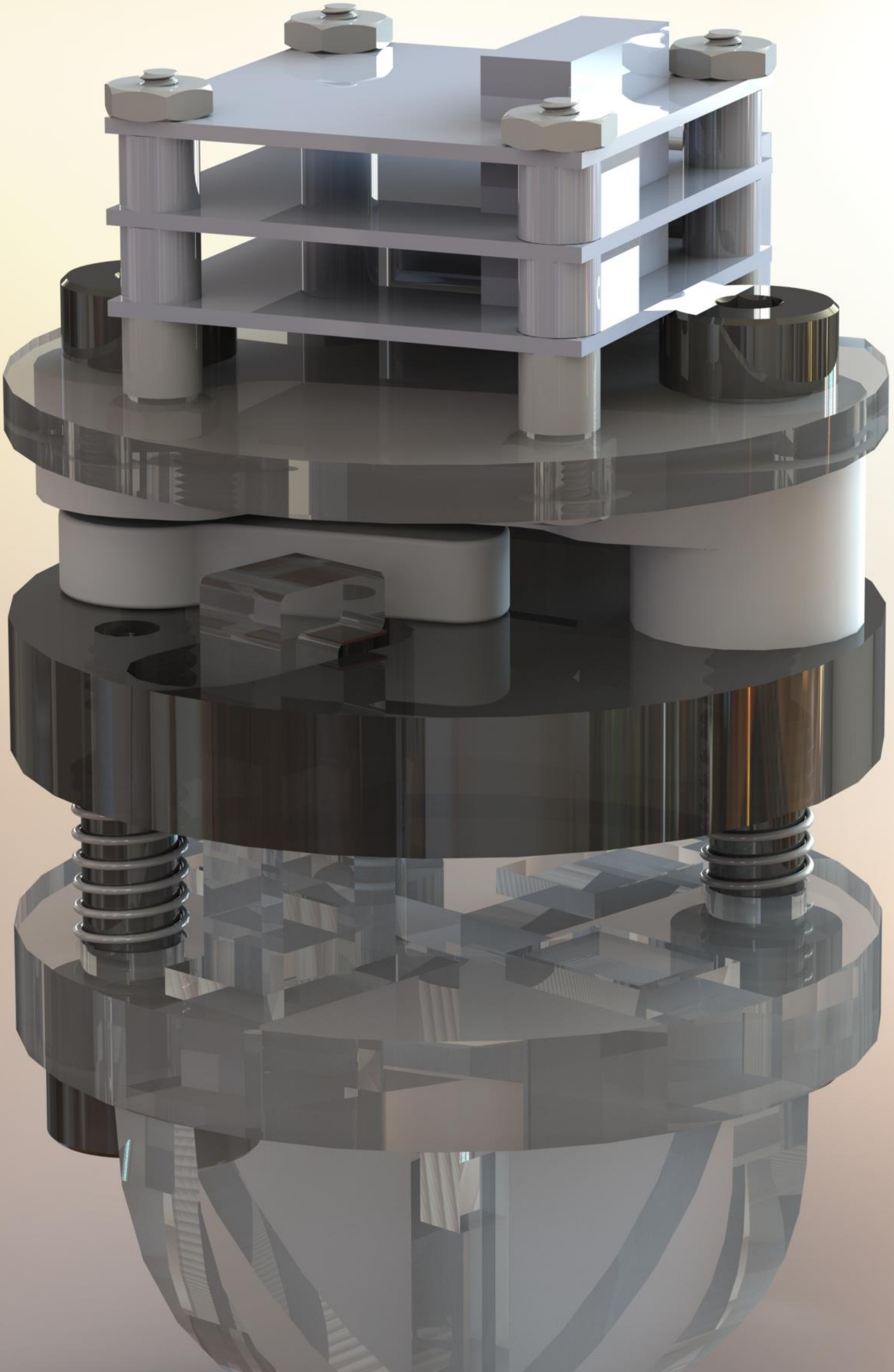

Creating an Egg Sized Flight Accelerometer Switch

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Introduction

As a case study for long-term design cycles, Sandia National Labs has asked teams from six universities across the United States to take part in a competition in which each team designs, manufactures, and tests a mechanical flight accelerometer switch (FAS). In the context of this design competition, a FAS is a device that will act as a payload in the nose cone of an Apogee Egg-Tosser hobby rocket. Additionally, the FAS must record elevation and temperature data upon closure of a mechanical switch, which will trigger upon reaching a specified acceleration. The FAS must be the size of a chicken egg and robust enough to survive multiple launches.

Since September of 2019, the CU Boulder team has designed, redesigned, and completed the first iteration of a mass-spring system which focuses on simplicity and ease of use. The FAS that has been designed is durable, low-cost, simple to manufacture, and easy to assemble.

Project Requirements

In the project description given to the team there were several generalized requirements that dictated the capability of the FAS. After a few discussions with the clients from Sandia National Laboratory; the team determined that the customer requirements for this project could be accurately defined by the following:

- Maximum assembly mass must not exceed 50 grams.
- Maximum assembly mass must not exceed the volume of the EggTosser nose.
- The FAS must contain a unique single axis mechanical switch, which will close at a specific acceleration, and must be resettable. Furthermore, this switch must not be commercially purchased.
- The activation of the mechanical switch must trigger the collection of elevation and temperature data, which should be recorded and stored.
- Flight data must be easily extractable from the FAS post flight.
- Unit must survive multiple flights without failure.

With the project requirements clearly defined, the team could then begin the design process by starting with brainstorming solutions.

Systems

The foundation of this project came from initial brainstorming about how the mechanical switch of the FAS would trigger. Through discussion, collaboration, and several decision matrices we determined that a simple and reliable system for the switch would be a spring mass system. The general concept of this design would have the FAS split into an upper and lower section with springs located in-between, with the upper half containing most of the total system's weight. When the FAS experienced an upward acceleration, the two sections would compress the springs and latch into place starting the data collection. This outline of the FAS design was the starting point for design process and would be expanded and developed based on project requirements and design choices.

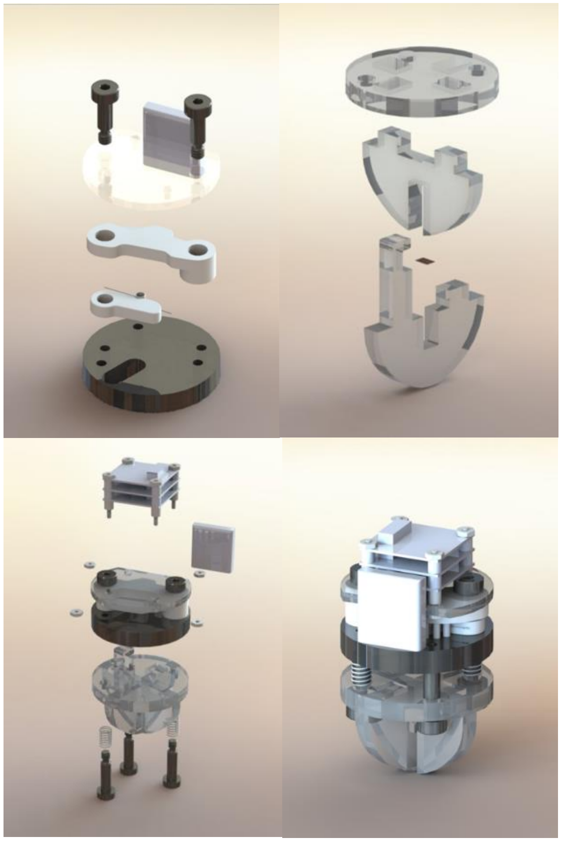


Figure 1: (Top Left) Upper assembly exploded view showing the positioning of the latch and support plates. (Top Right) Bottom assembly exploded view displaying the pin connection that interlocks with the latch. (Bottom Left) Exploded view of FAS showing the positioning between the upper and lower sections. (Bottom Right) Fully assembled FAS render.

FAS Mark I

Thunderboard Sense 2

The initial design for the FAS started with the selection of a circuit board that incorporated the necessary sensors to collect the required data. The Thunderboard Sense 2 was recommended to the team as general-purpose development board that contained a 6-axis inertial sensor, a temperature sensor, and 1024 kB flash memory. With these components it was feasible for the FAS to accomplish the required data collection.

Mechanical Design

With the circuitry selected the FAS design evolved to utilize the mass of electrical and data recording components as part of the actuating mass instead of including a separate, heavy mass as part of the switch. Additionally, the initial design needed to be constructed around the Thunderboard Sense 2 geometry, which had a length that barely fit inside the nose cone. These two considerations led to the parts being designed with the intention of using 3D printing.

Due to the large size of the circuit board, the original design was constructed around the Thunderboard to ensure its operation and electrical access was not hindered. The mechanically actuated switch and linear guide were shifted off the central axis to accommodate this design choice. We were aware this might increase the chance of the FAS seizing up due to friction during closure but believed that through controlling the tolerance stack-up the problem could be minimized to an acceptable level.

Despite the FAS being enclosed in the foam-insulated nose of the rocket, we wanted to ensure an adequate level of impact protection. Specifically, there was initial concern as to the amount of damage the Thunderboard and battery may experience in situation that the EggTosser's parachute failed to deploy during flight. Addressing this, a thin 3D printed cylindrical cover was added to the top of the mass-side of the FAS.

Challenges

Through design review, there were multiple challenges that hindered our design. One of the biggest challenges in this version of the prototype was tolerance stack-up between the numerous interconnected parts. This issue was compounded by our choice of manufacturing method. Although 3D printing allows us to create the complicated shapes we needed; its wildly inconsistent tolerances ultimately made this manufacturing method unfeasible for most of the parts we were hoping to make.

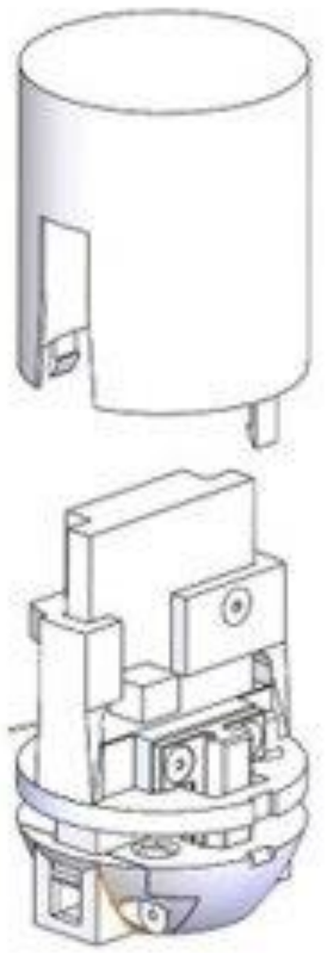


Figure 2: Initial FAS model that incorporated the Thunderboard Sense 2 and had a majority of its components manufactured using a 3D printer

Another major challenge was determined when upon uploading the initial code it was discovered the accessible part of the flash memory was less than a fourth of what was advertised in the specifications sheet. This detail, along with the board's challenging physical dimensions, finally forced us to look for a new data recording and sensor board. Additionally, the smaller size of the boards we ended up utilizing allowed for the entire design of the FAS to be more streamlined while weighing less.

FAS Mark II

Tiny-Circuits Platform

Our newest design is centered around the same fundamental idea of the first iteration but needed significant changes in order to accommodate a new accelerometer with more flash memory space. This was needed so that we could ensure our onboard storage could collect an entire flight's worth of data. Unfortunately, the ThunderBoard Sense 2 did not have enough flash memory for us to feel confident in basing our final design around it, so the FAS required an overhaul.

Figure 3: Tiny Circuits Breakout Boards. Going clockwise from the top right, there is an accelerometer/barometer, proto board, SD card writer, and microprocessor.

Tossing aside the Sense 2, we decided to pursue a new circuit board. We settled on using the Tiny Circuits system, which consists of 4 small, lightweight circuit boards stacked on top of one another which provides us with plenty of space to store elevation and temperature data.

Mechanical Design

The second design mirrors the first design in many ways, one of which is that it is separated into two halves, the top half and the bottom half. The top half consists of the mass assembly and the latch itself, while the bottom half is composed of the bottom cross assembly which adheres our FAS inside of the EggTosser nose cone. Another way in which the two designs are similar is that the mass spring system from the first design is recycled and optimized in the newest design. By taking these solid concepts and applying them to our new system, we were able to develop a much more efficient and effective FAS.

Mass Assembly

The new hardware system is considerably smaller and more compact than the Sense 2, allowing us to cut our overall weight by roughly 10% while providing the storage space we needed. Since the system is composed of 4 PCB's stacked on top of one another, we decided to incorporate their mass into the mass spring system we were using to actuate our switch by housing them at the top of our FAS.

The top of the FAS above the latch mechanism is called our mass assembly, due to its role in actuating the switch with its weight. It consists of 2 circular plates, the polycarbonate latch plate, and the acrylic circuit plate, both of which are named in accordance to the component of the FAS they house. They are fastened together by 3 shoulder bolts that connect the top and bottom halves of the design. The circuit plate not only houses the PCB's, but it also provides space for the battery to be adhered as well as provide power to the Tiny Circuits System.

The latch plate is made of polycarbonate to provide solid material for the shoulder bolts to thread into without stripping the material. These bolts also fasten the latch to the latch plate and have very light springs with a spring constant of 0.76 lb/in to ensure our system doesn't misfire and close before we want it to.

Bottom Cross Assembly

The bottom cross assembly is designed to adhere and stabilize the entire FAS inside of the nose cone of the EggTosser, as well as house the pin that allows the latch to close and actuate the FAS itself. The entire assembly can be broken down into 3 parts, the bottom cross plate, the pin cross plate, and the tab cross plate. These three plates adhere together via adhesive applied to the slots in the bottom cross plate shown below.

The pin rises through the bottom cross plate and into the latch plate, when experiencing a closing force, it will interact with the spring-loaded latch, and close the FAS, generating electrical contact and triggering data write to the SD card inside of the Tiny Circuits System.

The bottom cross assembly will be adhered into the EggTosser nose via Velcro strips that are connected to the curved sections of the cross and the inside edge of the EggTosser. This allows us to remove the FAS easily for post processing and enables for multiple tests with the same FAS.

Latch

The latch assembly is a series of 3D printed PLA parts that lock the top and bottom assemblies together upon closure of the switch. The top of the latch has copper foil adhered to its top surface, which will come into contact with copper foil that is adhered to the bottom surface of the pin, creating electrical contact that tells the hardware to start collecting data. This entire process takes place when a force (like the rocket launching) pushes the FAS upward, which pushes the pin upward, and allows the spring-loaded latch to swing into place.

The spring that is used in this assembly is a torsional spring with a maximum torque of 0.05 in.-lbs., which provides enough force to cause the latch to swing into its closed position, locking the top and bottom halves of the FAS together during the launch phase of the EggTosser rocket.

Design Challenges

We were able to address many of our concerns from the first design in our final prototype. First, the series of Tiny Circuit boards we purchased allowed for data collection to a micro SD card, making running out of storage space a non-issue. Second, the more compact size and stackable nature of the boards allowed us to switch to using laser-cut acrylic, ultimately reducing the number of parts and enabling us to use a more structurally consistent material.

As the laser-cut design was developed, we encountered an issue with tolerance stack up causing holes on neighboring plates to become misaligned. This was easily fixed, although we became aware of just how much the calibration on a given laser-cutting can affect the tolerances on a batch of parts.

One of the largest concerns arose from the vast reduction in weight we were able to achieve by using a “flat pack” design. Due to the smaller number of heavy components, the asymmetrical location of one of the liner guide shoulder bolts and battery shifted the center of gravity of the overall FAS. Since the rocket can only compensate for a small amount of off-center mass, we worked to bring the center of mass as close to the center of the FAS as possible. We accomplished this by bringing the battery closer to the center axis. Future modifications would include strategically remove material from the acrylic and polycarbonate plates to further shift the center of mass inwards.

Testing

Summary

We were able to perform rocket tests in two sessions. The first launches were done with only the rocket in order to audit safety and test procedures. The second set of launches occurred with the Tiny-Circuits board system inside the EggTosser nose in order to collect initial altitude data.

Further testing could not be performed due to social distancing requirements; In contingency, drop testing plans were created as if testing will move forward in the future.

We used Open Rocket to create simulation data in order to get an idea of how the EggTosser would perform in different conditions and testing post-processing techniques that would be used to process data collected from rocket launch data.

Initial Rocket Testing

All the rocket tests for this project were conducted at CU Boulder's South Campus. Initial testing for the project began on 11/14/19 and we had 3 successful launches. First launch was with practice rocket and Estes B-6 motor and was for us to practice our launch procedure. The next two launches were with the EggTosser and Estes C-4 motor. From these two launches we were able to verify our Safety and Test Procedures were functional and had a better understanding of the flight path of the rocket, and what we needed to test further.

Figure 4: Pinned launch location for rocket testing at CU Boulder South Campus

Drop Testing

The purpose of drop testing is to experimentally determine the spring rate necessary to trigger the FAS at a specified acceleration. Unfortunately, due to social distancing requirements, we were unable to conduct drop tests.

A drop test fixture, optimized to be fabricated on a 3D printer in a short amount of time, was designed to attach the FAS and nose cone of the EggTosser to the drop tester. The FAS will be secured inside eggshell with foam.

Simulations

Models and simulations were created with Open Rocket, which can account for a variety of different wind conditions. We modeled many different conditions in order to understand how the rocket would fly and used the data to verify post-processing methods. Calculated data includes flight path, velocity, acceleration, flight time, time to apogee, and max altitude.

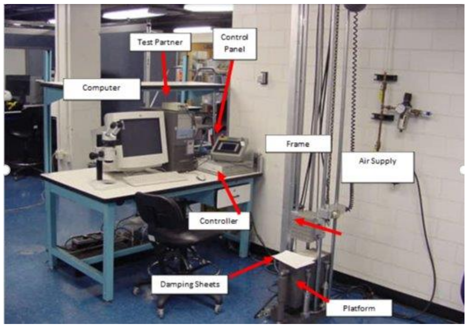


Figure 5: Drop testing fixture located within Idea Forge

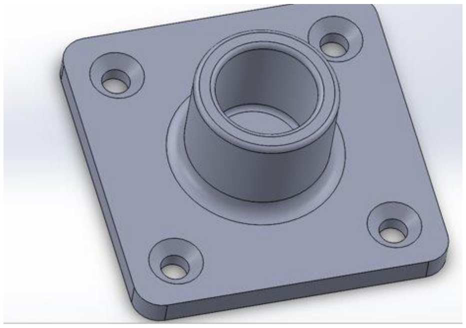
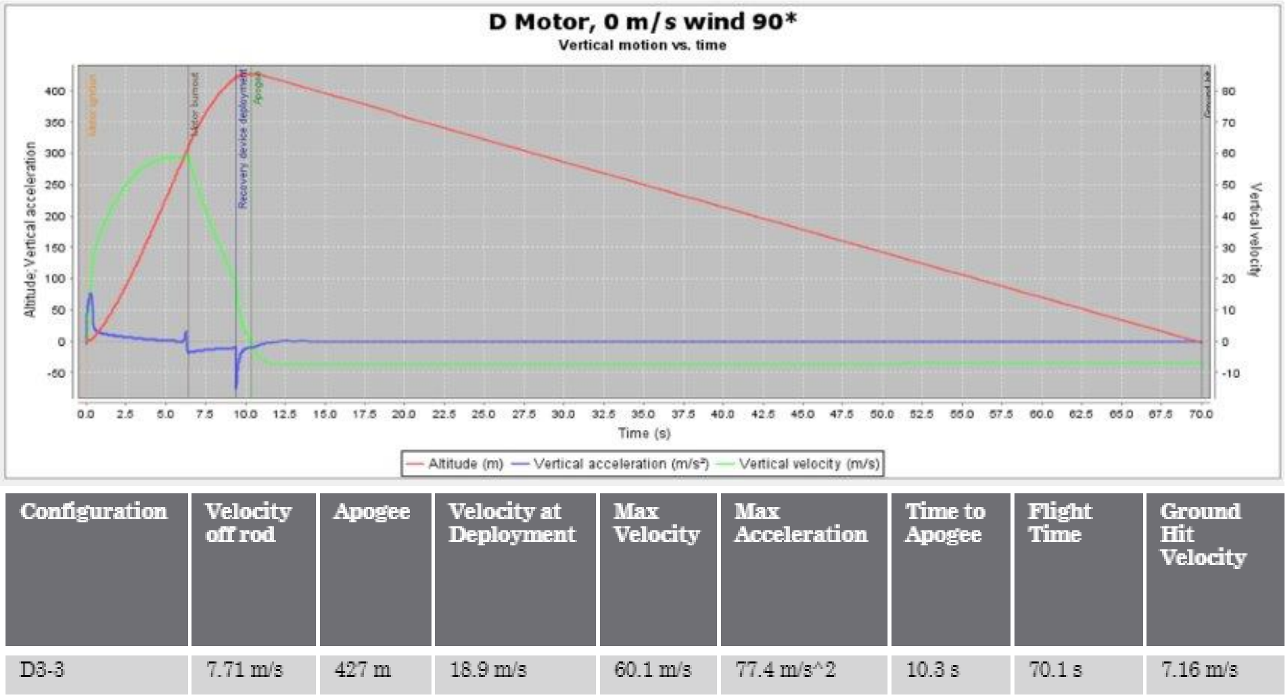


Figure 6: Drop test fixture. The bottom of the EggTosser's nose cone sits in the center hole.



Configuration	Velocity off rod	Apogee	Velocity at Deployment	Max Velocity	Max Acceleration	Time to Apogee	Flight Time	Ground Hit Velocity
D3-3	7.71 m/s	427 m	18.9 m/s	60.1 m/s	77.4 m/s^2	10.3 s	70.1 s	7.16 m/s

Figure 7: Simulation data collected from OpenRocket Simulator, using a D-class motor with 0 MPH wind.

Circuit Board Rocket Testing

From rocket launch data, we were able to capture two rocket launch profiles. A barometer on the circuit board was able to capture pressure data, which can be extrapolated upon to find elevation data. Data is shown below in Figure 8, which includes data before and after a processing routine that removes large spikes, smooths the data, and truncates the flight path after the rocket lands.

Summary

Weight

The final weight of the FAS came in at 38 grams; meeting and exceeding the 50g weight requirement.

Volume

The FAS fits within the nose of the EggTosser rocket which successfully meets the volume constraint.

Data collection

The Tiny Circuits board in the FAS collects altitude and temperature data from the rocket's flight. This data is stored onto the 2G microSD card which can be easily extracted from the FAS after a launch. This system for data collection and extraction meets the requirement set forth by the project.

Cost per Unit

To produce a batch of 25 units, we estimate a cost of $178.78 per unit. Overall, we spent $985.81 of the $2000 allotted from the Mechanical Engineering Department, so our solution was financially effective.

Continuation

The result of our efforts for this design cycle have in large part been successful. We met most of the project requirements, and if not for campus closures due to COVID-19, we would have been able to further our accomplishments on this project.

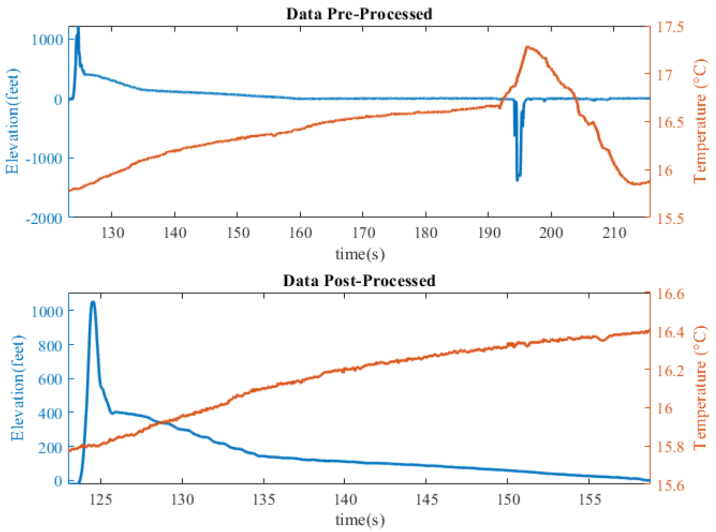
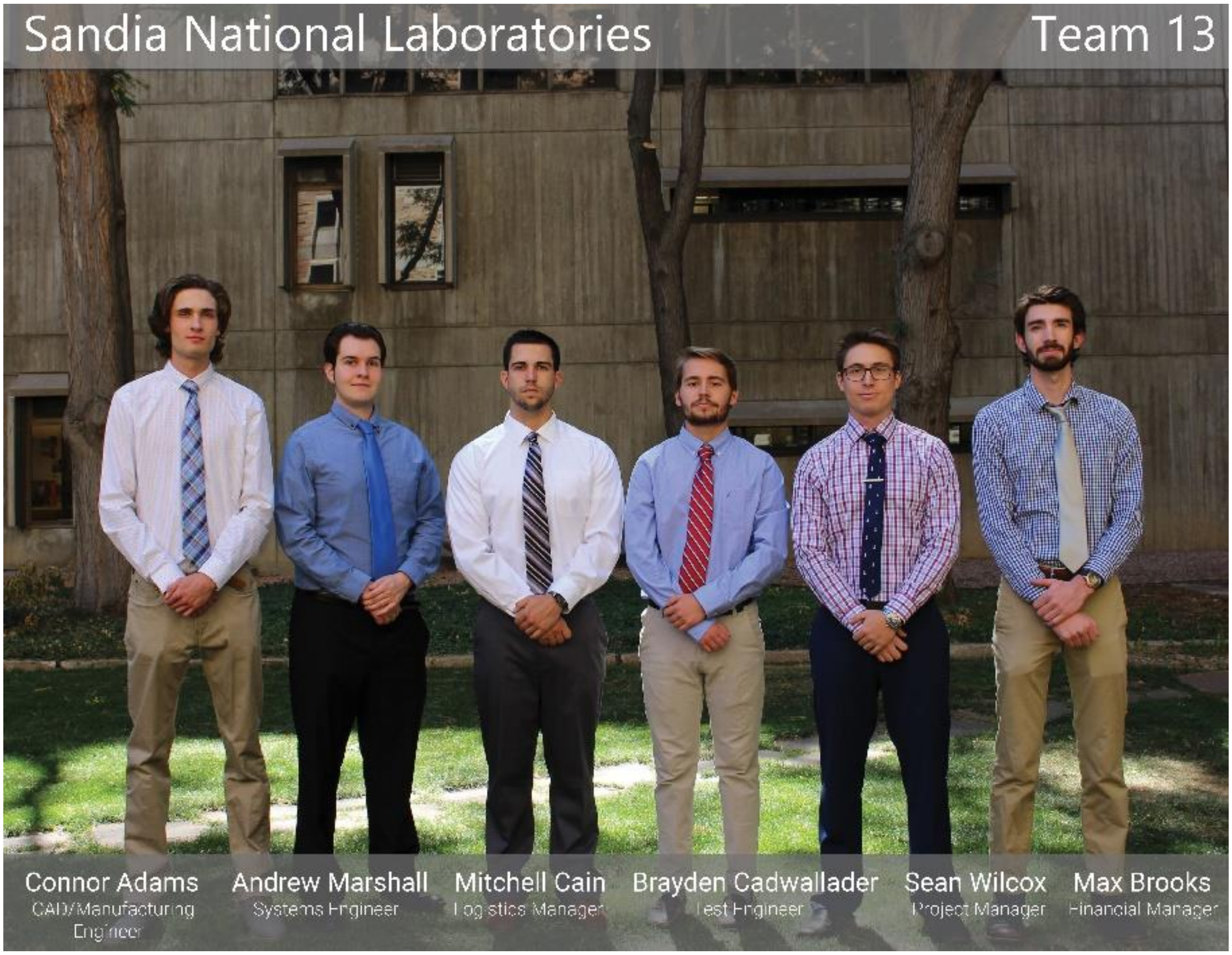


Figure 8: Rocket elevation data before and after being processed in MATLAB.

The major sections of the projects that we had planned on further developing were design improvements and testing. We had planned to make modifications to lighten our design by perforating the laser cut components and simplifying the 3D printed parts. Beyond weight optimization, the only major design change we would have liked to make is to add a fourth shoulder bolt between the top and bottom halves in order to get the center of mass closer to the geometric center of the design. For design testing, we had developed a test plan for drop testing to calibrate our FAS to trigger consistently at a specific acceleration. The next step we would have taken in testing would have been to conduct rocket test the FAS with data collection to verify that the FAS was triggering and data was collected.

Given the opportunity to develop this system for another design cycle, our team would recommend some improvements. The main improvement would be to obtain 3-axis acceleration and position data. The 3-axis acceleration data could be obtained with our current accelerometer, however, the error associated with time-stepping methods for ordinary differential equations grows exponentially with steps, which is sure to translate into data gathered from discrete data points. Additionally, our team would experiment with using lighter and stronger materials than acrylic and higher tolerance 3D printing methods for the latch mechanism.

Team Bios



Sean Wilcox

Sean is a senior majoring in Mechanical Engineering and minoring in Electrical Engineering. Next year he will be starting Graduate school at CU to get a Master's in Design for Mechanical Engineering. He has always had a passion for helping people, and by being an engineer he hopes to just that.

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Mitchell Cain

Mitchell is a senior in Mechanical Engineering, with a minor in Business. For this project, his main contributions were in the final design phase, where he created and managed the tolerance stack up of the final design as well as maintaining all meeting minutes for future reference. After graduating in May of 2020 Mitch is looking for an engineering or sales engineering job in either the Colorado or California area.

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Max Brooks

Max is a senior in Mechanical Engineering, with a minor in Applied Math, with a focus on scientific computing. For this project, his main contributions were writing the post-processing script, programming the TinyCircuits system, and managing the team's finances. After graduating in December of 2020, Max is hoping to attend a master's program for Materials Science.

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Brayden Cadwallader

Graduating in May 2020 with a bachelor's degree in mechanical engineering. Brayden has worked in a small engineering firm building machine vision systems to be installed in large production facilities as a mechanical engineering intern. He has also worked in wood/machine shop building custom furniture and gaining useful hands on experience.

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Connor Adams

Connor is a senior in Mechanical Engineering with minors in Computer Science and Business. He has worked for the past four semesters in the ITL Manufacturing Center and spent worked as an Engineering Support Student in the ITL Laboratory last summer. He hopes to work as a design engineer after graduating in May.

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Andy Marshall

Andy is graduating in May 2020 with bachelor's in mechanical engineering. He has worked three summer internships at SARA Inc. Rapid Prototyping, doing product design, prototype manufacturing, and working with high voltage electrical systems. He has passion for the engineering design process and learning new skills. Currently he is looking for career opportunities in the Denver/Boulder area.

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