I Executive Summary

This document outlines and proposes the design-build-fly (DBF) process to be implemented by the Brigham Young University (BYU) Team in the AIAA 2021-2022 DBF competition. Our approach, is to iteratively design, build, and fly a single wing, dual rotor, large capacity aircraft with semi-autonomous payload deposition capabilities. The design we propose is suitable for the competitive completion of the ground mission (GM) as well as the 3 flight missions (FM). The GM requires the rapid loading and unloading of the various payload units, necessitating the intuitive and accessible design described below. The flight mission requirements are as follows: FM1 requires the completion of 3 laps around the flight course within 5 minutes, carrying payload management hardware without any payload packages. The FM2 requirements are to carry as many 30 mL syringes as possible, as quickly as possible, within the time, energy, and weight constraints* for the competition. In an effort to maximize our FM2 score, we have selected a large payload capacity design. In addition, a dual rotor configuration increases the efficacy of the propulsion system in flight (avoiding obstruction from the fuselage), on-ground agility (differential thrust), and decreases takeoff distance (induction of wing lift). The requirements for FM3 are to transport and individually drop off as many mock vial packages as possible (though no more than one tenth the number of syringes carried in FM2) within the allowed time limits, all without exceeding 5 g accelerations. Our passive and active suspension systems will allow the gentle completion of the FM3 objectives.

This proposal is organized as follows: We first describe team management, organizational structure, schedule, and budget for this year in section II. We then describe our conceptual design approach in section III beginning with a decomposition of the mission requirements followed by a sensitivity study, written description of our design concept, and select images visually showing our aircraft concept. In section IV we describe the various phases in our build flow shown in figure 5, including specific materials and methods critical to bringing our design into reality. We finish in section V with our plans for phased ground and flight testing, including brief mentions of those we have already completed.

II Management Summary

II.A Team Organization

Figure 1 depicts the overall organization of our team structure. Each of the 4 subteams is lead by an individual who answers to the Engineering Lead. The subteam leads already have the skills described below for their respective subteams, but inexperienced members learn these skills along the way under the mentorship of upperclassmen.

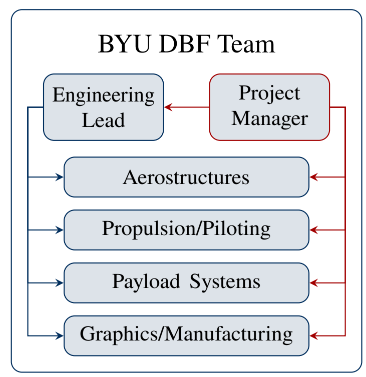


Figure 1 BYU DBF Team Leadership Organization

II.A.1 Engineering Lead The Engineering Lead has good decision making and leadership skills, qualities the BYU Aeronautics Club seeks to develop in all of its members. The Engineering Lead operates as a systems engineer and has a well rounded understanding of the various subsystems and both design and testing experience.

II.A.2 Project Manager The Project Manager acts as a logistical overseer for the team, working with the team leads on the various non-engineering tasks that need to be completed. The Project Manager has excellent organizational and technical writing skills, heading up proposal/report writing, budgeting, and scheduling.

II.A.3 Aerostructures The Aerostructures subteam members are responsible for the airframe design and testing. They have expertise in aerodynamic and structural analysis and testing, including design skills in hand calculations and computational analysis tools. They also have experience with wind tunnel, glide, and structural testing methods.

II.A.4 Propulsion/Piloting The Propulsion/Piloting subteam focuses on designing and testing the propulsion system efficacy and efficiency. Members also have skills in electronics related to the propulsion system as well as piloting skills used in simulation and flight testing.

II.A.5 Payload Systems The Payload Systems subteam is comprised of members with multi-disciplinary skills in structures, manufacture, design, and mechatronics. They bring these skills together to brainstorm, prototype, and test various payload system solutions.

*See DBF 2022 Rules for weight and energy constraints, `https://www.aiaa.org/docs/default-source/uploadedfiles/aiaadbf/dbf-rules-2022.pdf`

II.A.6 Graphics/Manufacturing The Graphics/Manufacturing subteam has skills in CAD design as well as graphical marketing for the team. They also assist in the manufacturing of prototypes and testing apparatus, as well as oversee the construction of the final, full, aircraft.

II.B Schedule

Figure 2 depicts our planned timeline for the year. Sections IV and V describe the flow of our schedule in more detail. We have completed the conceptual design presented herein and have moved on to our preliminary design phase. We also began prototyping early in order to apply a "fail fast, fail often" methodology to quickly fill any gaps in understanding and allow our underclassmen to develop their aircraft design intuition faster than if we waited to prototype after completing all the design phases. As shown in figure 2, each of our DBF phases ends with the required competition submissions and/or an internal design review.

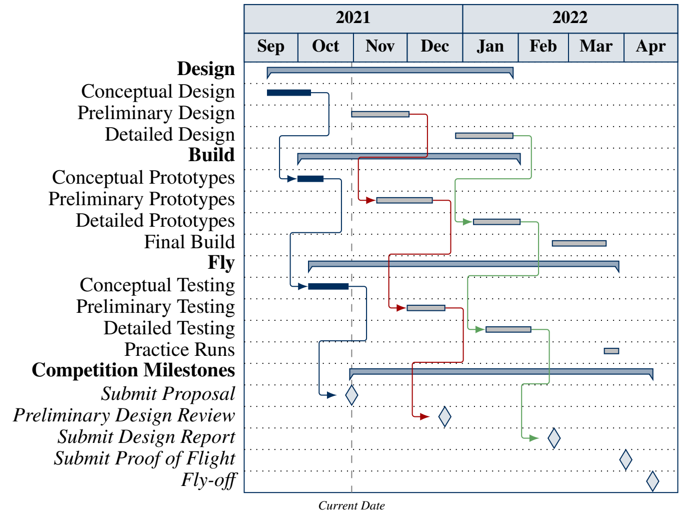


Figure 2 Our conceptual, preliminary, and detailed phased DBF timeline for this competition season.

II.C Budget

Table 1 contains a breakdown of our budget estimates for the 2021-2022 competition year. To obtain funding for our team this year, we submitted a grant proposal through the BYU Aeronautics Club to the Weidman Center for Global Leadership, an organization at BYU that provides funding for groups offering significant leadership growth opportunities to students. Upon receiving the proposed grant, the BYU Department of Mechanical Engineering matched the amount we acquired through the Weidman Center grant. A portion of these funds is allotted to general club activities and internal competitions, while the portion allotted to our team is itemized in table 1. Shipping costs for our aircraft will be $0, as we anticipate driving to Kansas, rather than flying, therefore we can transport the aircraft ourselves.

Table 1 Our estimated project budget is broken down into several categories and individual items as shown here.

Category	Items	Cost ($)
Propulsion	Brushless Motors (4) | Propellers (8) | ESCs (4)	470.00
Power	4S Lipo Batteries (3)	150.00
Structures	Balsa/Ply Wood Sheets | ABS Filament | Insulation Foam | Misc. Adhesives	130.00
Payload Systems	Syringes (150), Sensors (25), and Wood Blocks (15) | Prototyping Materials	350.00
Composites	Carbon Fiber Tubes/Spars (4/8) | Composite Fabrics | Epoxy | Vacuum Bagging Materials	480.00
Electronics	Servos (15) | Receivers (2) | Flight Controller (1) | Video & Peripheral Hardware	420.00
Travel and Shipping	Aircraft Shipping ($0) | Vehicle Rental (2500mi) | Gasoline	1500.00
Food & Lodging (x6)	Lodging (4 nights) | Meals (12)	1500.00
Total Cost		**$5000.00**

III Conceptual Design Approach

III.A Mission Requirements Decomposition

We decompose the mission requirements into subsystem requirements in table 2. We include the score equations in the second table column, and define the variables as part of the mission requirements stated in column 3. In column 4, we list the decomposed subsystem requirements. For the sake of brevity, we did not include the take-off distance requirement of 25 ft that applies to all FM. Also for the sake of brevity, we present the subsystem decompositions in column 4 cumulatively, for example, items that are listed for FM1 also apply to FM2 and FM3.

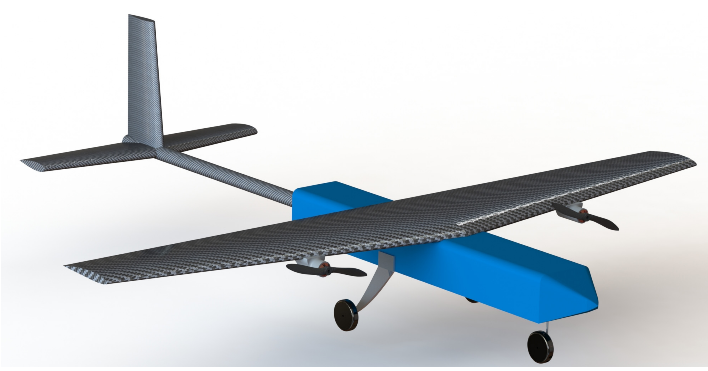
Table 2 Mission scores and requirements decomposed into subsystem requirements.

	Score Eqn.	Mission Requirements	Subsystem Requirement Decomposition
GM	$\frac{t_{min}}{t_n}$	• Manually load and unload FM2 payload • Manually load, and auto-deposit, FM3 payload • Complete in time, t_n	• Intuitive and accessible fuselage design • Simple, quick, gentle, and reliable package deposition capabilities
FM1	1.0	• Complete 3 laps within 5 minutes • Carry empty payload management hardware	• Wing and propulsion design capable of ≤25ft take-off • Efficiency in all systems to allow >3 laps in <5 minutes
FM2	$1 + \frac{N_s/t}{[N_s/t]_{max}}$	• Complete 3 laps in $t \leq 5$ minutes • Carry $N_s \geq 10$ syringes	• Strong, lightweight wing structure to carry heavy payload • Fuselage volume large enough to carry maximum N_s • High propulsion system thrust to maximize flight speed • Low wing lift coefficient at cruise, also to maximize flight speed • Wing, tail, and control surface rigidity to prevent flutter at high speed
FM3	$2 + \frac{N_{vd}}{[N_{vd}]_{max}}$	• Carry vial packages $N_v \geq N_{vd} \leq N_s/10$ • Deposit 1 of N_{vd} total delivered packages each lap • DO NOT trip shock sensors	• Wing stall speed low enough to not trip sensors due to take-off acceleration • Structure and landing gear capable of damping landing forces on payload • Payload management system that maintains aircraft static stability • Propulsion and control surfaces designed for on-ground agility.

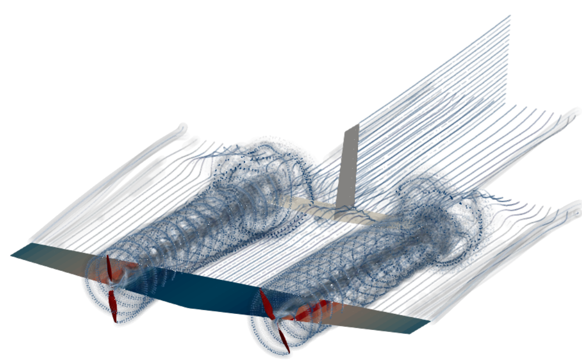
III.B Preliminary Design

After utilizing Pugh matrices to aid in configuration selection for our aircraft, we arrived at the configuration seen in figure 3a. Namely: a single high mount wing, dual tractor rotors, single boom, and conventional tail design. Using common hand calculation formulas[†] and XFLR5 software, we arrived at a conceptual design with the following specifications: a fuselage diameter and length of 7 in. and 4 ft, respectively, a wing span of 8 ft, an aspect ratio of 7.1, a wing loading of 1.67 lbs/ft^2, horizontal and vertical tail volume ratios of 0.82 and 0.06, respectively, a stall velocity of 32.4 ft/s, and a take-off distance of 18.2 ft. We have also initiated the setup of some of our preliminary design trades, simulations, and analyses; for example figure 3b shows a preliminary look at rotor-on-wing interactions using a vortex particle method.[‡]

Our current concept includes a section of the fuselage we call the "payload manager" which we will design to lower and release the vial packages one at a time. The payload manager will contain the vial packages suspended by elastic chords to absorb the acute accelerations produced by takeoff, turbulence, and landing. After a signal from the pilot, the payload manager will lower slowly to the ground by a motor-powered pulley system, and the elastic chord around one of the packages will be released by a servo, leaving the package safely on the ground. The package manager will then rise back to its stowed position and the aircraft will proceed with another flight sequence. In order to maintain static and dynamic stability, we will release the rear and front most packages in an alternating sequence, beginning with the rear most. This will shift the center of gravity (c.g.) forward by approximately half the width of a package (1.25 in.), then back to its original position when the front most package is released. We will design our airframe with both c.g. flight states in mind to ensure a stable aircraft throughout FM3.



a Rendered view of concept CAD



b Preliminary simulation using a vortex particle method to capture the near wake rotor-on-wing effects

Figure 3 Visualizations of our conceptual design.

[†]see *Flight Vehicle Design*, by Dr. Andrew Ning, https://scholarsarchive.byu.edu/cgi/viewcontent.cgi?article=1027&context=books
[‡]https://github.com/byuflowlab/FLOWUnsteady

III.C Sensitivity Study

For our sensitivity study, we first differentiated between design variables that could increase/decrease our score and those that were only related to the minimum requirements. We found the parameters that could affect the score to be: wing area, aircraft empty weight (including batteries), total lap distance, number of payload units, and available power. To perform our study, we took these parameters and ran them through common hand calculations to find the mission objective scores. In order to normalize the scores as done in the competition, we ran the analysis first without normalization, from which we saved the maximum scores. We then used those maxima as the normalization factors and re-ran the analysis. We found (as shown in figure 4) that the wing area and parasitic drag (not plotted) had the same sensitivities, thus we want to minimize drag and maximize wing loading (while still being able to take off). The available power was also important, and can be affected by battery capacity, discharge rate, voltage, and system efficiency. Interestingly, the lap distance is highly sensitive, thus we want to minimize turn radius. Obviously the number of payload units in FM2 and FM3 highly effect the overall score. We should also note that the aircraft empty weight had a relatively negligible effect on the overall sensitivity, but is important to keep in mind when designing for a feasible aircraft.

IV Manufacturing Plan

IV.A Manufacturing Flow

Our manufacturing flow follows the outline found in figure 2 which includes three DBF phases. Figure 5 shows this flow with more clarity. Note that for all phases, we will commence CAD roughly a week after design starts, and prototyping a week after that.

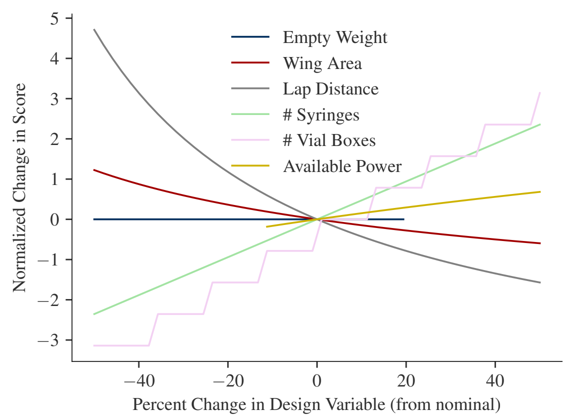


Figure 4 This plot shows the effects of those design parameters that directly affect the increase/decrease in mission scoring beyond simple completion. Lines that do not extend the full range are due to physical impossibilities.

IV.A.1 Phase 1 We have completed our conceptual design along with conceptual CAD (see figure 3a), from which we have built concept prototypes. Foam has dominated our airframe construction in this conceptual prototyping phase as it is cheap and easy to work with using hot-wire, laser-cutter, and hand tools. We have also built mock vial containers using basic woodworking power tools, as well as simple payload management prototypes using both foam and laser-cut plywood.

IV.A.2 Phase 2 We are currently beginning our preliminary design and CAD from which we will build preliminary prototypes for testing. At this stage, we will continue to use hot-wire cut foam wings/tails with tape hinges for our prototypes, and begin to employ 3D-printed plastic and laser-cut plywood/balsa components for our fuselage and payload manager. We will use prefabricated composite tubes for tail booms, and use 3D-printed attachment hardware for the various components.

IV.A.3 Phase 3 In January, we will start on our detailed design and CAD, which will lead to our final testing prototypes. After polishing the design and CAD after final testing, we will manufacture our final competition aircraft. We anticipate utilizing a combination of foam-core, composite wings and tails with live, aramid fiber hinges, 3D-printed plastic and laser cut balsa for the payload manager system components, prefabricated composite tubes for tail booms, and 3D-printed fittings for motor and tail attachments.

IV.B Critical Processes

The most critical processes this year revolve around composite manufacturing methods. Historically, there has been little to no aircraft production using composites in the BYU Aeronautics Club. Although there are many other materials and methods that can be used for successful designs, we seek to increase the knowledge base and hands on experience of the members of our team and club. Therefore, during phase 2, a subset of our team will need to learn, prototype, and teach various composite manufacturing methods to the other members of our team. We hope to utilize wet layup vacuum bagging techniques for our wing and tail surfaces. Pending further investigation and testing, we may also include a molded, composite fuselage outer shell, requiring the addition of CNC milling to our critical processes. In the mean time, our intermediate critical processes include hot-wire foam cutting, 3D printing, and laser-cutting, all of which our team members are familiar with.

V Testing Plan

As mentioned in section IV.A and shown in figures 2 and 5, each of our design and build iterations culminate in testing. Testing is divided into ground and flight testing. For all phases, we will start ground testing roughly a week after prototyping has commenced. We will perform formal flight tests near the end of each phase, in the week following the termination of the prototyping.

V.A Component/Ground Test Plan

V.A.1 Phase 1 We began with shock sensor drop tests to understand how gentle our take-off, turning, landings, and drop-offs need to be. This allowed us to narrow down our payload manager concepts, and limit testing to only a few potential payload manager concepts, gathering data on ease of loading, simplicity of design, and dependability in order to finalize major design details. We also brainstormed a variety of tests for our subsystems as described below.

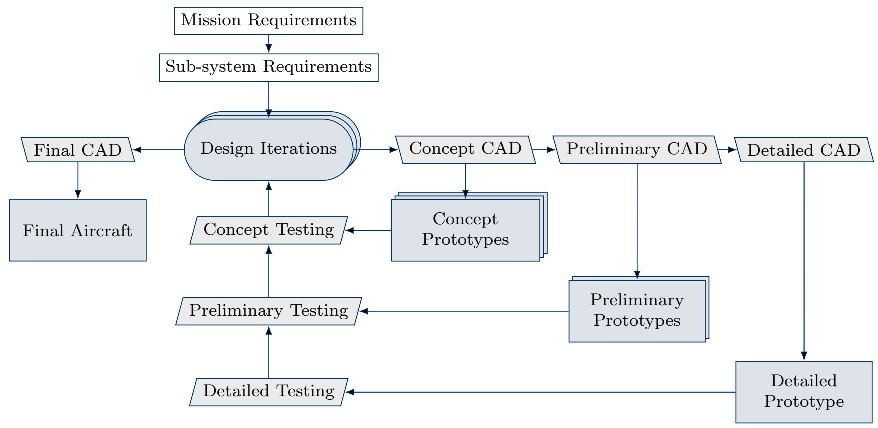


Figure 5 Iterative 3-phase development flow

V.A.2 Phase 2 In our preliminary testing phase, we will be looking at more detailed payload manager prototypes, also taking into account speed in order to finalize our designs. A major component of this phase will be wind tunnel testing in the BYU 3'x4' open circuit wind tunnel. For our propulsion system we will test across a full range of advance ratios using an RC Benchmark 1580 Dynamometer to validate the performance of, and make adjustments to, our selected propulsion system. We will also examine the performance of a small variety of high lift configurations for our wing in order to validate our simulations of short takeoff/landing configurations, including gathering data on rotor-on-wing interactions (see figure 3b). In addition to these wind tunnel tests, we will perform structural testing of our composite wing prototypes and other critical structures, including landing gear, gathering yield and failure data to apply appropriate safety factors to our final designs. It should be noted that at the beginning of this phase, we will assemble and test the safety systems required in this year's competition rules.

V.A.3 Phase 3 After finalizing our wing and tail manufacturing methods, we will need to test them in the wind tunnel again, this time gathering data on their aeroservoelastic behavior at high velocities in order to validate our structural design and manufacturing quality. Finally, we will do full system tests, performing dry runs of the ground mission as well as the on-ground components of FM3. This will allow us final tweaks on the design prior to our final competition build which we will similarly test with dry runs.

V.B Flight Test Plan

V.B.1 Phase 1 We began our flight testing with a hand-launched, unpowered, uncontrolled glider. Our primary goals for these tests were to validate our static stability and general structural calculations, as well as jump start the aeronautical intuition of our new team members.

V.B.2 Phase 2 In the preliminary phase of flight testing, we will begin with an unpowered, controlled, hand-launched glider to which we will add capabilities as our design progresses. As our preliminary design progresses and after the completion of some of the wind tunnel testing described above, we will perform flight tests with a fully operational, powered, airframe, though without payload capabilities. After adding propulsion capabilities to the airframe, we will utilize a flight controller as our main data acquisition device, along with cameras, chronometers, and measuring tapes to complete all our testing regimens. Our goal for the preliminary testing is to gather general flight data to validate our preliminary design simulations, record aircraft performance, and note any unexpected behavior in the aircraft dynamic responses before moving on to detailed design aspects and full system integration.

V.B.3 Phase 3 As our detailed design prototype will be sufficient to compete if needed, our goal for the final testing phase will be to fly the complete mission sequence, allowing for any final fine-tuning of the design before building our competition aircraft. We will collect all the data required for a complete design report, again using primarily a flight controller and other on-board, data acquisition hardware.