Design Build Fly Senior Design Project

High-Level Design

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1. Introduction

This year, the AIAA Design Build Fly Competition outlined one of the goals: to build an autonomous glider that separates from the main aircraft mid-flight and lands in a designated landing zone. Teams are scored based on several criteria, including the number of laps the main aircraft flies, the weight of the glider, and how close the glider lands to the landing zone. Our Senior Design team, partnering with the Design Build Fly (DBF) Club of Notre Dame, has taken on the challenge of creating the glider for this project. The DBF Club is responsible for the structure and aeronautics of the glider. Our senior design group will handle the electronics for the project. These include a printed circuit board equipped with an ESP32 microcontroller that processes data input from several sensors and actuates the aircraft's control surfaces accordingly. The purpose of this document is to outline the specifications of the competition, cover a high-level design of our solution, provide a summary of the work completed, acknowledge the unknowns, and provide an estimated cost summary of the project.

2. Problem Statement

The AIAA Design Build Fly Competition has a list of requirements and constraints on the glider aircraft that must be met in order to be eligible for the competition.

To begin, the glider can have a maximum weight of 0.55 pounds (250 grams). Teams are allowed to determine means of flight control and navigation. However, no radio controlled receivers are allowed to be integrated onto the glider. The glider must fit between the two external fuel tanks on the airplane and be secured to the airplane for all stages of flight, except for the mission during which it is launched. There is a minimum gap of 0.25 inches between any part of the airplane fuselage and the wings of the glider. The glider must have strobe lights that turn on after it is released from the airplane. No points will be received if the lights turn on before launch, or fail to turn on after launch.

The glider must be launched from the airplane at an altitude of 200-400 feet above the ground. To achieve bonus points, the glider must release itself from the airplane and execute a 180 degree turn. Then, using a descending or gliding pattern of choice, the glider will land on the ground. If the glider comes to rest within one of the landing zones as shown in Figure 1, bonus points will be awarded. The scoring calculation is shown in Equation 1.

$$Score = 2 + \#\,of\ laps\ flown + \frac{Bonus\ Box\ Score}{Glider\ Weight} \tag{1}$$

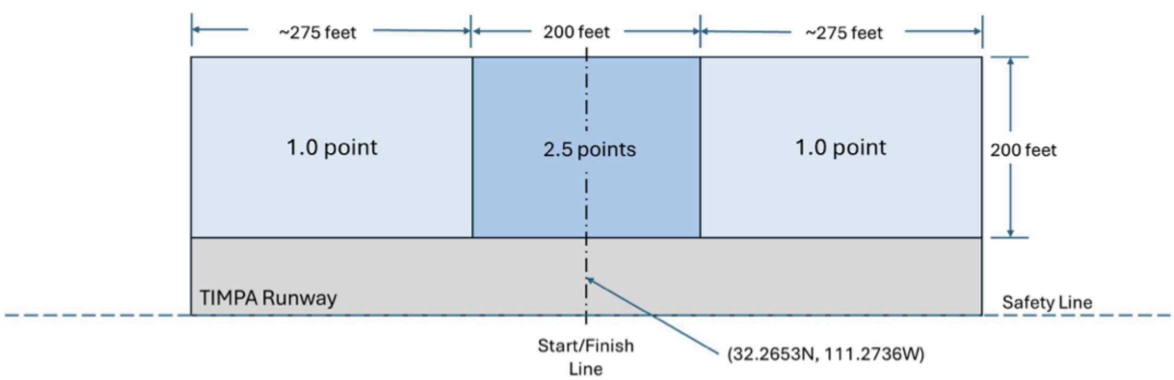

Figure 1. The Glider's Bonus Points Landing Box

The goal for our team is to allow the glider to receive as many bonus points as possible. Therefore, it is critical the glider lands in the highest-scoring landing zone, makes a successful 180 degree turn, and has a working set of strobe lights that both turn on at the correct time and are visible by the judges, while being as lightweight as possible.

2.1 Proposed Solution

As previously stated, our team is responsible for the electronics inside of the glider. To successfully complete this project and score highly at the competition, we need to implement several devices that work effectively and efficiently. At the center of our circuit board will be the ESP32 microcontroller. This will be responsible for the collection, processing, and outputting of data. Several sensors will be connected to implement data to this microcontroller. The ESP32 will process data collected from several sensors. These include an inertial measurement unit, differential pressure sensor with pitot tube (for airspeed), and GPS module. The sensors will be essential to the navigation and autonomous control of the glider. We will use a proportional-integral-derivative (PID) algorithm to determine the precise adjustments required for stable flight and optimal control surface actuation based on sensor data. This algorithm will ensure our glider lands in the desired landing to achieve maximum bonus points from the judges.

On the output side, the ESP32 will be connected to 2 servo motors to actuate the control surfaces of the aircraft. Our glider will have ailerons and an elevator, which is determined to provide adequate control. The glider design forgoes an actuated rudder to save weight that would be added from an additional servo motor and the structures associated with it, but will have a vertical stabilizer for aerodynamic reasons.

Our solution effectively leverages the sensors, motors, and the ESP32 microcontroller to process data inputs and provide real-time control outputs to ensure reliable flight performance.

3. System Requirements

Table 1 summarizes the system requirements based on the competition rules [1] and derived requirements from the DBF team or the EE Senior Design Course.

Table 1. System Requirements

System Requirement	Category
The X-1 test vehicle is a glider capable of autonomous flight.	Rules
The X-1 test vehicle will be launched from the airplane at an altitude of 200-400 feet above ground level.	Rules
The X-1 test vehicle must transition to stable flight after release from the airplane	Rules
The X-1 test vehicle must execute a 180-degree turn after launch	Rules
The X-1 test vehicle must fly a descending pattern or orbit of the teams choosing until landing on the ground	Rules
The X-1 test vehicle must land in one of the bonus boxes shown in Figure 1 or else no bonus points will be awarded.	Rules
The X-1 test vehicle shall have flashing lights or strobes that come on after release from the airplane. If the lights come on before launch or the lights fail to come on after launch, no bonus points will be awarded.	Rules
After the X-1 test vehicle comes to rest in a bonus box, the lights/strobes must still be working (flashing) to achieve bonus points.	Rules
The X-1 test vehicle flight control and navigation may include an autopilot/flight control with or without GPS	Rules
No RadioControlled receivers may be integrated into the X-1 test vehicle.	Rules
The X-1 test vehicle shall have a maximum weight of 0.55 lbs.	Rules
The X-1 test vehicle must be carried underneath the airplane fuselage	Rules
There must be a minimum gap of 0.25 inches between any part of the airplane fuselage, wings, or outer surface and X-1 test vehicle wings.	Rules
The X-1 test vehicle must be secured to the airplane for all phases of flight – take-off, flight, and landing – other than intentional launch in Mission 3.	Rules

The X-1 test vehicle must be capable of a commanded release from the airplane via the pilot's transmitter.	Rules
After completing the first lap or any subsequent lap, the X-1 test vehicle will be released after crossing the start/finish line and prior to executing the upwind turn. Each team will determine the number of laps flown prior to launching the X-1 test vehicle. The X-1 test vehicle must be launched to achieve a successful mission score.	Rules
The X-1 test vehicle must come to rest on the ground within the 5-minute flight window for any applicable bonus points to count.	Rules
The X-1 test vehicle must use an ESP32 microcontroller	Derived from EE SD
The X-1 test vehicle must be powered by a LiPo battery	Derived from DBF Team
The X-1 test vehicle board must use servos that interface with pitcherons for pitch and roll control	Derived from DBF Team
The X-1 test vehicle must be capable of logging data	Derived from DBF Team
The X-1 test vehicle board must have mounting holes to interface with the rest of the vehicle	Derived from DBF team

It should be noted that not all competition requirements will be fulfilled by the senior design team. Some will be directly fulfilled by the DBF team. However, coordination amongst both groups will be required to fulfill all requirements listed in Table 1.

4. System Block Diagram

4.1 Overall System

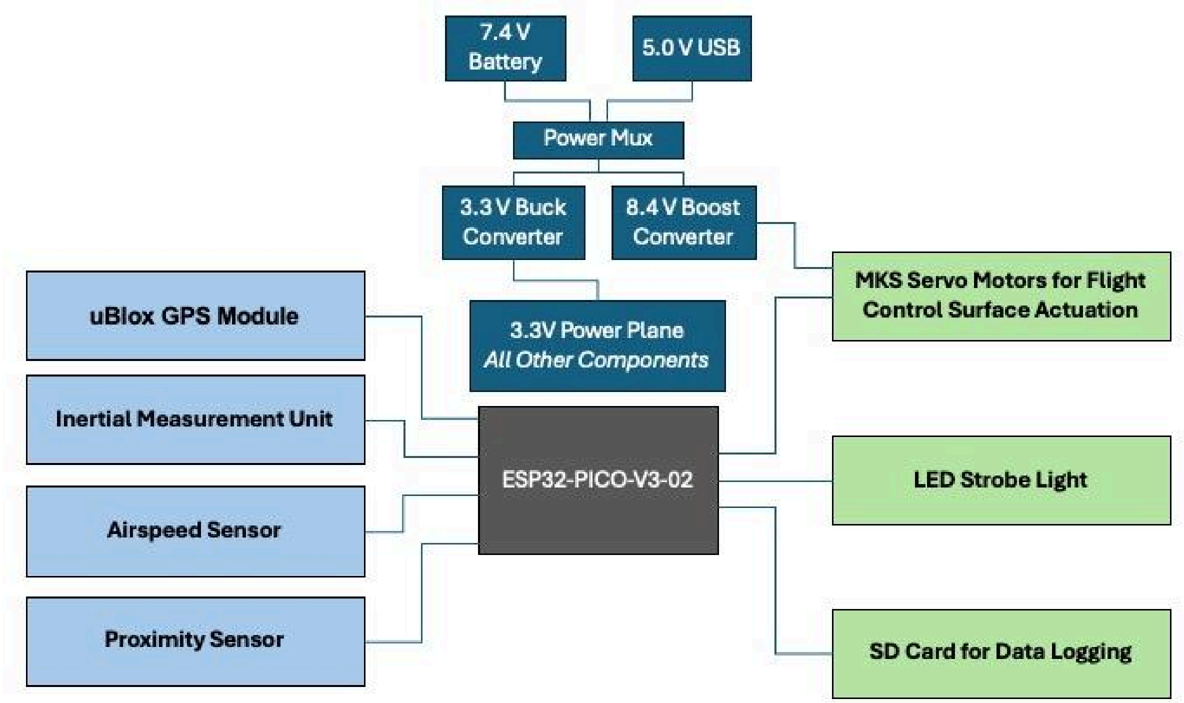

Figure 2. Overall System Block Diagram

4.2 Subsystem Requirements

The subsystem requirements for this project are split into three main categories: hardware, software, and integration. Each category addresses specific constraints and goals to ensure the successful development and operation of the glider's electronic system.

4.2.1 Hardware

This section covers the requirements of the hardware components of our project. Below is a list of each component followed by a description of what the component needs to do.

4.2.1.1 Microcontroller

The microcontroller must be compatible with all of the peripherals needed to accomplish the mission. According to competition rules, it also cannot have any receivers. Hence, a traditional ESP32 module with an F antenna cannot be used.

4.2.1.2 Sensors

The system must successfully integrate the following sensors:

1. Inertial Measurement Unit (IMU)
    - To measure glider orientation and angular acceleration data
2. GPS Module
    - To determine position and aid navigation to the landing zone
3. Differential Pressure Sensor
    - For measuring airspeed
4. Proximity Sensor
    - To detect separation from the main aircraft and activation of the autopilot and strobe lights after launch

Proper placement and connection of these sensors are critical to their functionality.

4.2.1.3 Power System

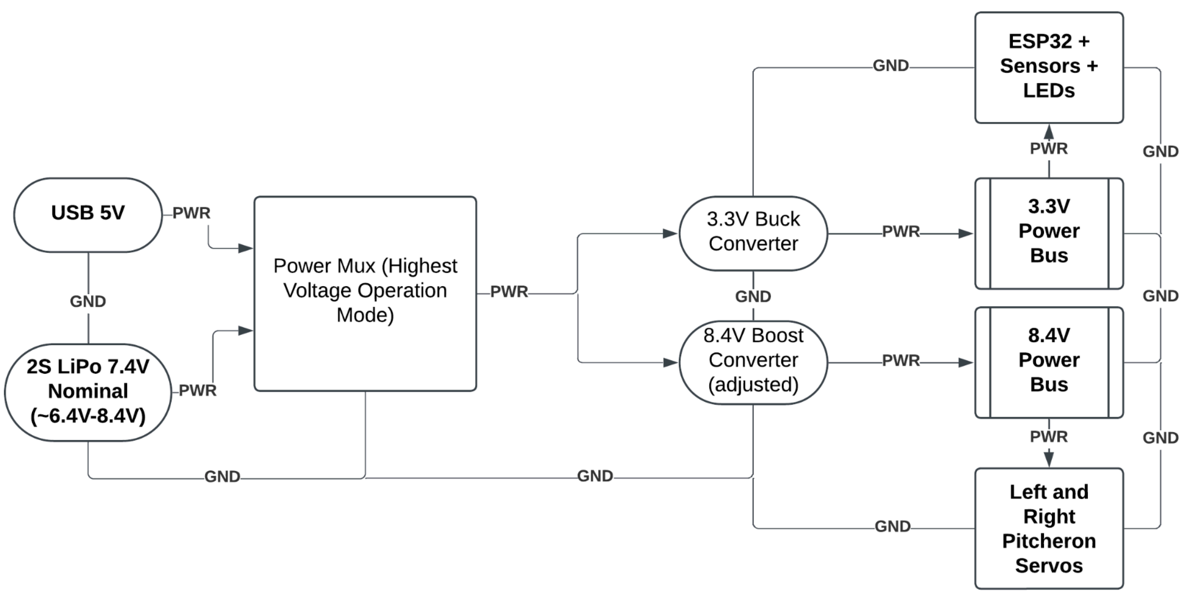

Figure 3. Power Path Block Diagram

In order to maintain control during flight, a stable and efficient power system for the circuit board must be created. This system needs to include the ability to power the board using a 5.0 V USB or 7.4 V battery, for programming and launch respectively. Additionally, there needs to be a 3.3 V Buck Converter to power the microcontroller and its peripherals from the PCB's power plane, and a 7.4 V Boost converter which will power the servo motors.

The power system must provide adequate runtime during the glider's flight and meet the power requirements of each individual component. This includes assembly time prior to the mission, the time spent in the air prior to launch, and enough time after launch to keep the LEDs on to confirm a mission score.

4.2.1.4 Flight Control Surface Actuation

The flight control surfaces must be actuated by the servo motors to maintain control of the aircraft. Based on load estimates by the aero squad, the servos must have a torque rating of 4 kg*cm or above to withstand load at high speeds, specifically at speeds of ~115 ft/s before launch from the main aircraft. To have adequate control authority, the servos must have a range of at least ±30º. Lastly, the servos must be able to use 3.3V logic to control its position and be powered by 8.4V.

4.2.1.5 Data Acquisition

A MicroSD card mount must be implemented into the board to allow for data logging during test flights. While this will add to the overall area and weight of the board, it will be critical for optimizing the autopilot code and will allow us to determine precise proportionality constants for pitch and roll controls.

4.2.2 Software

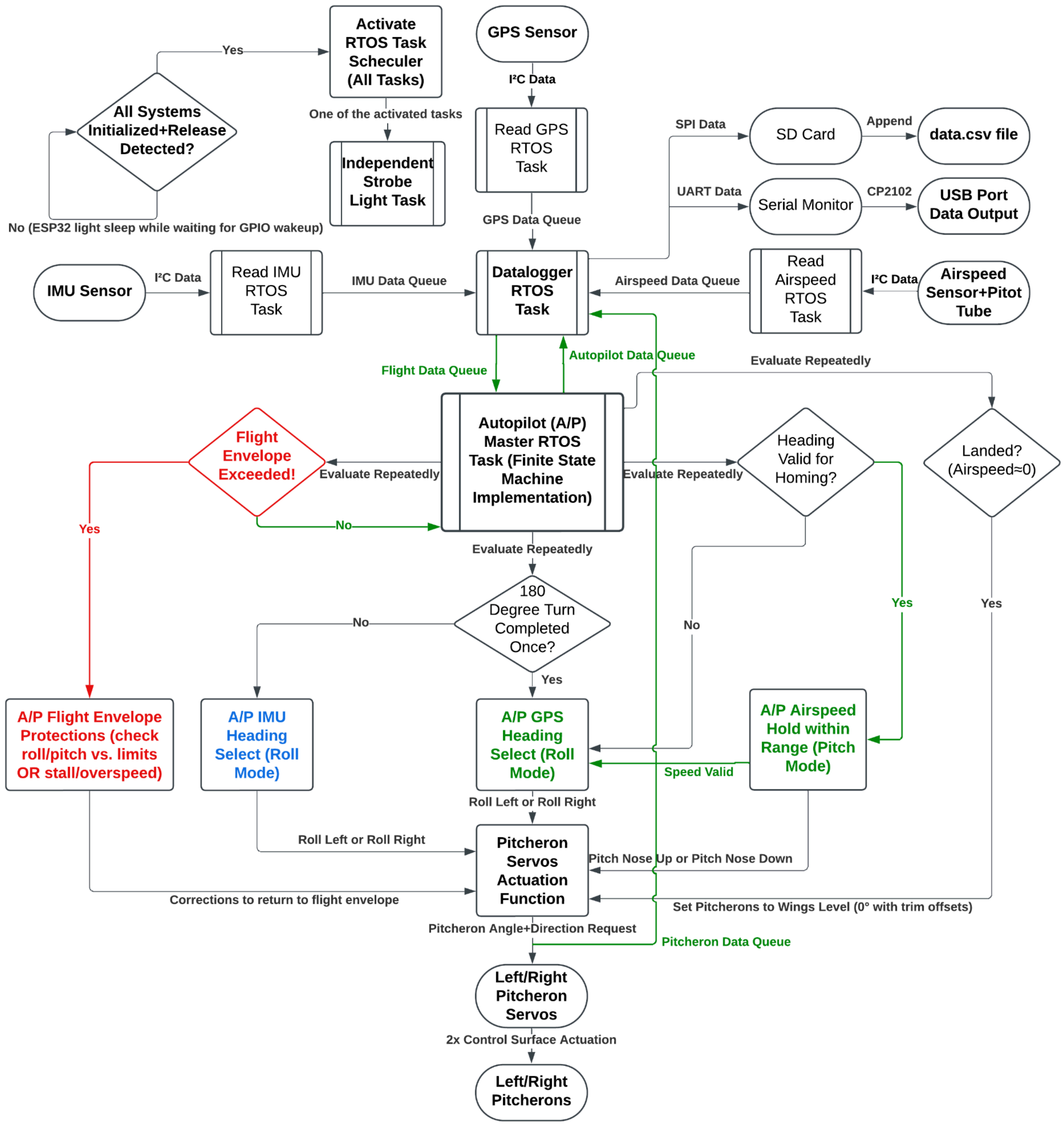

Figure 4. ESP32 FreeRTOS Software Control Logic Flowchart

4.2.2.1 Release Detection

The microcontroller will be put into a light sleep state after running all sensor, servo, and other initialization functions until it detects release from the main aircraft and wakes up to resume code execution.

4.2.2.2 Data Acquisition

The software must be capable of acquiring data from all sensors over the I2C bus and sending it to both the SD card for long-term storage as well as to the serial monitor for debugging via USB connection to a laptop. Data acquisition must be done in a way that avoids I2C bus contention (multiple access), and therefore we will use an RTOS mutex to only allow one sensor to access the I2C bus at a time. In addition, queues will be used between each of the three sensor reading tasks and a main data logger task to allow concurrent data processing to improve system performance, while allowing the data logger task to be in a blocked state until all sensors have collected data in each overall system loop.

4.2.2.3 Autopilot

This is essentially a finite state machine with a single master autopilot task that uses data from the sensors (sent in a single large queue from the datalogger task) to first decide what phase of flight the glider is in (e.g. making the 180 degree turn or homing onto the target GPS location, or landed). Based on the state, the correct autopilot mode is chosen (e.g. 180 degree bearing change with IMU, bearing change with GPS using current vs. target location, and speed adjustment through trim).

4.2.2.3 Strobe Light

The strobe light task will run continuously from the moment of release detection (as soon as the RTOS scheduler starts when the microcontroller receives the GPIO wakeup signal). It will keep running until the system is power cycled so that the judges can view it after the glider lands as well.

4.3 Future Enhancement Requirements

Our first iteration of the board only included one screw terminal for one LED. A board setup that allows for multiple LEDs must be included to ensure the LEDs are visible from all angles during descent. The power and GPS fix LEDs on the board will require a jumper so that they can be turned off at the competition, as these LEDs will count as strobe lights and could disqualify us since they would be on before launch from the aircraft.

5. High-Level Design Decisions

This section will cover the planned decision choices to meet the requirements outlined for the project described above.

The glider needs to be capable of autonomous flight. To realize this requirement, our team will code a proportional-derivative controller that will guide the glider to the landing zone via GPS. This will help the team meet the requirement of no radio-controlled receivers.

The proximity sensors will be responsible for detecting separation from the main aircraft and activating the autopilot and strobe lights after launch, which will stay on and functional after the glider lands. The launch of this glider will be guided by a radio receiver on the main aircraft. However, our glider must separately detect this launch via the proximity sensors.

Proper detection of glider launch is essential to this project's success. We plan to execute the 180-degree turn using the IMU and its corresponding algorithm. The descent pattern of the glider is still under consideration and requires further research. We intend to place the glider into a holding pattern to keep it within the bounds of the landing zone.

To meet the weight requirement, the board has been designed with weight savings in mind. We have created a compact design that allows room for modification if necessary. As of now, the glider is well under the weight limit, with our prototype coming in at 160 grams.

The flight control surfaces of the aircraft will be actuated by two servo motors. These motors will adjust the pitcherons to the desired angle.

All processing will be done by an ESP32 microcontroller, and all components will be powered by a 7.4 V LiPo battery. Data logging will be done via an onboard SD card that is responsible for tracking all components on board. To ensure all routines are properly executed, a real-time operating system will be implemented.

Lastly, mounting holes will be included on the board to ensure a stable connection with the structural components of the glider.

6. Summary of Work Completed

At the moment, our group has completed the first design of the circuit board, with two boards having been fabricated. The board integrates the components mentioned above. Additionally, a large portion of the software has been written. Our team has written or imported the code for the peripherals and integrated it with a real-time operating system.

There is currently an issue with the GPS antenna on the board, but it fails to connect to a satellite. This is presumably because of either a flaw in the placement of the component or a grounding issue. This will require a redesign, and in that process, several other components might be rearranged based on requirements put forth by the mechanical engineering team. The main intentions for this redesign are to improve the integration of the circuit board with the glider and correct the GPS antenna to get signal reception.

7. Known Unknowns

7.1 Aerodynamic Behavior and Precise Control

The team decided that "pitcherons" will be used for pitch and roll control and there will be no rudder, meaning no yaw control. Pitcherons have one servo per wing and either move the wings together to pitch the glider or move the wings opposite of each other to roll the glider. The reason for this decision is that the wings are so small that control surfaces would be difficult to implement and control. Neither the team nor our senior design group have experience with them so a lot of stability and control calculations will be made to estimate our control authority and verified through multiple flight tests. The stability analysis by the aero squad designed the glider to be inherently stable so that when no commands are given to the servos, the glider will have stable flight. However, this is yet to be tested and verified.

7.2 Structural Durability

AIAA released a Q&A stating that the glider does not have to remain intact upon landing. The only requirement is that the strobe lights must stay on to receive points for the mission. We currently do not know the structure squad's intention to keep the glider intact. This is important because if they want to build a lightweight but nondurable glider to maximize score, then as a senior design group we must design with the possibility that we would have to have multiple boards ready for testing and for the competition. If they decide to sacrifice the score for the sake of durability and reusability, then we will not have to worry about making a lot of boards. We also have to be deliberate with our placement of the LEDs because they must be visible from all angles during descent and they must stay on after landing so that the flight-line judge can verify it is on.

8. Major Component Costs

The biggest component costs will come from the sensors and the power management circuitry. Table 2 lists our most expensive components, their costs, and a brief description of their function. Materials used to construct the glider will be purchased by the team or will be provided by the EIH (for example 3D printer filament). The proximity sensor was salvaged from a broken laser cutter's interlock system.

Table 2. Major Component Costs

Component	Price ($)	Description
ABP2	31.71	Differential pressure sensor
NEO M9N	27.00	GPS Module
BNO085	16.36	IMU
CP2102	5.59	UART to USB for programming
MicroSD Card Mount	3.48	Data logging
ESP32-Pico	3.20	Microcontroller
Buck Converter, Boost Converter, Power Mux, Inductors	1.00 - 3.00	power management circuitry

If possible, the most expensive components (ABP2, M9N, and BNO) will be reused from board to board to minimize costs between board iterations and test assemblies.

9. Conclusions

The Design Build Fly Senior Design project is responsible for developing the electronics for an autonomous glider to compete in the AIAA Design Build Fly Competition. This project involves creating a lightweight glider and a high-performing navigation system for precise flight control.

The purpose of this project is to build the electronic systems for a glider that deploys at 200–400 feet of altitude, activates strobe lights, completes a 180-degree turn, and maintains stability while landing in a designated zone. The goal is to achieve the maximum number of points at the competition. To achieve this, we will focus on implementing sensors and actuators for accurate flight control, using lightweight materials to meet weight limits, and processing and recording data for in-flight usage and post-flight analysis.

At this stage, our team has successfully completed the first iteration of the circuit board, with two fabricated prototypes. The board integrates key components, including the ESP32 microcontroller, IMU, GPS module, and power system. Software development is underway, including release detection, data acquisition, and preliminary autopilot logic. Moving forward, our team will focus on refining the flight algorithms and validating sensor accuracy through testing. More flight testing needs to be done to ensure viability of the systems. Looking forward, our group needs to further explore the aerodynamic behavior and structural durability of the glider to ensure reliable flight control.

This project is particularly exciting because it involves aspects of electrical, aeronautical, and mechanical engineering. It is also an exploration of autonomous flight systems, with potential applications beyond the competition. By combining the experience our team has gained over the last four years, we hope to demonstrate a competitive and functional glider at the 2025 AIAA Design Build Fly Competition.

10. References

[1] *2024-25 Design, Build, Fly Rules Summary*, www.aiaa.org/docs/default-source/uploadedfiles/aiaadbf/resources/dbf-rules-2025.pdf?sfvrsn=7e2ef7d8_6. Accessed 17 Dec. 2024.