Badger Ballistics
University of Wisconsin - Madison

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1.0 EXECUTIVE SUMMARY

The University of Wisconsin - Madison Badger Ballistics team is incredibly excited to once again compete in the Midwest High-Power Rocket Competition. With the support and guidance from industry professionals and the American Institute of Aeronautics and Astronautics, we are deeply grateful to be able to be presented the challenge and resources of this year's competition. Through a collaborative environment involving university faculty, aerospace professional mentors, and many excited undergraduate engineers we are confident in our approach to this year's task of controlling the roll orientation of a high powered rocket.

The Badger Ballistics rocket is built around a 4 in fiberglass body tube. The exterior of the body tube is then fashioned with a 5.5:1 Von Karman fiberglass nose cone and four G10 fiberglass stabilizing fins. With the rocket's structural frame and internal components considered, the total dry weight is estimated to be 10 lbs (4.5 kg). The rocket's engine will be an AeroTech J570, providing 973 N-s of impulse over a 1.9 s burn time. From these general characteristics, we expect a flight performance of 3200 ft (1000 m), while reaching a maximum velocity if 540 ft/s (165 m/s) and a maximum acceleration of 9 g's.

The competition objectives for this year require the rocket to do a series of roll maneuvers after motor burnout. To combat the challenge of roll control, our team has chosen to use dynamic control surfaces along the bottom of four fins located symmetrically around the rocket's base. The control surfaces will be controlled by high-torque servo motors. The servo motors are managed by a roll control algorithm programmed into the onboard Arduino microcontroller. The roll control algorithm will receive flight data from the onboard inertial-measurement-unit, which will calculate and appropriate servo response. As the rocket's roll begins to correctively change, the algorithm will continue to receive this new data, and hone in on the final desired roll orientation.

The roll orientation will be verified by a downward facing camera and an LED array which signals the control algorithm's intentions. Horizontal video will be streamed to a television on the ground, as well as first person view goggles by use of a video transmitter/receiver system. In addition to the downward/horizontal facing video, the rocket will communicate dynamic flight performance back to the ground via an XBee Pro - Series 1 transmitter and receiver system. This provides redundancy for data recording if an undesired event happens and the rocket can not be recovered.

The team is currently in the building/testing phase of the project, with plans to test fly the data acquisition system on a previously built level 2 rocket on March 10, 2018. Our projected first test flight of the Badger Ballistics rocket is on March 24th, with a backup date on April 7th.

2.0 DESIGN FEATURES

This year's Midwest High-Power Rocket Competition revolves around the challenge of controlling the roll orientation of a single stage high-powered rocket system. The rocket must complete two successful flights on a I-class or J-class motor. Flight 1: Maintains a fixed orientation initiated at a specified time (no more than 3 seconds) after motor burnout, in accordance with preflight specifications. Flight 2: Maneuvers to several specified roll angle orientations starting at a specified initiation time (no more than 3 seconds) after motor burn-out, in a specified order, holding each position for a specified period (no more than 1 second), as well as rotating in specified directions between requested orientation angles. Roll orientation will be recorded by a downward facing camera and visible markers in the 4 cardinal compass directions. A bank of bright LEDs in the view of a downward facing camera will provide feedback of the control system by indicating whether the rocket is attempting to null roll, roll counter-clockwise, or roll clockwise. Roll angle orientation will be recorded by an inertial measurement unit, which contains a magnetometer, gyroscope, and accelerometer.

Recovery will be achieved by use of a PerfectFlite StratoLogger CF altimeter, which will deploy a 24 inch drogue parachute at apogee, and a 58 inch main parachute at 700 ft AGL. Backup motor ejection will be used for redundancy, with a 14 second delay to deploy the drogue parachute if the commercial altimeter fails. OpenRocket simulations estimate the rocket will have a ground hit velocity of ~20 ft/s in this configuration.

2.1 Rocket Airframe

The airframe of the rocket is constructed entirely out of fiberglass for maximum strength and minimal weight. The body tube is a 4 inch diameter (0.065" wall thickness) G12 fiberglass with an overall length of 52 inches. The nose cone is of a 5.5:1 Von Karman shape with a metal tip to provide the least aerodynamic drag possible. The fins are a basic trapezoidal shape constructed out of G10 fiberglass with a cutouts that act as control surfaces (Dimensions shown in Figure 2). Basic construction of the airframe is underway and can be seen in Figure 3.

The rocket has an overall length will be 70 inches (178 cm), and is expected to have a dry weight of approximately 10 lbs. As shown in Figure 1, the CG and CP locations are 120 cm, and 138 cm aft of the tip of the nose cone, respectively. This gives the rocket a stability of 1.73 cal with the motor installed.

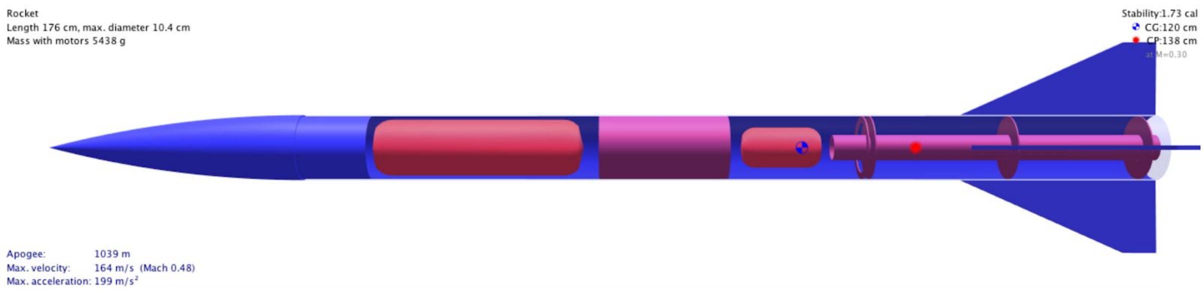

Figure 1. Rocket CP/CG locations and dimensions. Center of pressure is indicated by the red dot and center of gravity is indicated by the blue circle crosshatch.

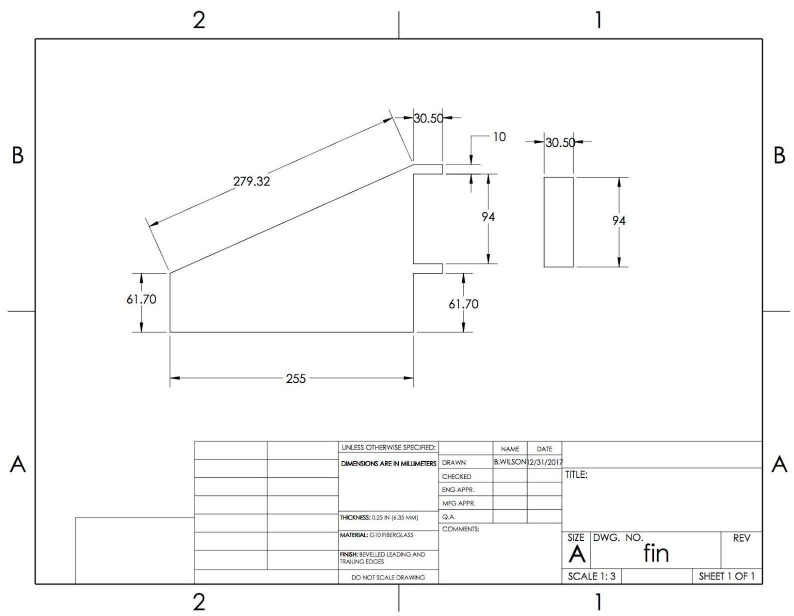

Figure 2. Fin and control surface dimensions.

Figure 3. Rocket airframe construction

2.1.1 Structural Integrity

The servo-controlled control surfaces (Figure 4) will be the most likely source of failure for this competition. It is critically important to ensure that each control surface is capable of withstanding the intense dynamic forces throughout flight. In addition to basic structural concerns of the airframe, nose cone, and fins, it is critical to make sure that the servo and control rod relationship is sufficient to produce highly accurate roll angle adjustments in a very short amount of time. The angular dynamics of the control surface's corrective maneuvers will instill even higher levels of stress on the component, which was analyzed in detail to ensure integrity of the design.

A model of the fin/control surface assembly was created in SolidWorks, then transferred to ANSYS APDL. It was modelled with *8-Node solid Brick 185* elements. This element is used for three dimensional solid structures and has three degrees of freedom at each of the eight nodes which will identify mode shapes in all three dimensions. The model was fixed in all DOF at the outer area of the rod on the side that protrudes out further. The other end was fixed in Y and Z direction such that UY = UZ = 0. The weld was modeled to have no slip, which is a reasonable assumption as long as the shear stress is less than the tensile strength of the JB weld bond (~30 MPa). This stress criteria was verified, and the maximum shear stress at the bond location was found to be 23.7 MPa (see Figure 5). Von Mises criterion was then used to determine whether the fin assembly would yield or not with a safety factor of 1.5 (167 MPa would indicate yield). To model the largest expected loading to provide a worst case scenario, the pressure acting on the fin was calculated using analytical methods. This was done by using the equation:

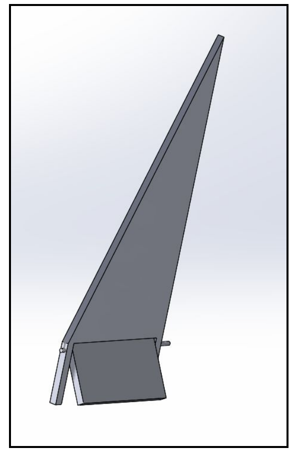

Figure 4. Fin Assembly

$$P = \frac{F}{A}; \qquad F = \frac{1}{2}\rho A C_D v^2$$

where A is the area of the plate (0.005 m^2), rho is the density of the air, v is the velocity, and C_D is the coefficient of drag. The maximum velocity was calculated using MATLAB by integrating the equation of motion over time using numeric methods (See Appendix). This resulted in a maximum velocity of 160 m/s. The coefficient of drag was calculated by using flat plate aerodynamics [1]. This resulted in:

$$C_D = K\, C_L^{\,2} = K(sin(\alpha)cos\,(\alpha))(K_P cos(\alpha) + \pi sin(\alpha))$$

where α is the angle of attack of the control surface and K and K_P are constants from the geometry of the fin and the angle of attack [1]. This resulted in a C_D of 0.4755, which gave rise to the solution F = 37.13 N. To model this in ANSYS, an area pressure of 7.4 kPa was applied to the area of the control surface. Figure 6 shows the Von Mises Stress plot of this loading scenario, which resulted in a maximum stress of 137 MPa, well within the safety factor. The maximum displacement was 0.359 mm (Figure 7), which can be considered negligible.

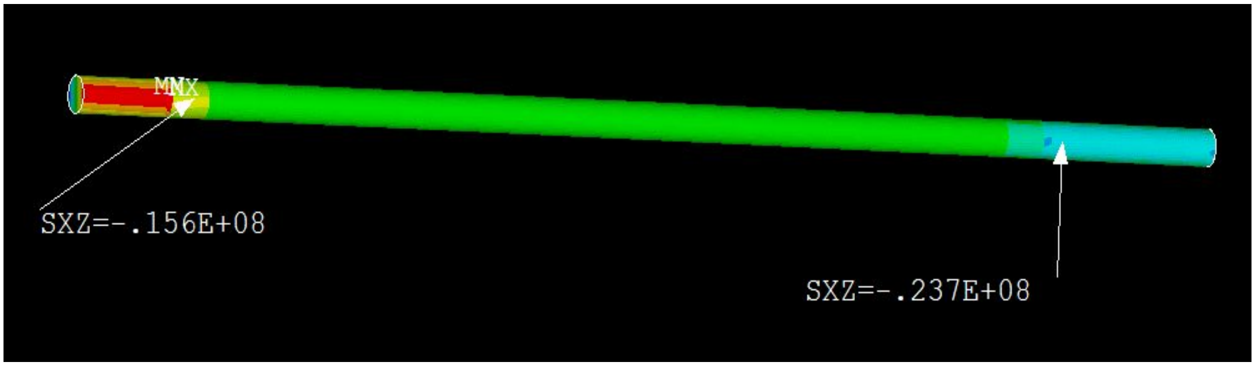

Figure 5. The shear stress contour for the XZ direction of the control surface rod. Notice that the values which are called out indicate the locations of the JB welds.

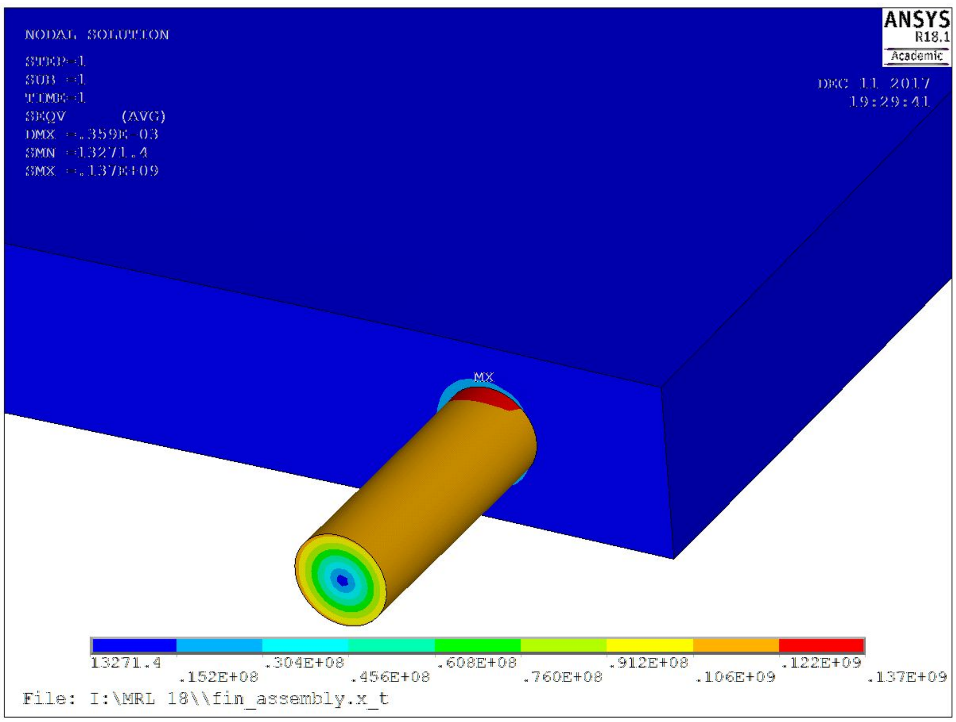

Figure 6. Von Mises stress, Maximum (137 MPa) at the junction.

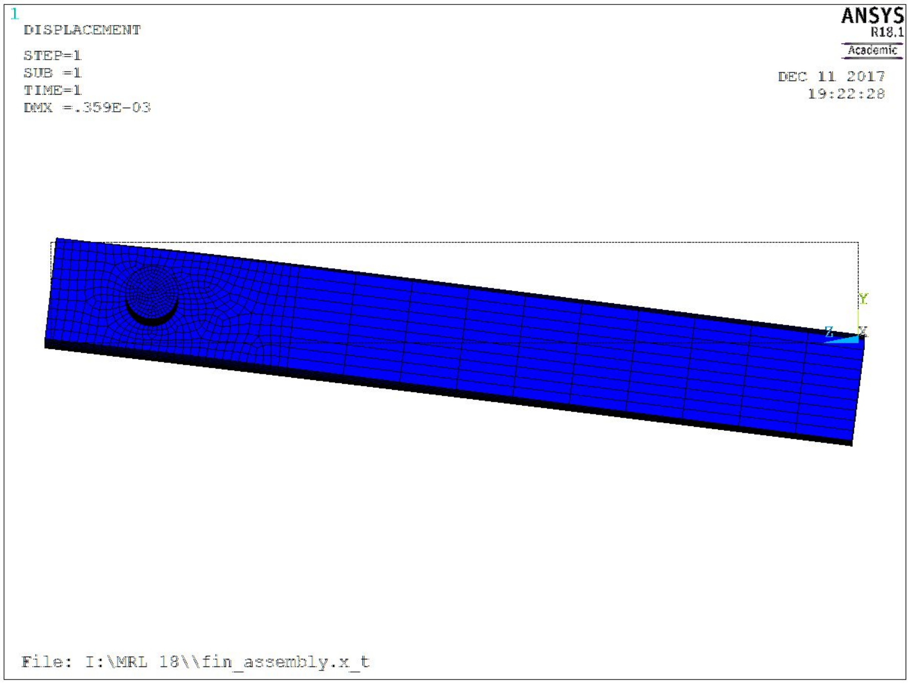

Figure 7. Displacement of the control surface assembly (0.359 mm in the y-direction)

A transient analysis was utilized to model the back-and-forth corrective nature of the roll control mechanism. As the internal control system seeks to orient the rocket in a certain way, it will trigger a shift of the control surface, which will produce roll rotation. Since the control algorithm will likely not be able to perfectly predict the necessary shifts to achieve a desired control, there will be phases of overcorrection and subsequent recorrection. If these oscillations are near the natural frequency of the rocket, they can exasperate and the integrity of the fins can become compromised. Figure 8 shows the response of the transient analysis, however many factors, such as the moment of inertia, control system response, and damping coefficients were assumed. More research as well as possible wind tunnel testing will be done prior to the competition to obtain a more solid mathematical model.

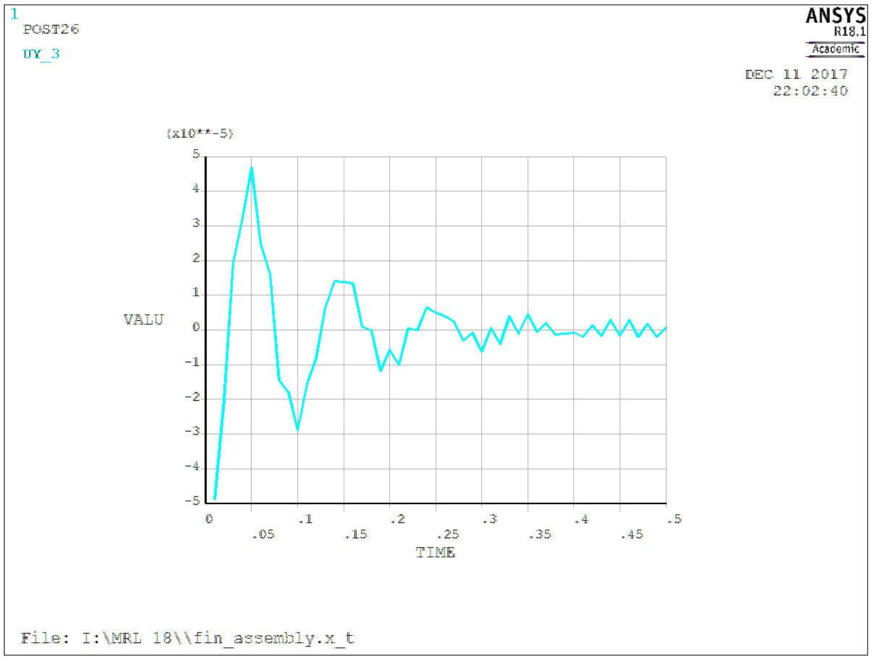

Figure 8. Transient response of control surface

2.2 Video Recording Capabilities

The Badger Ballistics competition rocket will be equipped with two different cameras, each with their own unique purpose. The first camera will be mounted in a downward facing direction in order to satisfy the competition requirement for ground-facing video. The second camera will be situated so that it faces away from the vertical axis of the rocket in order to provide a unique view of the Earth's horizon as the roll control mechanism takes effect.

2.2.1 Downward Facing Video

The downward facing video footage will be captured using a Mobius Mini 1440P HD camera. At 1.56oz and an incredibly compact volume of roughly 3 square inches, this camera is an ideal fit for the videography requirements of this rocket competition. In regards to video, the Mobius camera boasts a range of recording qualities at 30fps, 60fps, and 120fps. More importantly regarding display quality, the camera comes equipped with wide angle lens capable of capturing a view field of 135 degrees which should provide an ample reference to the rocket's roll performance. Additionally, the camera has a built in 300mAh battery which should be sufficient for 35 minutes of video recording, a time frame which is well within the needs of this competition. The video data is then stored on a 32GB class 10 micro SD card which can be removed and given to the judges for future analysis.

The camera will be mounted on the exterior of the body tube, along the midpoint of the avionics bay, as shown in Figure 9. The Mobius Mini is manufactured with a mounting bracket consisting of four ¼”-20 threaded holes translated to a ½”-20 threaded bolt connection. This stronger ½” bolt will protrude through the body tube wall to serve as the secure connection point for the camera. In order to ensure the force on this bolt in minimized, am aerodynamic Mobius ActionCam Shroud will be used to eliminate the force of drag attacking the camera. The shroud itself is secured to the body tube via two nut and bolt couples.

Figure 9. The Mobius Mini 1440P HD Camera and Mobius ActionCam Shroud which will be used to retrieve downward facing video footage of the rocket flight.

2.2.2 Auxiliary Transverse Video

The transverse video camera will be mounted inside the avionics bay with the housing of the camera lens epoxied to the body of the rocket. The camera is a RunCam Swift FPV camera utilizing a TBS Unify Pro HV Video Transmitter. This will allow the judges and audience to see a live feed of the rocket throughout the entirety of the flight via a small TV and video receiver. A pair of first person view goggles will also available for a judge to wear, if they desire, to experience in first person how well the rocket is being controlled.

2.3 Active Roll / Orientation System

The roll and orientation system will be controlled via dynamic control surfaces mounted along the bottom of each rocket fin. Each control surface will be controlled by a high torque servo motor, which will interface the assembly via bevel gears. The four servo motors will be driven by a central control algorithm delivered via arduino board. The control system is a simple proportional, integral, derivative (PID) feedback algorithm that receives the angular velocity of the rocket from an Adafruit 10-DOF inertial-measurement-unit and outputs a calculated control surface deflection.

2.3.1 Roll Control Algorithm

Initial testing of the rocket will use a simple proportional feedback loop, which can be expressed as: $u(t) = k_p e(t)$, where u is the control signal, k_p is a constant coefficient, and e(t) is the error determined by a setpoint (which will be the angular velocity of the rocket, for nulling roll). This means the deflection of the control surface will be directly proportional (and opposite) of the angular velocity to null out any unwanted roll. Further development of our control system will likely be that of a PID controller, which can be expressed as:

$$u(t) = k_p e(t) + k_I \int e(\alpha) d\alpha + k_D \frac{de(t)}{dt}$$

This form of control takes the current error, sum of past errors, and the rate of change of error to provide an output that will null any roll as quickly as possible, with little settling time.

Controlling the orientation of the rocket will use the same PID control, however the error will be the difference in angle $(\theta(t) - \theta_{desired})$. Thus, the control sequence will be to first null any roll using the angular velocity as the setpoint for error, once this is achieved, the IMU will determine the desired angle the rocket needs to roll to, finally the PID setpoint will be that of the difference in rotation angles. Once this is achieved the setpoint will return to the angular velocity to hold the rocket for the desired period of time.

2.3.2 LED Indicator System

The status of the rocket's roll control system will be conveyed through the use of three LED lights located within view of the downward facing Mobius camera. The LEDs will receive on/off instructions from the Arduino microcontroller. As soon as the flight system is powered on, the LED class will begin sending a function call to the Adafruit inertial-measurement-unit to receive velocity data. The code will then instruct the LEDs to turn on for two seconds and then off for two seconds in a while loop which will be maintained until launch is detected. The LEDs will then be directed to stay on until the LED class receives information from the master code that apogee has been reached. The LEDs will then remain on for an additional three seconds before moving into the next phase.

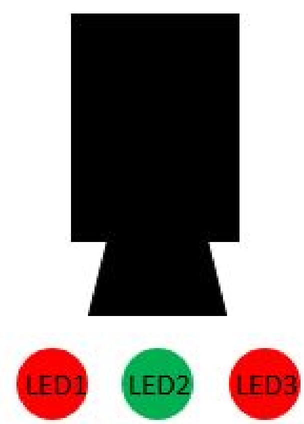

Figure 10. Downward facing video camera with relative LED location designation.

During active roll control, the LED class will request information from the roll control algorithm to determine how the rocket is attempting to orient itself. If the rocket is attempting to correct the roll orientation in a clockwise direction then LED1 will rapidly flash on and off. If the rocket is attempting to correct the roll orientation in a counter clockwise direction then LED3 will rapidly flash on and off. Finally, if the rocket is attempting to maintain the current roll orientation then LED2 will flash on and off.

Once the Arduino registers that the rocket has reached apogee, the LED class will shift into its final phase which will continue throughout descent, landing, and recovery. Once apogee is detected, all three LED lights will flash on for 0.5 seconds and off for 0.5 seconds in a continuous loop until the rocket is recovered and the flight system is turned off.

2.4 Avionics Bay Design

The avionics bay is a key component in the rocket. The competition requirements specify that the avionics bay should be “tough but user friendly”. To achieve this, all of the circuitry and wiring for the flight computer will be integrated into a compact circuit board (shown in Figure 11). The components in the bay include:

- Arduino Mega
- Custom made circuit board
- 12V battery
- StratoLoggerCF altimeter
- LSM303 10-DOF IMU
- Adafruit Ultimate GPS
- Adafruit SD shield
- LED indicating system
- Rocket tracking device
- XBee wireless transmitter
- FPV Camera

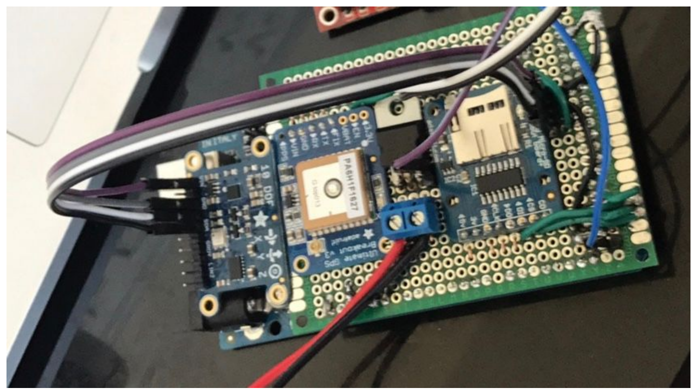

Figure 11. Custom Circuit Board

The avionics bay will be constructed of fiberglass, and will consist of a “sled” (Figure 12) to which all components will be mounted to. The custom made circuit board will be mounted directly onto the Arduino mega, utilizing all of the pinouts on the arduino. The circuit board consists of a 5V Bus, which will regulate the 12V battery input to a 5V output that will be used to power the Arduino, IMU, GPS, SD shield, LED indicating system, FPV, camera, four servos, and the XBee wireless transmitter. The GPS and SD shield are soldered directly to the circuit board for compactness and neatness. Figure 13 shows the flight computer assembly installed onto a 3-inch avionics bay sled (which will be flown for testing in a smaller 3 inch rocket on March 10th).

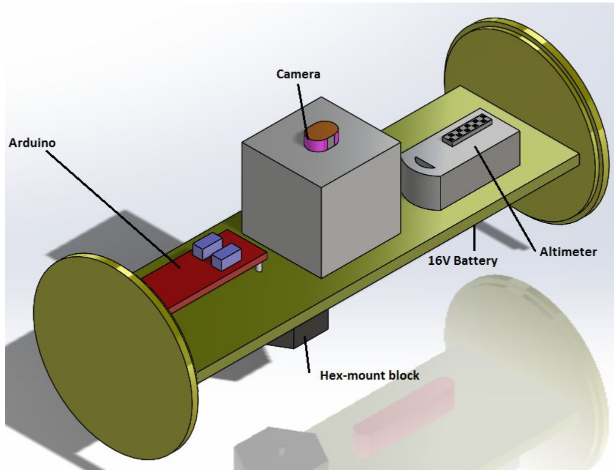

Figure 12. Layout of avionics bay

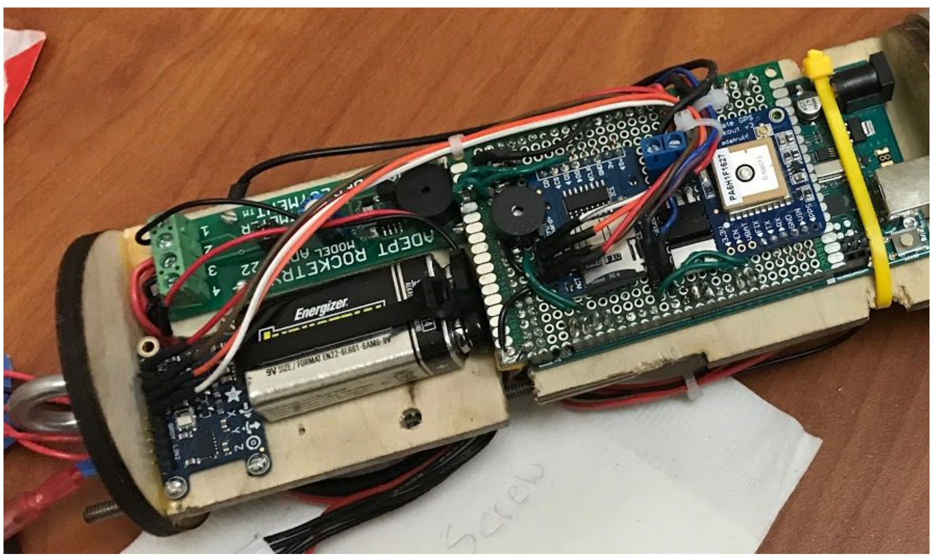

Figure 13. Flight Computer installed onto sled of test rocket

Since the servos are located in the aft end of the rocket and powered by the central flight computer in the mid section of the rocket, quick disconnects will be installed in a clever manner to allow the servo wires to detach during drogue parachute ejection. This is accomplished by epoxing the servo connectors to the upper-most centering ring on the motor mount assembly. Steel cables are attached to the avionics bay and run down to the top end of the motor mount. At the motor mount side of the steel cables is attached a small common connector with the male servo connectors. When the aft section of the rocket separates at apogee, the common connector that is attached to the avionics bay will pull the servo quick disconnects apart, while placing no strain on the servo wires themselves.

Ejection charge terminals will be mounted on both sides of the avionics bay for ease of access while installing new ejection charge canisters for both the drogue parachute ejection, and main parachute ejection. The ejection charges will be powered by the StratLoggerCF using a separate power supply and switch for safety purposes.

3.0 ANALYSIS OF BASIC FLIGHT PERFORMANCE

The predicted flight performance of the Badger Ballistics rocket were modeled primarily in MATLAB with supplementary calculations provided by OpenRocket. The simulation takes the known rocket properties such as mass, geometry, and motor potential to develop initial conditions for flight. From this point, environmental factors such as air drag, decreasing air density, and decreasing fuel mass can be applied to generate the overall flight characteristics.

The flight can be broken into three distinct sections; launch, post-motor burnout, and descent. Each section will have a different driving variable. For the initial launch, the mass of motor propellent is constant with time, and can therefore be used a benchmark to define the period which this phase lasts. After burnout, velocity will control the dynamic and environmental effects up until apogee. Finally, as the rocket enters a free fall from a calculated height, time will overcome as the factor which drives all properties affecting the rocket system until ground contact. The equation of motion can be expressed as:

$$m(t)\frac{d^2x}{dt^2} + \frac{1}{2}(\rho C_d A_{ref})\frac{dx}{dt} = F_t - m(t)g$$

This equation of motion was numerically integrated in a MATLAB piecewise function that incorporates each of these three phases (see appendix for code).

3.1 Altitude, Velocity, and Acceleration Predictions

The projected maximum altitude, velocity, and acceleration were calculated using numeric integration techniques with MATLAB and compared with OpenRocket's predictions for additional confidence in our mathematical model. The projected altitude with the AeroTech J570 motor resulted in 3281 ft (1000 m), and reached apogee at 14 seconds after launch. The maximum velocity is predicted to be 540 ft/s (165 m/s), and the maximum predicted acceleration is 91 m/s^2 (9.27 g's). These values compared nearly identically to OpenRocket's predictions, with the exception of the maximum acceleration, which is off by a factor of 2. This deviation is unknown, however, we have confidence in our numerical approximations.

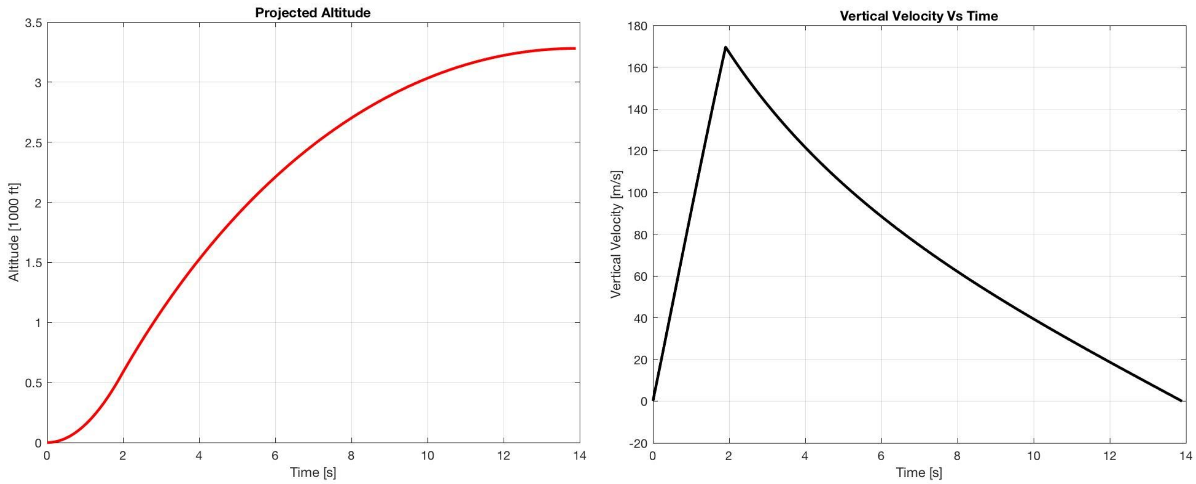

Figure 14. Projected altitude as modeled by MATLAB (left), Projected vertical velocity (right)

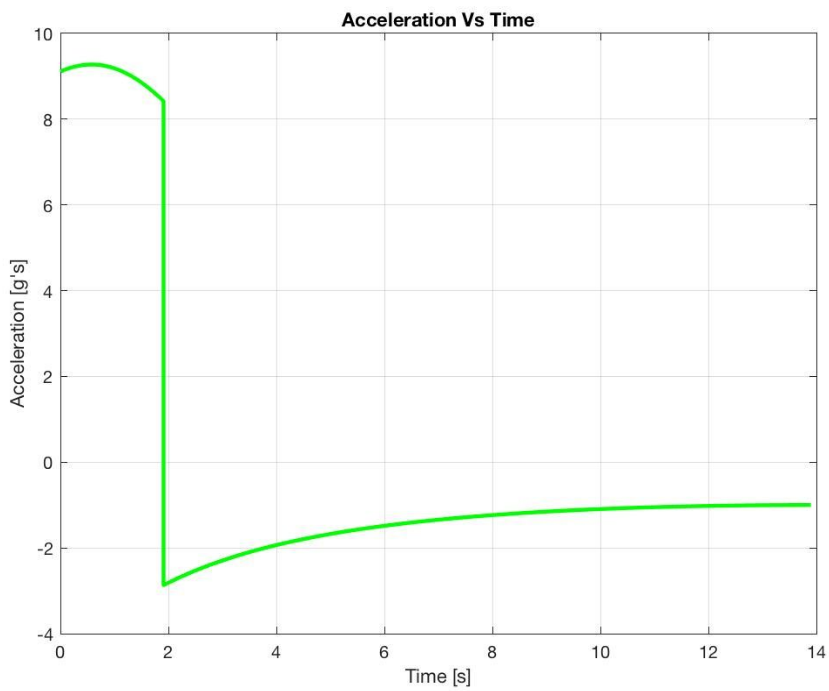

Figure 15. Projected Acceleration Vs time as modeled by MATLAB

3.2 Descent Characteristics Predictions

The flight recovery system will need to be taken into special consideration. Since the competition requires two distinct launches within a short time span, it is crucial that the recovery system operates effectively and consistently to ensure the safe, reliable return of the rocket for subsequent launches. With this in mind, the competition handbook also outlines some additional descent requirements to ensure overall safety. In summary, the recovery system must not deploy earlier than apogee, a motor ejection backup is required, and the landing speed must not exceed 24 ft/s.

Recovery will be achieved by use of a PerfectFlite StratoLogger CF altimeter, which will deploy a 24 inch drogue parachute at apogee, and a 58 inch main parachute at 700 ft AGL. Backup motor ejection will be used for redundancy, with a 14 second delay to deploy the drogue parachute if the commercial altimeter fails. OpenRocket simulations estimate the rocket will have a ground hit velocity of ~20 ft/s in this configuration (shown in Figure 16).

Figure 16. OpenRocket estimations of Altitude, Vertical Velocity, and Vertical Acceleration Vs time. (*Note simulations show descent velocity ~20 ft/s with given configuration.)

3.3 Motor Performance Predictions

The motor selected for this competition is the AeroTech J570 due to it's high thrust, short burn time, large impulse. This provides the rocket with a large change in momentum within a short period of time, which maximises the coast time to apogee. Simulations were ran with several similar motors, which varied thrust and burn time while maintaining a constant total impulse. The calculations with higher thrust, and lower burn time provided additional coast time to apogee, which would be beneficial to provide additional time for roll maneuvers, however, the estimations showed that the rocket would not reach a minimum altitude of 3000 ft. The J570 provides us with the best balance between coast time and maximum altitude. It has a total impulse of 973.1N-s, an average thrust of 509.3N, and a burn time of ~2 seconds [4]. Figure 17 outlines the measured thrust curve of the motor [4], which shows a regressive style burn.

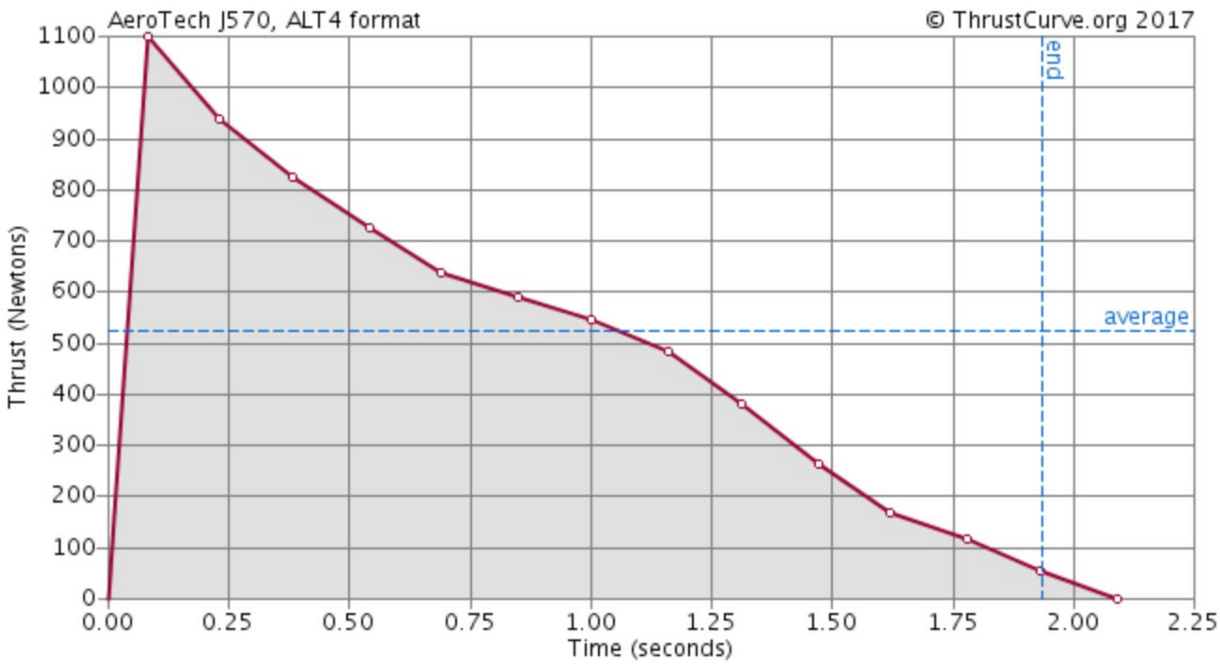

Figure 17. Thrust curve of AeroTech J570

3.4 Flight Performance Summary

The preliminary prediction tools have confirmed that the Badger Ballistics rocket should meet all competition safety and performance requirements within a reasonable margin of error. The largest takeaway from this analysis should be the velocity over time, and the time interval between engine burnout and apogee. These two pieces of information will play directly into a much larger role of the rocket's competitive performance and success.

The velocity function of flight will be directly fed into the stress analysis calculations. Since the force of drag will be the dominant inducer of stress on the rocket, it is crucial that our team examines the worst case scenarios to ensure that the rocket will maintain structural and functional integrity. As was stated in Section 2.3, the control surfaces, which control roll, will likely be the most sensitive rocket component to these dynamic forces. If you revisit section 2.3, you will see that the above velocity results were utilized within those calculations.

Additionally, the time interval between burnout and apogee will directly correlate to the likelihood of a roll orientation success. With roughly 12 seconds of post apogee coast time, minus a the 3 second window outline by the competition handbook, the rocket will have ~9 seconds to arrive at as many desired roll orientations as possible. Therefore, it is absolutely crucial that the roll control algorithm is as finely tuned as possible to ensure that the desired orientation is reached before descent begins. This information will be very useful as experimental testing and test flights begin in the near future. Initial research and computational predictions indicate that the algorithm should be able to respond quickly enough. However, if real world factors show something contradictory, additional measures will need to be taken to improve the roll orientation response time.

4.0 ANALYSIS OF LINKED COMMUNICATIONS

The Space Grant Midwest High-Power Rocket competition has given the option, this year, to pursue a bonus challenge based around designing and implementing a communications system within a rocket. The Badger Ballistics team will pursue this challenge to its full extent. The challenge entails a radio module relay to facilitate uplink/downlink communications prior to and during flight. Our team will utilize this system to transmit alternative roll orientation commands to the rocket prior to launch. To demonstrate the rocket to ground transmission capabilities, the communications system will also relay live flight data back to the ground. Finally, as a demonstration of the system's capabilities as a whole, the rocket should be able to receive a very basic mathematical question and transmit the answer back to ground control. At this point in the design process, our team has not yet begun testing any of the communications hardware or source code. However, within the section, the research which has been done up until this point will be shared.

4.1 Radio Module

The Badger Ballistics team will be using a XBee Pro 60mW Wire Antenna - Series 1 radio module for the communications system. This module operates at 2.4 GHz as is specified by the competition parameters. The power consumption of an individual module is 3.3V at 215mA. Due to the 60mW output, this XBee Pro is capable of transmitting data up to 1500m (1 mile) which will be provide an ample range for the rocket's projected apogee of roughly 3200 feet. A design feature of this radio module which is worth noting is the antenna protruding 35mm. If the electronics bay layout is lacking space, this is an area where we could make design changes by substituting a radio module with a built-in antenna.

Figure 18. The XBee Pro 60mW Wire Antenna - Series 1.

In order to set-up and operate the radio module within the rocket system, a few addition pieces of software and hardware will be necessary. The modules themselves will be told how to operate using the XCTU coding package. Through this software, the modules are able to be designated as either a transmitter or receiver which use the designations of coordinator or end point, respectively. The transmitter and receiver pair are then connected by setting a unique ID number. Within this program, the baud rate of the module can also be established. All of this information can then be uploaded onto the module via an XBee Explorer USB board. The USB board will also be utilized to install the modules source Arduino code, which will tell it how and what to operate.

4.2 Ground Command - Flight Communication

At this stage in the design process, our team does not yet have experimental results to provide to this section of the preliminary design report. However, research and product specifications have provided a strong path to follow in regards to how this obstacle will be approached in the coming weeks. For the two-way communication system, a total of four XBee Pro radio modules and the relevant coupling devices (outlined above) will be need. This translates to a Coordinator and an Endpoint module on both the rocket and at the ground control station.

The Arduino code governing the Coordinator transmittance is reasonably simple. Essentially, an Arduino pin needs to be allocated as the data input point for the XBee. The potential at this input pin can then be translated into a format which is compatible with the XBee. The XBee coordinator will then store this data in a value matrix and the information can then be "printed" to a signal which is sent to it's connected receiver End Point (designated using XCTU).

The code governing the receiver Endpoint is slightly more complicated. Once again, the XBee must be connected to a specified Arduino pin where data will be stored. The data which is expected to be received will then need to have a variable name established. This poses some potential complications regarding unknown operations which the competition may present. Once appropriate storage locations have been defined, the reading of incoming signals is a few simple lines of code [2]. After this point, the information is at the Endpoint and the challenge now revolves around how to handle the data. Whether this means reading in roll orientations or accepting flight data, if a thoughtful variable structure is set up consistently, then everything should go where it needs to.

Being able to collect flight data from a rocket is one of the most valuable pieces of information that can be gained from any given launch. Whether the launch and flight is successful, or a complete failure, flight data can provide incredible insight into what we are doing right and what we are doing wrong.

4.3 Communications Security

The primary security functions of the XBee radio modules relies on the deep level of configurability which they possess. In terms of configurability within point-to-point connections, there are three primary levels of safeguards to prevent unsolicited interference.

1. The first level is the most basic and relies on the channel which the radio module operates on. This protocol is essentially built in to every radio module,as it described that radio bandwidth which the communications will be traveling on. The system which our team will be using or this competition is the 2.4GHz band which was specified by the competition handbook. Since all competition teams will be using this bandwidth, it is absolutely necessary to develop a more secure connection for our communications system.
2. The next strongest stage of security relied on the personal area network (PAN) ID. This network ID allows the programer to assigned a hexadecimal value between 0 and 0xFFFF to each individual XBee radio module within a network. Once this designation is made, radio modules are only able to communicate with other modules which share the same PAN ID number. With over 60,000 PAN ID iterations possible, it is incredibly unlikely that another competition team would choose to use the same ID as our team. However, to absolutely ensure that there is not intentional or unintentional tampering with the rocket system, one additional measure can still be taken.
3. Similar to the PAN ID system, the XBee radio modules are also capable of being assigned a deeper level of naming codes. Each radio module can be assigned a “MY address” and a “destination address”. These designations tell each module that it can only receive information from an XBee module which has the same destination address as the receiver's MY address. This additional level of classification virtually ensures that an outside transmittance source will be unable to interfere with the rocket’s flight system. Additionally, this address system can be utilized internally within the communication system to add an extra level of assurance that there is no miscommunication between the flight system and ground control.

With these built in XBee security measures set aside, it will also be advantageous to hardcode a security clearance password into the Arduino’s receiver protocol. This can be done simply by inserting an If Statement in the Endpoint’s reception code, which will not proceed without a two digit password. For the Badger Ballistics team, the security code will be ‘^B’. Any radio transmission which is received by the radio modules which is not initiated with this simple two-digit ASCII code will not be processed by the Arduino.

5.0 SAFETY

Safety is paramount to having successful launches on competition day. To ensure people's safety on site, many steps and checks need to be established prior to launch.

5.1 Flight & Recovery Safety Design Aspects

Badger Ballistic's rocket is designed to meet and exceed safety regulations that NAR, NFPA, and Tripoli require. The recovery system employed ensures that our vehicle will descend at 20 feet per second, which is less than 24 feet per second maximum. A NOMEX cloth and flame resistant recovery wadding is used to separate the parachute from the pyrotechnic charges, preventing the parachutes from being damaged. Additionally, our rocket utilizes Kevlar shock cords to attach the avionics bay to the nose cone and lower fuselage, keeping our vehicle intact. With respect to the weight limit put in place, our rocket is capable of producing and average thrust of 509.3 Newtons while only weighing 49 Newtons (12lbs) with motors and recovery system, which result in an estimated 66 ft/s velocity off the launch pad. This ensures the rocket will be stable and vertical as it leaves the launch pad.

5.2 Material Handling Procedures

Appropriate behavior needs to be in place while handling hazardous materials and working on the launch site. By adhering to the follow precautions and safety guidelines, the risk of someone being harmed is drastically reduced.

- Always wear safety glasses when using power tools, pyrotechnic charges, or small hardware components are present
- Pants and closed toed shoes need to be worn at all times during machining processes
- Never point the rocket or pyrotechnic charges at or near anyone and do not look down the body of the rocket when the charges are live
- Refrain from handling electronic devices when working with the pyrotechnic charges
- Do not smoke or light any flames within 30 feet of the rocket or avionics bay
- Keep the rocket engine and propellant an acceptable distance away from heat sources
- Fire protection equipment is nearby with personnel trained to use it
- Wear a facemask while holding fiberglass to prevent the inhalation of unwanted particles
- Gloves need to be worn when applying epoxy to minimize skin irritation
- Waste materials will be discarded in appropriate trash bins
- Abide by the NAR, NFPA, Tripoli, and state safety codes

5.3 Pre & Post Launch Procedures

The purpose of pre and post launch procedures is to create strict guidelines that need to be followed to promote a safe launch and recovery. By having checklists, we are able to quickly and effectively complete a course of action as a team. These steps are described below.

Preflight Checklist

- Confirm that rocket has been properly assembled
  - Check that center of gravity (CG) and center of pressure (CP) are marked correctly, promoting a stable flight
  - Check shock cords and parachute for cuts, burns, or tangles
  - Motor is installed correctly
  - Check that the fins are secure
  - Make sure the nose cone is secured
  - Secure the aft section
  - Verify that the control surfaces are secured and free to deflect
  - Confirm that the motor and its retainer are secure
- Verify that the area around the launch pad is clear of flammable materials
- Refrain from launching when surface winds are greater than 20mph (32/km/h)
- Do not launch at an angle greater than 20 degrees from vertical
- Do not launch the rocket at a target, into the clouds, or beyond the bounds of the site
- Verify that rocket will exit the launching device with minimal friction from the guides
- Only install the ignition system at the launch pad
- Switch will arm the rocket by energizing the circuit once the rocket is in launching position
- Listen for correct arming tone
- Ensure that the High Power Rocket distance requirements are met before launch (100 feet away from pad)
- When arming or disarming the rocket at the launch pad, only those needed to safely to do so will be present
- Countdown from five seconds before launch, loud enough to alert all spectators

Postflight Checklist

- Maintain visual contact with rocket during launch and descent
- Do not attempt to catch the rocket as it lands
- Approach rocket with caution as ejection charges may still be live, carefully removing them if so
- Do not retrieve the rocket if it lands in a hazardous area, most commonly power lines

- Verify that all parts are intact and safe to be flown again

6.0 BUDGET & TIMELINE

The framework of every true engineering feat is the cost potency of the project. Between money, time, and resources it is a necessity to overcome the natural constraints around a given challenge in the most effective way possible. The Badger Ballistics team has used a combination of approaches to ensure that the greatest possible rocket could be built at the lowest cost with the best quality.

6.1 Bill of Materials and Competition Costs

Badger Ballistics is primarily self funded by the members this year due to a lack of grant opportunities. Our Parent organization AIAA graciously donated $800 to cover the competition registration fee, and a portion of our travel to North Branch MN in May. However, the cost of the rocket is being covered completely by the group members. Therefore, we are utilizing as many free assets as possible from previous projects. The Bill of Materials below outlines the current monetary requirement for this project. A majority of the parts have already been procured and construction of the rocket is in its infant stages.

Badger Ballistics Preliminary BOM

University of Wisconsin - Madison
Midwest Rocket Launch Competition 2017-2018

This preliminary budget was put together based on the assumptions that three test flights would be conducted, along with two competition flights. This budget also assumes that all 7 members will be attending the launch in North Branch, MN.

Accurate as of 9-March-2018 - subject to change

System	Part	Cost	Dealer	Quantity	Total Cost
Airframe					
	Body tube (4 in fiberglass)	$105.00	Apogee		$105.00
	Motor Mount Tube (fiberglass)	$60.00	Apogee	1	$60.00
	Fin Material	$30.00	public missiles	1	$30.00
	1010 Airfoil Rail Buttons	$7.00	Apogee	1	$7.00
	Coupler tube	$30.00	Apogee	1	$30.00
	centering rings (4 in to 38 mm fiberglass)	$14.00	Apogee	2	$28.00
	Fiberglass Nose Cone (5.5:1 Von Karman)	$69.00	Madcow	1	$69.00
	Quick Links	$7.88	Apogee/Hardware Store	2	$15.76
Recovery					
	44" LOC Angel Main Parachute (subject to change)	$0.00	on hand	1	$0.00
	24" Nylon Drogue Parachute	$0.00	on hand	1	$0.00
	Kevlar shock cord	$1.25	apogee	20	$25.00
	12" Nomex Chute Protector	$8.15	Apogee	2	$16.30
	Dog Barf	(Already Have)	-	1	$0.00
	Ejection Charge Canisters w/ Igniters (10/pk)	$17.95	Wildman	1	$17.95
Electronics					
	FPV Camera	$0	on hand	2	$0.00
	Mobius Camera and shroud	$0	Borrowing from mentor	1	$0
	10 DOF Accelerometer/Gyro/Multi-Sensor	$25	Adafruit	1	$25
	Arduino mega	$30	Arduino	2	$60.00
	Adafruit SD Shield	$8	Adafruit	2	$15.00
	8GB Micro SD card	$5	Amazon	1	$4.99
	1600mah 3S 25~50C Lipo Pack	$24	Amazon	1	$23.89
	Strattologger CF Altimeter (Primary)	$50.00	-	1	$50.00
	Terminal Blocks	$3.41	Apogee	2	$6.82
	Jolly Logic Altimeter Two Holster	$10.65	Apogee	1	$10.65
	Buffer Price for Unspecified Electronics/Replacements	$100.00	-	-	$100.00
Motor	AeroTech J570	80	Wildman	5	$400.00
	AeroPack 38 mm Motor Retainer Set	$31.03	Apogee	1	$31.03
Misc.	Shipping & Tax Estimate For All Orders	$50.00	-	1	$50
	Black Powder	Have	-	-	$0.00
	2-56 Nylon Shear Pins (20/pk)	$3.10	Apogee	2	$6.20
	Clear Coat Paint and Various Grit Sandpaper	$20.00	Local Hardware Store	1	$20.00
	Epoxy/West systems	$50.00	Wildman	1	$50.00
	Misc. Hardware (Nuts, Washers, etc.)	$20.00	Local Hardware Store	1	$20.00
Travel/Logistics	Registration Fee	$400.00	-	1	$400.00
	Hotel Fee (Per Night - double Twin Bed Room)	$90.00	-	3	$270.00
	Transportation	(Paying Personally)	-	-	$0

Airframe Subtotal:	$344.76
Recovery Subtotal:	$59.25
Electronics Subtotal:	$296.30
Motor Subtotal:	$431.03
Misc. Subtotal:	$146.20
Rocket total	$1,277.54
Travel Subtotal:	$670.00
Total:	$1,947.54

6.2 Timeline

Initial testing of the control system, and data acquisition is currently being completed. As can be seen in Figure 19, we are launching a level 2 high powered rocket on March 10th to test our data acquisition system and flight computer. This will give us insight on the level of signal clarity from the inertial measurement unit, as well as reveal any possible bugs in our code. Following that, we plan to have the lower assembly of the rocket, as well as the control system complete by March 18th, so we can begin testing the response of the control surfaces via wind tunnel (pending approval). If we don't get access to the wind tunnel on campus, we will be building a jig which will allow the rocket to be spun up and spun down to visually verify the deflection of the control surfaces. Our initial goal for the first launch is March 23rd, with April 7th as a backup. If necessary, April 21st will be a backup day for test flying prior to the competition on May 19th.

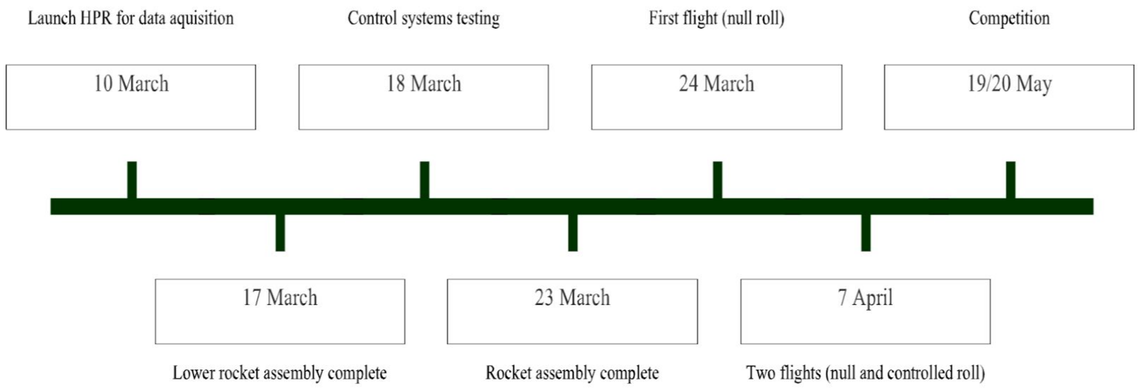

Figure 19. Current timeline of build and testing.

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APPENDIX

Altitude, Velocity and Acceleration Calculations

```
clear; clc;
%%%%%%%%%%%%%%%%%%%%%%%%% Free Parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

r_vehicle = 2*0.0254;    % Vehicle radius
m_rocket = 4.6;          % Vehicle dry mass, kg
Cd = 0.6;                % Coefficient of drag


%%%%%%%%%%%%%%%%%%%%%%%%% Motor Specs %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

F_eng = 509.3;           % Thrust [N]
ISP = 185;               % Specific Impulse [s]
m_propellant = 0.536;    % Initial propellant mass, kg
m_motorMount = 0.4;      % Mass of motor mount (0)
additiveMass = 0;        % Mass added in nose cone for CG adjust


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


dt = .001;               % Time step, sec
t = 0;                   % Starting time, sec
a = 0;                   % Instantaneous acceleration, m/s^2
h = 0;                   % Altitude, m
F_g = 0;                 % Force due to gravity, N
m_total = 0;             % Total vehicle mass, kg
dh = 0;                  % Incremental change in alt, m
v = 0;                   % Vehicle velocity, m/s
rho = 0;                 % Air density, kg/m^3
g = 9.807;               % gravitational constant [m/s^2]
p0 = 101.325;            % sea level pressure [kPa]
T0 = 288.15;             % Standard temperature [K]
L = 0.0065;              % Temperature lapse rate [K/m]
R = 8.31447;             % Ideal gas constant[j/(mol*K)]
M = 0.0289644;           % Molar mass of dry air [kg/mol]
p = 0;                   % Atmospheric pressure [kPa]
T = 0;                   % Temperature [K]
m_dot = F_eng/(g*ISP);   % Propellant consumption, kg/sec
A = r_vehicle^2 * pi;    % Cross Sectional area of rocket
burnTime = m_propellant / m_dot;
totalImpulse = F_eng * m_propellant / m_dot;
m_vehicle = m_rocket + m_motorMount + additiveMass;
mToFt = 3.28084;
```

```
i = 1;
while (m_propellant >= 0)

    % Total mass [kg]
    m_total = (m_propellant + m_vehicle);

    % Force due to gravity [N]
    F_g = m_total * g;

    % Temperature as a function of altitude
    if (h > 10972)
        T = 216.6;
    else
        T = T0 - L*h;
    end

    % Pressure as function of altitude and temperature
    p = p0 * (1 - (L*h) / T0)^(g*M / (R * L));

    % Air density as a function of pressure and temp [kg /m^3]
    rho = ((p * M) / (R * T)) * 1000;

    % Force due to drag [N]
    F_d = Cd * A * .5 * rho * v^2;

    % Sum of forces [N]
    F = F_eng - F_g - F_d;

    % Acceleration [m/s^2]
    a = F / m_total;
    a_step(i) = a;

    % Velocity [m/s]
    v = v + (a * dt);
    v_step(i) = v;

    % Differential height [m]
    dh = v * dt;

    % Current height [m]
    h = h + dh;
    h_step(i) = h;
```

```
    % Mass of propellant [kg]
    m_propellant = m_propellant - (m_dot * dt);

    % Time [s]
    t = t + dt;
    t_step(i) = t;

    i = i+1;
end


fprintf('Altitude at burnout: %4.1f m',h);
fprintf(', %4.1f ft\n', h * mToFt)
fprintf('Velocity at burnout: %4.1f m/s\n',v);
fprintf('Burn Time: %4.2f seconds\n', burnTime);
fprintf('Total impulse: %4.2f N-s\n', totalImpulse);

while (v > 0)
    F_g = m_total * g;

    % Temperature as a function of altitude
    T = T0 - L*h;

    % Pressure as function of altitude and temperature
    p = p0 * (1 - (L*h) / T0)^(g*M / (R * L));

    % Air density as a function of pressure and temp [kg /m^3]
    rho = ((p * M) / (R * T)) * 1000;

    % Force due to drag [N]
    F_d = Cd * A * .5 * rho * v^2;

    % Sum of forces [N]
    F = -F_g - F_d;

    % Acceleration [m/s^2]
    a = F / m_total;
    a_step(i) = a;

    % Velocity [m/s]
    v = v + (a * dt);
    v_step(i) = v;
```

```
    % Differential height [m]
    dh = v * dt;

    % Current height [m]
    h = h + dh;
    h_step(i) = h;

    % Time [s]
    t = t + dt;
    t_step(i) = t;

    i = i+1;
end
fprintf('Apogee: %4.1f m',h);
fprintf(', %4.1f ft\n', h * mToFt)


plot(t_step, h_step * mToFt / 1000, 'r-', 'LineWidth', 2.2);
title('Projected Altitude')
xlabel('Time [s]')
ylabel('Altitude [1000 ft]')
grid on

figure
plot(t_step, v_step,'k-', 'LineWidth', 2.2);
title('Vertical Velocity Vs Time')
ylabel('Vertical Velocity [m/s]')
xlabel('Time [s]')
grid on

figure
plot(t_step, a_step /g ,'g-', 'LineWidth', 2.2);
title('Acceleration Vs Time')
ylabel('Acceleration [g''s]')
xlabel('Time [s]')
grid on;
```