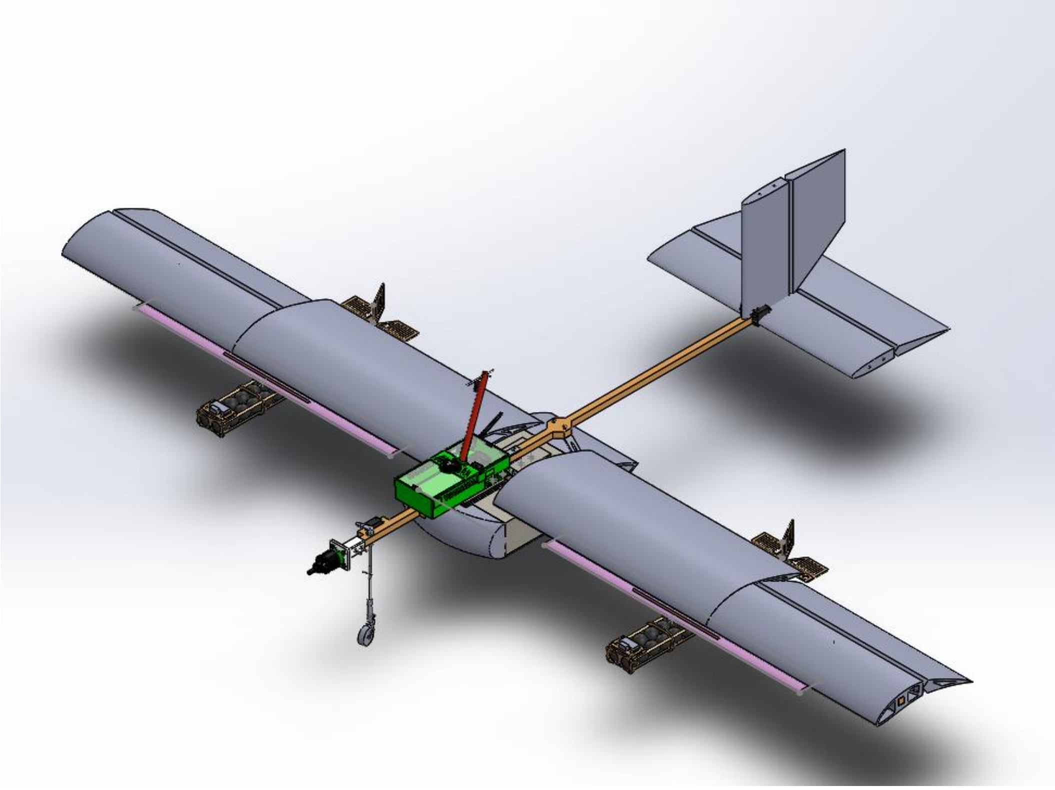
Kennesaw State University Aerial Robotics Team

Team 220



Name	Role
Joel Morel	Team Captain and Lead Electronics Engineer
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STATEMENT OF COMPLIANCE

Certification of Qualification

Team Name	Kennesaw State Aerial Robotics	Team Number	220
School	Kennesaw State University		
Faculty Advisor	Dr. Adeel Khalid		
Faculty Advisor's Email	akhalid2@kennesaw.edu		

Statement of Compliance

As faculty Adviser:

AK (Initial) I certify that the registered team members are enrolled in collegiate courses.

AK (Initial) I certify that this team has designed and constructed the radio-controlled aircraft in the past nine (9) months with the intention to use this aircraft in the **2020** SAE Aero Design competition, without direct assistance from professional engineers, R/C model experts, and/or related professionals.

AK (Initial) I certify that this year's Design Report has original content written by members of this year's team.

AK (Initial) I certify that all reused content have been properly referenced and is in compliance with the University's plagiarism and reuse policies.

AK (Initial) I certify that the team has used the Aero Design inspection checklist to inspect their aircraft before arrival at Technical Inspection and that the team will present this completed checklist, signed by the Faculty Advisor or Team Captain, to the inspectors before Technical Inspection begins.

[signature]	01/21/2020
Signature of Faculty Advisor	Date
[signature]	01/21/2020
Signature of Team Captain	Date

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Table of Acronyms

CDA…………………………………………………………………………Colonist Delivery Aircraft

CFD…………………………………………………………………Computational Fluid Dynamics

CNC……………………………………………………………………..Computer Numeric Controlled

FEA…………………………………………………………………………Finite Element Analysis

KSUARCT………………………………Kennesaw State University Aerial Robotics Competition Team

KSU…………………………………………………………………………Kennesaw State University

SAE…………………………………………………………………...Society of Automotive Engineering

FPV……………………………………………………………………...…………First Person View

GPS……………………………………………………………………….....Global Positioning System

AOA………………………………………………………………….…………..…..Angle Of Attack

EWT…………………………………………………………………………..Educational Wind Tunnel

CG……………………………………………………………………………...………...Center Of Gravity

1. Executive Summary

This year serves as the second year that the Kennesaw State University Aerial Robotics Competition Team (KSUARCT) will be competing in the Society of Automotive Engineering (SAE) Aero Design East Division in the advanced class category. The purpose of the advanced class division is to construct a large size bomber-type aircraft and a small size Colonist Delivery Vehicle (CDA). The Bomber and CDA are designed and fabricated to achieve the goals set by the competition rulebook. The large bomber aircraft will carry releasable payloads, an FPV camera, and altitude-logging capable equipment. The CDA will be capable of a glide ratio of four and safely reach its destination without tripping the shock sensors onboard.

The design approach for this year has been to ensure the bomber will successfully takeoff, fly, release the CDA, release the other releasable payloads, and land. This marks a design philosophy change within the team, where we are more focused on reliability and verified performance than experimental design concepts. It is projected that the CDA will be able to glide to the target zone assuming it was released from the bomber at the appropriate time window. After reviewing the capabilities of the personnel on the team and the content covered in the university's aerospace minor, an organizational shift from prioritizing calculations and simulations to physical testing data was made. Therefore, this paper is more experimental data focused than calculation focused as previous years have been.

KSUARCT finds that the competition plane is within the SAE Aero Design rules [1], and within the team and university's general and specific goals. The team would like to thank Kennesaw State University (KSU), SAE, and our faculty advisor, Dr. Adeel Khalid for their support, and enabling us to compete in the SAE Aero Design East 2020 Event in Lakeland, Florida.

2. Schedule Summary

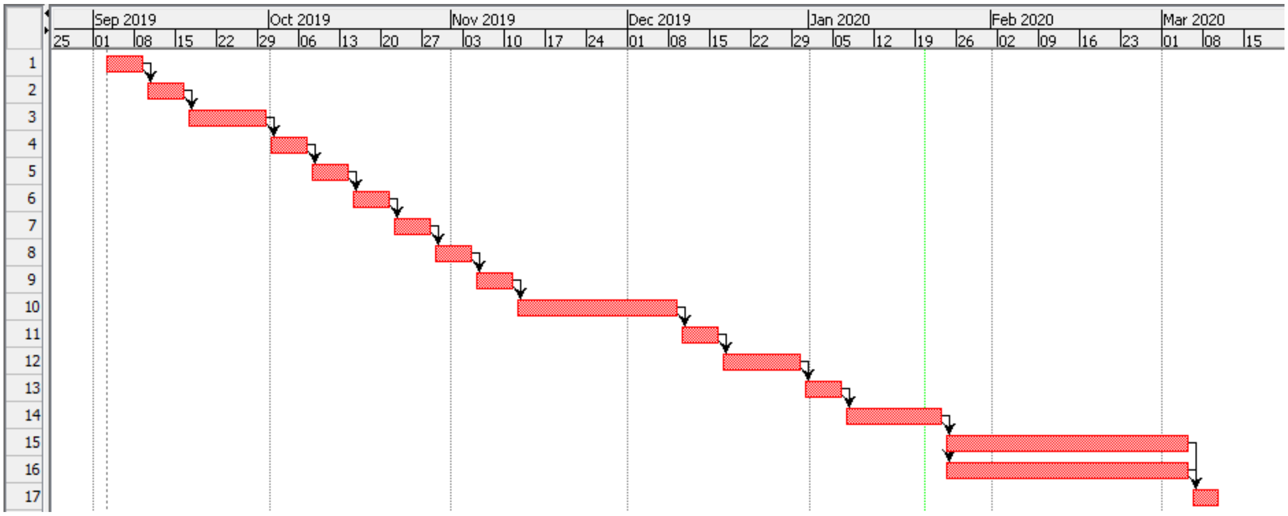

Figure 1. Gantt chart showing the team's progress over the competition season.

Table 1. Written Gantt chart for timeline clarification

	Name	Duration	Start	Finish	Pred.
1	Rule and Strategy Analysis	5 days	9/3/2019	9/9/2019	-
2	Preliminary Design	5 days	9/10/2019	9/16/2019	1
3	Trade Studies	10 days	9/17/2019	9/30/2019	2
4	Initial Design Revisions	5 days	10/1/2019	10/7/2019	3
5	Initial Design Prototype Manufacturing	5 days	10/8/2019	10/14/2019	4
6	Prototype Testing	5 days	10/15/2019	10/21/2019	5
7	Design Review and Analysis	5 days	10/22/2019	10/28/2019	6
8	Design Revisions	5 days	10/29/2019	11/4/2019	7
9	Secondary Prototyping Manufacturing and Testing	5 days	11/5/2019	11/11/2019	8
10	Final Design Review and Analysis	15 days	11/12/2019	12/9/2019	9
11	Final Design Revisions	5 days	12/10/2019	12/16/2019	10
12	Final Prototype Manufacturing	5 days	12/17/2019	12/30/2019	11
13	Final Prototype Testing and Optimization	5 days	12/31/2019	1/6/2020	12
14	SAE Design Report	13 days	1/7/2020	1/23/2020	13
15	Competition Aircraft Manufacturing	30 days	1/24/2020	3/5/2020	14
16	Practice Flights	30 days	1/24/2020	3/5/2020	14
17	SAE Competition	3 days	3/6/2020	3/10/2020	15;16

The team began first preparing for this competition's aircraft over the summer based off the prior years' experience. Basic designs were started and planned for, but the entire process fully activated once the fall semester began and the whole team, plus new members, were assembled. For the mechanical and structures team, prototypes were made from the very beginning with the first ideas for testing and the team used the results from those tests to move forward with new designs. The airfoil had been decided during the summer and, minus a few weight reductions changes, were able to be used for all the tests to allow for the focus to be on the frame and various components of the aircraft. Some alterations were made simultaneously and then added to the overall aircraft as they reached completion. Compared to the progress and time ratio that was seen last year, this year saw significant improvement. The designs were completed earlier which allowed for more testing and prototypes, and significant frame design changes allowed for cheaper prototyping. For a significant portion of the testing, price was a large factor in decisions, so the team produced more prototypes for a reduced cost which allowed an increase in the number of tests able to be performed.

3. Environment and Requirement Review

3.1 Environmental Considerations

The differences between Standard Day and Lakeland, Florida environment based off historical data are as follows [2,3]:

Table 2. Environmental Considerations Table of Data

	Air Density (Slugs/ft^3)	Temperature (F)	Pressure (lbf/ft^2)
Standard Day	0.002377	59	2116
Lakeland, Florida	0.002317	66	2133
Average Percent Difference	2.56%	11.2%	0.80%

Another environmental consideration that is looked at is wind. Following a review of historical weather data for Lakeland, Florida, wind during the competition could range from zero to eleven miles per hour. As a way of compensating for this, the Bomber cruise speed was set to be at fifty feet per second to be able to handle a twenty mile per hour head wind.

3.2 Competitive Scoring and Strategy Analysis

In order to begin creating a scoring strategy the team decided that our amount of static payload would be the remaining weight that the team felt comfortable adding on to the plane after considering the supply payloads and frame weight. After making this decision, the next step was to decide how many payloads the team would bring.

Table 3. Score analysis

	w	16.9	33.8	50.7	67.6	84.5	101.4	118.3	135.2
h		1	2	3	4	5	6	7	8
1		10.2496	10.2496	10.2496	10.2496	10.2496	10.2496	10.2496	10.2496
2		29.7482	29.7482	29.7482	29.7482	29.7482	29.7482	29.7482	29.7482
3		31.5998	43.5753	43.5753	43.5753	43.5753	43.5753	43.5753	43.5753
4		31.5998	52.8904	52.8904	52.8904	52.8904	52.8904	52.8904	52.8904
5		31.5998	54.5609	59.4534	59.4534	59.4534	59.4534	59.4534	59.4534
6		31.5998	54.5609	64.2925	64.2925	64.2925	64.2925	64.2925	64.2925
7		31.5998	54.5609	65.6484	67.9966	67.9966	67.9966	67.9966	67.9966
8		31.5998	54.5609	65.6484	70.9186	70.9186	70.9186	70.9186	70.9186
9		31.5998	54.5609	65.6484	72.0406	73.2803	73.2803	73.2803	73.2803
10		31.5998	54.5609	65.6484	72.0406	75.2278	75.2278	75.2278	75.2278
11		31.5998	54.5609	65.6484	72.0406	76.1801	76.8608	76.8608	76.8608
12		31.5998	54.5609	65.6484	72.0406	76.1801	78.2494	78.2494	78.2494
13		31.5998	54.5609	65.6484	72.0406	76.1801	79.0747	79.4444	79.4444
14		31.5998	54.5609	65.6484	72.0406	76.1801	79.0747	80.4837	80.4837
15		31.5998	54.5609	65.6484	72.0406	76.1801	79.0747	81.2113	81.3956
16		31.5998	54.5609	65.6484	72.0406	76.1801	79.0747	81.2113	82.2022
17		31.5998	54.5609	65.6484	72.0406	76.1801	79.0747	81.2113	82.8525
18		31.5998	54.5609	65.6484	72.0406	76.1801	79.0747	81.2113	82.8525
19		31.5998	54.5609	65.6484	72.0406	76.1801	79.0747	81.2113	82.8525
20		31.5998	54.5609	65.6484	72.0406	76.1801	79.0747	81.2113	82.8525

After analyzing Table 3 above, the team found that the optimum payload layout was to drop two nerf footballs and one 16.9 oz. water bottle. This is what the team determined to be a “payload set.” After determining this “payload set” the team began to examine how different payload sets score in comparison to the number of colonists dropped. The team did this originally in a table like the table above, however, as the size of this table was large and could not be fully realized in a document like this, the team have created a simplified version below. The number of colonists chosen reflects the number of CDAs dropped as each CDA consists of 28 colonists. In this calculation, the team also observed diminishing returns in both adding payload sets without adding more colonists and adding more colonists without adding more payload sets. These diminishing returns would eventually turn negative and take away from our total score. The max number of payloads sets by number of colonists is shown on the left-most column of Table 4, as well as the max number of colonists by payload sets in the bottom most row. These scores also consider the amount of static payload the team could be carrying. The static payload amount for the purpose of this table takes the max carry weight of the aircraft (determined to be 23 lbs.) and subtracts the frame weight in order to give a potential payload weight. From this point, the weight of each payload set is subtracted (estimated using scales to equal about 1.424

lbs. per set) from the potential payload weight and the remainder is used as the static payload weight. For easy reference, the assumed static payload weight is given by payload set in Table 4.

Table 4. Payload Set Analysis

# of Colonists Dropped	Score w/ 1 Payload Set	Score w/ 2 Payload Sets	Score w/ 3 Payload Sets	Score w/ 4 Payload Sets	Score w/ 5 Payload Sets	Max # of Payload Sets before score begins to decrease
28 (1 CDA)	41.34	61.07	69.07	72.29	73.19	5
42 (1.5 CDA)	36.29	66.55	83.11	92.20	97.25	8
56 (2 CDA)	30.09	65.68	89.93	105.15	114.87	10
84	20.95	55.57	90.02	116.10	135.19	15
Static Payload Weight (lbs.)	6.80	5.09	3.39	1.68	0	
Max # of Colonists before score begins to decrease	23	46	69	92	115	

For the purposes of the design, the team decided to build a CDA that could carry as many colonists as possible and then proceed to create a payload system that could meet the needs of the CDA. The team eventually developed a CDA that could house 28 colonists and began to optimize the releasable payload system. The team soon found that the team could only fit two standard payload sets into the payload system at a time. This immediately ruled out dropping three CDAs as odds were that it would ultimately hinder performance. Dropping only two payloads would have no negative effects on the score if the team could drop an average of 1.5 CDAs per round; however, the team intends for every CDA to land and therefore would prefer an average of three sets dropped per round. After examining this issue, the team discovered that the team could drop an average of three payload sets per round by mixing the amount of each the team drop per round. This would give an average of three sets dropped per round over the course of two rounds. Therefore, the team decided on the competitive scoring strategy to drop an average of six footballs, three water bottles, and two CDAs per round while dropping either more footballs or water bottles each round in order to achieve this target average.

4. Risk and safety

When determining the safety of the aircraft, team, and surrounding environments, many precautions were taken to ensure that all risk was as low as reasonably achievable. Table 5 lists risks along with important criteria and mitigation/responses to those risks.

Table 5. Risk Analysis

	Risk Desc.	**Likelihood**	**Severity**	**Mitigation/Response**
Aircraft	Loss of Motor	Unlikely	Moderate	Motor and all other electronics are on separate batteries, so a loss of motor power does not mean loss of aircraft control. Aircraft can be glided down to safety.
	Loss of Transmitter	Unlikely	Catastrophic	Aircraft transmitter and receiver have been field tested to prove that signal strength has more than enough range for the SAE competition. Transmitter battery is always monitored for acceptable battery power.
	Loss of All Power	Unlikely	Catastrophic	All electrical components are checked before flight at least three times and with both visual and powered tests to ensure proper operation.
	Damage to Electronics in a Crash	Seldom	Moderate	Team maintains spare electronics to replace damaged electronics. Team has also designed a Blackbox that successfully protects all electronics. In addition, with the specific design of the safety plugs harness in the event of a crash the impact would cause an immediate disconnection of power
	Damage to aircraft in a Crash	Occasional	Minor	Team maintains many spare components to replace damaged aircraft parts, and all parts are easily replaceable.
Personnel	Aircraft Strikes Person	Seldom	Critical	All team members wear PPE and the aircraft wings are built from a foam that would break upon significant impact.
	Aircraft Component Drops During Flight	Seldom	Moderate	All components are checked via a checklist to ensure that everything is properly secured.
Environment	Aircraft Crashes into Building	Unlikely	Minor	The aircraft is flown at an airfield where few buildings are present.
	Aircraft Crashes and Catches on Fire	Unlikely	Catastrophic	Test flights have at least five team members involved who each have quick access to many fire extinguishers.

All flight test took place at the Cobb County Radio Control Club Field in Acworth, GA, where there is plenty of space for testing and control of the surrounding environment. When determining cost risk, the cost of each aircraft was mostly tied to the cost of electronics, so the creation of a battery box eliminates most of the cost risk. The airframes and wings take little cost and time to build, so a crash only sets the team back about fifty dollars. Scheduling risks are also minimal as each aircraft takes less than twenty-five manhours to construct from beginning to end. Also, in the event of aircraft crashing, the team is never set back on schedule as the team expects the aircraft to crash each time, and properly schedules rebuild times. Due to the rapid manufacturing and design change processing that the team follows, each aircraft features some design change that is different from its predecessor, so we do not expect the aircraft to be used for more than one flight-test day, or about five flight tests.

5. Engine

Prop Manf.	Prop Size	Input Voltage	Motor Amps	Watts Input	Prop RPM	Pitch Speed	Thrust Grams	Thrust Ounces	Thrust Eff. Grams/W
APC	16x10-E	22.2	25.11	557.4	5,654	53.5	3113	109.81	5.58
APC	16x12-E	22.2	31.51	699.5	5,426	61.7	2631	92.80	3.76
APC	17x8-E	22.2	24.94	553.7	5,662	42.9	3399	119.89	6.14
APC	17x10-E	22.2	30.12	668.7	5,474	51.8	3493	123.21	5.22
APC	17x12-E	22.2	33.84	751.2	5,344	60.7	3424	120.78	4.56
APC	18x8-E	22.2	25.98	576.8	5,622	42.6	3772	133.05	6.54
APC	18x10-E	22.2	30.62	679.9	5,459	51.7	4001	141.13	5.89
APC	18x12-E	22.2	42.43	941.8	5,053	57.4	3785	133.51	4.02
APC	19x8-E	22.2	35.28	783.3	5,294	40.1	4556	160.71	5.82
APC	19x10-E	22.2	34.70	770.3	5,317	50.4	4576	161.41	5.94
APC	19x12-E	22.2	40.42	897.3	5,126	58.3	4866	171.64	5.42
APC	20x8-E	22.2	37.37	829.5	5,228	39.6	5046	177.99	6.08
APC	20x10-E	22.2	41.52	921.7	5,021	47.5	5227	184.38	5.67
APC	20x11-E	22.2	45.11	1001.5	4,973	51.8	5233	184.59	5.23
APC	20x13-E	22.2	46.25	1026.8	4,836	59.5	5294	186.74	5.16
APC	20x15-E	22.2	58.00	1287.5	4,533	64.4	4558	160.78	3.54
APC	21x12W-E	22.2	54.50	1210.0	4,679	53.2	6062	213.83	5.01
APC	21x14-E	22.2	51.27	1138.3	4,733	62.7	5887	207.66	5.17
APC	22x10-E	22.2	52.60	1167.7	4,703	44.5	6362	224.41	5.45
MAS	16x8x3	22.2	23.37	518.8	5,719	43.3	3256	114.85	6.28
MAS	16x10x3	22.2	29.07	645.2	5,415	51.3	3744	132.06	5.80

Figure 2. c4130/20 Prop Chart

Between fiscal and motor performance constraints, the team had on-hand a total of 2 motors and 3 props. The team tested the APC 17x12, 19x8, and 20x8 and used the provided prop charts for the Cobra c4130/20 and c4130/12. After rounds of thrust tests with and without the watt limiter, the decision settled with the Cobra c4130/20 motor with a 20x8 propeller. With this configuration, the motor draws 829.5 watts with a max thrust of 5046 grams. After considering the watt limit of 750 watts extensive tests on the propeller resulted with a max thrust of 4800 grams or about 10lbs.

Figure 3. Motor Test Stand

For the aspect of better planning, the thrust tests were conducted in a room with varying temperature from forty to eighty degrees Fahrenheit proving a fifteen percent change in thrust. Therefore, the plane was to be designed with the assumed max thrust of eight pounds after taking into consideration the effect of power loss from air density and dynamic flight of 30mph.

6. Design Layout & Trade Studies

6.1 Overall Design Layout

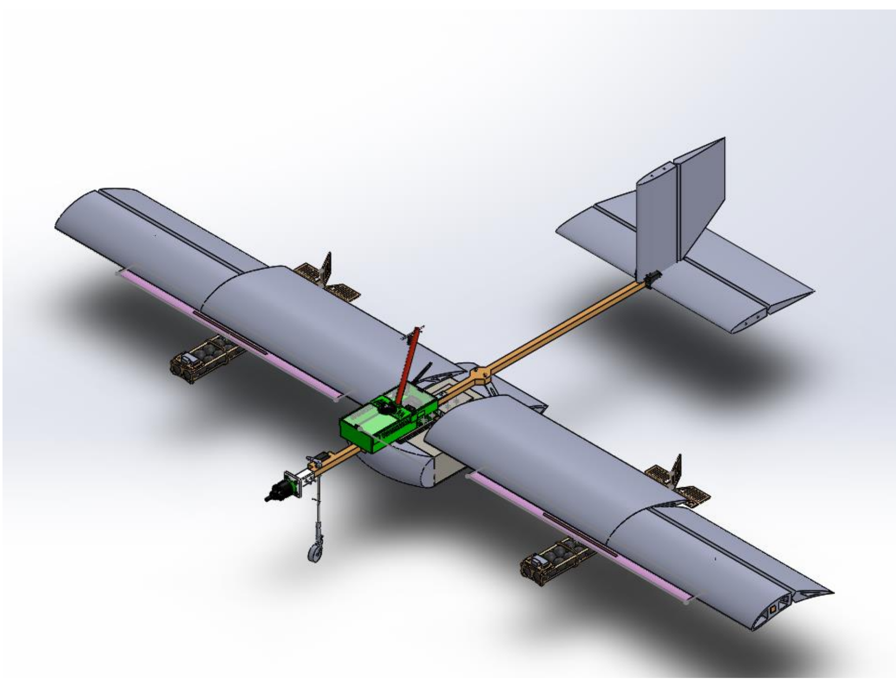

Figure 4. Final design of bomber.

The final iteration of the aircraft is shown in Figure 4. The final design incorporates the payload bay, CDAs, and a Blackbox. The aircraft wingspan is nine and a half feet, and the center of gravity is located twenty-five point nine inches from the aircraft nose. Hickory wood is the airframe material as it both very strong and low cost. Insulation foam is the wing material as it once again is fairly low cost, and with the team's manufacturing capability, each wing set can be made in only three hours. The front landing gear is a mix of a sturdy off-the-shelve suspension system and a team-built landing gear support system. The rear landing gear has an eighteen-inch wheelbase and is made of aluminum. All hardware on the aircraft is the same M5-0.8 bolts of varying lengths.

The CDA has an AG35, three-inch chord airfoil that spans three feet, and has a glide ratio of about 4. The CDA is made mostly of balsa, except for two pine, dowel fuselage rods, and an acrylic dropping plate used to allow the deployment from the bomber. The CDA is built to hold 28 ping-pong balls and weigh less than nine ounces.

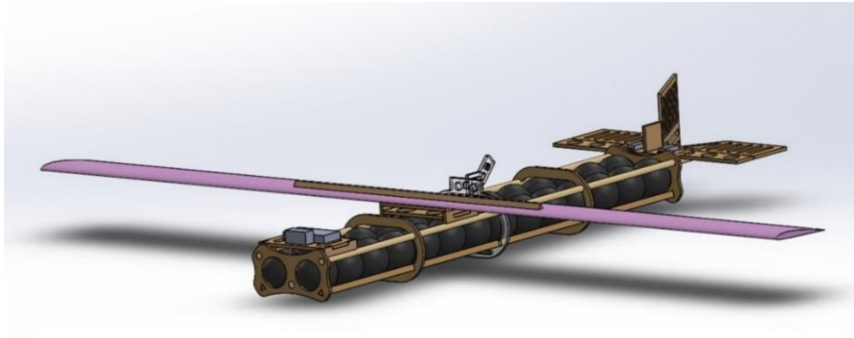

Figure 5. Final CDA design that hold 28 colonists.

6.2 Payload Systems

6.2.1 Payload Bay

Figure 6. Final payload bay design that can hold six footballs or four water bottles.

The payload bay's internal area measures twelve inches by twelve and a half inches as this was determined to be the perfect size to fit either six footballs or four water bottles. A curved front is attached to the front of the bay to reduce the drag produced by the box, and the rear of an arbitrary airfoil shape was added to the back to reduce drag as well. Two servos with eighth-inch thick aluminum servo horns are used to keep the payload bay doors in place during flight, and once the payload is released, the horns have curved arms that are able to scoop the doors back up into the closed position.

6.2.2 CDA Release Mechanism

Figure 7. Initial dropping Mechanism Test

The purpose of the CDA release mechanism is to release the CDA in a flyable configuration during flight of the bomber aircraft. The original CDA had the tendency the clime locking them in place. During Figure 7, the mechanism failed to release one the of the dummy CDAs, resulting in a severe imbalance during flight with the aircraft. The failure of the initial dropping mechanism resulted in a success in the aircraft design as

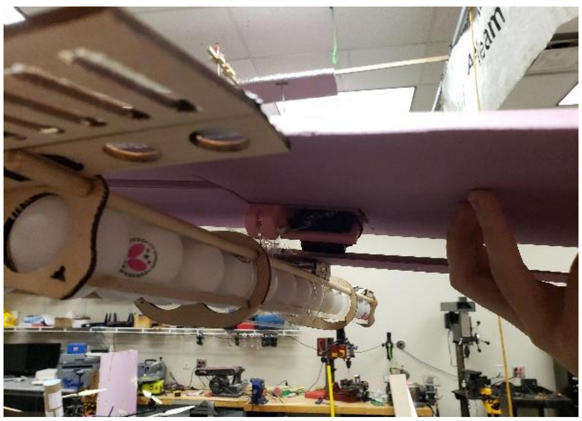

Figure 8. Final CDA Dropping Mechanism

resulted into a success in the aircraft design as surprisingly, the aircraft remained under full control with only one CDA onboard. The final design resulted with a simple slider crank with a 45-degree angle to ensure release at angle instead of relying on only gravity to separate the aircraft. The drag also assists in simple pulling the CDA back thus guaranteeing successful release.

6.3 Trade Studies

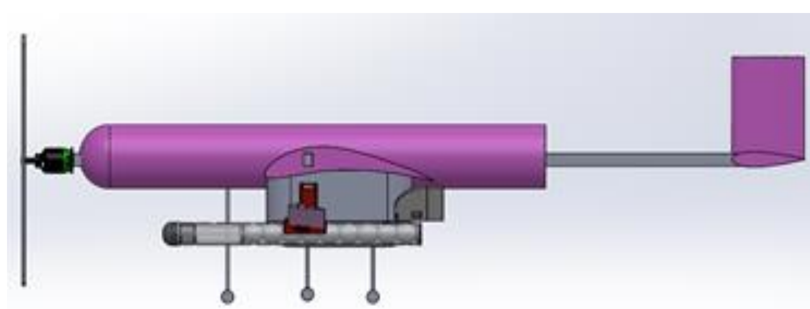

Figure 9. Side view of initial concept aircraft highlighting the CDA and payload dropper

The first iteration of the aircraft’s overall design was used as the base concept for what the team wanted for the aircraft’s look and function. Key features include: a basic wood cross frame, basic stick landing gear, likely locations for the CDAs and cargo bays, and a foam fuselage. It was never built, but much like concept cars, the design gave the team a starting direction. In the second iteration, which was built

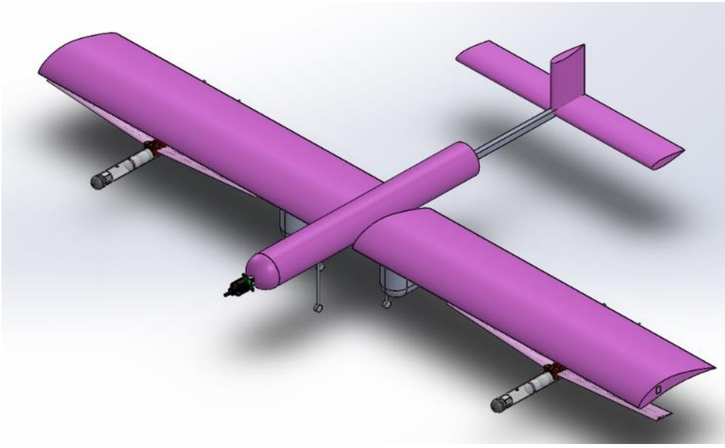

Figure 10. Isometric view of initial concept aircraft

and flown, the frame was made of maple wood and the wings were made of house insulation foam. The stick landing gear was a thick aluminum tube, each landing gear featured two wheels, and the frame was put together using lap joints and a combination of wood glue and nails. The fourth iteration of the aircraft saw major improvements such as the tails spars becoming quarter-inch dowels, and the landing gear being moved back off the wing spars. A second wing spar was also added. The aircraft joints were no longer lap joints, and instead an aluminum t-plate was incorporated on the both the top and bottom of the wing spars to allow for easy detachment of the wings.

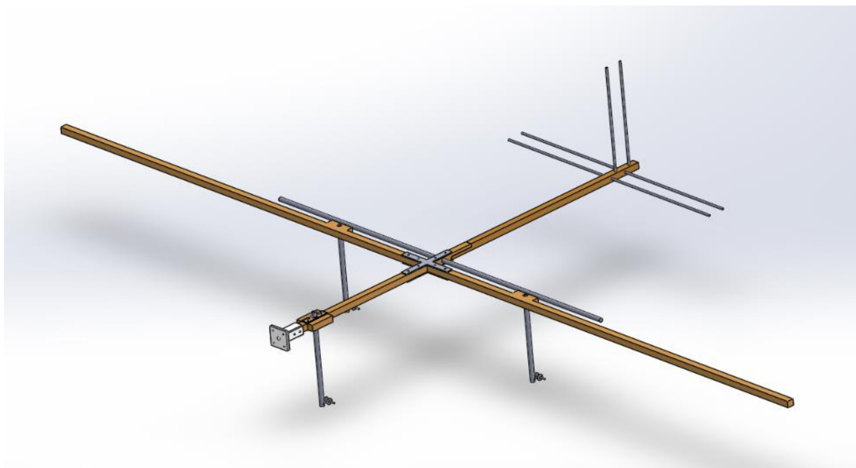

Figure 11. Second iteration airframe concept.

The fifth iteration saw the largest aircraft change. In this iteration the rear landing gear was moved back and made into an inverted "V" design, and a spring in the front landing gear along with a protective battery box were added. The wood was switched to hickory, instead of maple, as hickory is far stronger than maple. Tires on the landing gear were swapped to pneumatic tires from the prior foam due to noticeable flat spots caused by the weight of the plane.

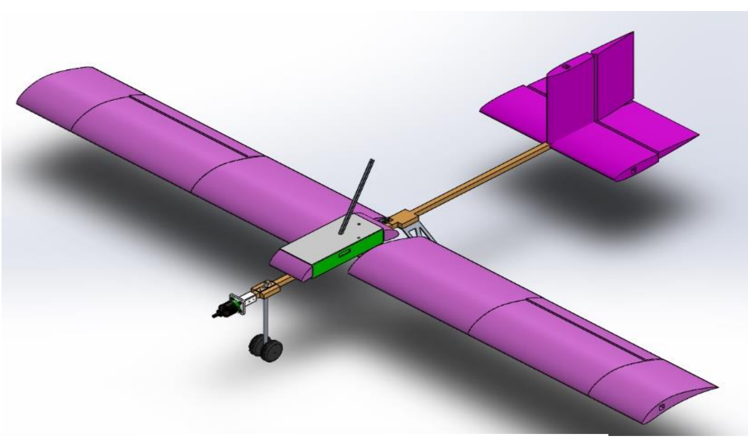

Figure 12. V 5.0

7. Analysis

7.1 Analytical Tools

The analytical tools used in our design process were Solidworks, Solidworks Flow Simulation, Solidworks FEA, and Microsoft Excel. All software was provided by Kennesaw State University under an academic license.

7.2 Developed Models

The aircraft was designed and built in Solidworks to allow the use of the analytical tools within Solidworks. Once the models of aircraft were evaluated using FEA or CFD, proper design changes were implemented, and then physical testing was used to validate the computer models.

7.3 Performance Analysis

7.3.1 Steady Level Flight

The team attached sensors to the aircraft such as a GPS, Pitot tube, accelerometer, gyroscope, and a Pixhawk flight computer to read and record the plane data. This flight data was used to quantify the performance of the aircraft under different conditions and different iterations. The team ran over seven recorded flights. Below is an example of flight data after takeoff. Using the weight of the aircraft and the wattage running through the known prop and engine, the plane lift and drag values can be calculated.

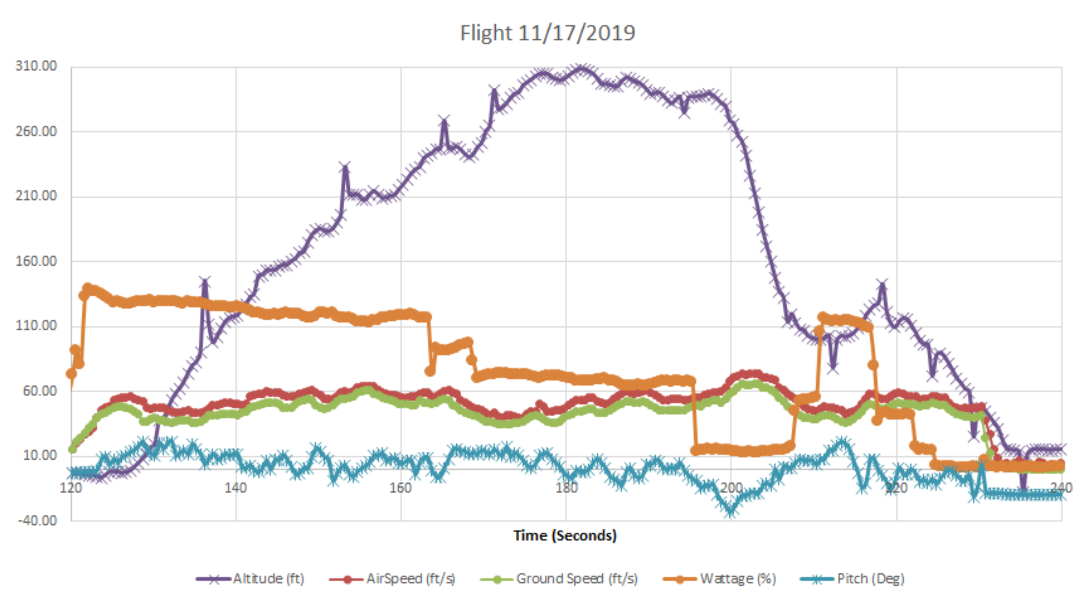

Figure 13. 11/17/19 Flight log

Later, a twelve-foot wingspan plane was attempted and as seen in Figure 14, the increased wingspan required more than the watt limiter would allow. Had this test been performed with the watt limiter, the plane would have likely crashed on the runway. This flight data allowed the team to not need to look into investigating possible stall from other issues and change the design to a smaller wingspan quickly.

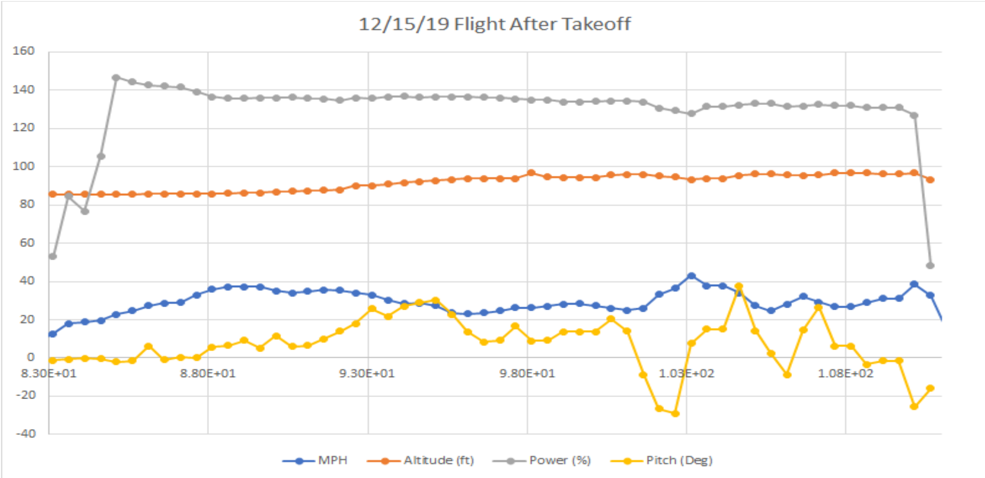

Figure 14. 12/15/19 Flight log

7.3.2 Bombing

As stated, before in the previous design report, since the rules and the laws of physics relevant to the problem have not changed." The mechanics and theory used for bombing was perfected by the end of World War Two. Figure 15 shows the required variables, courtesy of the United State Air Force [4]. Altitude will be provided by the avionics and the time off fall is approximately two and a half seconds or one hundred feet based off both theory and previous competition footage. The difference between the actual range and whole range is negligible due to the short distance that the aerodynamic payloads are falling, the assumed under thirty mile per hour winds, as well as the large size of the target. The whole range is theoretically calculated and based off the bomber cruising speed the plane will have a two second window over the

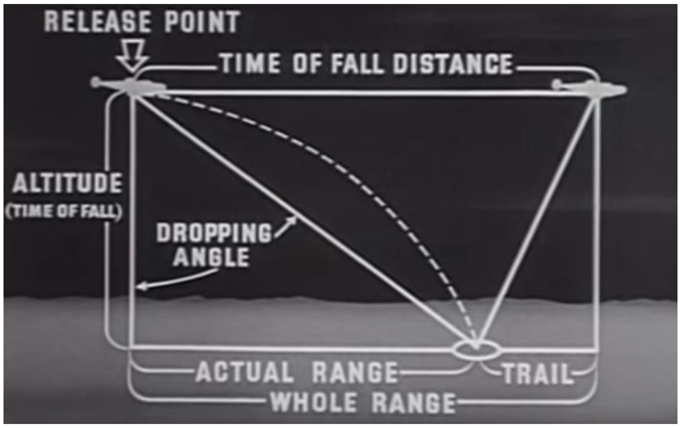

Figure 15 Bombing Path

target. Assuming the bomber is lined up properly during the run, the team is confident in its ability to hit the target" [6] successfully.

7.3.3 CDA Flight Path

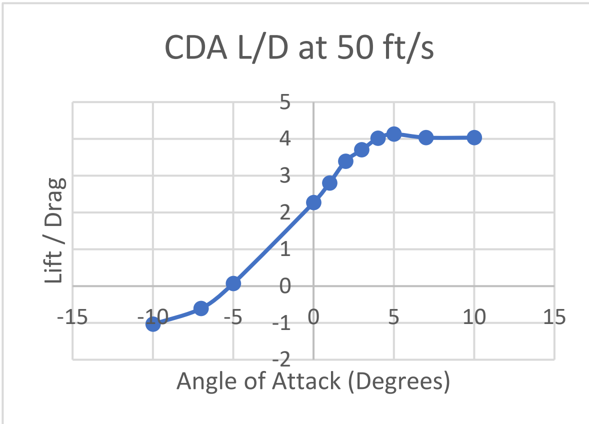

Figure 17 CDA L/D vs AOA

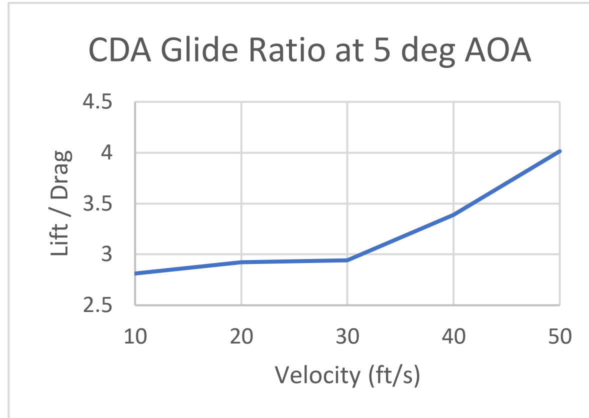

Figure 17 CDA Glide Ratio

The CDA was improved from last year to double the passenger capacity and switch to a GPS guided flight path. The glide ratio of the aircraft was proven using real flight data and using validated CFD.

7.3.4 Lifting Performance, Payload Prediction, and Margin

The aircraft was initially designed with a level cruise at 55 ft/s with a weight of 35 pounds using hand calculations from Raymer's Aircraft Design textbook [5]. After taking the structural forces on the wing spar into account, a wingspan of nine feet was chosen initially. An airfoil tool website assisted the team in initial ideas for the airfoil type, and the Eppler 420 was chosen due to its superior lift over drag performance [7]. To better determine some of the characteristics of our airfoil, we ran wind tunnel testing on the chosen airfoil, the Eppler 420. Due to the sensor that measures lift and drag being in for repair, no lift or drag data could be gathered. Instead, the stall angle, reattachment angle, amount of bend in the wing, and verifying structural integrity of the wing were tested. The wind tunnel tests were done using a to scale twelve-inch section of the wing on the actual wing spar section.

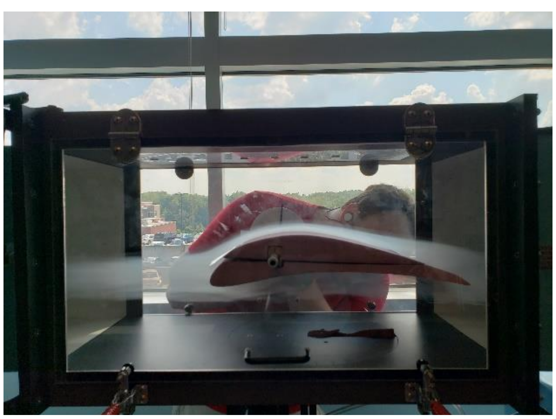

Figure 18 EWT Eppler 420 Original

As seen in Figure 18, the Eppler 420 Airfoil was placed in the wind tunnel to verify structural integrity and stall angle using smoke. As seen in Figure 19, the Eppler 420 Airfoil was optimized in terms of weight and tested to verify no measurable changes in its shape during flight conditions and no measurable change to stall angle. The predicted payload will be variable each flight to best fit the team's goal of gaining maximum points, but it has a maximum capability of two CDAs with 28 ping pong balls each, 3 water bottles, 6 Nerf footballs, and 2.5 pounds of static payload. This is based off proven flight data showing max weight that our pilot can fly with.

Figure 19 EWT Eppler 420 Optimized

7.3.5 Runway

Figure 20. 1/12/20 Flight Log

Based off the Flight data referenced from Figure 20 of physically testing the aircraft, resulted in a 300-foot takeoff and 150 foot landing.

7.3.5 Shading/Downwash

In order to maintain control of the aircraft, the tail was designed to operate within the propwash. This proved to be very effective and shown when in the first iteration the rear landing gear was too close to the CG and the aircraft tilted back until it hit the floor. The aircraft was still able to be balanced by spinning up the prop and using the propwash on the elevator to keep the plane upright while stationary, thus allowing to go down the runway. The tail control authority has increased in size since then.

7.3.6 Dynamic & Static Stability

A dihedral of approximately five degrees has been added with the CG below the dihedral to act as a stable aircraft. Since the wing spar is flat, the dihedral is provided from the bend caused by aerodynamic forces during flight. This is possible due to using a strong but flexible wood such as hickory. This was measured by clamping the wing spar into a vice and applying load of similar magnitude as level cruise before payload drops.

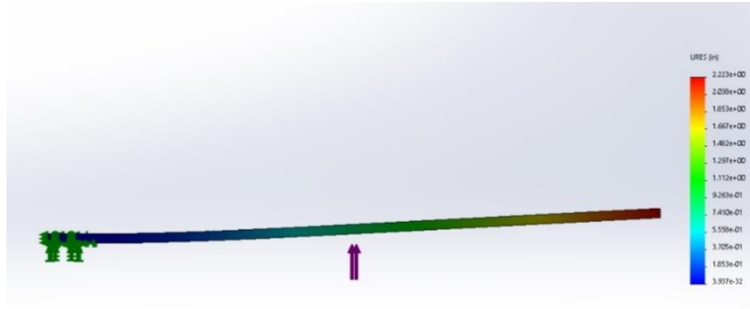

Figure 21. Pine Spar Stress Analysis

7.4 Structural Analysis

7.4.1 Design Loads

Wood was chosen as the frame material of choice due to the team's prior experience using many different materials. Factors such as material cost, manufacturability, and general material strength was taken into consideration. The team wanted to build many aircraft for testing, so expensive materials like carbon fiber was disqualified due to the cost, and metals were excluded as the manufacturability of metal is generally unforgiving. Wood was selected as the best structural material as it was very inexpensive, less than five dollars a frame, and very strong compared to many aluminums. The max take-off weight of the aircraft is expected to be twenty-three pounds. This was determined via flight tests of prototype aircraft where the team systemically loaded steel plates onto the aircraft until the performance of the aircraft considerably hindered and safe operation was no longer possible.

7.4.2 Frame

Figure 21 depicts the airframe structural components in the final version of the aircraft. FEA using Solidworks was performed on the wing spars assuming an upward force of eleven and a half pounds midway down the spar, and the analysis is shown in Figure 21 assuming an ultimate strength of 20,200 psi for hickory wood [8]. The team's goal was wing deflection of about five degrees to form a five degree-dihedral during flight. The FEA predicted about 2.22 inches of deflection, which give a dihedral of about 4.5 degrees.

7.4.3 Control Surfaces

The control surfaces were initially sized using Raymer's Aircraft Design textbook. From that initial sizing flight tests and determined changes. If the plane seemed to have trouble turning in certain wind conditions, the control surfaces were either made larger or the maximum deflection was increased. The team are currently using 20 kg*cm servos on all control surfaces for the main bomber.

8 Avionics

8.1 Blackbox

With monetary constraints, the safety of costly electrical components is paramount, so the design of a sturdy compartment was necessary to protect the components for repeated use. At most, the loss of one electrical package would not be catastrophic as spares were planned in the design of the aircraft. The initial iteration composed of using lightweight aluminum for protection with foam dampening included. But for the purposes of weight saving and as the intent to centralize as much of the components as possible, the initial design proved to be flawed as the metal enclosure interfered with the signal connections and sensor imbedded in the data acquisition system.

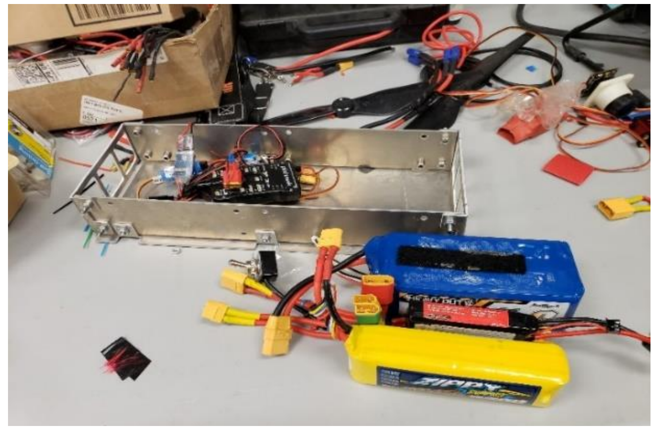

Figure 22. Concept Blackbox

Figure 23. Effectiveness of Blackbox Design

The final design resulted in a simple 3D printed box referred to as the Blackbox. This design consisted of three main compartment the battery compartment, communications, and power modulation. In total, the Blackbox went through eight iterations as systems were moved and separated to prevent interference and optimize the size of the Blackbox. For instance, during the fourth iteration, the BECs and ESC caused interference with the telemetry module. Moreover, with the separated compartment the heat regulation was greatly improved.

Overall, the Blackbox survived many crashes as seen in Figure 22, so the team can say with confidence that the Blackbox is strong enough to withstand a crash at competition.

8.2 Electronics

This year, the decision was made to go against a camera system as the team's testing of the camera from a high altitude proved that a camera implemented for accurate dropping is not viable. As a result, many sensors were implemented in assisting an accurate payload delivery. The electronics used consists of a GPS module, airspeed sensor, watt meter, the required watt limiter, the AR6600T dual band receiver, and the Pixhawk 2.4.8 flight controller. With the combination of the Pixhawk built in barometer, air speed sensor and GPS module, accurate tracking of the aircraft position is possible in both terms of positioning and altitude. The implementation of the watt meter was deemed necessary for tracking of battery capacity in order to prevent sudden loss of power. Lastly, with all the included sensors the main gain is the used of the collected data for future optimization, thus instead of relying only on simulated data next year design can be built and optimized from the real-world data collected by the ground station used of the collected data for future optimization, thus, instead of relying only on simulated data next year, design can be based on and optimized from the real-world data collected by the ground station.

Figure 24. Blackbox Wiring Layout

The Blackbox consist of three batteries for each critical system as per the design rules it was only necessary to have two, one for the thrust and one for the control. It was decided to implement a

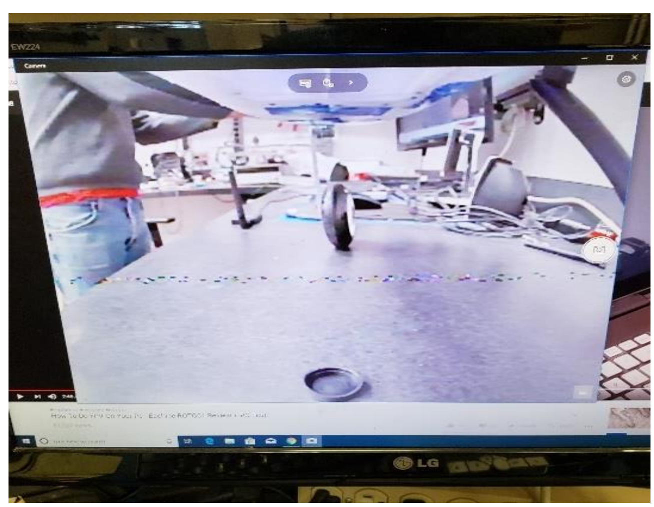

Figure 25. Video Testing

separate battery for data acquisition, which resulted in a more stable system, as theorized, for sharing a battery with the controls and data acquisition causes minor noise. With the separation of the systems, the effect of cross interference was reduced and provided for greater accuracy on the ground station.

9 Manufacturing

The wing spars and fuselage of the aircraft were constructed out of hickory wood which was cut to size with both a circular and table saw. There was difficulty in achieving a consistent measurement due to the imprecision of the tools being used, so jigs were designed to help guide and allow for more accurate measurements and cuts. The wood was the placed in a vertical mill to drill all the holes on the aircraft. The T-plate that and rear landing gear were both cut on a waterjet and then placed on a press-brake for the necessary bends on the rear landing gear. A high tolerance 3D printer was used to make many parts including the motor mount, servo holders, and CDA dropping mechanisms. A CNC foam cutter was employed to cut all the airfoil shapes. This was the largest change in manufacturing processes for the team as it saved a large amount of time compared to the hand cuts done in previous years. The CDA was built from pieces of balsa and acrylic that were cut out using a laser cutter, and the wings were made using the CNC foam cutter. Most of the CDA is held together with CA glue or hot glue, sparingly, in cases where the CA glue would melt the material.

10. Cost

The cost breakdown for the bomber, the CDA, and the electronics Blackbox are listed in Tables 6,7,8, respectively. The table include columns for how many items are used per aircraft, the cost of the item in quantities that can be purchased, and the amount that each aircraft employs.

Table 6. Airframe Cost Breakdown

Aircraft Parts	Qty	Price per Item	Total Price
Clamping Shaft Collar - 1/4"	1	$2.37 per item	$2.37
Shaft Collar - 5/32"	4	$1.32 per item	$5.28
Washer - 0.156" ID, 0.5" OD	8	$9.12 per 50	$1.46
M5 30mm	6	$5.74 per 10	$3.44
M5 50mm	4	$4.26 per 5	$3.41
M5 75mm	4	$4.22 per 25	$0.68
Carbon Steel Shaft - 5/32"	1 ft	$5.09 per 3 ft	$1.69
Serrated Locknut - M5	12	$8.86 per 100	$1.06

1/4" OD Steel Tube	6 in	$7.14 per 1 ft	$3.57
Cushioning Washer - 1/4"	2	$3.44 per 10	$0.69
Body Pins	2	$5 per 20	$0.50
COTS Landing Gear	1	$15 per item	$15.00
Hickory Wood	1.2 board ft	$5 per board ft	$6.00
1/8" Aluminum Plate	0.5 sqft	$200 per 25 sqft sheet	$4.00
1/4" Wooden Dowels	4	$1.39 per item	$5.56
Steel Cable	2 ft	$8 per 100 ft	$0.16
House Insulation Foam - (2"x4'x8')	1/3 of Board	$37.83 per item	$12.61
Treaded Wheels - Dubro 3.25"	2	$12 per 2	$6.00
3D Filament - PLA	400 g	$15 per 1 kg	$6.20
4 sets servo 20KG Full Metal Gear	2	$53.99 per item	$107.98
			$187.66

Table 7. CDA Cost Breakdown

CDA Parts	Qty	Price per Item	Total Price
1/4 in Balsa Wood - (4 in x 36 in sheet)	1	$4.85 per item	$4.85
Acrylic Sheet (2 ft x 3 ft sheet)	3 in x 3 in	$30 per item	$0.31
Wooden Dowel - 1/4 in Pine	3	$0.89 per item	$2.67
Wooden Triangular Dowel - 1/4 in Balsa	2	$1.20 per item	$2.40
House Insulation Foam - (2 in x 4 ft x 8 ft)	3 ft x 0.5 ft	$37.83 per item	$1.77
3DR Pixhawk mini package	1	$150.00 per item	$124.95
			$136.95

Table 8. Blackbox Cost Breakdown

Blackbox Parts	Qty	Price per Item	Total Price
Pixhawk px4 2.4.8	1	$73.99 per item	$73.99
AR6600T DSMX 6-Channel	1	$64.99 per item	$64.99
SAE Adv 750Watt Limiter	1	$75.00 per item	$75.00
5000mAh 6S 60C Lipo	1	$74.54 per item	$74.54
2000mAh 2s Lipo	1	$11.99 per item	$11.99
2200mAh 4S 25C Lipo Pack	1	$17.82 per item	$17.82
External 5V 3A UBEC	1	$7.99 per item	$7.99
Castle Creations CC Bec 10A	1	$23.99 per item	$23.99
Turnigy Plush-32 60A	1	$34.76 per item	$34.76
Voltage and Current Meter	1	$13.99 per item	$13.99
Holybro Air Speed Sensor	1	$39.99 per item	$39.99
100mW Transceiver Telemetry	1	$39.99 per item	$39.99
M8N GPS Module Built-in Compass	1	$27.89 per item	$27.89
PLA 3d printing material: 268grams	1	$0.015 per gram	$4.02
Wiring and connections	1	$5.00 per item	$5.00
			$475.96

11 Conclusion

The team's approach this year was to build a reliable aircraft that met all competition requirements, for the team felt that a stable and dependable aircraft is the key to success at a competition like SAE Aero Design. Through many major and minor design iterations, the team has built a combination bomber and CDA duo that should perform well at the competition. The bomber is able to take off at a max weight of twenty-three pounds and carry all three forms of payload. The CDA is able to carry twenty-eight passengers, which, if all CDAs hit the target, should yield a high score at the competition. The constant physical building and testing of the aircraft have been the paramount reason for the team's current success of over a dozen test flights before paper submission, and an expected dozen more before the competition. Being able to evaluate the designs in the real-world and compare them to the computational models not only made the team stronger, but also made the team stronger engineers overall. The team expects to land two CDAs per flight, carry static payload, and drop both water bottles and footballs to achieve competitive score that places the team in a higher placement than the previous year.

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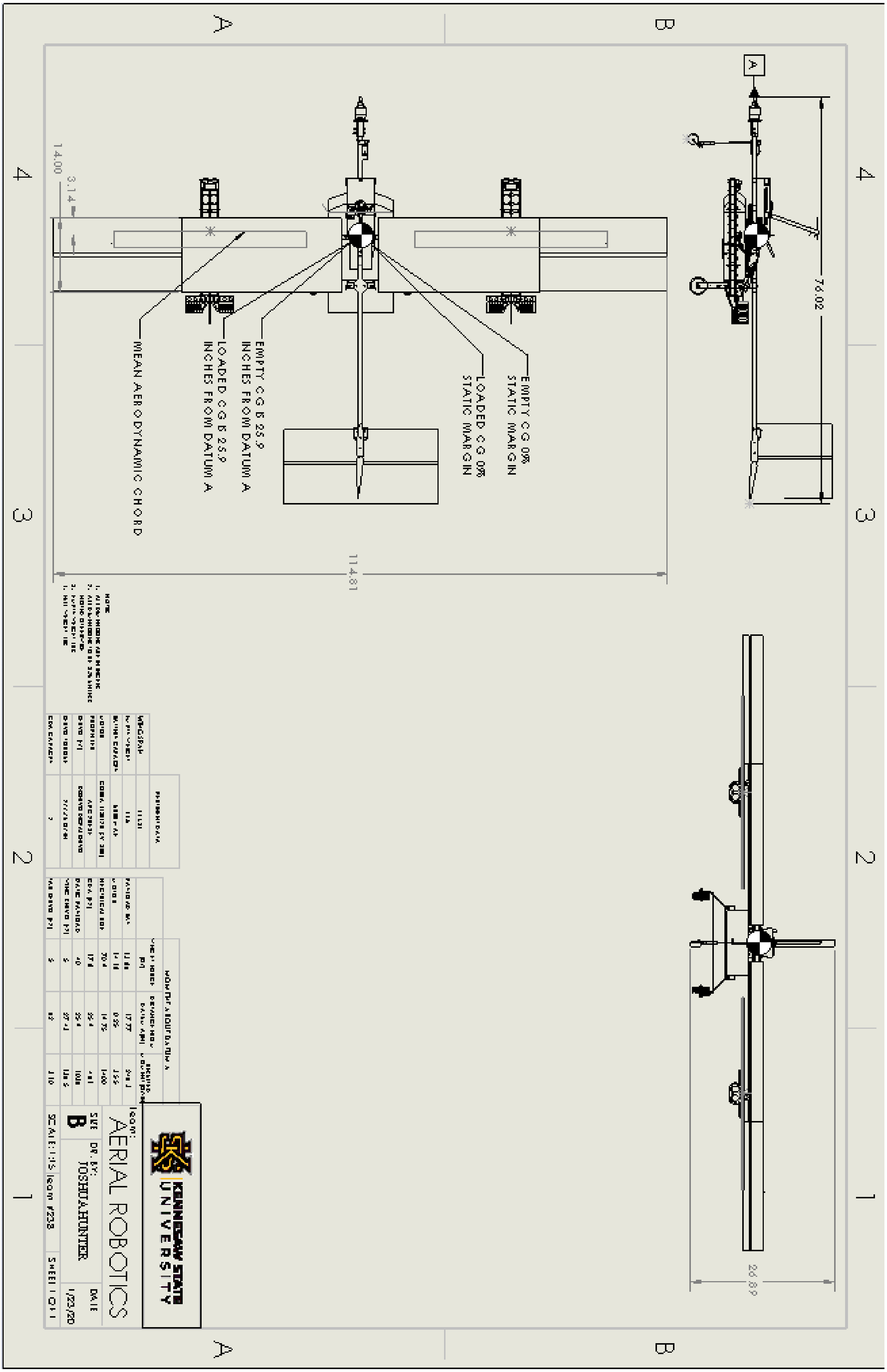
Appendix



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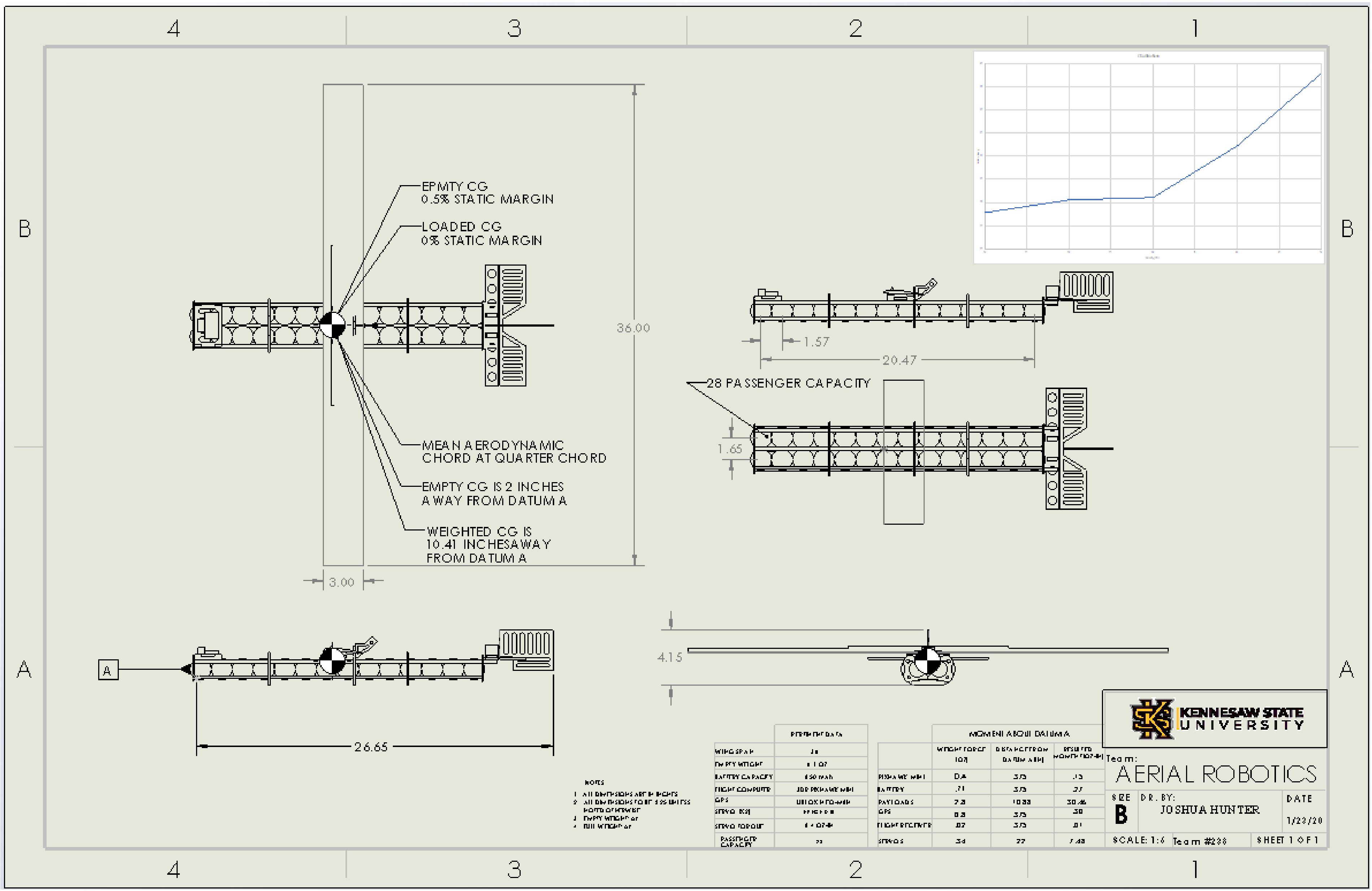
KENNESAW STATE UNIVERSITY
AERIAL ROBOTICS
DR. BY: JOSHUA HUNTER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