Embedded Systems Final Project Proposal

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Project Overview:

The overall goal of this final project is to implement a set of electrical components inside a model rocket to collect data and store this data for later use. In this rocket payload, we plan to use an Altimeter, an SD card, and a Radio Beacon in communication with the MSP432.

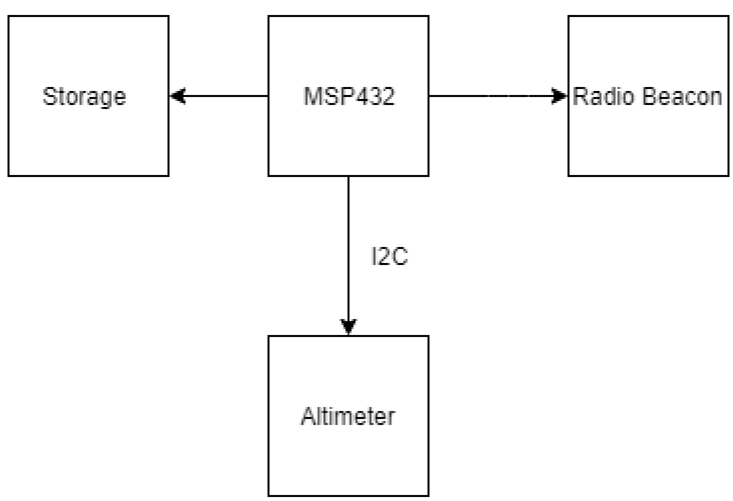
Project Scope:

The complete project involves making an electronic payload, mounting that payload inside a rocket, and launching that rocket. There will be a radio inside the rocket that transmits morse code signal, which we can use to locate the rocket. The electronic payload will also include an altimeter and a storage device to record that data.

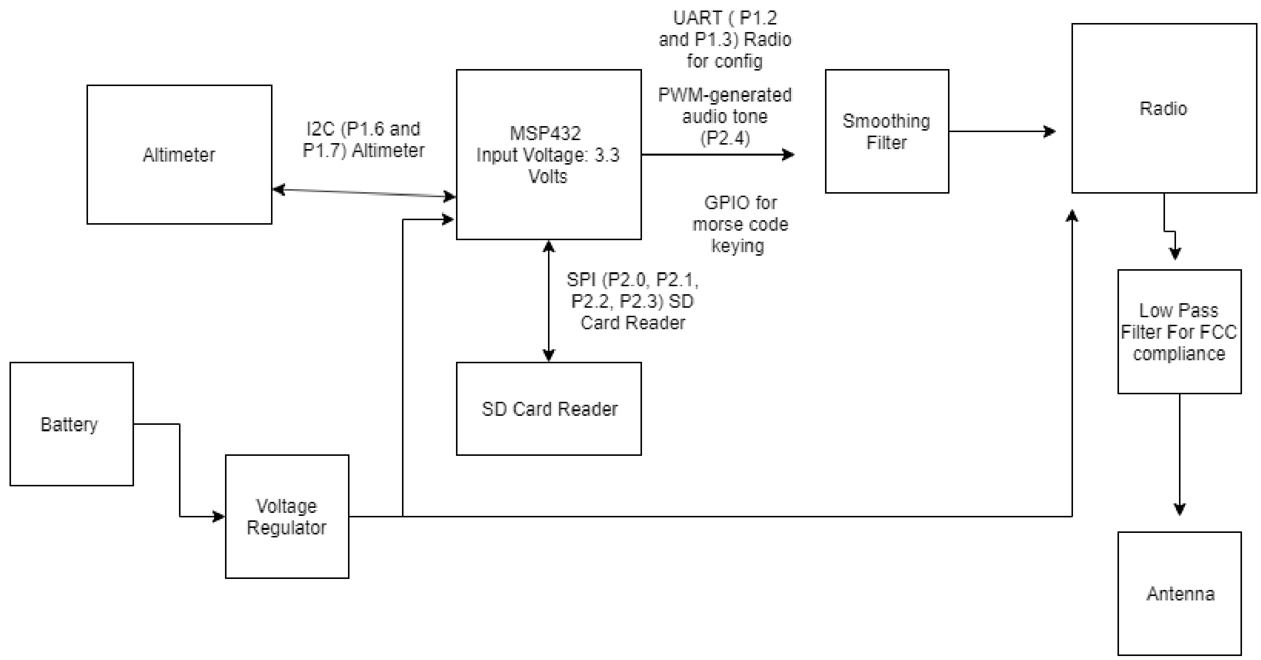
During initial conception of the project, we considered including an IMU, and also logging this data. However, we determined that obtaining an IMU that suits the flight would be unfeasible for this project. More information is in the Trade Study section of this proposal.

The scope of this project will mainly focus on the electronic payload, connecting all the components to the MSP432, getting all the components to work in conjunction, manufacturing the PCB and housing for the payload, getting the radio connected to the MSP432, transmitting a signal from the radio, and powering the entire payload.

Functional Block Diagram:



Wiring Diagram:



Project Requirements:

General Project Requirements, desired behavior

- Needs to fit in rocket section
- Needs to be able to activate before launch
- Needs to be able to store data.
- Needs to record altitude (and possibly use for parachute deployment)
- Needs to transmit a beacon signal via radio when it lands
- Needs to function in cold weather - it’s winter

Electronics flight requirements:

All:

- Needs to fit in 4” diameter x 10” rocket coupler
- Must operate at the same logic level, or have necessary signal step-up or step-down
- IC package must be solderable by us (or, we will have to make the decision to not include it on our custom PCB)
- Must tolerate cold temps, high acceleration and high vibration environments
- At least one component should use UART (Radio)

Microprocessor Requirements:

- Breakout board containing microprocessor must fit within 4” diameter rocket
- Handle communication with sensors, data logging, radio, etc.
- Be able to easily implement code on the microprocessor platform to configure sensors, deploy parachute, etc.

Operator Interface Requirements:

- Have a switch plate that we can mount switches and indicators to
- Have indicators for status of each component, i.e have an LED to show if the SD card is connected, have an audible tone for the radio status, switches to turn on electronics, etc.

Data Logging Requirements:

- Record data 10 times per second on apogee time, once per 5 seconds on descent (estimate)
    - Running the altimeter at full speed and taking as many measurements as possible (50 measurements / s) and having each measurement be 16 bits, the total amount of information transmitted from the altimeter during apogee would be 1200 bytes. 4GB is more than enough storage to ensure we can store all out information
- SD Card with 4 GB Capacity Minimum (estimate)
- Be able to retrieve SD card and view information post-flight

Altimeter Requirements

- Be able to record data up to 4k feet (~1.25 km) with ~1m data resolution
- Reliable enough to use for parachute deployment

Radio Requirements:

- Be able to configure to 2m ham band & meet FCC requirements
- Be able to transmit CW generated from our microprocessor
- Be able to function for extended periods of time
- Transmit over 3 miles max (1 mile nominal) for distance to rocket

Battery Requirements:

- First portion of flight (5 minutes):
    - Altimeter Peak Current Draw: 210 uA
    - Radio Beacon: 60 mA
    - SD-Storage: 10 uA
    - MSP432: 8 mA
- Second Portion of Flight (25 minutes):
    - Altimeter Peak Current Draw: 1 uA
    - Radio Beacon: 700 mA
    - Sd-Storage: 10 uA
    - MSP432: 8 mA (peak current draw if the 48 MHz clock is used, which would waste the most power, the fastest) for precaution.

Therefore we need a battery with a capacity of at least 1600 milliAmp/Hours. Currently the lab team is looking into either a Lipo battery or an adafruit battery that has this capability and also can sustain the temperatures of colorado winter weather. The battery has to have a voltage output of 3.3 Volts to avoid using a step-up or step-down circuit.

https://blog.flitelab.com/2014/11/26/lipo-battery-cold-weather-usage-tips/
http://www.techlib.com/reference/batteries.html

PCB Design Plan:

- Create a custom PCB, MSP432 Shield Mask that sits on top of the MSP432
- The Radio and the SD card storage components will be soldered directly onto the custom PCB
- The altimeter will be a separate breakout board that we will have on hand or purchase

Theoretical Analysis

We did Theoretical analysis on Rocket flight requirements to determine what conditions our electronics will have to experience, Radio requirements to determine if the radio components we selected would be able to transmit at the range we specified in requirements, and Battery Power requirements to determine what kind of battery and power specifications we need.

Rocket flight requirements:

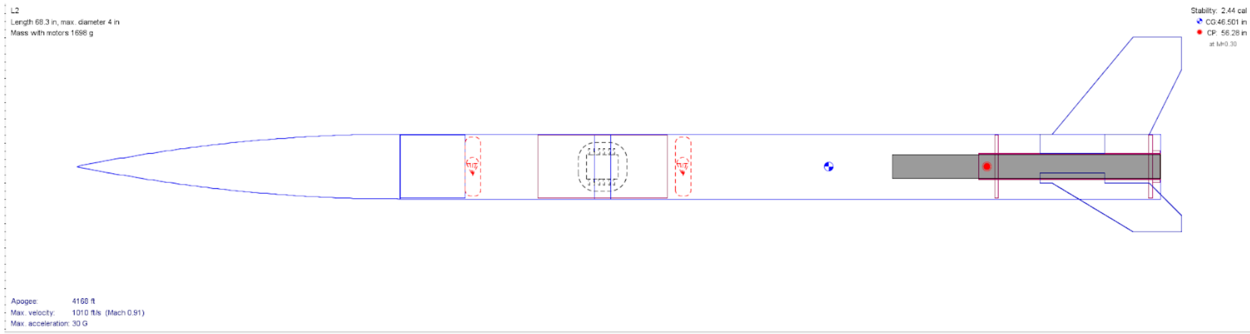
The design and construction of the rocket is out of the scope of this project. However, general specifications about the rocket are required in order to build an electronics payload that is suitable for the vehicle.

We will be flying this on a 4” diameter rocket, with an engine of impulse between H and J. In order to have a safe takeoff, the following requirements must be met:

- Rocket must have a stability > .9 cal
- Off the rail speed > 30 ft/sec
- Ejection charge delay (for safe parachute deployment) should be within 1 sec of recommended delay.

We modeled the launch vehicle with a range of motors using the OpenRocket software.

J-354 with 11 second delay (~largest motor)



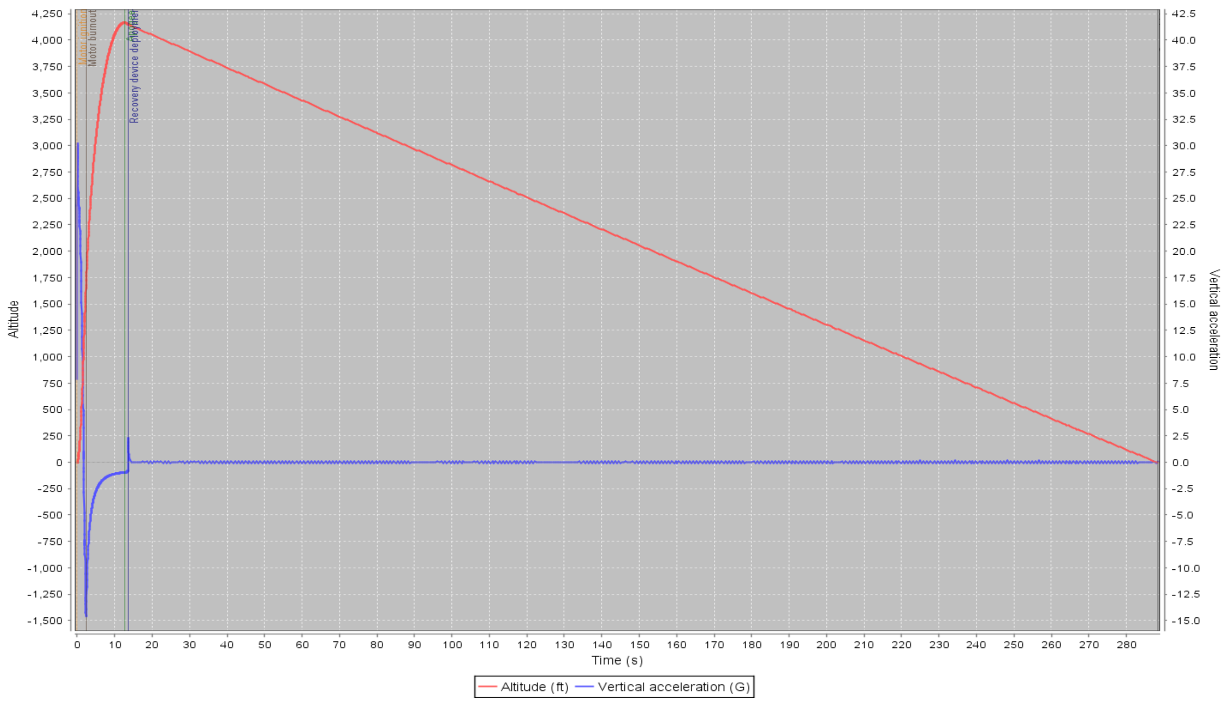
OpenRocket model showing CP, CG, and cal

Rocket safety info:

Stability: 2.44 cal / Off the rail speed: 82 ft/sec /Ejection charge delay: 11 sec (rec: 10.2 sec)

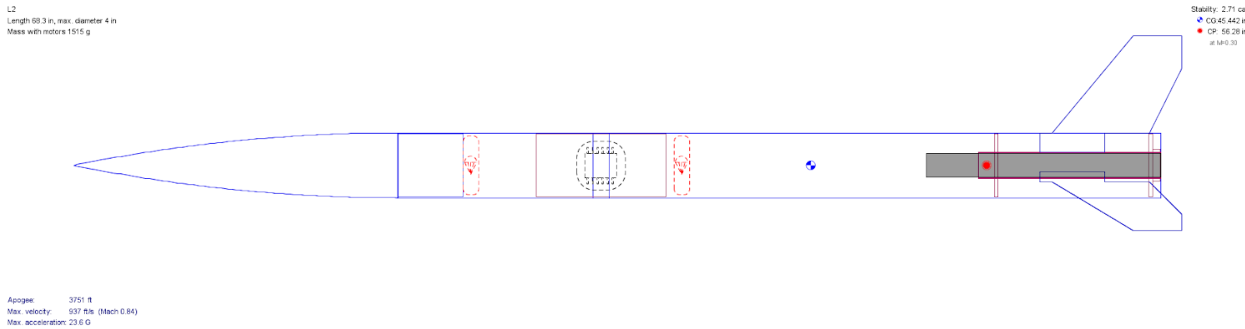
Information for specifying our electronics:

Max Acceleration: 30 G, Apogee: 4164 ft, time to apogee: 12.6 sec, flight time: 288 sec.



Graph of flight on J-354-11 motor

J-285 with a 10 sec delay (target motor)



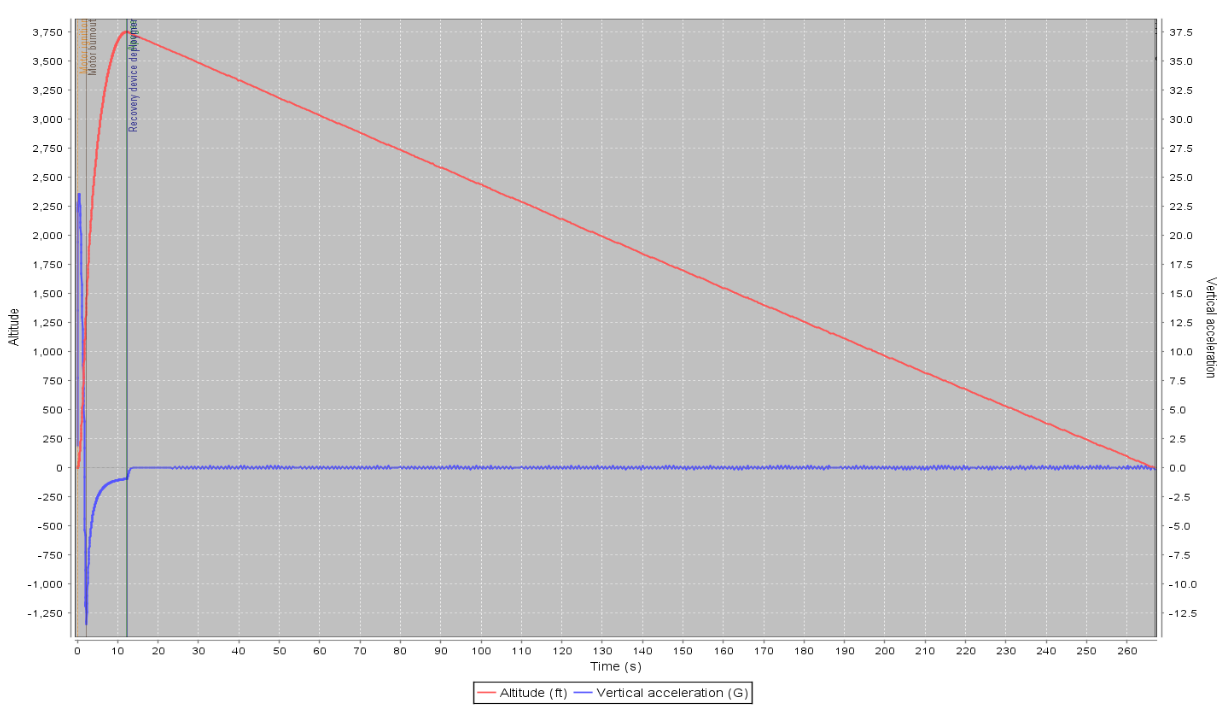
OpenRocket model showing CP, CG, and cal

Rocket safety info:

Stability: 2.71 cal / Off the rail speed: 68.6 ft/sec /Ejection charge delay: 10 sec (rec: 9.94 sec)

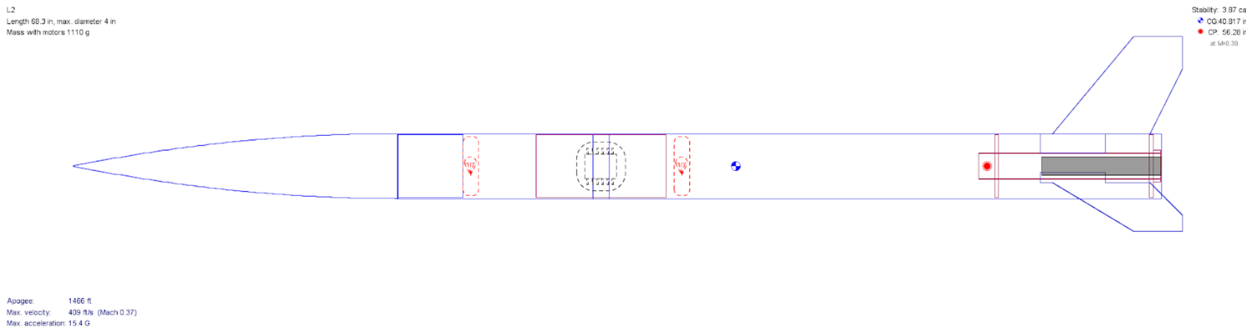
Information for specifying our electronics:

Max Acceleration: 23.6 G, Apogee: 3751 ft, time to apogee: 12.2 sec, flight time: 267 sec.



Graph of flight on J-285-10 motor

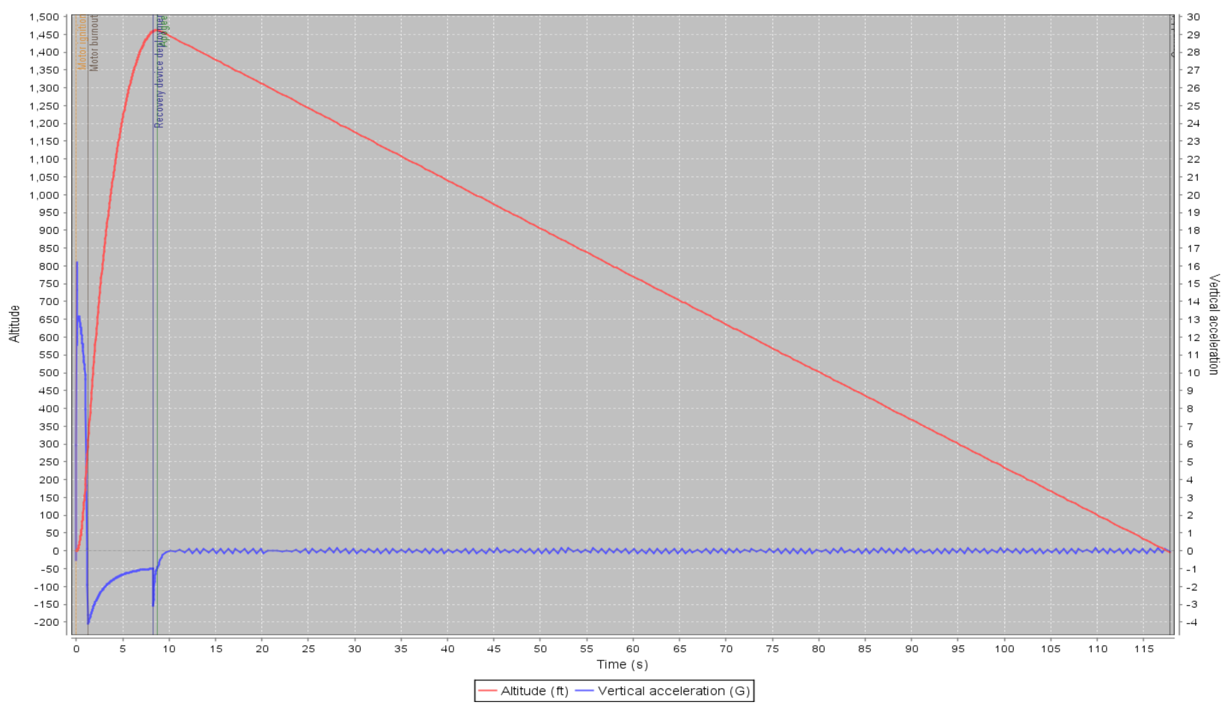
H-133 with a 7 sec delay (smallest motor)



OpenRocket model showing CP, CG, and cal

Rocket safety info:
Stability: 3.87 cal / Off the rail speed: 54.1 ft/sec /Ejection charge delay: 7 sec (rec: 7.57 sec)

Information for specifying our electronics:
Max Acceleration: 15.4 G, Apogee: 1466 ft, time to apogee: 8.61 sec, flight time: 118 sec.

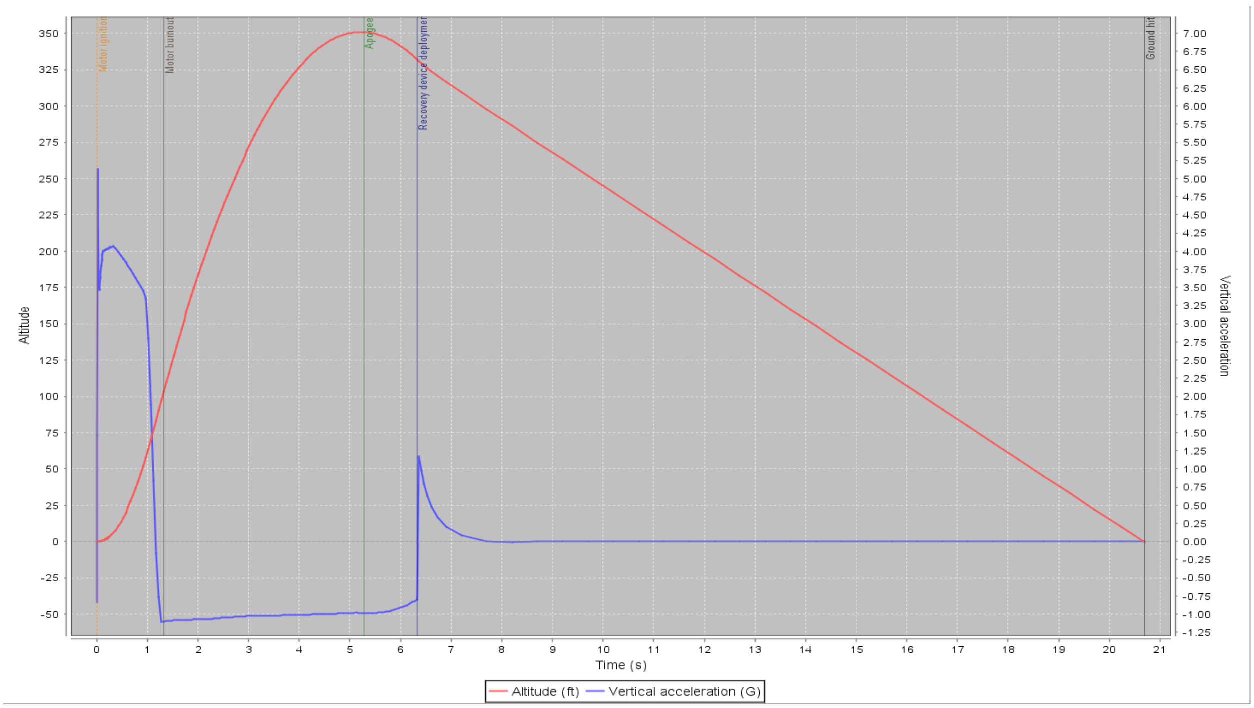


Graph of flight on H-133-7 motor

We have to consider how weight affects our rocket, so we added a payload object to the rocket which we can test various weights.

It turns out, adding weight to the front of the rocket increases its stability. This is because adding weight to the front of the rocket counteracts the additional weight from the motor itself, bringing the center of gravity closer to the front of the rocket. All of the rockets were stable with zero grams of electronics payload, so that won't be an issue.

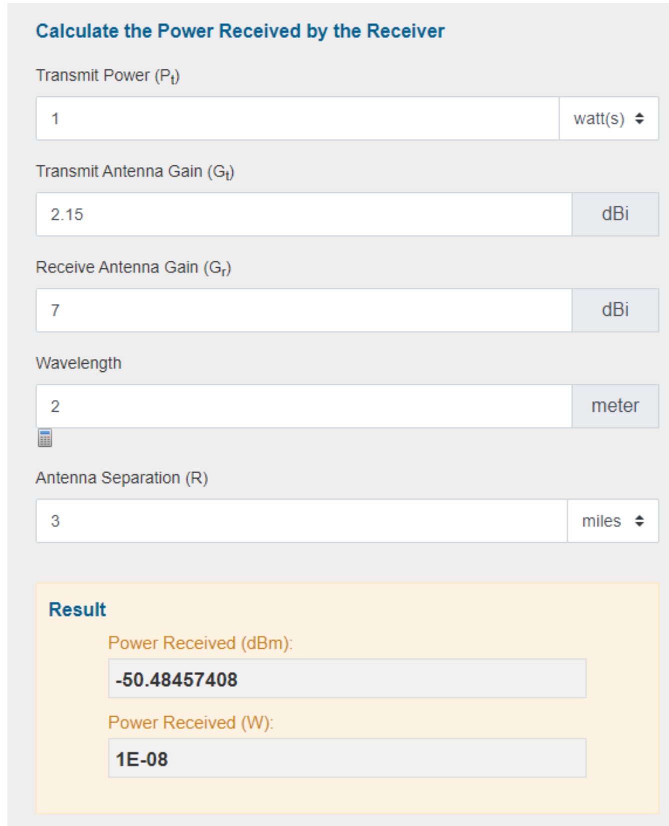
Therefore, we must look at the smallest rocket to find upper bounds of the weight: will a small motor still be able to take off safely with a larger load? Simulating with a 1kg payload results in a 37.3 ft/s velocity off the rod, which is still greater than our minimum of 30 ft/s. Even a 2kg payload results in a 29.9 ft/s velocity off the rod. Therefore our upper weight limit is 2kg. This is pretty high - another launch vehicle we have launched has a total mass of 2kg, including electronics payload and mounting.



Graph of flight on H-133-7 motor with 2kg electronics payload

Radio Module

Power



We did calculations In order to determine if the radio module we selected would be sufficient to transmit a beacon across our maximum expected distance. The DRA818V operates on the 2 meter band and can be configured to transmit at .5 watt or 1 watt power. We selected the 2 meter band due to availability of transmitters and because it is a well documented and popular HAM radio band. We will be operating under Giselle's Amateur Radio license (KC1KKR).

Preliminary rocket antenna research found that we could purchase a reasonably sized omnidirectional antenna with gain around 2.0 - 2.5 dBi [Appendix C: 1,2,3] For the ground station antenna, we need a directional antenna. We looked into making a Yagi Uda antenna because there are lots of tutorials on how to make 2 meter Yagis out of cheap materials (ie. tape measures) or other simple materials available at a hardware store. [Appendix C: 4, 5, 6, 7]. We can use YagiCad to model the antenna we build. [Appendix C: 8] We selected a 3 mile max / 1 mile nominal target range by consulting students from CU's Sounding Rocket Lab (SRL) rocketry club (formerly COBRA) who recently flew rockets at the same size and power class. On a windy day, one of them had to walk 3 miles to retrieve his rocket, but hopefully it will be closer to 1 mile.

We entered these numbers into a Friis Transmission calculator [Appendix C: 9] to calculate the power we will receive from the farthest distance. This assumes that our antenna will be in optimal orientation for its radiation pattern. We will have to consider this when we mount the antenna in our rocket.

In order to actually determine whether we can receive this signal, we need to look at the sensitivity of our ground station radio. We plan on using a Handheld Yaesu VX-3R which has a published sensitivity of 16 uV for 12 dB SINAD (140-150 MHz, NFM) [Appendix B: DRA818V].

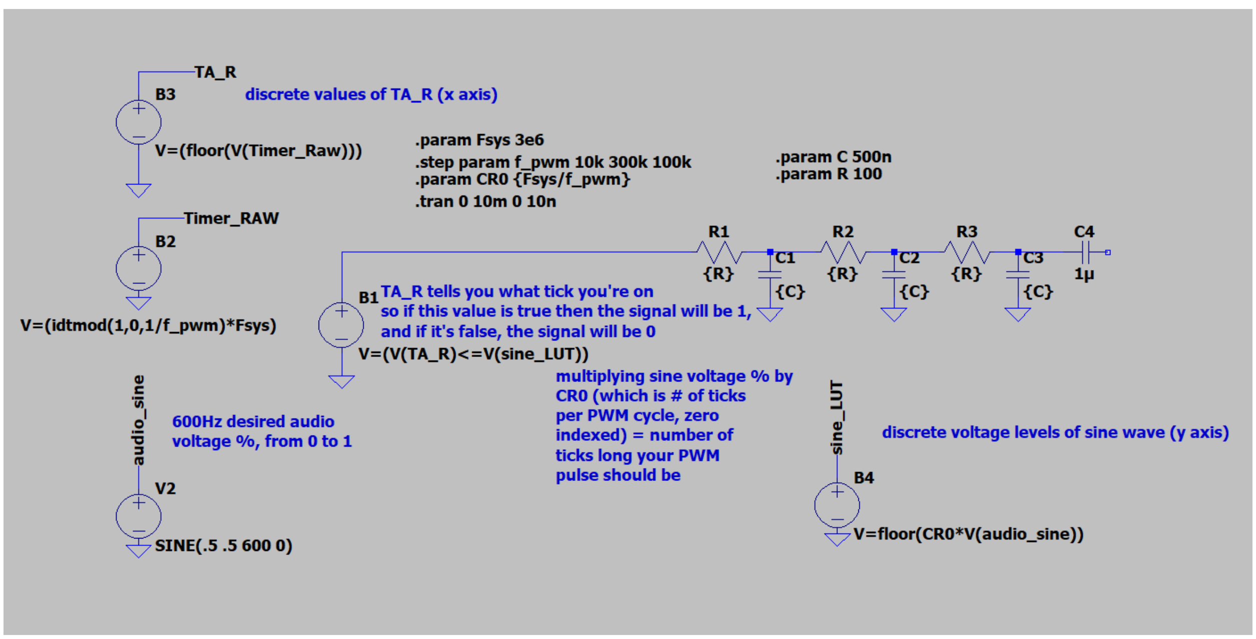
We assume 50 ohm resistance in the radio equipment, because this is a common value in RF equipment. To convert to dBm: $P = V^2 / R \rightarrow (16uV)^2 / (50\ \text{ohms}) = 5.12\times10^{-12}$ watts = 10log(5.12×10^-12) = **-259.9 dBm.** This is the sensitivity of the receiver if the signal is 12 dB above the noise floor. Our radio can detect changes of -259.9 dBm under these conditions. If we assume the noise floor is -60 dB, at our worst case of 3 miles we are only 10 dB above the noise floor, so it will probably be a bit worse than this. However, we chose to transmit CW, which is possibly the simplest signal to transmit, so it's likely still receivable.

Filtering

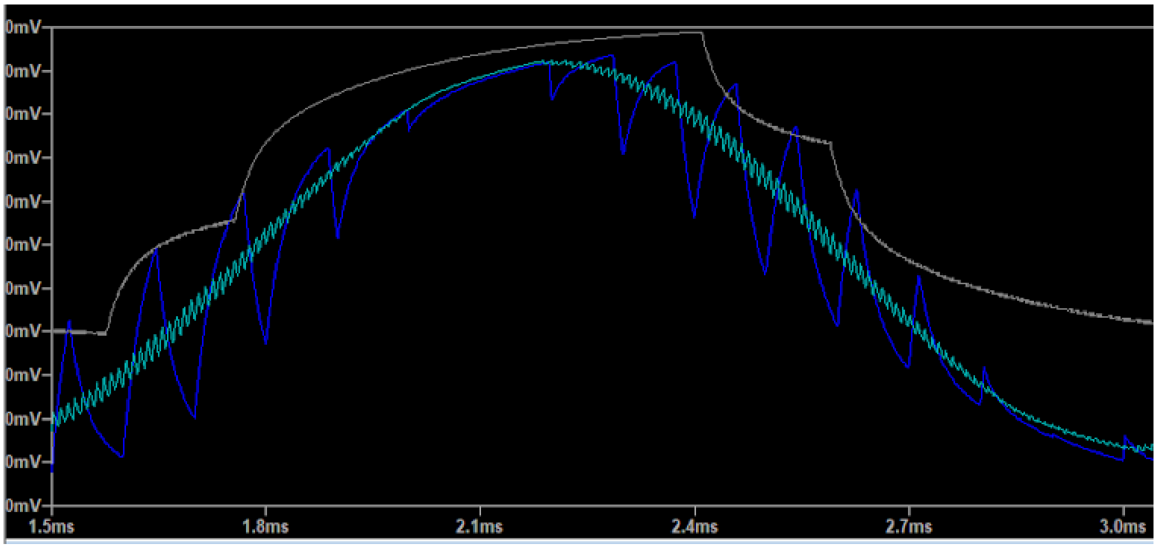
The DRV818 module takes an audio input. For a walkie-talkie type application, this would be attached to a microphone output, but in our case, we want to generate morse code (CW) using the MSP432. CW can be transmitted on the bottom of the 2 meter band [Appendix C: 12]. CW is usually an audible tone around 600 Hz [Appendix C: 13]. We can generate this tone digitally by using PWM.

The quality of the signal is affected by the selected PWM frequency: a faster PWM frequency means the sine wave will have a higher step resolution (more pulses per wave) but will limit the discrete voltage levels that can be produced.

We developed a model in LTSpice to simulate a sine wave generated using MSP432's Timer A, along with varying orders of filtering. Then, we did a sweep to show how the sine wave would change over different PWM frequencies



LTSpice model



All shown with 1st order RC low pass filter set at 800 Hz cutoff

Dark blue = 10kHz pwm signal

- Very jagged, the pulses appear more like pulses rather than a smooth voltage signal
- This is because there are not enough "points" to make up the sine curve (x-axis resolution is too low)

Cyan = 100kHz pwm signal

- Smooth, but still very noisy. Actually looks like a sine wave, though.

Gray = 1MHz pwm signal

- Looks more like a continuous signal, but you can see the discrete
- This is because the number of discrete voltage levels that can be produced are too low (y-axis resolution is too low) - so each "peak" on this graph represents a different pulse width value, and multiple time steps are actually outputting the same pulse value.

Adding higher order RC low pass filters makes the signal look even smoother.

Work Breakdown

<u>Phase 1:</u> Altimeter → Storage (Lead: XuTao)

Code / Testing Goals:

Part 1: Altimeter

- Use breakout board with altimeter to write software & obtain altitude data
    a. Test this: Print altimeter data. Go up a mountain or something - our altimeters are supposed to have 1ft resolutions

Part 2: SD card

- Develop general SPI library
- Write SD card or Flash library

    Test this: Write arbitrary data to SD card

Part 3: Combined:

- Write altimeter data to the SD card.

PCB Goals (Lead: Dustin)

- Schematic for altimeter → MSP432
- Schematic for SD card → MSP 432

<u>Phase 2:</u> 2-state system, Radio (Lead: Giselle)

PCB Goals (1st priority)

- Connections for DRA818V
- PTT, Sleep Mode
- RC Filters before & after DRA818

Code / Testing Goals:

- UART for configuration
- PWM 600Hz sine wave
- Transmit a straight sine wave tone
- Transmit CW (morse code)
- Do these tests with handheld and whip antenna (not directional)

<u>Phase 3:</u> Rocket integration

- 2 meter yagi antenna
- Mounting hardware for electronics
- Switches and indicators for switch plate
- Launching the Rocket

In general, XuTao will be focusing on writing the software libraries for communication between components and recording information, Dustin will focus on creating the PCB, soldering components onto the boards, and creating housing for the electronics in the E-Bay, and Giselle will focus on the radio and designing the rocket structure.

Bill of Materials:

https://docs.google.com/spreadsheets/d/1xirpfvdMJ3LmwNdnBA9QlbEDPEPnDHAtqRjiSS4HJ-Q/edit#gid=0

Trade Study

Select a Microprocessor:
The lab team concluded that with previous experience and on hand components, that the MSP432 will be a great microprocessor for this project. Additionally, the lab teams environment for designing this project, is based around coding MSP432, therefore it will be easier to focus on the extra components of this project with an understanding of the MSP432.

All of the trade study research is on this spreadsheet with different sheets for the different components:
https://docs.google.com/spreadsheets/d/1zz2ovbzpejVfeZSvuKAd6pYSIXkym6xaUXt1aMF3v40/edit?usp=sharing

Select an IMU
During brainstorming for this project, we considered recording IMU data for further flight analysis. According to our theoretical analysis, we need an IMU that can record up to 30g's of peak acceleration.

Our trade study research found that such an IMU would cost at least $300 (if not more — we found one that was $10,000!). Another option would be to essentially design our own IMU by specing out individual components and writing our own sensor fusion, but since that is an entire project in itself, and none of the other components depend on this IMU data, we decided it was best to drop this feature in the payload.

Select an altimeter:
For the Altimeter Trade Study the lab team conducted research based on 4 different altimeters. After further research the lab team concluded that the ICP 10111 altimeter was the best fit for this project because the lab team has it on hand, it has great accuracy with measurements, it has a very low operating voltage, and communicates through I2C.

Product Name:	Price:	Manufacture	Altimeter	Communication:	Supply Voltage	Logic Level Voltage	Data Resolution	max alt	pressure range - note: lower p
MIKROE-1489	$14.50	MIKROE	MPL115A2	I2C capability	3.3 volts	3.3	30 cm precision (20bit)	10km (?	20-110kPa
BMP280 Breakout	$15	Adafruit	BMP280	I2C / SPI	3-5 Volts	3.3 (5V tolerant break	1 meter accuracy (16 bit)	9000 m	30-110 kPa
MPL3115A2 Breakout	$10.00	Adafruit	MPL115A2	I2C capability	3-5 volts	3.3 (5V tolerant break	30cm 0.3 m precision (16 bit)	10km	50-110 kPa (idk why this is dif
ICP 10111	on hand	TDK	ICP-10111	I2C interface type	1.8 volts	1.8 (3v3 tolerant break	1 Pa, 0.5 m precision (16 bit)		30-110 kPa (max 25-115kPa)

Select a radio:
After further research the lab team decided to use the DRA818V radio communicator due to the fact that the lab team has it on hand and has a good understanding of how to implement this communicator. The lab team researched the Radiometrix HX-1 radio communicator, but decided not to use it due to lack of datasheet information, and specification of how this communicator works, in addition to its limited output power (300 mW vs 1W).

Select a storage device:
The two choices for the storage device were between an SD card and flash. Ultimately we decided on using an SD card because we already had two breakout boards for using an SD card. While it is harder to code with the SD card, the ease of start up was enough to choose using it over flash storage.

Appendix for Citations and Links

Appendix A: Table for Altimeters

- https://www.mikroe.com/altitude-click - MIKROE 1489
- https://learn.adafruit.com/adafruit-bmp280-barometric-pressure-plus-temperature-sensor-breakout?view=all - BMP 280 Breakout Board
- https://www.adafruit.com/product/1893 - MPL3115A2
- https://www.mouser.com/ProductDetail/TDK/ICP-10111?qs=%252bEew9%252b0nqrBWGDChI3rokg%3D%3D&gclid=Cj0KCQiAtf_tBRDtARIsAIbAKe2XgLN9d4E7rhp3vpUgmmJYeNzxpnJ_NUrjc4u4MhRzKohDxFBdRokaAjttEALw_wcB - ICP 10111

Appendix B: Table for Radios

- **http://www.dorji.com/docs/data/DRA818V.pdf - DRA818V**
- http://www.radiometrix.com/content/hx1 - Radiometrix HX1

Appendix C: Radio Theoretical Analysis Sources

Omnidirectional Antennas

1. https://www.amazon.com/Authentic-Genuine-NA-701-SMA-Female-BTECH/dp/B00KBZLOHC/
2. https://www.amazon.com/Antenna-SMA-Female-Handheld-Baofeng-BF-888S/dp/B07KG4R1MQ/
3. https://www.amazon.com/Nagoya-NA-701-SMA-Male-8-Inch-Antenna/dp/B07RGXBM87/

Yagi Uda Antenna Tutorials

4. http://www.arrl.org/files/file/Technology/tis/info/pdf/9304054.pdf
5. http://www.dcarc.club/2016%20N8PR%202%20Meter%204El%20Yagi.pdf
6. http://www.harc.net/docs/2_meter_tape_antenna-2016.pdf

7. https://www.qsl.net/dk7zb/PVC-Yagis/4-Ele-2m.htm
8. http://www.yagicad.com/yagicad/YagiCAD.htm#_Downloads

Friis Transmission Resources

9. https://www.everythingrf.com/rf-calculators/friis-transmission-calculator
10. https://www.analog.com/media/en/training-seminars/tutorials/MT-003.pdf

Noise Floor

11. https://audible-acx.custhelp.com/app/answers/detail/a_id/6746/~/what-is-the-noise-floor%3F

CW

12. http://www.k0nr.com/wordpress/my-articles/2m-frequency/
13. https://www.dummies.com/programming/ham-radio/how-to-listen-to-morse-code-on-ham-radio/

SINAD / Receiver Sensitivity

14. https://www.electronics-notes.com/articles/radio/radio-receiver-sensitivity/basics.php