HAR: A Low-Cost Modular Flight Computer for High Altitude Ballooning

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Reliable systems for collecting, storing, and transmitting sensor data are critical for high-altitude balloon experimentation. However, existing COTS systems are expensive, inflexible, or difficult to source, and are out of reach to low-budget academic or amateur ballooning organizations. Our solution, the High Altitude Reporter (HAR), is a flight computer designed for stratospheric ballooning that collects and transmits GNSS and atmospheric data, and is intended to be cheap, accessible, and easy to use for small teams. HAR utilizes SparkFun's MicroMod ecosystem to increase modularity and reduce complexity by taking advantage of MicroMod's M.2 form factor. The onboard ESP32 processor allows the wireless linking of onboard devices through the processor's WiFi transceiver in addition to standard wired communication protocols (SPI, I2C, UART). HAR utilizes a 915 MHz LoRa transceiver module to provide a data down-link and command up-link during flight. In this paper, we describe the HAR architecture and implementation. As a demonstration of HAR's capabilities, we also analyze data collected during various test flights. Results indicate that HAR is a consistent and reliable flight computer for high-altitude ballooning, and is easily expandable to allow for the implementation of many additional features.

Avionics | ESP32 | Flight Computer | Wireless Communications

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Introduction

Since 1993, Iowa State University's High Altitude Ballooning Experiments in Technology, HABET, has served as a platform for students to gain practical engineering experience by designing and building systems to support near-space experimentation and testing by other students, professors, and external clients. One of the most critical systems for high-altitude balloon experimentation is a reliable flight computer. As the HABET program continues to evolve and grow, the need for a dependable avionics system, and the definition of what that entails, has grown with it. In order to meet the needs of the team and future customers, several features were identified as requirements for any flight computer to be considered a success. First, it must be able to record atmospheric and GPS data and store it onboard. Second, it must communicate with the ground using a common LoRa frequency, such as 433 MHz or 915 MHz. Third, the chosen processor must be able to communicate with a variety of sensors and electronic devices through both physical and wireless connections. Finally, it must be expandable, adaptable, cheap, and easy to build. Over the past year, the current HABET team has been focused on the task of creating a new flight computer, the High Altitude Reporter (HAR), which meets these requirements.

Investigation of Methods

Early in the development process, the team experimented with a few potential solutions. One of these relied on Adafruit's Clue board, which has built-in atmospheric sensors and a processor with a Bluetooth transceiver. While the Clue board is compact and capable of meeting many of the stated requirements, it also has several drawbacks. The Clue board does not have easy direct access to its pins without the use of a breakout board. Onboard data storage is highly important, and the Clue board does not have an SD card slot, instead relying on 2 MB of internal storage, which is insufficient for longer flights or higher volumes of data. While the Clue board does have on board regulation, it is limited to how much power it can supply to external devices and there is no on board charging circuit for use with Li-Ion batteries. Finally, all external components, such as the radio or GPS modules, must be soldered to a breadboard. While none of this is overly complex, it is the goal of HABET to be accessible to students and to have a greater amount of flexibility in anticipation of future technologies. A custom PCB for the Clue was also explored, but was ultimately abandoned, as it introduced new costs and reduced flexibility.

Ultimately, the team opted to move forward with SparkFun's MicroMod ecosystem. The MicroMod main boards and components use the M.2 form factor, which allows easy assembly and the ability to swap and add components and processors with little effort, fulfilling the requirement for both expandability and adaptability. There are a variety of processors available for use with the MicroMod base board, allowing for additional flexibility. The board includes two Qwiic connectors, providing a simple interface for connecting I2C sensors. The board also includes a USB-C port for programming the processor. Additionally, the MicroMod base boards come with built-in power regulation. No soldering is required for assembly, which means that students with little to no knowledge of electronics can quickly put together a functional board.

The ability to collect and store accurate GPS and sensor data is an integral feature of any ballooning flight computer. The u-blox NEO-M9N GPS was chosen due to its high accuracy and maximum altitude of 80,000 meters and is connected over I2C using one of the MicroMod board's two Qwiic connectors. HAR uses a BME680 environmental sensor to gather temperature, pressure, and humidity data. Testing has been conducted with additional sensors, such as a 9-DOF IMU and a differential pressure sensor (to measure pressure differences between the atmosphere and the gas inside the balloon). While these have not been permanently implemented, the addition and removal of these and other I2C sensors to the HAR board is made very straightforward using the Qwiic system. Onboard data storage is simplified as well, as the main board includes an SD card slot and a dedicated chip select pin to access it.

MicroMod's 915 MHz LoRa transceiver function board provides communication between HAR and the ground and is slotted into the main board's first M.2 function slot. It has a maximum transmit power of 30 dBm, and is capable of alternative modulation techniques, such as frequency-shift keying and on-off keying. Unlike the rest of the HAR system, which operates at the 3.3V logic level, the LoRa module operates at 5V. This level conversion is handled automatically by the MicroMod main board, without the need for any additional steps by the user. Through testing, performance has been verified at altitudes of up to approximately 30,000 meters, varying based on output power and choice of antennae.

As mentioned previously, there are many available processors for the MicroMod ecosystem. HAR uses the ESP32 processor, which meets all of HABET's stated requirements for a processor. For wired communication protocols, the ESP32 provides one USB, one UART, two I2C, and one SPI as dedicated peripherals, with additional peripherals available on shared pins. The ESP32 also contains an integrated WiFi and Bluetooth transceiver for short-range wireless communication. Programming is done using the Arduino IDE, with code written in C/C++. Many of the SparkFun components that HAR relies on have robust, well-written, and well-maintained libraries for Arduino, which greatly simplifies the programming process.

One advantage of the MicroMod eco system is that we can now swap out different components or processors based on what is needed for the mission. While the ESP32 was selected as it meets the requirements, a different processor could be swapped in if needed. This might be an updated version of the ESP32 or even switching to a completely different processor like a Cortex M4 or even a RP2040. As each of one of these have different capabilities, we now have a more flexible system that can better adapt to the needs of the mission at hand.

As pictured below in Figure 1, the HAR system consists of the following equipment, broken down by cost in the table below:

Component	Cost (Dollars)	Quantity
SparkFun MicroMod Main Board - Double	19.95	1
SparkFun MicroMod ESP32 Processor	16.95	1
SparkFun NEO-M9N GPS	69.95	1
SparkFun MicroMod LoRa Function Board	39.95	1
915 MHz Antenna	9.95	1
32 GB microSD Card	10.00	1
Qwiic Cables	N/A	2

Collectively, the cost per unit to build HAR is approximately 185.70 USD. This compares favorably to available COTS solutions, the cheapest of which are approximately 300 USD. In addition to their cost, the few existing COTS options for ballooning avionics tend to be fairly inflexible, and often do not provide all of the same features without additional expenses. While the number of commercial options available can be expanded by considering CubeSat flight computers, cost again becomes a major factor, as the cost of CubeSat flight computers starts in the thousands of dollars.

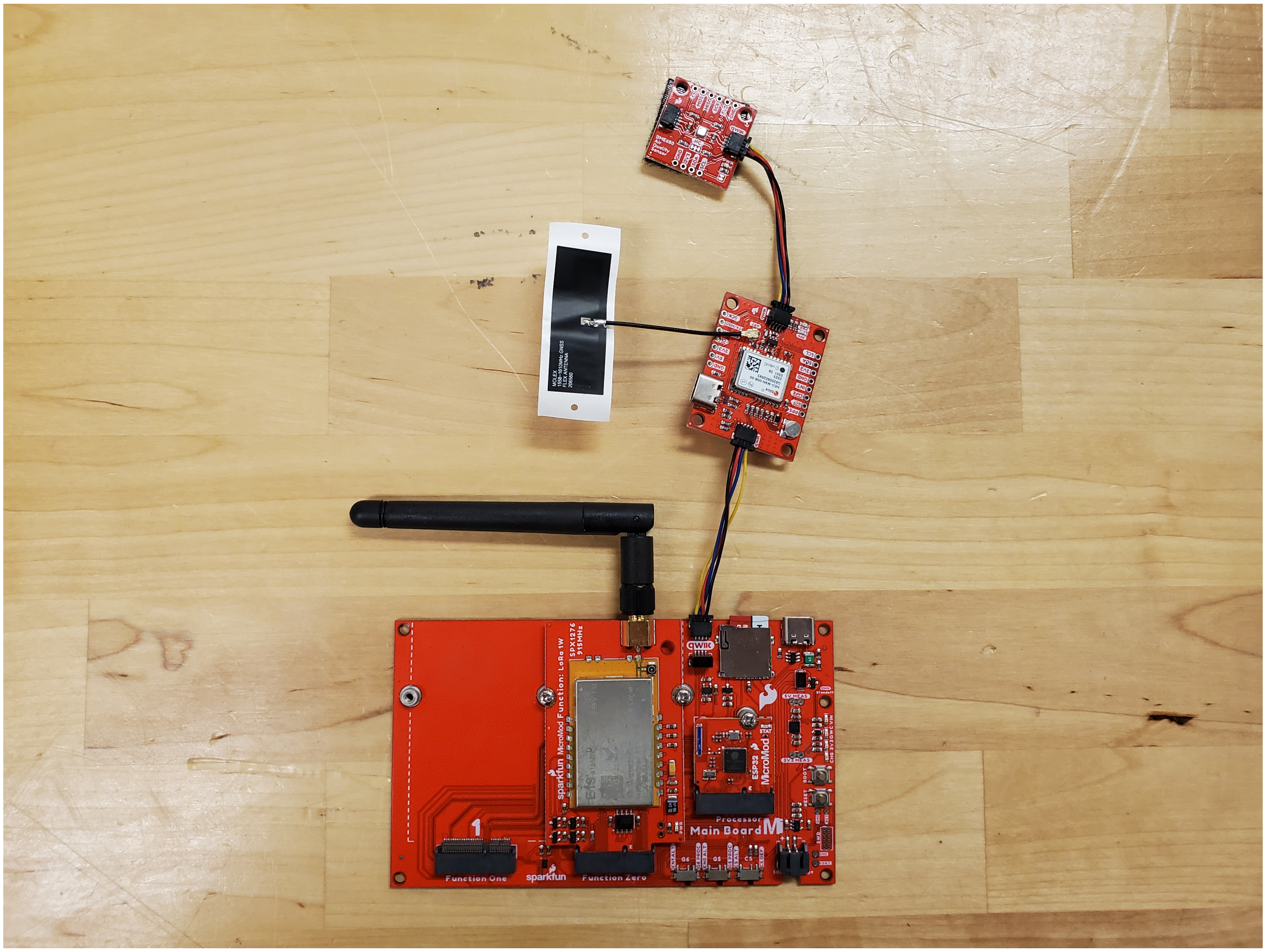

Fig. 1. An assembled HAR unit.

Results

During flight testing, HAR has consistently demonstrated the ability to reliably gather atmospheric and GPS data. Results will be shown from two separate flights: radio repeater test flight L-174-A, flown on March 23, 2024 from Ames, IA, and total solar eclipse flight L-169-C, flown on April 8, 2024 from Carbondale, IL.

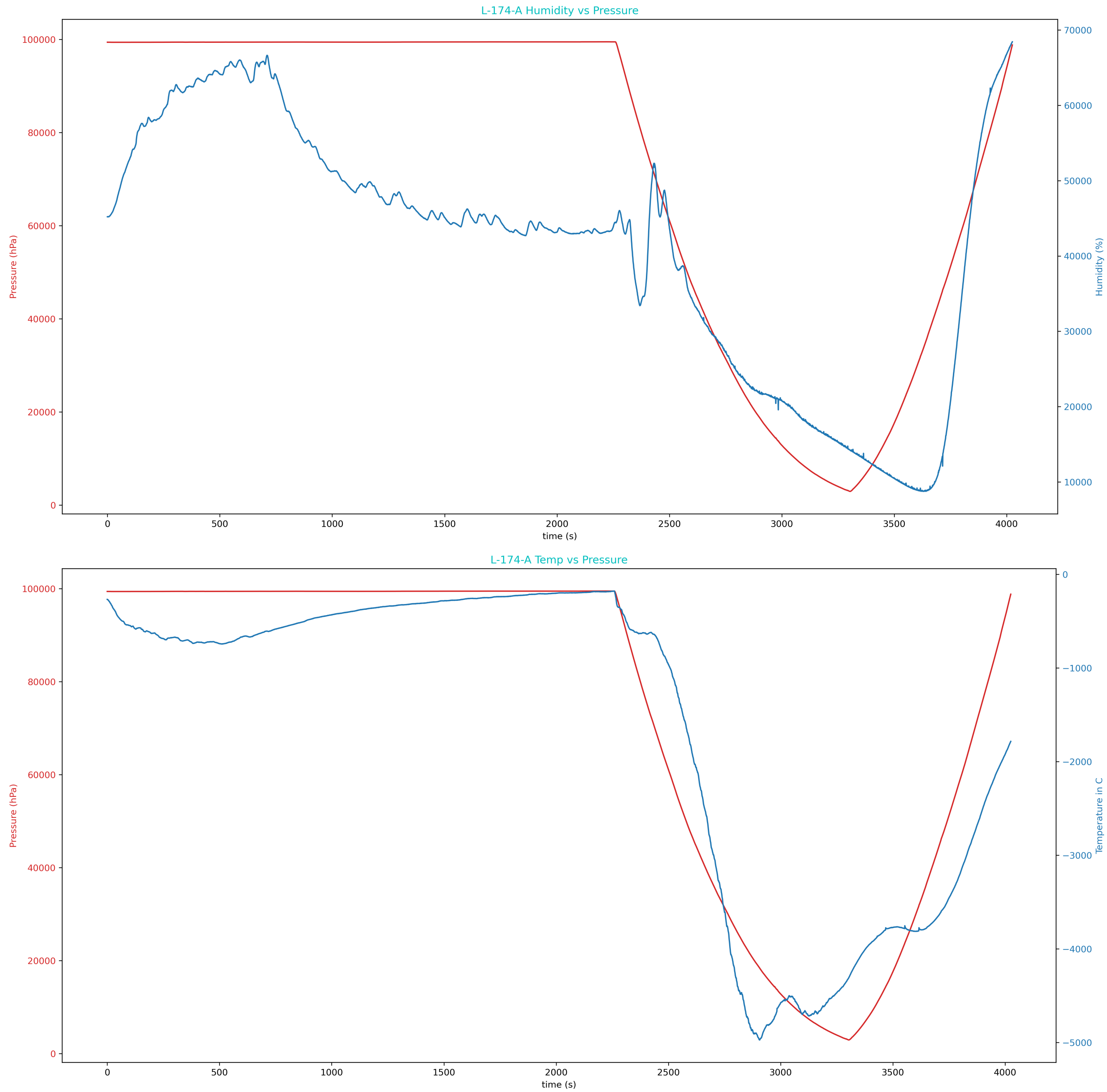

Fig. 2. Plot of humidity (top) and temperature (bottom) vs. pressure.

The primary atmospheric data gathered by HAR's BME-680 environmental sensor is temperature, humidity, and atmospheric pressure. Figure 2 above shows recorded values for humidity and temperature plotted against atmospheric pressure for flight L-174-A, while Figure 3 below shows the same data for eclipse flight L-169-C. It can be seen that while the humidity data is somewhat noisy, the temperature and pressure data contains minimal noise.

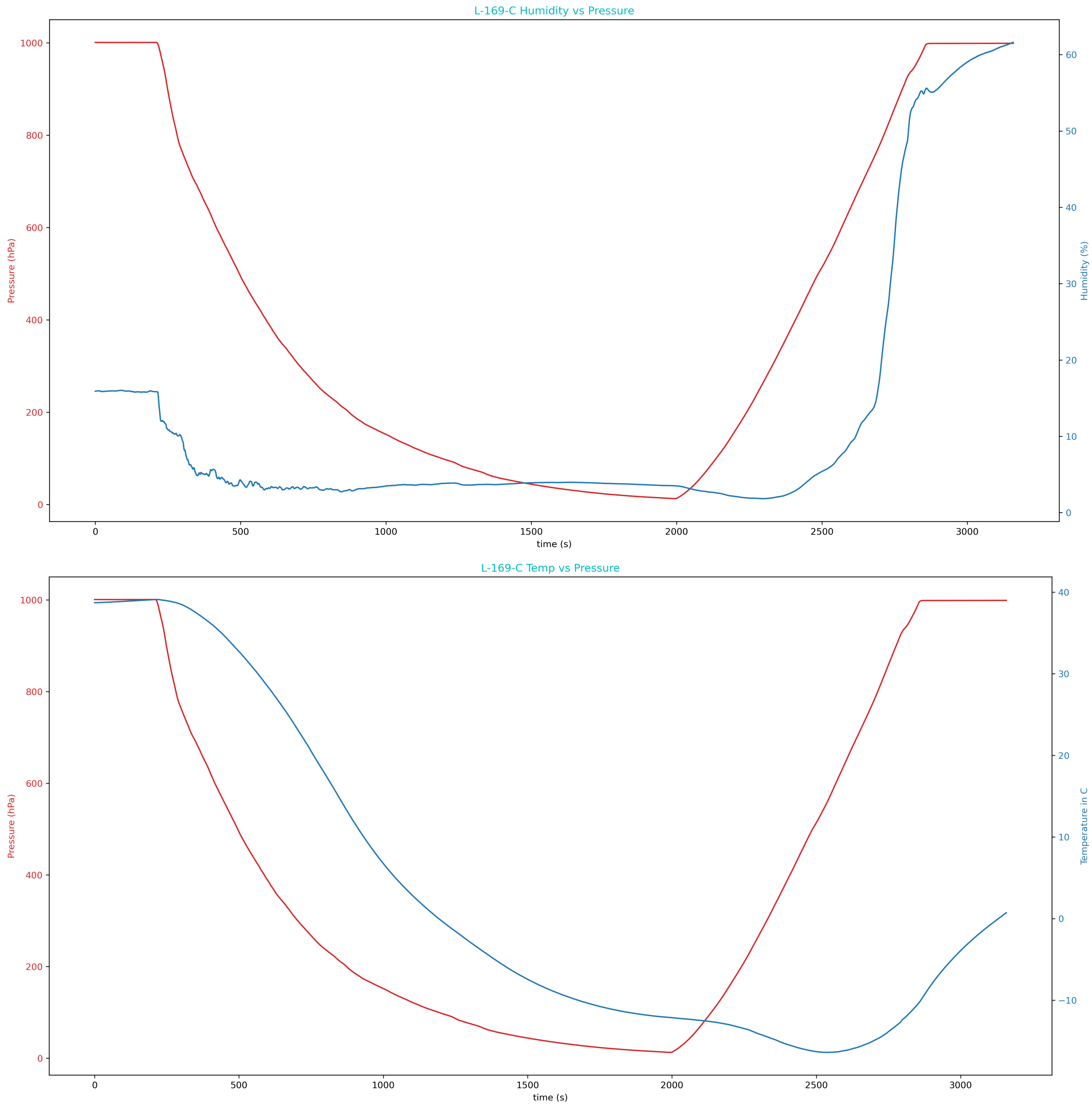

Fig. 3. Plot of humidity (top) and temperature (bottom) vs. pressure.

Figures 4 and 5 below show latitude, longitude, and altitude data gathered by HAR's onboard GPS during flights L-174-A and L-169-C. During the early stages of testing, the GPS function board would sometimes freeze during flight. The cause of this issue is not clear, but upon replacing the GPS M.2 function board with a Qwiic-connect GPS breakout for reasons discussed below, the issue resolved.

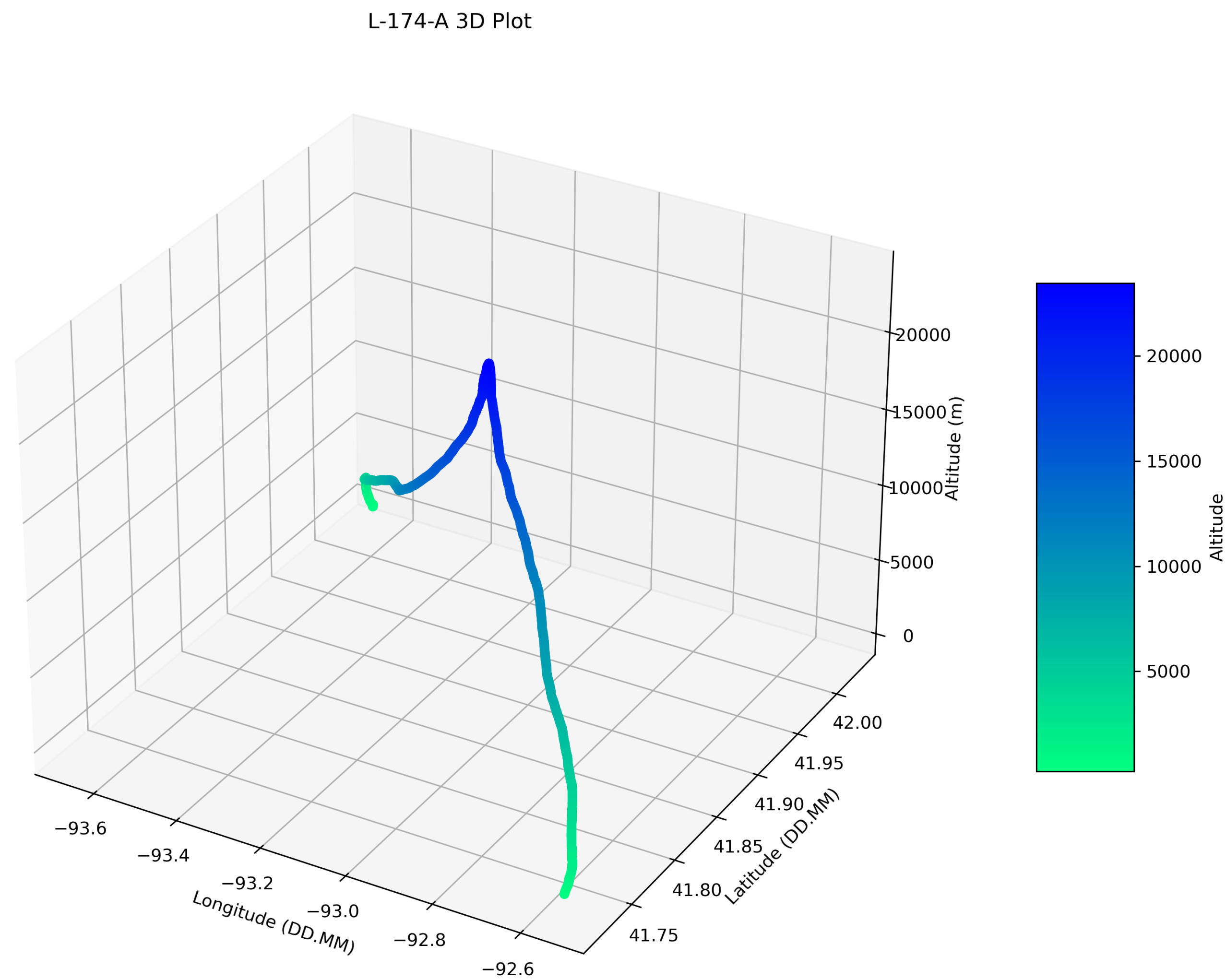

Fig. 4. 3D plot of L-174-A flight path.

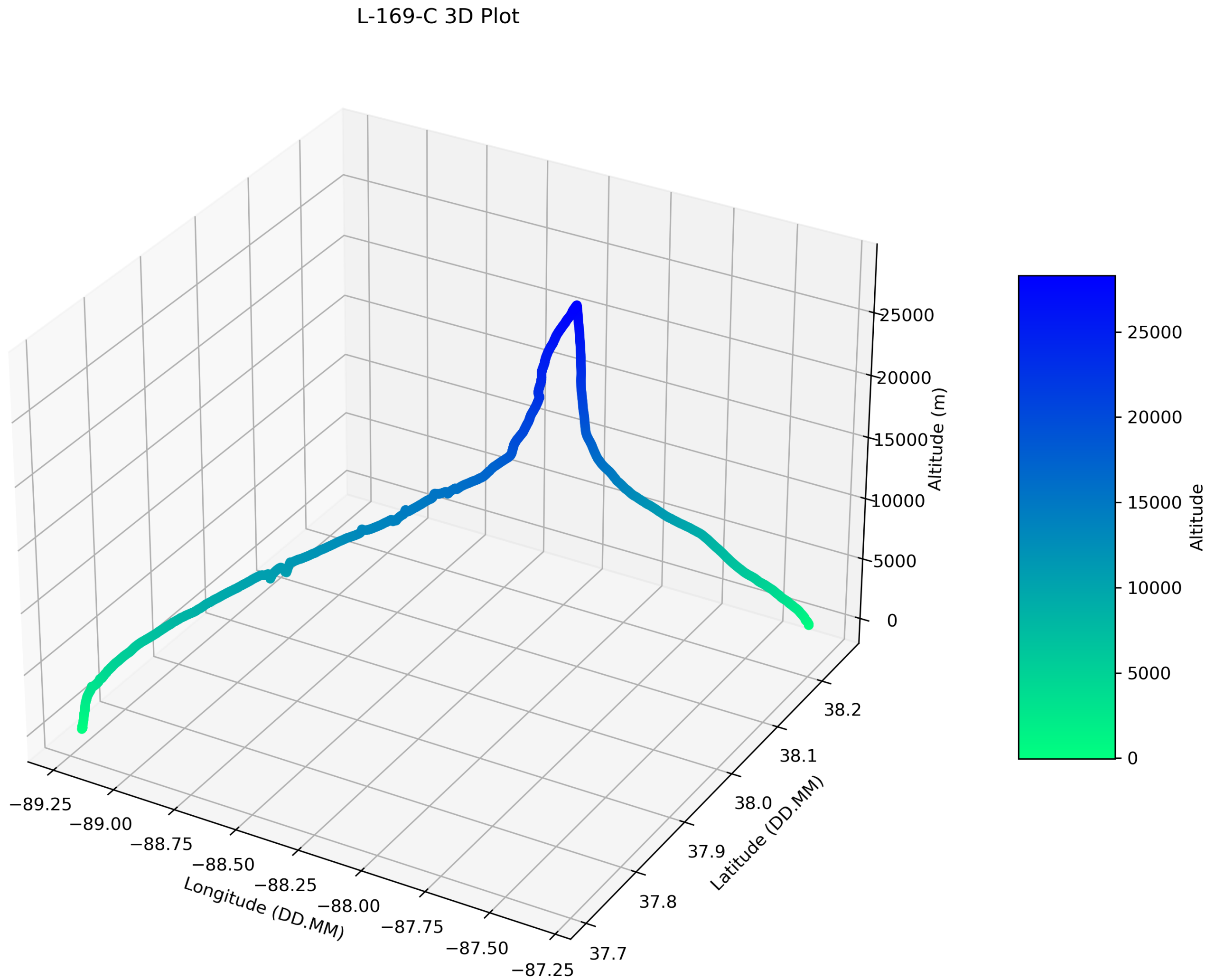

Fig. 5. 3D plot of L-169-C flight path.

1. Lessons Learned

Throughout the development process, the HABET team has discovered a few issues with some MicroMod components and the MicroMod ESP32 processor. Most notably, the second function slot on the MicroMod main board is for all practical purposes unusable with the MicroMod ESP32 processor. This is due to conflicting pin assignments, as certain pins which the ESP32 requires to be open during boot are assigned to the second function slot, so any component plugged into this slot will cause a fatal error during startup. This can be circumvented by waiting until after startup to plug in the component. However, this is not a practical solution for this application, as if the flight computer becomes frozen or resets at any time during a flight, it cannot then be rebooted.

An additional point of failure is the SMA connector on the 915 MHz MicroMod LoRa function board. During two separate test flights, the SMA connector has broken off the board, rendering the flight computer unable to communicate with the ground, but still capable of recording data. Since the connector's attachment to the board is fairly weak, minimizing the stress placed on it is imperative.

It has also been observed that the NEO-M9N GPS module does not perform with the expected accuracy, often reporting high dilution of precision values. This could be caused by interference with other onboard GPS systems and RF transmitters, as HABET flies at least two trackers on every flight for the purpose of redundancy. Poor antenna placement and damage to the antenna may also play a role, as the flexible Molex antennae that are often used with HAR are not very durable.

Future Work

In the future, the team would like to test the ability to connect multiple devices to HAR using a local WiFi network. HAR's functionality can also be expanded by the addition of more sensors, such as the previously discussed 9-DOF IMU. As HABET continues to work with client payloads, the creation of a standardized interface for providing clients with power and data transfer needs to be further explored. To improve the performance of the GPS module, tests need to be carried out with different antenna types and placements, as well as adding a layer of foil beneath the receiving antenna to reduce interference from nearby sources. Additionally, further testing needs to be conducted on improving the performance of the LoRa module across longer distances and protecting the module's SMA connector from stress. However, in its current state, HAR is a cheap, versatile, and reliable solution for a low-budget high-altitude ballooning flight computer.

References