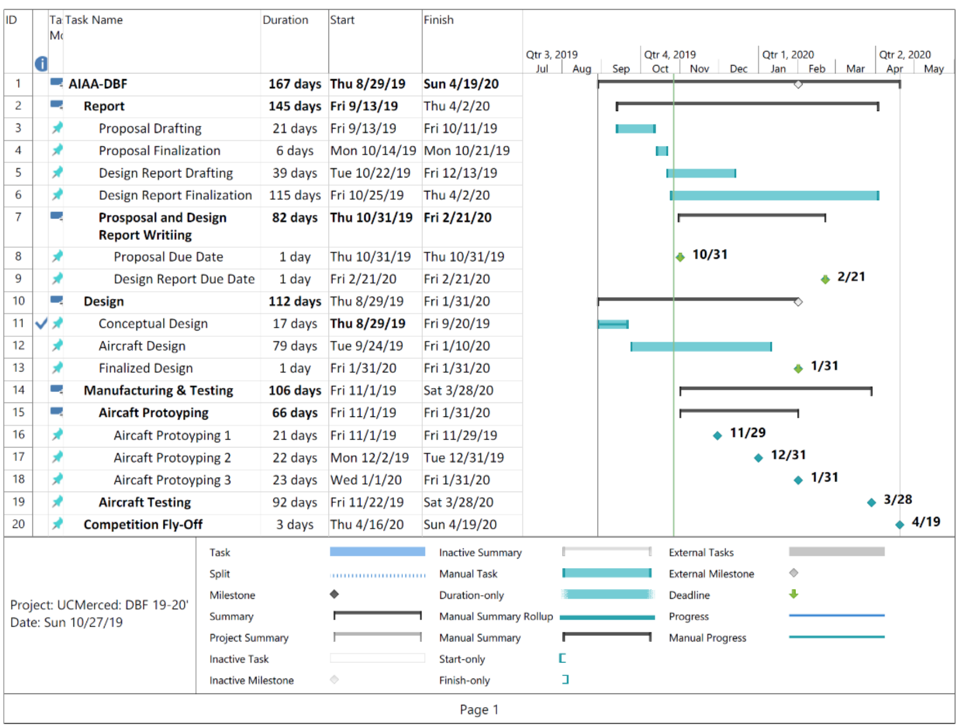
Design Build Fly
SOHCAHTOA
University of California Merced

Executive Summary

This report entails the design, manufacture, test procedure, and commitment for the University of California, Merced team SOHCAHTOA to attend the AIAA 2019-2020 Textron Aviation/Raytheon Missile Systems Design-Build-Fly (DBF) student competition. UC Merced is dedicated to building an aircraft that will pass ground inspection and successfully execute the three flight missions within their respective parameters: Test Flight (1), Charter Flight (2), and Banner Flight (3). The conceptual designs are described below with full compliance of the 2019-2020 DBF Rules and Regulations. The team will address this year's ruleset with a blended body design aircraft. The structural components of the wings and fuselage will be comprised of carbon fiber (CF), high density foam, plywood, balsa, and assorted hard woods. Thermoplastic film will encompass non-structurally critical components along with lightweight CF rods for the mechanical linkages, and structural components as necessary. The first aircraft is designed to carry a minimum of 20 passengers with a wing span of 60 inches and a fuselage length of 45 inches. All material and design choices are preliminary, as this document covers the initial approach of creating a plane that satisfies all the DBF 2019-2020 rules.

Management Summary



ID	Task Name	Duration	Start	Finish
1	**AIAA-DBF**	**167 days**	**Thu 8/29/19**	**Sun 4/19/20**
2	**Report**	**145 days**	**Fri 9/13/19**	Thu 4/2/20
3	Proposal Drafting	21 days	Fri 9/13/19	Fri 10/11/19
4	Proposal Finalization	6 days	Mon 10/14/19	Mon 10/21/19
5	Design Report Drafting	39 days	Tue 10/22/19	Fri 12/13/19
6	Design Report Finalization	115 days	Fri 10/25/19	Thu 4/2/20
7	**Prosposal and Design Report Writiing**	**82 days**	**Thu 10/31/19**	**Fri 2/21/20**
8	Proposal Due Date	1 day	Thu 10/31/19	Thu 10/31/19
9	Design Report Due Date	1 day	Fri 2/21/20	Fri 2/21/20
10	**Design**	**112 days**	Thu 8/29/19	Fri 1/31/20
11	Conceptual Design	17 days	**Thu 8/29/19**	Fri 9/20/19
12	Aircraft Design	79 days	Tue 9/24/19	Fri 1/10/20
13	Finalized Design	1 day	Fri 1/31/20	Fri 1/31/20
14	**Manufacturing & Testing**	**106 days**	Fri 11/1/19	Sat 3/28/20
15	**Aircaft Protoyping**	**66 days**	Fri 11/1/19	Fri 1/31/20
16	Aircaft Protoyping 1	21 days	Fri 11/1/19	Fri 11/29/19
17	Aircaft Protoyping 2	22 days	Mon 12/2/19	Tue 12/31/19
18	Aircaft Protoyping 3	23 days	Wed 1/1/20	Fri 1/31/20
19	**Aircraft Testing**	92 days	Fri 11/22/19	Sat 3/28/20
20	**Competition Fly-Off**	3 days	Thu 4/16/20	Sun 4/19/20

Figure 1: Gantt Chart

This year, the 2020 DBF management was restructured to better reward motivation and passion for the competition, resulting in a much-improved productivity and passion for the competition in comparison to previous years. This year our team is focused on using the agile method along with optimization to compose the ideas of the whole team into a unified design. Figure 2 below depicts the team structure. Members were assigned to the following sub-teams: design, optimization, manufacturing, writing, electronics, and piloting teams. Team assignments were made by the recommendations of project managers, based on a member's previous experience in DBF, leadership skills, knowledge of the sub-team tasks, and specific skills or interests of each team member. It is important to note that team members are encouraged to work in multiple areas while contributing to the writing of the proposal and report.

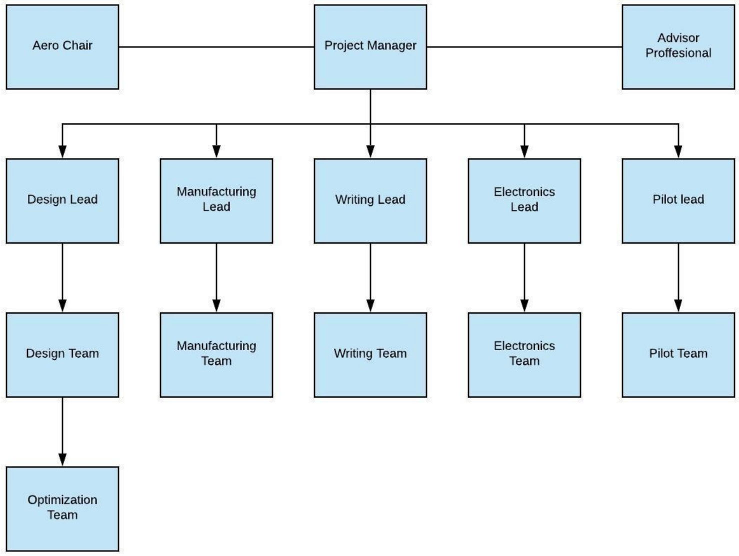


Figure 2: Management Flow Chart

The design team proposes, drafts, and consolidates the design for the aircraft taking into account ideas from other sub-teams, individuals, and the constraints presented by the optimization team. Technical software used in our design team include LaTeX, ANSYS AIM, SolidWorks, MATLAB, Arduino, and Python. The manufacturing team constructs several prototypes with a focus on selecting appropriate materials and ultimately building the final aircraft. The prototypes undergo a concurrency plan that conducts design tests while the aircraft is being manufactured to speed up plane development and train our newest members. With each new test iteration, critical details are being provided across teams to improve manufacturing processes and optimize designs. A feedback loop exists between the design, electronic, and manufacturing teams to revise the design and propulsion system based on suggestions from the manufacturing team and test results. The writing team leads the writing and review of the proposal and design report, documents the teams status as described in the Gantt chart, and keeps documentation organized in the team's cloud storage drive. The electronics team design and assembles necessary components for control, propulsion, and diagnostics of the aircraft. The pilot along with the electronics and design teams execute the testing methodology to ensure the plane is competition ready.

DBF: 2019-2020			
Plane Item	**Price**	**Quantity**	**Total**
Plane Material (Blasa, Plywood,ect.)	$ 300.00	1	$ 300.00
Voltage Regulator (YEP 20A HV)	$ 16.00	3	$ 48.00
Servos (Variety)	$ 10.00	10	$ 100.00
Banner	$ 50.00	1	$ 50.00
T-Motor: AT3520 Long Shaft (560KV)	$ 85.00	3	$ 255.00
T-Motor: ESC: 75 A	$ 40.00	4	$ 160.00
Spektrum 5000mAh 22.2V Smart LiPo 30C	$ 109.00	4	$ 436.00
Travel			
Plane Tickets	$ 500.00	10	$ 5,000.00
Hotel (3 Rooms)	$ 60.00	3	$ 180.00
Rental Car	$ 640.00	1	$ 640.00
Gas	$ 600.00	1	$ 600.00
Shipping (Tool & Plane)	$ 500.00	1	$ 500.00
Total Cost ($)			$ 8,269.00
Project Budget ($)			$ 9,793.81
Remanining Budget ($)			$ 1,524.81

Figure 3: Budget Summary

All material requirements are already allocated by the Associated Students of the University of California, Merced (ASUCM) totaling $10,000. The majority of the budget for this year will be utilized for travel and lodging as the competition is out of driving range. We will utilize materials that we have on hand from previous years to maximize this year's budget. Figure 3 serves as an approximation of expenses, for the bill of materials and travel; of 10 - 15 students.

Conceptual Design Approach

Based on the scoring criteria, the aircraft must be designed to accommodate the optimum amount of passengers and cargo alongside ample room to deploy a banner. With this, the team eagerly went to work on designing a plane that would be optimized for Mission 2 as this mission would create the greatest impact on our overall score. However, due to previous year's experiences, weather patterns must be accounted to help predict flight dynamics. In Wichita, Kansas, the average temperature is 68°F, winds of up to 13 mph, and a slight chance of rain. With this, the team is able to calculate the Reynolds number range of 378,193 - 859,530, for further calculations. Analyzing the sensitivity study, the design team found it prudent to maximize the power to weight ratio to ensure takeoff in 20 feet with a full load. The necessary take-off thrust for a 12 – 15 lb plane is approximately 12 - 15 lbs of thrust to achieve a velocity of 39 - 49 ft/s within 20 feet for the given airfoil and wing dimensions. Thus, the design goal is set to achieve the maximum number of passengers and luggage as well as a maximum banner size given the wingspan and takeoff restraints. Batteries are a large contributor to the weight and power of the airplane. The allowed usage of Lithium-Polymer (LiPo) batteries this year allows us to maximize power while maintaining a lower weight. We will be using a pair of 6S 6000 mAh LiPo batteries that have a nominal voltage of 22.2 volts and fully charged voltage of 24 volts. The main advantage of LiPo batteries is their high energy output which will allow us to generate 767 watts at 35 amps with a 13x6.5 propeller making 7.9 lbs of thrust per motor. Since we are running 2 motors this will allow us ample power to take off with a large load or to take off on a short runway with no load.

The overall plane design was inspired by the Burnelli CBY-3 aircraft. Upon conducting research on historical aircrafts, the team was highly impressed by CBY-3 unique blended body design which reduced drag by decreasing the number of vorticities that develop yet increasing the overall wing area with the airfoil's unique gradual blend into the fuselage. Due this the airfoil's gradual blend, this design provides a large increase in the aircraft's lift allowing the plane to maintain a high velocity during flight and ultimately increase the aircraft's carrying capacity. With that, the team settled on designing an aircraft that is inspired by the CBY-3 yet tailored to the competition constraints. Research quickly began on the next critical component of the aircraft – the airfoil.

During the research of airfoils, our design lead had a major focus of searching for airfoils that possess the characteristics of a high lift coefficient within a reasonable angle attack to minimize drag but optimize lift. The team decided upon the NACA M21 airfoil. This airfoil was able to produce a lift coefficient of 1.3 at an angle of attack of 7 degrees which will allow us to produce an estimated 21 lbs. of lift at a velocity of 50 ft/s.

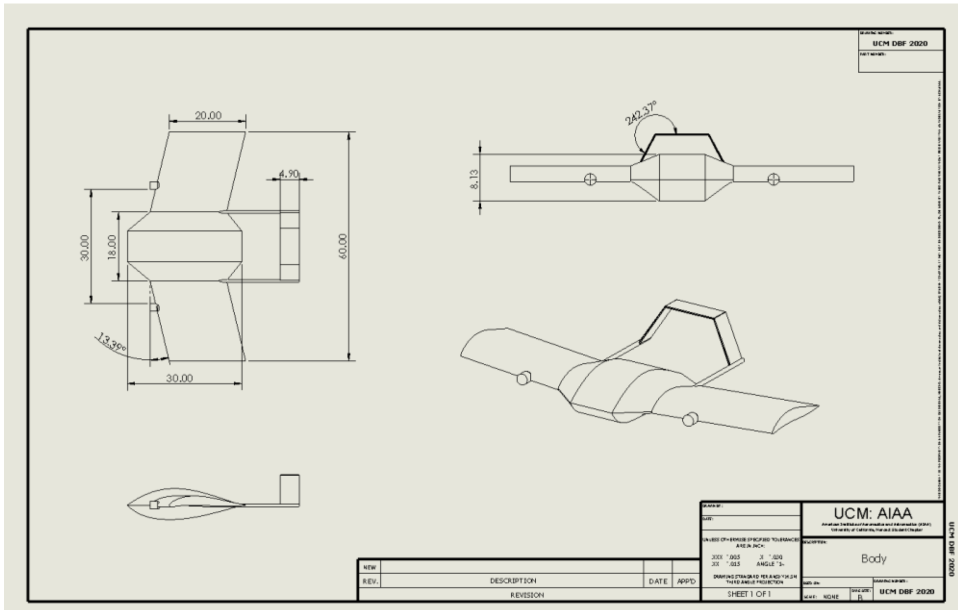


Figure 4: Assembly Drawing

In order to achieve lift-off at maximum capacity, the team decided to utilize a twin motor design with each motor producing a max thrust of 7.9 lbs each. This, along with the blended body design, will allow the aircraft to produce sufficient lift and thrust to achieve takeoff within the 20 ft maximum takeoff distance.

The fuselage is designed to provide a large area for passengers, luggage, electronics, and batteries to be stored and will implement a lifting body design. We will accomplish a lifting body design by incorporating an airfoil shape into the design of the fuselage essentially turning the fuselage into a wing. This will allow us to maintain the large area within the fuselage while adding more carrying capacity to the aircraft.

<u>Manufacturing Plan</u>

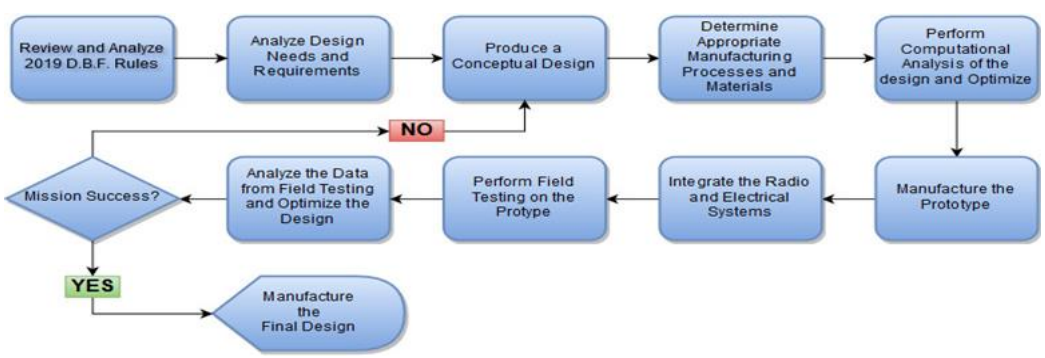


Figure 5: Manufacturing Flow Chart

The team will create a conceptual design with the intention of first meeting the requirements of the mission tasks. Multiple design iterations will be manufactured, tested, and analyzed to optimize the aircraft for the given mission objectives.

After building and evaluating multiple prototypes, the finalized prototype will be used by the pilot to practice the competitions missions. Feedback from the pilot along with onboard telemetry will help finalize the design and proceed with a competition ready design ready to be built. Testing will be finalized on the competition version. Figure 8 above displays the Manufacturing Flow Chart. The structure of the aircraft will be made using traditional model building techniques which allow for a lightweight yet strong airframe. The traditional technique uses a balsa wood structure of ribs, stringers, leading edge and trailing edge sheets along with a Monokote surface to provide rigidity without adding a significant amount of weight. The main structural pieces such as the wing spar, tail booms and major connection points will be made from either carbon fiber or hobby grade plywood to provide increased rigidity, impact resistance, and durability. More complicated components of the plane such as the banner, and passenger restraint system will utilize 3D printing to enable more sophisticated designs that would be otherwise out of reach for the skill set of the team.

Test Planning

The purpose of test planning is to analyze the flight performance, characteristics, and mechanics of the plane with respect to the mission requirements. These factors are tested in the context of the mission parameters under normal and severe weather conditions. The flight test consists of three phases: Ground test, Flight Data Gathering, and Data Post Processing.

During the ground phase, the structure of the plane will be tested by (1) loading to maximum weight, including passengers, luggage, banner, and (2) ensuring the wings, landing gear, and other critical structural components can withstand the allocated weight. Using advanced testing methods such as an Arduino powered prop/motor test bench, and servo tester, the team performs both mechanical and electronic tests to check the integrity of the servos (binding, travel, trim), motors (vibrations, surges, etc.), electronic speed controllers (heat dissipation abilities), and batteries (output power, endurance, etc.) for airworthiness. Furthermore, a range test between the receiver and transmitter will be performed to ensure a safe radio linked flight.

The in-flight data gathering process utilizes open source autopilot equipment that the team has assembled together to create a meaningful data acquisition system. This system leverages the ArduPilot source code and 3D Robotics open source hardware, allowing the team to integrate a pitot-static tube, GPS unit, barometer, a 6-axis accelerometer/gyroscope, and a telemetry unit to stream all the data back to the Ground Control Station. In this phase, the following data is gathered: Maximum flight velocity, stall speed, arrival stalls, accelerated stalls, slow-flight characteristics, turn rates, flight speed, flight time, power draw, and behavior under various wind speeds. To ensure consistent control and acceptable data, the plane will be flown with and without the passengers, luggage and banner to account for all flight scenarios.

In the post-processing phase of test planning, the team will analyze the plane's performance with ArduPilot’s Mission Planner, which helps recreate real-time flight behaviors of the plane using flight simulation functions and telemetry data logs. This allows the team to see the trajectory and the path of the plane during the specific weather conditions as it flies, which will provide significant insight into predicted lap times. This proves to be a viable method, which will significantly enable the team to recreate all variables that lead up to design failures and illustrate what improvements and iterations need to be made. Quintessentially, this will demonstrate the strengths and weaknesses of the design, allowing the pilot the confidence in making better judgements during flight.