1. Executive Summary

GW DBF's objective is to design, manufacture, and successfully test an aircraft that can (1) transport sensors stored inside shipping containers, and (2) deploy and retract a sensor connected to a tow cable from the fuselage during flight. These capabilities will be demonstrated by completing a ground mission, an empty-aircraft flight, a cargo flight, and a sensor deployment and retrieval flight.

To achieve these objectives within the constraints of GWU's COVID-19 guidelines, a comprehensive management plan, conceptual design, manufacturing plan, and testing plan were developed. The team is organized into four main groups: leadership, sub-teams, senior design "contractors", and a board of advisors. Each group plays a critical role in designing, manufacturing, reviewing, and testing the aircraft. Sub-system requirements were identified, and a design parameter sensitivity study determined that the team should focus on creating an aircraft with high flight reliability and controllability. As such, a high-wing monoplane with a cylindrical fuselage and a propulsion system capable of generating 12.5 lbf of thrust was selected because of its aerodynamic stability and lift generation properties. These properties will reduce the risk of aircraft failure during the cargo and sensor towing missions. In Mission 1, basic flight capabilities are verified. In Mission 2, the aircraft will transport sensor shipping containers stowed in a rack attached to the inside of the fuselage. In Mission 3, a cylindrical sensor with a rounded nose cone and dihedral fins will be deployed, towed, and retrieved by the aircraft. COVID restrictions limit the amount of time GW DBF can allot to manufacturing and testing the aircraft. Discrete tasks will be created to produce the design, and a system integrator will oversee construction of the assemblies. Laser cutting and 3D printing are critical technologies for manufacturing. Testing will occur in three phases: (1) modeling and simulation, (2) individual sub-system testing, and (3) system flight test. Three system flight tests, one for each flight mission and a ground test, will be conducted in the spring.

2. Management Summary

The 2020/21 George Washington University Design, Build, Fly team (GW DBF) is organized into four main groups: leadership, sub-teams, senior design "contractors", and a board of advisors, as shown in Figure 1. Each sub-team is composed of a sub-team lead and sub-team members who focus on a specific aspect of the project. The controls team oversees an additional group responsible for the special mission component (e.g. sensor, sensor deployment mechanism, and shipping containers). All teams meet with each other twice a week to discuss project progress and next steps. The project manager, chief engineer, and sub-team responsibilities are shown in Table 1.

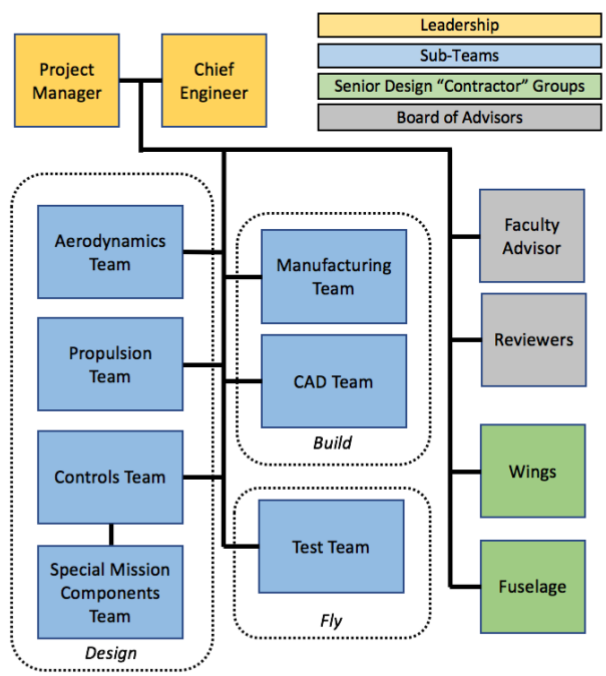


Figure 1: GW DBF Organization Structure

GW DBF has two senior design "contractor" groups that are responsible for the design and integration of the wing and fuselage. The leadership team is working in conjunction with the senior design groups and course instructors to create a "contract" for each group that details a statement of work, deliverables, requirements, a schedule, milestones, and deliverable acceptance criteria for the group's components. The senior design "contract" will be finalized by December, 2020. The deliverables and responsibilities for each group are shown in Table 2. The schedule for all senior design

Position or Sub-Team	Responsibilities
Project Manager	Manages the team and team culture; ensures team progress and adherence to the schedule; organizes team meetings; oversees the budget
Chief Engineer	Manages the design of the aircraft; sets direction for all technical aspects of the project; approves all component designs
Aerodynamics Team	Selects, designs, and integrates the airfoil and tail onto the aircraft; models the aerodynamics of aircraft; tests aircraft performance via simulation
Controls Team	Designs, tests, and integrates the control and power system into the aircraft
Propulsion Team	Designs, tests, and integrates the propulsion system into the aircraft; works with the Aerodynamics Team to ensure the aircraft generates enough lift for all missions
Manufacturing Team	Develops a manufacturing plan based on the aircraft design; builds and integrates all components of the aircraft
CAD Team	Works closely with the design teams (Aerodynamics, Controls, Propulsion) and the Senior Design "Contractors" to model all aircraft components
Test Team	Develops and executes a test plan to verify aircraft sub-system functionality, manufacturing integrity, and flight performance
Special Mission Components Team	Designs, builds, and integrates the sensor, sensor deployment and retrieval mechanism, shipping containers, and simulator shipping containers

Table 1: Leadership and Sub-Team Responsibilities

Senior Design Team	Deliverables and Responsibilities
Fuselage	Will deliver the complete design of the fuselage, including, but not limited to interfaces with the sensor, shipping containers, simulator shipping containers, wings, tail, and propulsion and control systems. Will support the greater DBF team in manufacturing and testing of the fuselage.
Wings	Will deliver the complete design of the wings, including, but not limited to all interfaces with the fuselage and controls system. Will support the greater DBF team in manufacturing and testing of the wings.

Table 2: Senior Design "Contractor" Group Deliverables

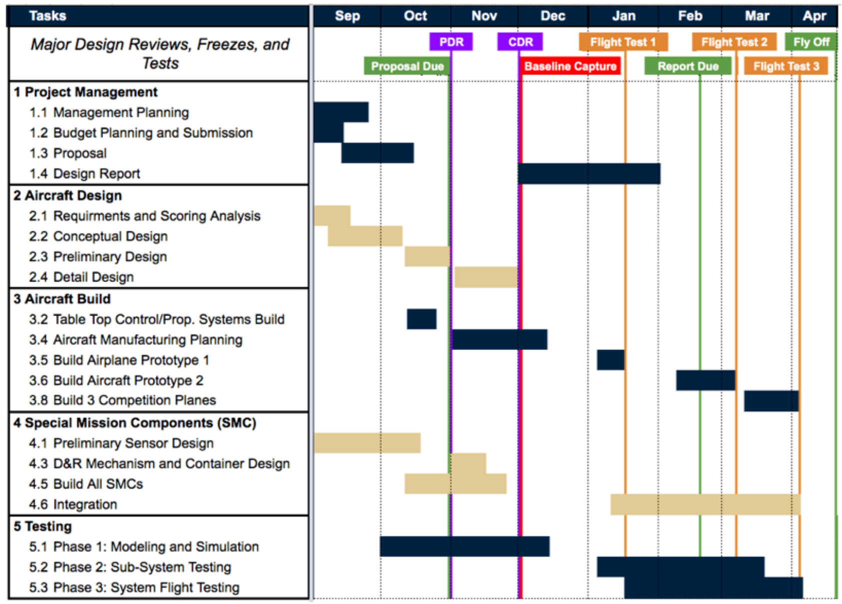


Figure 2: Schedule and Major Milestones

milestones will align with the greater GW DBF schedule. Senior design "contractor" groups will interface with relevant GW DBF teams for design, manufacturing, integration, and testing purposes; and will report directly to GW DBF leadership.

The Board of Advisors is composed of GW DBF's faculty advisor and an ad-hoc group of graduate students, faculty, and industry members. The faculty advisor regularly meets with the team, and acts as a mock customer and mentor. The Preliminary and Critical Design Reviews will be presented to the ad-hoc group, which assesses aircraft design quality and provides feedback to the team.

2.1 Schedule, Major Milestones, and Budget

Figure 2 shows the schedule and major milestones for GW DBF. Schedule delays during the build and test phases are possible as GWU's COVID-19 restrictions will limit the amount of time the team is allotted for manufacturing. Table 3 shows GW DBF's proposed budget for 2020/21. GW DBF expects to take 8 students and the advisor to the competition. Team members will be selected for competition travel based on the level of their contributions to the project.

Cost Category	Amount
Motors and Propellers	$1,200
Electronic Speed Controls	$240
Batteries	$250
Misc. Electronics	$500
Aircraft Build Materials	$2,900
Special Mission Component Build	$450
Drone Field Membership	$150
Testing Logistics	$750
Aircraft Transportation	$500
Student Transportation/Lodging (x8)	$5,000
Advisor Transportation and Lodging	$1,000
Total	**$12,940**

Table 3: Proposed Budget

3. Conceptual Design Approach

3.1 Requirements Analysis

The 2020/21 DBF fly-off is composed of a ground mission, an empty-aircraft flight, a cargo flight, and a sensor deployment and retrieval flight. Each completed mission receives a score based on mission performance. The scoring function for each mission can be found in the rules document. Translation of the mission requirements into sub-system requirements is critical for designing and testing the aircraft. The sub-system requirements will be used to (1) inform the design team of sub-system performance expectations and (2) create testing procedures to verify sub-system functionality. The team has identified six key sub-systems whose requirements are dictated by the missions. Each sub-system and its requirements is presented in Table 4.

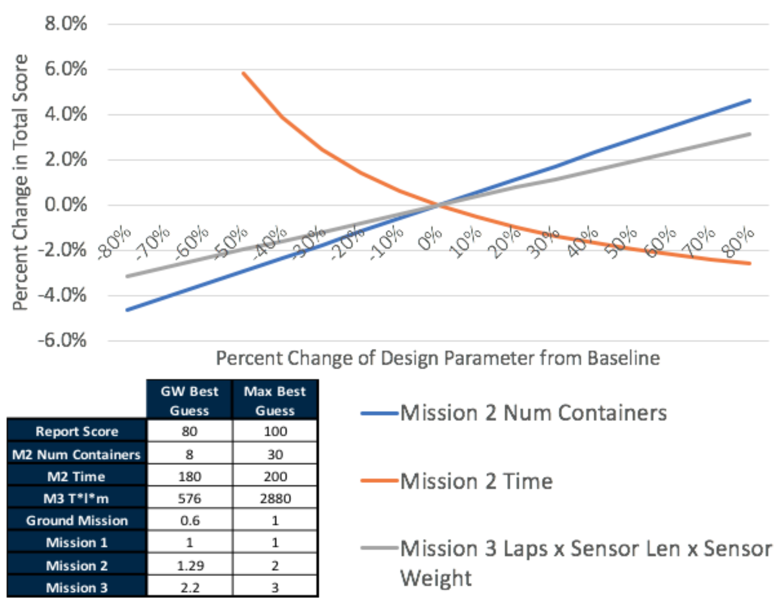
Sub-System	Requirements
Propulsion and Aerodynamics	- The aircraft shall take off in all configurations within 100 feet of the throttle being advanced to full power - The propulsion system shall generate enough thrust to fly the aircraft while the sensor is deployed from or shipping containers are stored in the aircraft - The aerodynamics of the aircraft shall remain stable while the sensor is deployed
Fuselage	- The fuselage of the aircraft shall securely store a sensor shipping container and simulator shipping containers during flight - The sensor deployment and retrieval mechanism shall operate internally to the aircraft fuselage and be secured inside the aircraft during flight
Controls	- The aircraft shall maintain dynamic stability of the aircraft during flight - The controls surfaces shall maintain control and ensure stability of the aircraft while the sensor is deployed
Sensor	- The sensor shall be at least one inch in diameter and have a length of at least four times the diameter - The sensor shall be connected to the sensor deployment and retrieval system via a tow cable - The sensor shall not spin or rotate when it is deployed outside of the aircraft - The sensor shall contain at least three lights capable of receiving commands to turn on and off via a physical connection to the aircraft along the tow cable - The powered up sensor lights shall (1) operate one at a time in a unique pattern and (2) be visible from the ground in all flight environments (e.g. Arizona in April) - The sensor shall contain NiCad/NiMH or Lithium Polymer (LiPo) batteries that (1) power the sensor lights and (2) comply with all provisions outlined in the rules document - The aircraft transmitter shall be capable of sending commands to the aircraft to (1) turn on the sensor lights and (2) turn off the sensor lights
Sensor Deployment and Retrieval	- The sensor deployment and retrieval mechanism shall deploy the sensor on a tow cable from inside to outside of the aircraft fuselage - The sensor deployment and retrieval mechanism shall deploy the sensor on a tow cable a distance of at least ten times the sensor length from the sensor's exit point of the aircraft - The sensor deployment and retrieval mechanism shall retrieve the sensor via the tow cable from outside of the fuselage and bring the sensor fully inside the aircraft fuselage - The aircraft transmitter shall be capable of sending commands to the aircraft to (1) deploy the sensor and (2) retrieve the sensor
Simulator and Shipping Containers	- The shipping container shall protect the sensor from damage due to drop shock events - The simulator shipping containers shall be +/- ⅛ inch the size of the shipping container with the sensor inside it - The simulator shipping containers shall be the same or greater weight as the shipping container with the sensor inside of it

Table 4: Sub-System Requirements

3.2 Sensitivity Study of Design Parameters

One-way sensitivity analysis is used to measure how much the total score changes when the design parameters are changed. Baseline estimates and the scoring sensitivity analysis results are shown in Figure 3. Designing the aircraft to maximize one of the parameters could result in a marginal total score increase, but will push the physical limits of the aircraft and increase the risk of a flight failure. A failure on Missions 2 or 3 would result in loss of the "free points" awarded for successful mission completion that are not dependent on performance. A design that executes the missions with high reliability is the best option for collecting the most mission points in the fly-off.

The results underscore the importance of designing for reliability and controllability. Aircraft testing requires multiple flight tests within a limited timeframe. Having an aircraft with high flight reliability and controllability will (1) allow GW DBF to conduct more flight tests and (2) reduce the likelihood an aircraft will be significantly damaged due to a flight failure. More testing translates to more design improvements, which will increase the aircraft's probability of success during the fly-off. As such, the focus of the team will be (1) designing a mission-capable aircraft with high flight reliability and controllability, and (2) iterating on the design until it is demonstrated through testing.



	GW Best Guess	Max Best Guess
Report Score	80	100
M2 Num Containers	8	30
M2 Time	180	200
M3 T*l*m	576	2880
Ground Mission	0.6	1
Mission 1	1	1
Mission 2	1.29	2
Mission 3	2.2	3

Figure 3: Baseline Scoring Estimates and Sensitivity Analysis Results

3.3 Preliminary Design, Sizing Results, and Concept Sketch

The goal of the preliminary design is to create an easily controllable, highly reliable aircraft that can transport shipping containers, and deploy and retract a sensor during flight.

A high-wing monoplane with a cylindrical fuselage was selected because it (1) has high aerodynamic stability for towing a sensor mid-flight, and (2) generates large amounts of lift necessary for cargo transportation. Payload weight estimates for the cargo and sensor deployment mission are 3 and 0.5 lbs, respectively. The St. CYR 24 (Bartel 35-IIIC) airfoil will be utilized due to its ease of manufacturability and high maximum coefficient of lift. A CFD study showed the wing's C_L and C_D to be 0.81 and 0.014, respectively, at 0° angle of attack. The fuselage will be 36" in length and 6" in diameter to allow for the batteries, control system, shipping containers, and sensor deployment and retrieval mechanism to be securely stowed inside. An E-Flite Power 160 2.7 kW motor, 20x8 propeller, and 22.2 V LiPo battery were selected for the propulsion system. This combination will provide 12.5 lbf of thrust, which is sufficient for the aircraft to take off, climb, and cruise while carrying cargo or towing the sensor. A nose cone will be attached behind the propeller and smoothly connect with the start of the fuselage to reduce drag. The fuselage, airfoil, and tail will be wrapped in heat shrink or a similar material to improve the aerodynamic properties and structural integrity of the aircraft. The empty aircraft weight is estimated to around 13 lbs. Figure 4 shows the aircraft three view and concept sketch.

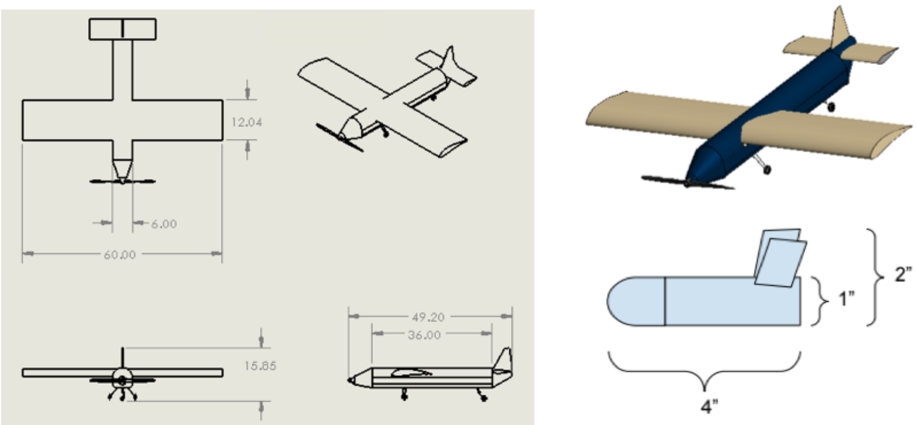


Figure 4: Aircraft Three View, Aircraft Concept Sketch, and Sensor Concept Sketch

The sensor is cylindrical in shape with a rounded nose cone and dihedral fins to (1) limit the negative aerodynamic effect on the aircraft and (2) stabilize the sensor during deployment. Initial wind tunnel testing showed the design will remain stable during flight. An Adafruit Feather M0 Adalogger and battery pack were selected to control the LEDs on the exterior of the sensor because of their small size. The shipping containers will be stored in a rack that is attached to the fuselage. The sensor deployment and retrieval mechanism will consist of a cargo door and two servos located under the wing. Signals from the receiver will activate the servos to (1) open and close the cargo door and (2) winch the sensor in and out of the fuselage. The sensor concept sketch is shown in Figure 4.

Center of gravity and computational fluid dynamics studies were performed using SolidWorks to analyze the aerodynamic behavior of the aircraft. The center of gravity study found that positioning the cargo within a 12" window around the center of lift does not drastically alter the balance of the aircraft. At different velocities, angles of attack, and configurations the computational fluid dynamics study mapped the aerodynamic conditions around the aircraft. This allows the team to anticipate how performance conditions will change during sensor deployment to proactively alter the design for improved aircraft flight controllability. Initial analytical results show that the aircraft produces ample lift during takeoff, climb, cruise, turns, descent, and landing; more detailed studies will be conducted as the design is further developed. The airfoil's high lift generation, propulsion system's high thrust generation, and highly aerodynamic body provide a controllable aircraft that meets the team's design goal for the preliminary design.

4. Manufacturing Plan

GWU's COVID restrictions will limit the amount of time the team can allot to manufacturing the aircraft during the spring semester. As such, the manufacturing plan will focus on organizing the team to produce all aircraft components within the schedule constraints. The preliminary manufacturing flow is shown in Figure 5. Before the spring semester, the manufacturing and design teams will create a systematic, reproducible, and easily understandable procedure of discrete tasks to (1) manufacture sub-system components, (2) assemble the sub-systems, and (3) integrate all sub-systems into the aircraft assembly. These procedures will be executed over multiple build events during the spring semester. A system integrator will assign discrete tasks to individuals participating in the build events, and will oversee construction of all assemblies. All components, sub-systems, and produced aircraft will be visually and mechanically inspected to ensure adherence to the design acceptance criteria.

A comprehensive bill of materials (BOM) will be compiled by the design teams and approved by the manufacturing and leadership teams. Based on the BOM, and working within the budget, the team will procure all materials necessary to produce the design. The team will primarily utilize 3D printing and laser cutting to manufacture parts. Components designed by the team will be manufactured in-house using GWU facilities.

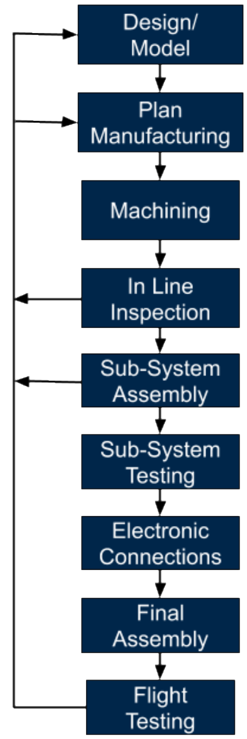


Figure 5: Preliminary Manufacturing Flow

5. Test Planning

The test plan has three phases: (1) modeling and simulation, (2) individual sub-system testing, and (3) system flight test. Phases 1 and 2 assess the capabilities of the aircraft and its subsystems relative to the allocated requirements. Phase 3 verifies flight mission performance of the aircraft. Phase 1 testing is completed iteratively as the aircraft and its sub-systems are developed. The design teams will conduct various analyses, including substantiating aircraft controllability by modeling the stability and maneuverability of the design. Phase 2 testing is conducted after each sub-system is assembled. The test team will identify testing procedures and acceptance criteria that each sub-system will have to meet before it can be integrated into the aircraft. Additionally, a full set of tests will be developed for the special mission components, including a drop shock test for the sensor and shipping container.

Phase 3 is composed of three major flight test events, where each event is dedicated to verifying aircraft performance for one competition mission. The first flight test event will demonstrate the basic flight capabilities of the aircraft, with a focus on the performance of the motor and propeller combination, integrity of the fuselage and airfoil, and performance of the flight control system. The second flight test event will test the capabilities of the aircraft with a full load of cargo and demonstrate fuselage structure integrity and shipping container security during the flight. The third flight test event will test the sensor deployment mission, and demonstrate sensor deployment and retrieval, execution of the unique light pattern and visibility to ground observers, as well as aircraft and sensor aerodynamic stability during flight. Before the third flight test, a ground test following the procedures identified in the rules document will be conducted. The pilot and a flight data recorder will evaluate the stability and maneuverability of the aircraft during each flight event. In the event of a test failure, a failure analysis will be conducted to identify the underlying issue with the design or manufacturing of the aircraft. If the aircraft is damaged during testing, the team will conduct on-site repairs and part replacements so that testing can continue.