawing Moment	C_{n_α}	—	C_{n_β}	0.2189	C_{n_p}	-0.039	C_{n_q}	—	C_{n_r}	-0.260

Table 6 Dynamic stability characteristics.

	Mode	Eigenvalue		
		M1	M2	M3
Lon. Modes	Short Period (I)	$-7.64 \pm 9.85i$	$-8.14 \pm 15.7i$	$-7.68 \pm 12.2i$
	Phugoid (II)	$-0.0103 \pm 0.69i$	$-0.011 \pm 0.49i$	$-0.012 \pm 0.60i$
Lat. Modes	Roll (III)	$-22.59 \pm 0.00i$	$-34.88 \pm 0.00i$	$-27.3 \pm 0.00i$
	Dutch Roll (IV)	$-1.83 \pm 6.99i$	$-2.55 \pm 10.8i$	$-2.09 \pm 8.44i$
	Spiral (V)	$0.099 \pm 0.00i$	$0.066 \pm 0.00i$	$0.083 \pm 0.00i$

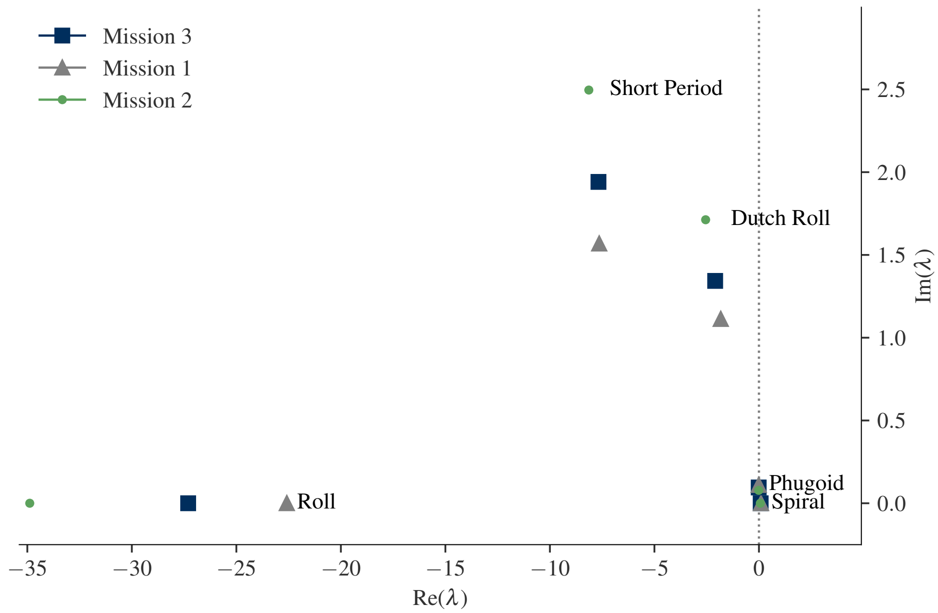


Figure 7 Root-locus plot for stability modes.

IV.B.4 Mission Performance

The estimated performance characteristics for each of the missions for the aircraft are shown in table 7.

Table 7 Estimated Mission Performance.

Parameter	Mission 1	Mission 2	Mission 3
Total Weight (lbs)	4.3	10.3	6.3
Wing Loading (lbs/ft^2)	1.14	2.74	1.67
V_C(mph)	36.9	57.1	44.7
Payload	Empty	3 Containers	1 Container

V Detail Design

V.A Dimensional Parameters

The full dimensional parameters for the current design are shown in table 8 with further details in the drawings package.

Table 8 Dimensional Parameters.

(a) Main Wing

Parameter	Value (units)
Airfoils	ClarkY
Span	5.0 (ft)
Root Chord	1.0 (ft)
Tip Chord	0.5 (ft)
Aspect Ratio	6.664
Dihedral	0.0 (°)
Incidence Angle	3.0 (°)

(b) Horizontal Tail

Parameter	Value (units)
Airfoil	NACA 0009; NACA 0018
Span	2.0 (ft)
Root Chord	0.5 (ft)
Tip Chord	0.2 (ft)
Aspect Ratio	5.71

(c) Vertical Tail

Parameter	Value (units)
Airfoil	NACA 0009; NACA 0018
Span	1.0 (ft)
Root Chord	0.5 (ft)
Tip Chord	0.2 (ft)
Aspect Ratio	5.71

(d) Fuselage

Parameter	Value (units)
Total Length	2.0 (ft)
Nose Length	1.0 (ft)
Tail Length	1.0 (ft)
Width	0.5 (ft)
Height	0.6 (ft)

(e) Propulsion

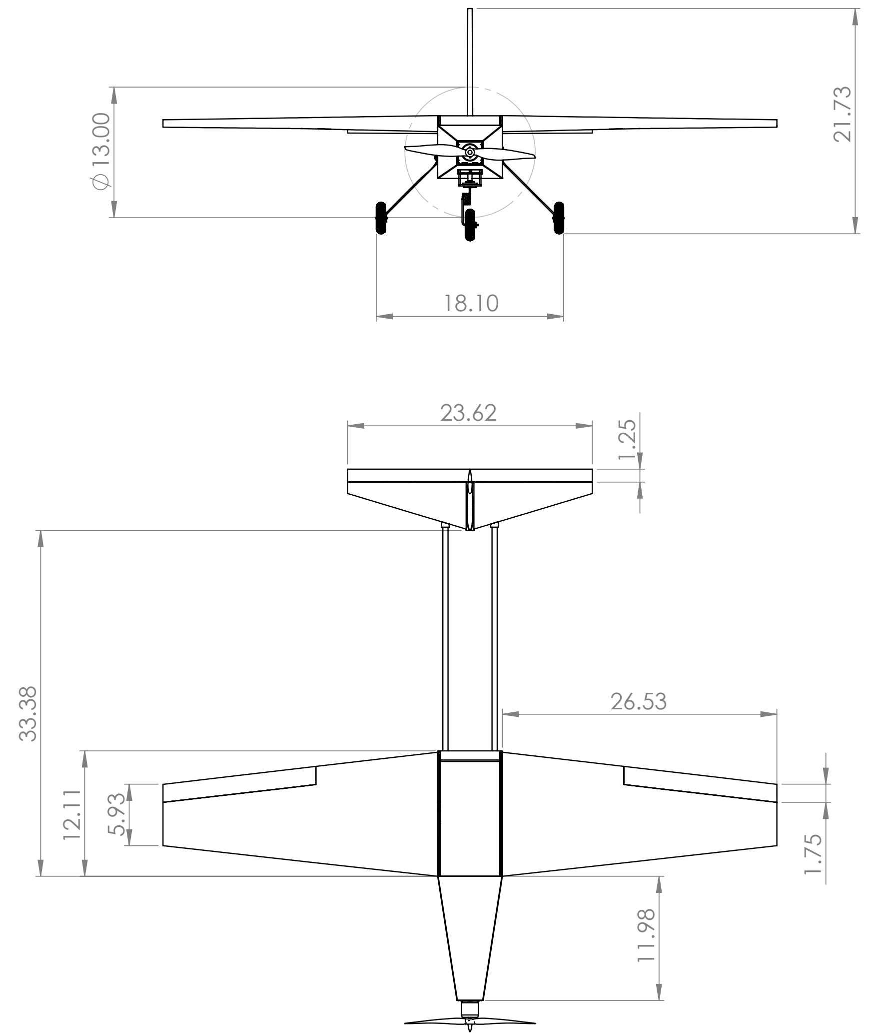
Parameter	Value (units)
Motor	Turnigy SK3 4240
Kv	740 (RPM/V)
No-Load Current	2.89 (A)
Internal Resistance	0.013 (Ω)
Propeller	Master Airscrew Electric 12 × 9 and MAe 13 × 8.5

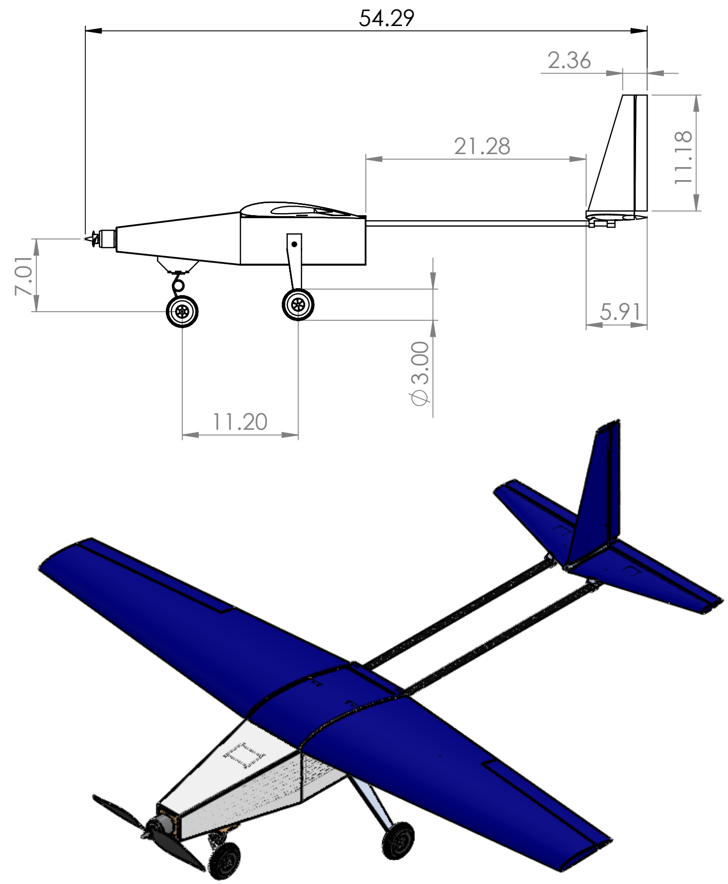
(f) Controls

Parameter	Value (units)
Transmitter	FrSky Taranis X9
Receiver	FrSky X8R
Servos	Emax ES3054 17g
Flight Controller	EagleTree Vector

V.B Drawing Package

The following are drawings including a 3-View drawing with dimensions of all configurations, a structural arrangement drawing, a systems layout/location drawing, and payload accommodation drawings.





	NAME	DATE
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DIMENSIONS ARE IN INCHES

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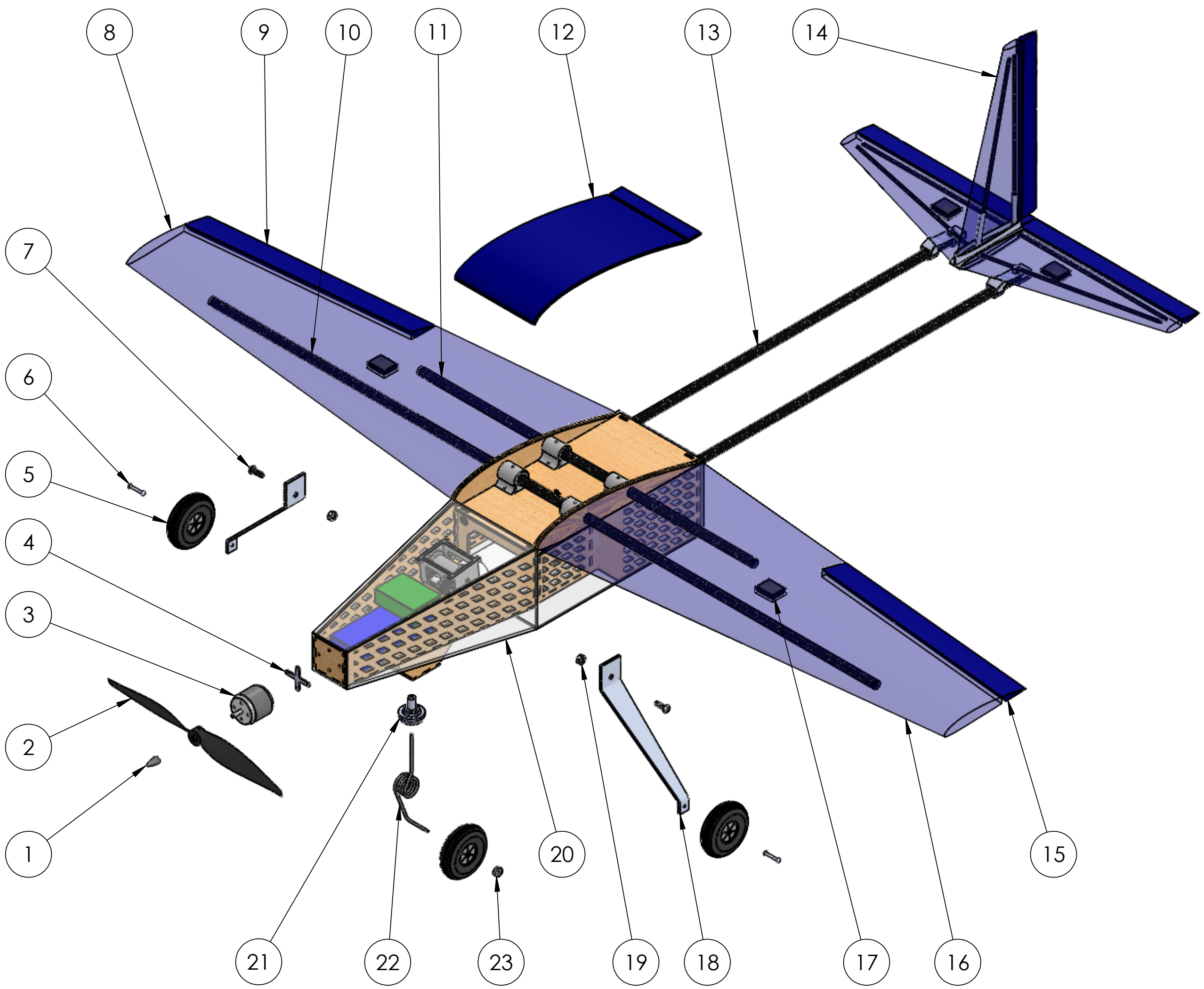
SIZE	DWG. NO.	REV
B	Assembly Drawing 1	1
SCALE: 1:12	Drawing Package	SHEET 1 OF 3



ITEM NO.	COMPONENT	DESCRIPTION	QTY.
1	Nosecone	Plastic	1
2	Propeller	Plastic	1
3	Motor	Miscellaneous	1
20	Fuselage Cover	Foam	1
5	Wheel	Plastic	3
6	Axel	Aluminium	2
7	Button Hex Screw	Stainless Steel	2
9	Right Wing Aileron	Foam	1
11	Rear Wing Spar	Carbon Fiber	1
8	Right Wing	Foam	1
12	Wing Center Cover	Plastic	1
14	Tail Assembly	Miscellaneous	1
15	Left Wing Aileron	Foam	1
16	Left Wing	Foam	1
18	Landing Gear Bracket	Aluminium	1
21	Nose Gear Mount	Plastic	1
22	Spring	Aluminium	1
4	Motor Mount Bracket	Aluminium	1
13	Boom	Carbon Fiber	2
10	Front Wing Spar	Carbon Fiber	1
19	Hex Nut	Steel	2
23	Set Screw Mount	Steel	1
17	Servo Motor	Miscellaneous	4

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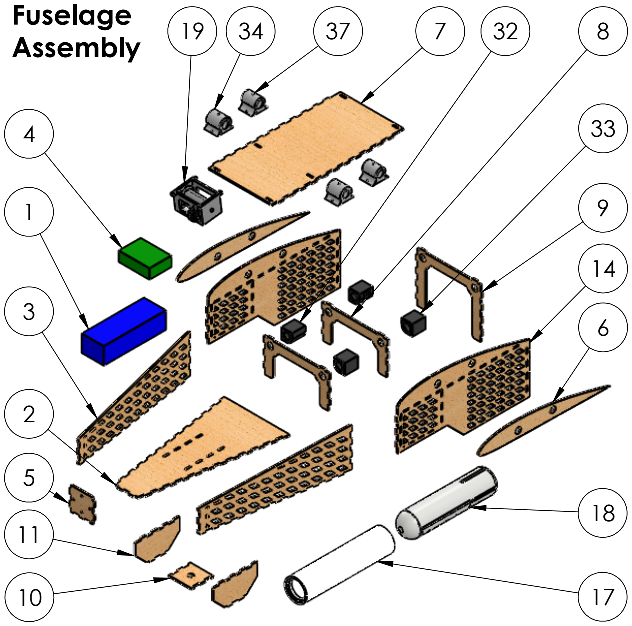
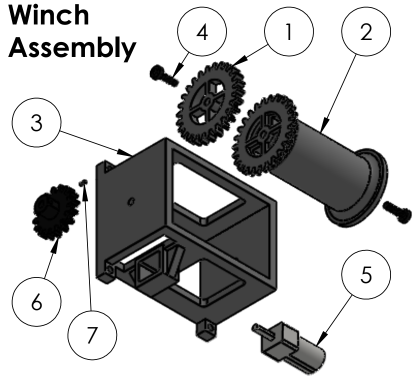
SCALE: 1:6 | Drawing Package | SHEET 2 OF 3

Fuselage Assembly



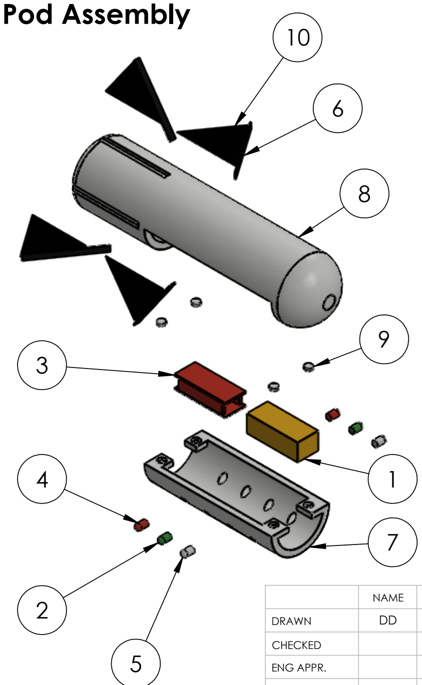
ITEM NO.	COMPONENT	DESCRIPTION	QTY.
1	Battery	Miscellaneous	1
2	Box Bottom	Balsa Wood	1
3	Box Side Wall	Balsa Wood	2
4	ESC	Miscellaneous	1
5	Firewall	Balsa Wood	1
6	Fusalage Wing Mount	Balsa Wood	2
7	Fuselage Top	Balsa Wood	1
8	Interior Wall 1	Balsa Wood	2
9	Interior Wall 2	Balsa Wood	1
10	Landing Gear Box	Balsa Wood	1
11	Landing Gear Mount	Balsa Wood	2
14	Fuselage Side	Balsa Wood	2
17	Shipping Container	PVC	1
18	Spring Pod Assembly	Miscellaneous	1
19	Winch Assembly	Plastic	1
32	Boom Support 1	Plastic	2
33	Boom Support 2	Plastic	2
34	Main Spar Mount	Plastic	2
37	Secondary Spar Mount	Plastic	2

Winch Assembly



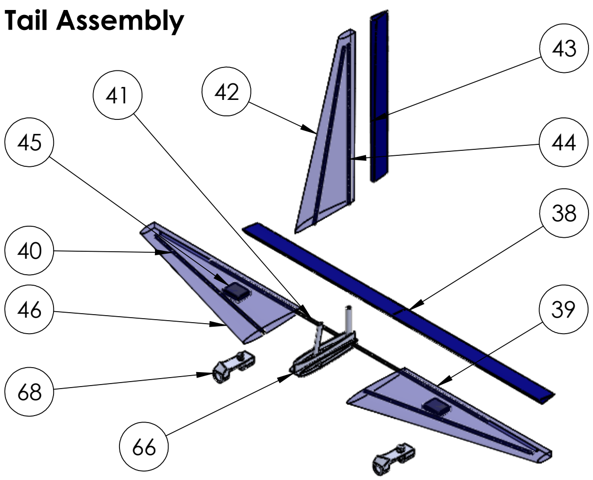
ITEM NO.	COMPONENT	DESCRIPTIO N	QTY.
1	Spur Gear	26 Teeth	1
2	Winch	Plastic	1
3	Winch Housing	Plastic	1
4	Socket Screw	Steel	2
5	Geared Motor	Misc.	1
6	Spur Gear	16 Teeth	1
7	Set Screw	M1.6x0.35	1

Pod Assembly



ITEM NO.	PART NUMBER	DESCRIPTIO N	QTY.
1	2S 350mah Lipo	Misc.	1
2	Green LED	LED	2
3	PCB	Misc.	1
4	Red LED	LED	2
5	White LED	LED	2
6	Spring Rod	Plastic	4
7	Pod Bay	PVC	1
8	Main Pod Housing	PVC	1
9	6mm Magnet	Neodymium	4
10	Stabilizer	Fabric	4

Tail Assembly



ITEM NO.	COMPONENT	DESCRIPTION	QTY.
38	Horizontal Stabalizer	Foam	1
39	Left Tail	Foam	1
40	Main Tail Spar	Carbon Fiber	3
41	Secondary Tail Spar	Carbon Fiber	1
42	Vertical Tail	Foam	1
43	Vertical Stabalizer	Foam	1
44	Vertical Tail Spar	Carbon Fiber	1
45	Servo Motor	Miscellaneous	4
46	Right Tail	Foam	1
66	Tail Attatchment	Plastic	1
68	Boom Attatchment	Plastic	2

	NAME	DATE
DRAWN	DD	2/12/21
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MFG APPR.		
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COMMENTS:		

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SIZE B | DWG. NO. Subassemblies | REV 1

SCALE: 1:8 | Design Package | SHEET 3 OF 3

VI Manufacturing Plan

VI.A Wing Manufacturing Process Selection

The wings of the prototypes will be composed of hotwire cut foam that is connected by a spar assembly fastened in the center for the desired angle. On the final product, the wings will be manufactured from laser-cut balsa wood.

VI.B Fuselage Manufacturing Process Selection

The fuselage will be composed of a laser-cut plywood structural box that has mounting locations for shipping containers during transport and for the winch that will deploy and recover the sensor pod. The box will provide structural support for the wing mounts, tail boom mounts, landing gear, and firewall. A foam board shell will be used to cover the box and enclose the payload during each mission. The foam shell will not be structural.

VI.C Sensor Pod Manufacturing Process Selection

The sensor pod is made of a 1 inch diameter PVC pipe cut to 12 inches. This is because PVC is strong, easily available, and economically viable. Carbon fiber would be a great substitution for this design, but lacks the ability to easily cut and fabricate. The nose cone for the pod is 3D printed and sits in the pipe. It is epoxied in place in order to keep the electronics contained within their respective places. The fins at the rear are made of polycarbonate because of the light weight, they are not expensive, and easy to manufacture. Slots were milled in the PVC such that the fins can slide into them and will be epoxied into place. The sensor electronics are placed within the electronics bay and will be held in place via magnets. Electronics were chosen carefully after considering the design requirements. A team member developed a shield for an Arduino nano which can be programmed with the pattern that the LEDs flash in. The program also can be set up such that the release/recovery can be completely automated. A 2 cell 350mAh lithium-polymer battery powers the sensor pod.

VII Testing Plan

VII.A Completed Testing

The team tested the first payload prototype in a wind tunnel. The data collected showed that the pod was unstable below the target velocity, which was unacceptable. In that testing scenario, the team tested various towing points on the sensor pod. The team found that towing from the center of gravity provided optimum stability. Additionally, it was found that the electronics inside needed to be stable, i.e. not shift during flight as that would upset the balance of the pod.

The team tested two different sizes of pods as well. The team found that the larger pod was stable to a higher wind speed than the smaller pod. This was likely due to the larger surface area of the stabilizing fins. This was factored in when designing the final prototype, where the team wanted to have large stabilizing fins in order to maximize stability. After analyzing the results of the wind tunnel, the team decided to modify the nose cone from a circular and flat nose cone to a much more circular and rounded one. The team wanted to reduce drag at the front of the pod and found that a rounded nose cone was much more aerodynamic.

The electronics were selected after testing the brightness of the LEDs. They will be sufficiently bright to be seen in bright sunlight. The pod will be painted in such a way that the lights cannot be mistaken. The battery contained within exceeds the power requirements to sustain the payload electronics. This was done because the team wanted to make sure that there is enough capacity in case something unexpected happens.

VII.A.1 Ground Testing

As of the submission of this report, the team has completed little actual testing of the physical components of the airplane.

VII.A.2 Flight Testing

The team has completed flight tests with a half-scale model of the airplane constructed from foam board. The lifting surfaces resemble those from the original design featuring wide twin booms and a U-tail configuration. Testing indicates that the original design was stable.

VII.B Planned Testing

The team is currently working on construction of the first full-scale prototype, with the intent to complete and fly it within one week of submitting this report. Current progress is shown in figure 8.

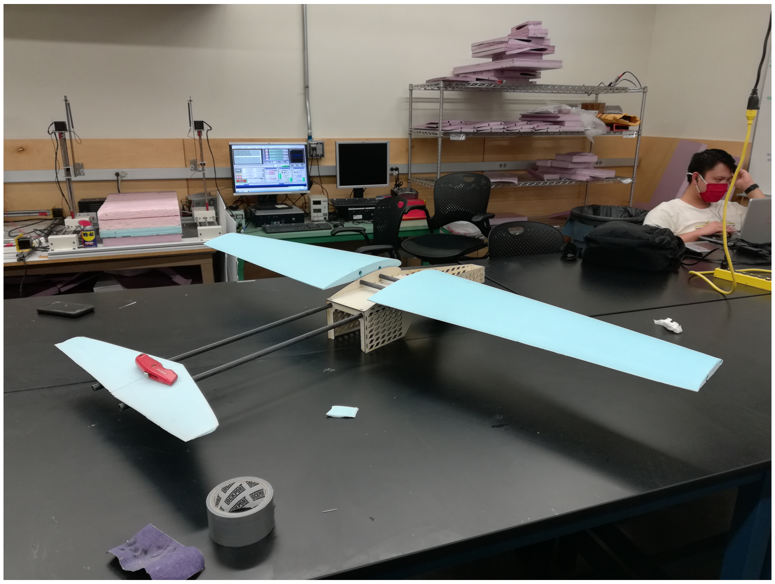

Figure 8 A view of the current build status

VII.C Test and Flight Checklists

Table 9 shows the pre-flight inspection checklist.

Table 9 Pre-flight Inspection Checklist

Component		Task
Propulsion	☐	Propeller is balanced and free of visible damage
	☐	Propeller is securely fastened to motor shaft
	☐	Motor is free of visible damage and rotates smoothly
	☐	Motor is securely fastened to airframe
	☐	Wired connections are undamaged, unexposed, and fit securely
	☐	Safety fuse/arm switch are undamaged, secured, and fully functional
	☐	ESC is functional and properly connected
	☐	Battery is fully charged and properly shaped (not puffy)
Fuselage	☐	Internal components are secure and fuselage is free of debris
	☐	Landing gear is securely attached an
	☐	Fuselage is free of damage at all attachment locations
	☐	All component wiring/connections are correct and secure
Wing & Tail	☐	Wing and tail surfaces are damage free
	☐	Control linkages are secure with minimal play
	☐	Control surfaces are secure and move smoothly and freely
	☐	Wing and tail are securely mounted to fuselage
	☐	Wing and tail attachment points are without damage
Controls	☐	Transmitter arm/disarm switches are functional
	☐	Receiver and flight controller are connected, secured, and functioning
	☐	Control surfaces appropriately respond to control inputs
	☐	Pilot is aware of control mixes and levels
	☐	Throttle appropriately responds based on arm/disarm settings