# Electronics and Instrumentation

## Objective

For this project to be successful a number of electronic systems are being designed. The goal of these systems is to provide a safe and reliable method to test, launch and recover all aspects of the rocket, while also collecting invaluable flight data, supporting payload and abiding by strict standards.

## Flight Critical Electronics

### Introduction

The purpose of the Flight Critical Electronics is to safely and reliably control ignition of parachute charges and to provide GPS tracking capability to find the rocket. Last year the G-Wiz flight computer was used in conjunction with the BigRedBee GPS transmitter in order to cover these functions, however, the E&P team decided not to use this flight computer again for SRT-3 due to its programming set up difficulty and unreliability due to system crashes. Therefore, we decided to select a new flight computer based on reliability, user-friendliness (programmability), pyrotechnic outputs, price, and the ability to accurately record altitude.

### Primary Flight Computer and Vehicle Tracking

After looking at different brands of computers the selection came down to the AIM Xtra produced by Entacore Electronics or the TeleMega by Altus Metrum, which both had more than the minimum two pyrotechnic channels required and also included various sensors and features to record the data necessary. After reconsideration the TeleMega was decided upon as the primary flight computer to be used in the rocket because it comes highly recommended and has a high amount of programmable pyro channels and multi axis accelerometers and gyro sensors. The telemetry capabilities of the TeleMega will not be used this year as this would require purchasing several more components. As such, the TeleMega can act as the platform for expansion of the rocket in the future as the multiple features and channels can incorporate more advanced designs.

The primary computer will be programmed to fire the drogue parachute charge at apogee and the main parachute charge at a predetermined altitude above ground level, likely 1500 ft.

### Secondary Flight Computer

The secondary flight computer will be the Stratologger CF by Perfectflite which will act as the redundant system for the primary TeleMega and will also record and store some acceleration data for flight analysis. The Stratologger CF will function independently from the TeleMega and apart from ensuring safe pyro activation through redundancy it will also provide a set of data to compare with the TeleMega for a more accurate post-flight analysis.

The secondary computer will fire the drogue parachute charge at one half of a second after apogee and the main charge at the same altitude as the primary computer.

### Radio Transmission and Altitude Logging

One important aspect of the competition is the accurate measurement of altitude our rocket can achieve. In order to log the altitude both the primary and secondary flight computers will record altitude with barometric sensors in accordance with the rules. Similar to the comparison of accelerometer data between the TeleMega and Stratologger the altitude will also be compared for the highest degree of accuracy. Concerning data packet transmission and radio signals in general the carbon-fiber assembly of the rocket adds the issue of radio transparency. In preliminary connectivity testing with last year’s BeeLine GPS transmitter in the rocket carbon fiber assembly with a polycarbonate gap we discovered an RF blind-spot can occur when the BeeLine faces the opposite direction of the receiving radio. Since the body of the rocket is composed of non-radio transparent carbon-fiber the goal is to place the BeeLine GPS in the fiberglass nose of the rocket, which will allow much clearer radio contact.

The BeeLine GPS will transmit its location at five second intervals, which will be received using a commercial 430 MHz antenna on the ground on a HAM radio receiver. The packets will be decoded using a mobile phone app allowing a rocket recovery team to track the last known location of the rocket on the go.

## Flight Sensors and Instruments

### Introduction

The E&P team is responsible for ensuring that the proper data is measured at all stages of flight. Not only this, but the data must also be transmitted, evaluated, and recorded as necessary. To this end, it is E&P’s job to make sure that the vehicle will receive the proper launch commands when it is time but not prematurely. After launch, the electronics must record flight data while analyzing pertinent data to determine if an engine shutoff is warranted.

### Data Transmission

There will be one data stream that will connect the vehicle to the team via a launch operations computer. The launch computer will be connected to an XBee/Yagi antenna system that will communicate with a second XBee/Yagi antenna system connected to an Arduino within the launch box. The wireless system will operate with the use of a S3B Digimesh XBee. This system will communicate at 900 MHz and has a range of at least 9 miles. The launch box itself will handle all pre-flight operations as commanded by the launch operations computer, as discussed in section 1.5 below. This will go up to and include opening the valve for oxidizer flow and igniting the engine. The launch box will accomplish its interactions with the vehicle through a hardwired connection between the vehicle and the launch box that will be disconnected when the vehicle lifts off from the rail. This two way communication between the launch operations computer and the rest of the launch system will be handled through MATLAB with commands being sent from the serial monitor of the program. All commands will be protected from outside interference through the use of a password phrase in front of every command. When the launch box does receive a verified command, it sends back an acknowledgment of the command. When the command is finished executing, a subsequent status update is sent confirming the command was completed.

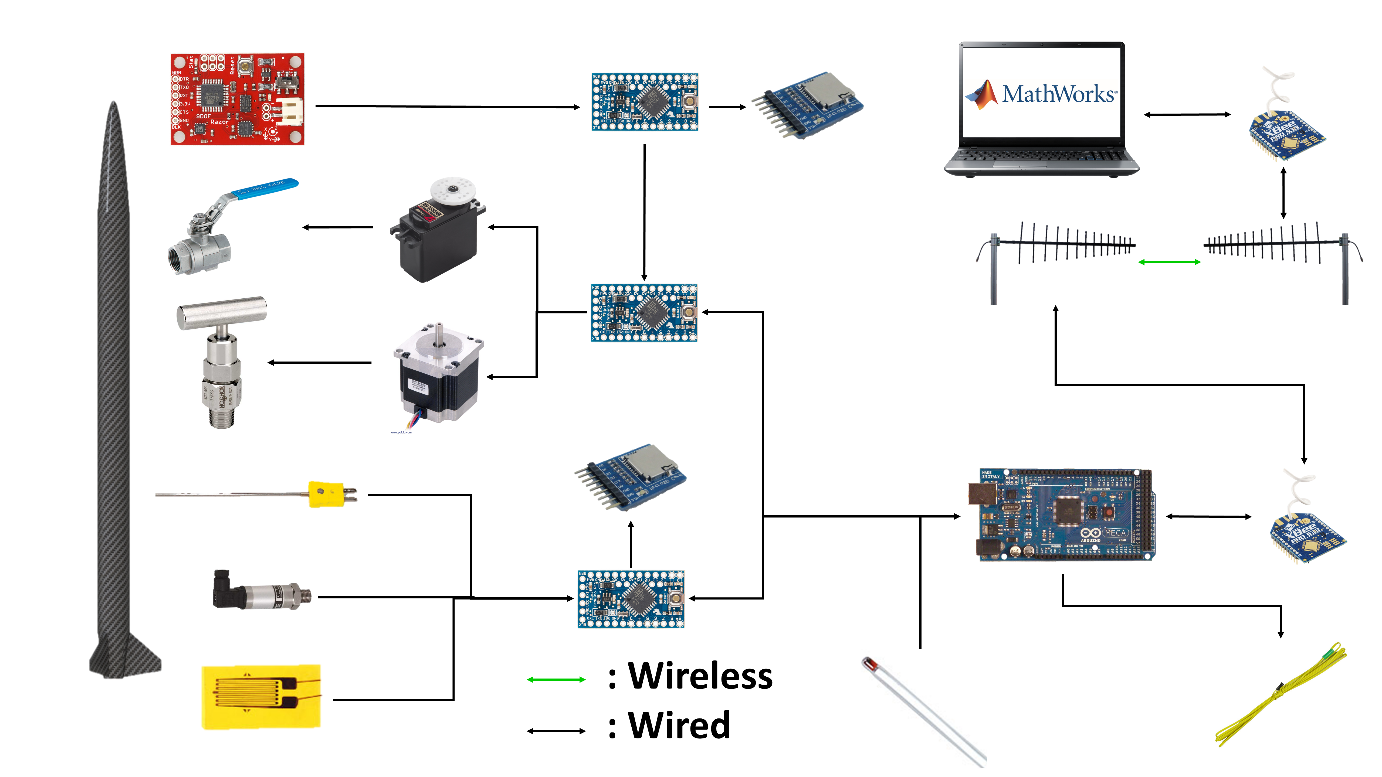


Figure 1. Data & Communication Systems Architecture Diagram

### Sensors

The propulsion team desires information on how the engine is performing from ignition to burn out. The information gathered from testing the scaled down prototype engine will help the propulsion team to redesign a better final engine, and data gathered from testing the final engine will help them to develop a thermodynamic model specific to our engine. As such, the rocket and launch pad this year will contain a variety of sensors to gather data deemed necessary or helpful during both flight and pre-flight operations. This will be useful for both testing and operational use of the rocket. For testing, temperature readings are a good indicator of the performance of the engine, so the temperature near the exit of the nozzle, on the outside of the combustion chamber, and in the plumbing will be measured. XC series Ceramic braided thermocouples are able to function at temperatures up to 2200o F and will be used to measure the temperatures on the nozzle and on the outside of the combustion chamber. The propulsion team also desires information on the mass flow rate of the oxidizer and the total mass flow rate. To address this, two Omega pressure transducers will be purchased to be used during engine tests. A 1,000 psi transducer will be used to measure combustion chamber pressure and a 2,000 psi transducer will be used to measure the pressure of the oxidizer in the plumbing. During flight, the rocket itself will contain an inertial measurement unit, two pressure sensors, and three thermocouples. The IMU will be a 9DOF Razor IMU and includes a triple-axis accelerometer, triple-axis magnetometer, and a triple-axis gyroscope. It will be used to find an acceleration profile for the rocket as a whole. The pressure sensors will be PX171-2.0KSGIs. One of the pressure sensors will be placed inside of the nitrous oxide tank and the other will be placed in the combustion chamber. The thermocouples will be high temperature K type placed on the outside of the combustion chamber, with the possibility of one thermocouple used in the oxidizer tank.

Three onboard microcontrollers (which will all be Arduino Pro Minis further discussed in section 1.3.5) will be used to read in the sensor data and store the data onto microSD cards for later analysis. One of the microcontrollers will handle the pressure transducers, thermocouples, and strain gauges, one of the other microcontrollers will collect and process the data from the IMU, and the last microcontroller will control the ball and needle valves and will receive inputs from both the IMU’s microcontroller and the launch box during pre-flight operations.

### Engine Safety Shutoff

The propulsion team has asked for the ability to perform an automatic emergency safety shutoff. Though this will be tactically straining, and thorough testing will be required of the sensors before any such system is implemented, a plan has been made for how this would be implemented. Once again, this system is contingent upon accurate and “non-jumpy” data from the sensors and will not be utilized if thorough testing does not prove to be completely successful.

If the IMU’s microcontroller detects that the rocket has fallen below a certain orientation, it will send a signal to the microcontroller responsible for the needle valve and ball valve. This signal would interrupt the microcontroller’s normal operation and the servo would be used to close the oxidizer tank and effectively turn off the engine. At the same time, a stepper motor will open the needle valve and a vent process will begin. This would ensure that if the rocket were to lose stability, it would not begin to accelerate horizontally or downwards under propulsion from the engine. This orientation determination will be done with the use of the IMU’s gyroscope. Not only will a direct orientation check be continuously performed, but a rotational velocity check will be as well. If the vehicle ever begins to tilt off center too quickly, the engine shutoff will also be triggered.. Though the effectiveness of these shutdowns is somewhat dependent on the speed of propulsion’s ball valve and servo motor combination, this extra layer of safety has no drawbacks other than a premature shutdown. This would still allow the recovery of the rocket and would simply mean a lower maximum altitude.

### Computation and Data Storage

The BeagleBones from last year are being replaced with Arduino Pro Minis. The reason the Arduino Pro Minis were chosen is because they offer the same computational speed and power of the bulkier Arduino Mega This will greatly decrease the energy requirements of the vehicle while still allowing data collection, storage, and simple computations.. While the Minis do not possess all of the features of the Mega, in essence, they are a trim and sleek version of the Mega and will be able to accomplish everything we need them to be able to. In order to avoid the need to maintain a constant signal with the launch vehicle, all data being collected will be stored in onboard 32 GB microSD cards. These will be connected to the Arduinos via a microSD card breakout board and will each have the capacity to store many tens of minutes of data in case any delays prevent a prompt launch while the vehicle is waiting on the launch pad.

With all of the sensors and communications that will be going on, it is of some concern that a single Arduino would have some difficulty accomplishing everything it needed to. As a result of this, we have opted to include two additional Arduinos to split the load. It is not expected that a fourth would be required because of the limited computations being done onboard the vehicle, but thorough testing will be done to ensure that three Arduinos will be more than enough for the requirements. That said, due to the fact that Arduino Pro Minis have been chosen, it would be quite simple to add additional Arduinos in to the system to split the computational load further or implement a verification system in regards to the engine shutoff.

### Power Needs

As there have been no “game-changing” developments in the world of batteries over the past year, much of the information is the same as in the SRT 2’s PDR. That is, that weight and heat resistance are the two primary concerns in choosing a battery. With this in mind (along with a very heavy energy density of 50.8 Watt-hours per pound), lithium-iron-phosphate was once again selected as the best of the battery types.

With this and the fact that the energy requirements are significantly less than last year’s (due to the elimination of the BeagleBones), the battery from last year will supply more than enough energy (at 60 Watt-hours) and will give us plenty of extra power should any team decide they need extra equipment. For example, propulsion will be using a servo to open their ball valve but have not decided on a specific servo yet. Not only this, but they have asked us to remain flexible in terms of power requirements while they continue to work towards a design of their system.

Table 1.1. Flight Component Power Consumptions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sensor** | **Voltage**  **Draw** | **Current**  **Draw (ea)** | **Power**  **Draw (ea)** | **Quantity** |
| **Thermocouple** | 3.3 V | Negligible | N/A | 3 |
| **IMU** | 3.3 V | 1.2 mA | 3.96 mW | 1 |
| **Strain Gauge** | 5 V | 100 mA | 500 mW | 2 |
| **Pressure Transducer** | 12 V | 10 mA | 120 mW | 2 |
| **Arduino Pro Mini** | 5 V | 25 mA | 125 mW | 3 |
| ***Flight Total:*** | *-* | *296.2.2 mA* | *1.619 W* | *11* |

## Avionics Mounting Bay

### Introduction

In SRT 3 there are two major ‘bays’ to discuss. The first is the avionics bay, housing mission critical electronics; the other is the payload bay which houses and secures the two Cube Satellites. These two bays are physically integrated together using a similar style, but are functionally completely separate from one another.

The primary two concerns of the rockets avionics bay are the stability and control of electronics during the flight path, and the ability to remove the avionics bay from the rocket body at will. The second requirement is due to the flight critical systems requiring manual checks before each flight to ensure that wiring and components are securely attached per competition rules. An additional benefit of this is allowing the easy modification to electronics should our mission parameters or goals change.

### Assembly

Our avionics mounting bay (Figure 1.1) will be overall fairly similar to the one from SRT 2, as it worked quite well, and is still applicable to the current rocket design. Once again, we will construct the bay with the goals of portability, security of components and associability at the forefront. To meet these goals the design will consist of three horizontally placed circular bases connected by three bolts, with several vertically and perpendicular placed platforms to actually mount our electronics.

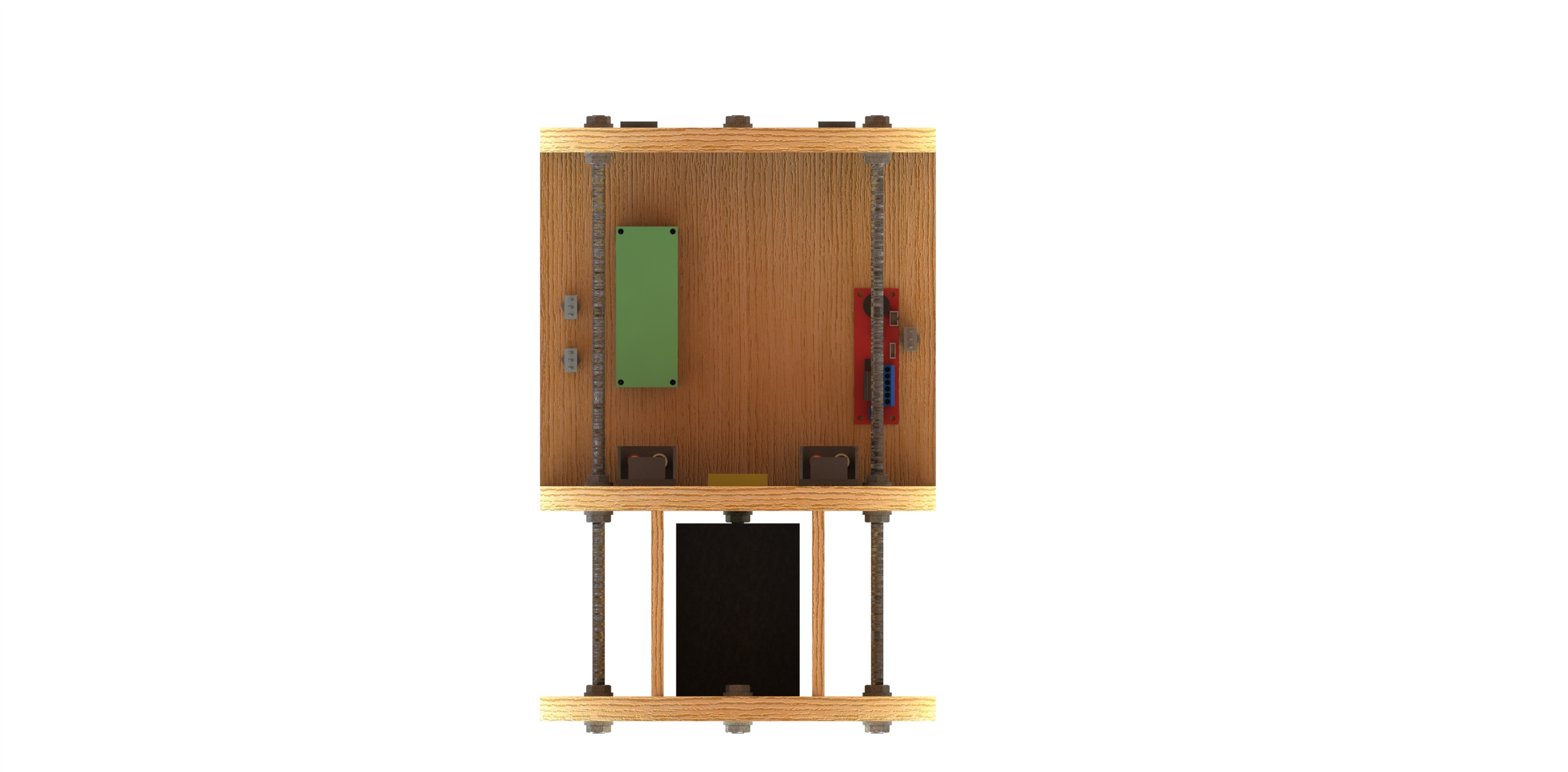


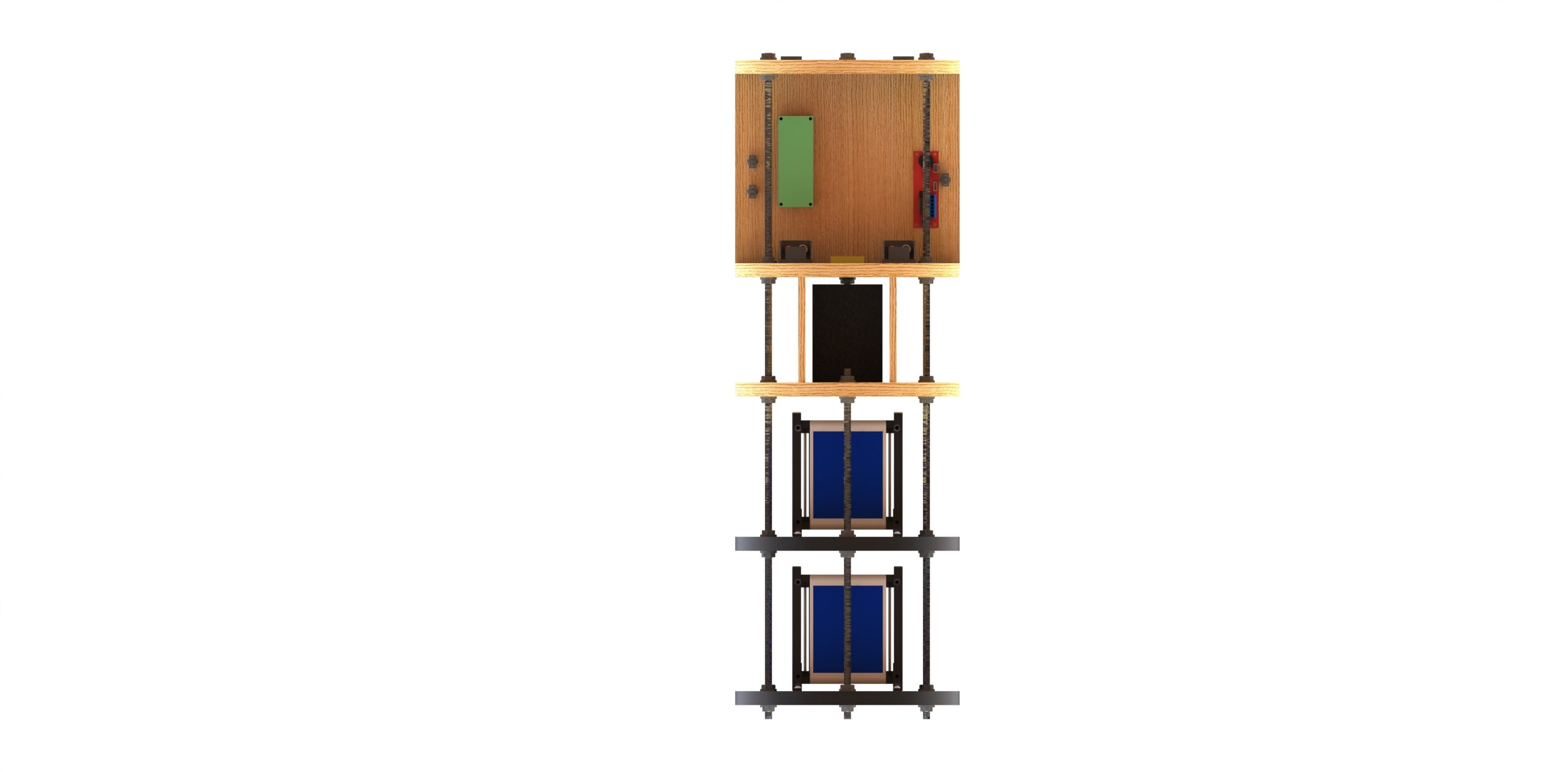
Figure 1.1. Avionics Mounting Bay CAD Model

Our avionics bay overall dimensions are twelve inches in height and eight inches diameter. The three horizontal circular disks are stacked vertically and separated into two sections, the upper and lower. These platforms are ½ inch thick, and will be machined after construction to include holes for passing through wiring, and which will be dependent on the final layout of electronics included. The bases will also include the smaller 9 volt battery mountings as they do not depend on axial direction stability the way more of our sensitive electronics do. The bases will once again be secured by running three low strength steel ¼ inch threaded rods through all of the bases, and attaching hex locknuts above and below each of the bases (18 in total, 6 per rod).

The bottom sections primary purpose is to house the large battery that will power the rockets more needy components. The battery will be secured using three zip ties once again, two over the battery and through the lower base, and another perpendicular to the first two attached to an all through bolt. This process is simple, cheap and most importantly reliable, having proven adequate on the last flight. One major change to the bays design is in this lower section, and is the addition of two vertical (perpendicular to the base) boards on either side of the battery. These boards will provide additional mounting space if needed during final stages, as well as proving more security for the battery.

The top section will consist of a vertical (perpendicular to the base) platform similar to the two in the lower section, but will be placed in the middle of the bases, along their diameter. This plate will serve as the mounting wall for all of our needed electronics such as microcontrollers, GPS, IMU etc. Holes will be machined in the wall for wires and mounting screws similar to the bases. Additionally this is where we will house the pre-flight switches. The purpose of these switches is to be able to leave power off to the avionics units until the rocket is completely ready to launch and stable on the rail. At this point a team member will activate the toggle switches by putting a shunt through the body tube and toggling the switches to the on position, providing power to the avionics.

It may be noted that there is a surprising amount of empty room on the model; there are several reasons for this. The first and most important is that we are unsure what exactly the Australian team would like to test about their satellites, and therefore we are including some room for that should they need much room. Another reason is the model lack wires and other small details that are difficult to model, but will accumulate to take up a not insignificant amount of room. The last reason is that the avionics bay was designed with a “legacy” approach. This years team spent a good amount of time designing and building the bay, with the idea being that the rocket dimensions would not change, and allow the avionics bay to be reused by following teams. This would allow more time to create and design more abstract tests and research possibilities.



Complete Mounting Bay CAD Model

The placement for the integrated assembly will be directly below the nose cone and recovery system. It will connect to the two recovery U bolts through the top bulk head by four half inch holes in the top of the avionics bay. The whole system will slide out of the rocket as one entire piece and then the two assemblies can disconnect from one another by unscrewing the lock nuts for whenever they need to separate. The entire combined assembly will hang freely, however we are placing a piece of soft material at the bottom of the hollow space to steady the system and lend horizontal stability.

## Electronic Launch Operations Control

### Introduction

In order to safely control the rocket before and through launch, an electronic control system was designed that will allow the operator to remotely send commands to and return live data from the rocket while it is on the ground. The IREC Advanced Category rule 7.2.2.1 requires all personnel to be 400 feet away, but the system must be capable of operating over a minimum safe distance of 1500 feet for testing, as specified in the Tripoli Rocketry Association Safe Launch Practices Distance Table. Arming and disarming the launch circuitry is required by IREC Advanced Category rule 3.4 and 7.2.2.2 such that the controller cannot provide any ignition signal to the rocket without first being armed. At minimum, the controls must allow filling and draining of the onboard nitrous tank, filling and draining of helium to pressurize the onboard tank, filling of an oxygen sting for starting, the actuation of either 2 quick disconnects (nitrous and helium) or one quick disconnect and a three-way selecting valve, signaling an onboard valve to open and start nitrous flow, and an igniter. To correctly fill the onboard nitrous tank with the correct amount of nitrous and helium, pressure, temperature, and load cell data will be streamed back live to the operator. A live, low frame-rate video feed is required to observe the vents and confirm the separation of quick disconnects, which will also be redundantly monitored by continuity across the connection. The launch control system must be in constant, reliable, and bandwidth-capable communication with the operator’s station. This year, more focus has been placed on creating a modular, expandable control system that will continue to meet the needs of future SRT teams and not require both AC and DC power to operate (as SRT-2’s did), all while reusing as much legacy SRT-2 hardware as possible.

### Launch Relay System

The Launch Relay System is the critical piece of launch hardware designed to meet these goals for SRT-3, and should offer more modularity and reliability than the previous launch controller. Initially, wired control was desired for the Launch Relay System to eliminate the wireless communication anomalies experienced last year, but the 1500 feet safety range required by Tripoli made this option prohibitively expensive. Category 6, BNC, serial, and USB connectors all work only under a range of about 300 feet. Category 6 cable alone is rated for lengths up to 328 feet, so an Ethernet extender must be used at both ends to give 1500 feet of range. Two appropriately sized extenders and 2000 feet of Category 6 cable would total $1970.98. A wireless system built using long-range xbee modules and external antennas can provide a much more streamlined solution with a 9 mile range for only ~$200 (discussed in detail in section 1.3.2). Future tests will be required to ensure the reliability of the wireless system, but a wired option is not an economically viable option.

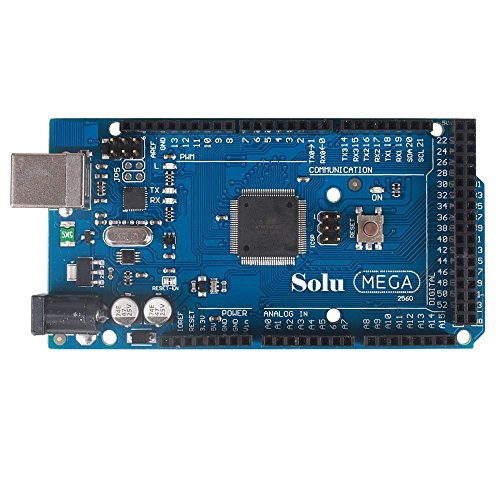


Figure 1.2. Ximico Mega 2560 R3 Microcontroller

The Launch Relay System is based around the simple and reliable Arduino microcontroller boards. The Ximico Mega 2560 R3 (Figure 1.2) was chosen because it provides the IO capabilities (54 digital inputs/outputs, 16 analog inputs, 4 serial connections) as an Arduino Mega, but costs less and has more favorable reviews. This board leaves plenty of channels for future expansion, and provides a simple programming atmosphere that works well with xbee.

The two helium AC solenoids from the SRT-2 control system will be replaced with two Extreme-Pressure Stainless Steel Solenoid Valves (McMaster-1190N23), which operate at 24 VDC and withstand up to 3000 psi, which is safe for the inert helium gas at 2000-2500 psi. Though this solution is not ideal, it is the best option because it allows everything from last year except 2 relays and 2 solenoids to be reused, including 2 car batteries. This was more economical than converting the remainder of the system to AC, and will not significantly complicate the Launch Relay System.

The relay control circuit diagram in the Launch Relay System is shown in Figure 1.4. The Ximico controller is powered by a separate 9V battery, so that failure of either car battery will not disable the controller. Dual N-Channel FQP30N06 MOSFETs rated at 60 V, 20 A (Figure 1.3) switch the ground of the relays to activate individual channels, and incorporate standard 10K Ω pull-down and 100 Ω safety resistors to protect the controller and transistor. System arming is achieved by a separately controlled relay that switches the (+) side of every other relay to either +12V (armed), or ground (disarmed). Two 28VDC relays with 12 volt coils provide the higher switching ability for the new helium solenoids. Only 5 of the 9 12V auto relays must be purchased because they are the legacy SRT-2 model, and all relays feature a 1000V flyback diode to prevent damage to themselves and the switching transistors. To provide 24V for the two helium relays, a second car battery is connected in series, and this system could easily power more 24V devices, if needed. A Duralast Ignition Coil will be used to control the planned spark ignition system, which operates at 12V and discharges ~50,000V when it’s transistor switches on for a few milliseconds and then switches off.

Table 1.2. Launch Box Upgrade Cost for Control Channels



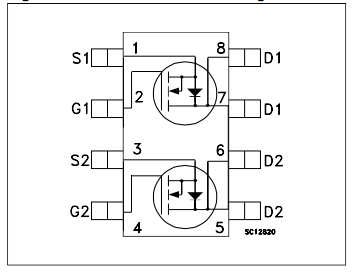


Figure 1.3. Dual N-Ch. MOSFET FQP30N06

Table 1.2 shows an itemized breakdown of the components needed to upgrade the control channels on the Launch Relay System. Pressure transducers, thermocouples, and an ArduCam OV2640 unit must also connect to the sensor inputs on the Ximico to provide an accurate mass measurement during filling and confirm that the rocket is ready for launch. These systems will require knowing propulsions exact monitoring needs, so they will continue to be refined throughout the year. A proof of concept to test the ability of a 5V Arduino UNO channel to switch a 12V auto relay through a MOSFET was developed and tested successfully. The relay clicked back and forth for several seconds and gave audible confirmation that the circuit worked.

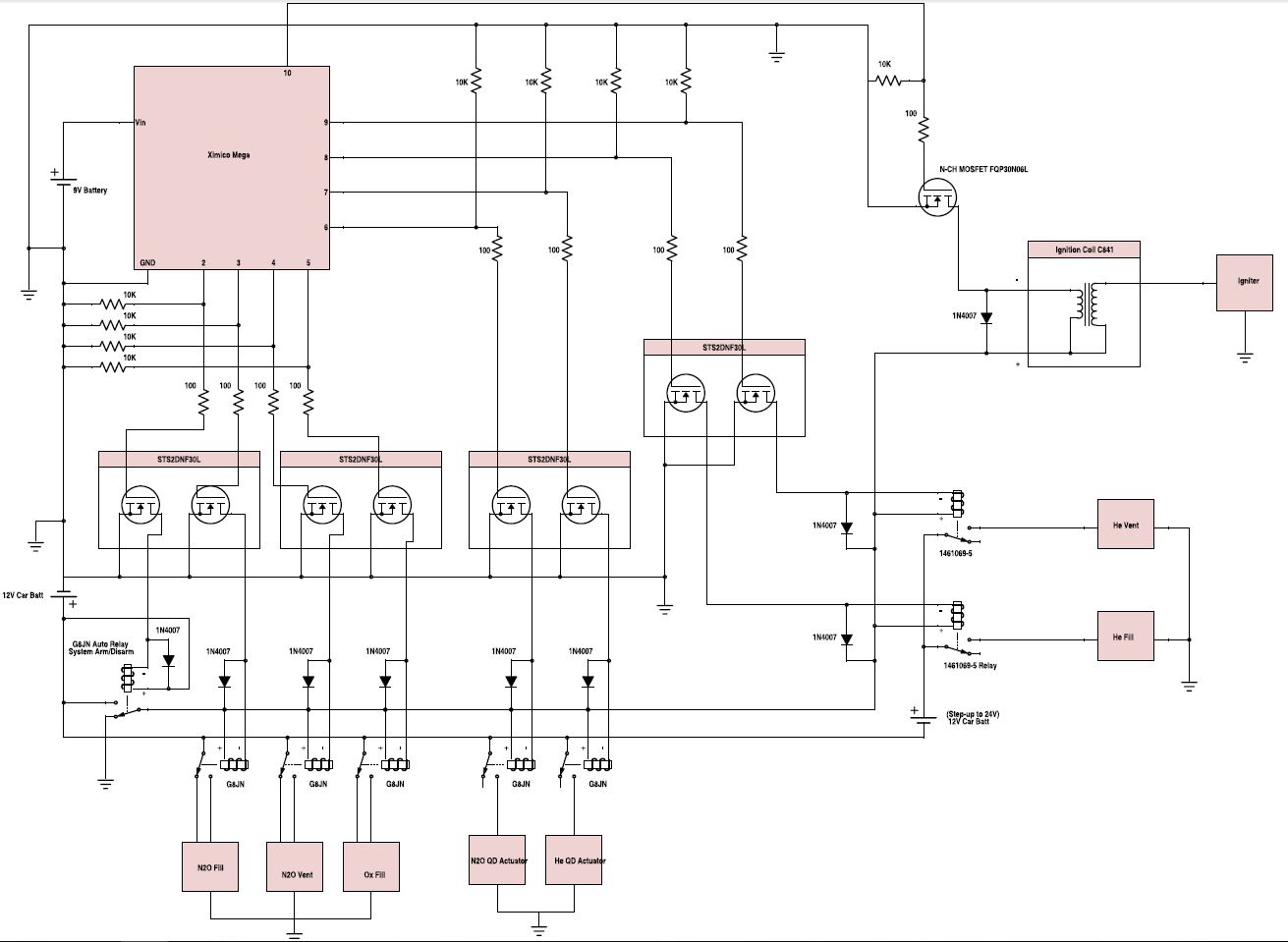


Figure 1.4. Launch Relay System Circuit Diagram

### Ignition Control

New propulsion requirements dictated a need for a new electric starting system. Two options are currently being developed: ignition system control from the Launch Relay System, and ignition system control through an onboard flight computer. Providing ignition control from the Launch Relay System would require a 5V signal wire (and a ground) from the Ximico to directly signal the onboard nitrous valve to open, and then fall off as the rocket launches. The 50,000 V igniter pulse must also be connected to the rocket and fall away, but the distance between metallic paths in the rocket may simplify the connection by relying on the resistance of the air. The second ignition option would give the benefit of facilitating a future restartable engine and eliminate the need for external break away wires, but would require careful research to make sure ITAR regulations are not violated. Two other design challenges are fitting the relatively heavy ignition coil (1.6 lbs.) onboard, and electrically isolating the radio distortion produced by the sparking process from the sensitive flight electronics. The integration of an electrical ignition system will be continually evaluated with the Propulsion Team over the next few months.

## Wiring

All wiring and connections of electronics, with an emphasis on those which are critical to flight function, will adhere to all rules outlined by ESRA. All wire will be copper stranded, insulated and a minimum of 22 AWG, unless a component requires the use of a smaller size wire. All wire connections will be terminated in a screw-type or crimp-type terminal block, or soldered to components which have built-in solder terminals. All individual wires will be fastened together, through the use of zip-ties, to make a wiring harness. The harness will be secured to the electronics mounting bay. Any splices, joints or exposed wires will be insulated with clear heat shrink tubing. All dry cell batteries shall be secured to the avionics structure using approved battery holders, all gel cell batteries will be clamped to the structure connected with the use of JST or “Quick-Disconnect” terminal connectors.

# Payload

## Objective

The purpose of the payload is to attain a scientific or technical achievement which is unique to this competition. Furthermore, per rules outlined for this competition, the payload is to weigh a minimum of ten pounds and remain independent of the rocket dynamics. The Team this year had once again been offered a unique opportunity to not only fulfill the requirements of above, but also help another university, while simultaneously providing actual engineering knowledge to the community.

## Design Considerations

Our payload this year is planned to be a CubeSat designed and built by a separate team of students in the aerospace engineering department at the University of Sydney, led by Dr. Xiaofeng Wu. We will collaborate with this team to test some properties or components of the satellite which has yet to be determined. This team will ship the CubeSat to us, and some of the key student designers are expected to join us at the ESRA competition this summer.

To achieve the objective outlined for the payload, several aspects were considered in the conceptual design. In addition to adhering to the rules set in place by the competition, the payload is expected to be of quality constructability--given our budget and time considerations, and to provide scientific merit which is relevant to the Texas A&M Rocketry Team specifically, all while remaining within the size constraints determined by the structure. One area that we wanted to pay particular attention to was making our payload as unique as possible, as this both makes our project stand out and raises awareness, but also is more likely to garner our team additional points at the competition.

Many tests are of merit to a satellite entering orbit, however as our rocket does not reach that altitude, some limits are inherently placed on us. With this in mind, we have chosen to focus on forces that the satellite will experience during a full scale launch which our rocket is capable of simulating. Many testable properties should present themselves. We are also planning on measuring other parameters that the Australian team wishes to know, which will be coordinated and designed as the teams move forward.

## Payload Mounting Bay

As discussed above the second major bay is for the payload (Figure 1.5). Its two major jobs securing the payload, and adding weight. This bay will be physically connected to the avionics bay above it by another set of all through bolts and lock nuts, similar in style, and giving a consistent look.

The first purpose of giving support to the two cube satellites during the accent and recovery, as well as housing the testing apparatus that the team from Australia may wish to implement, is the most mission critical. The second objective to increase the weight of the payload. The competition requires a ten pound payload minimum, which the two actual cube satellites only reach two 4.5 pounds of that. To make up for the remaining weight, we are including the payload (but not the avionics) bay into our weight, which should bump our total to just over the required weight.

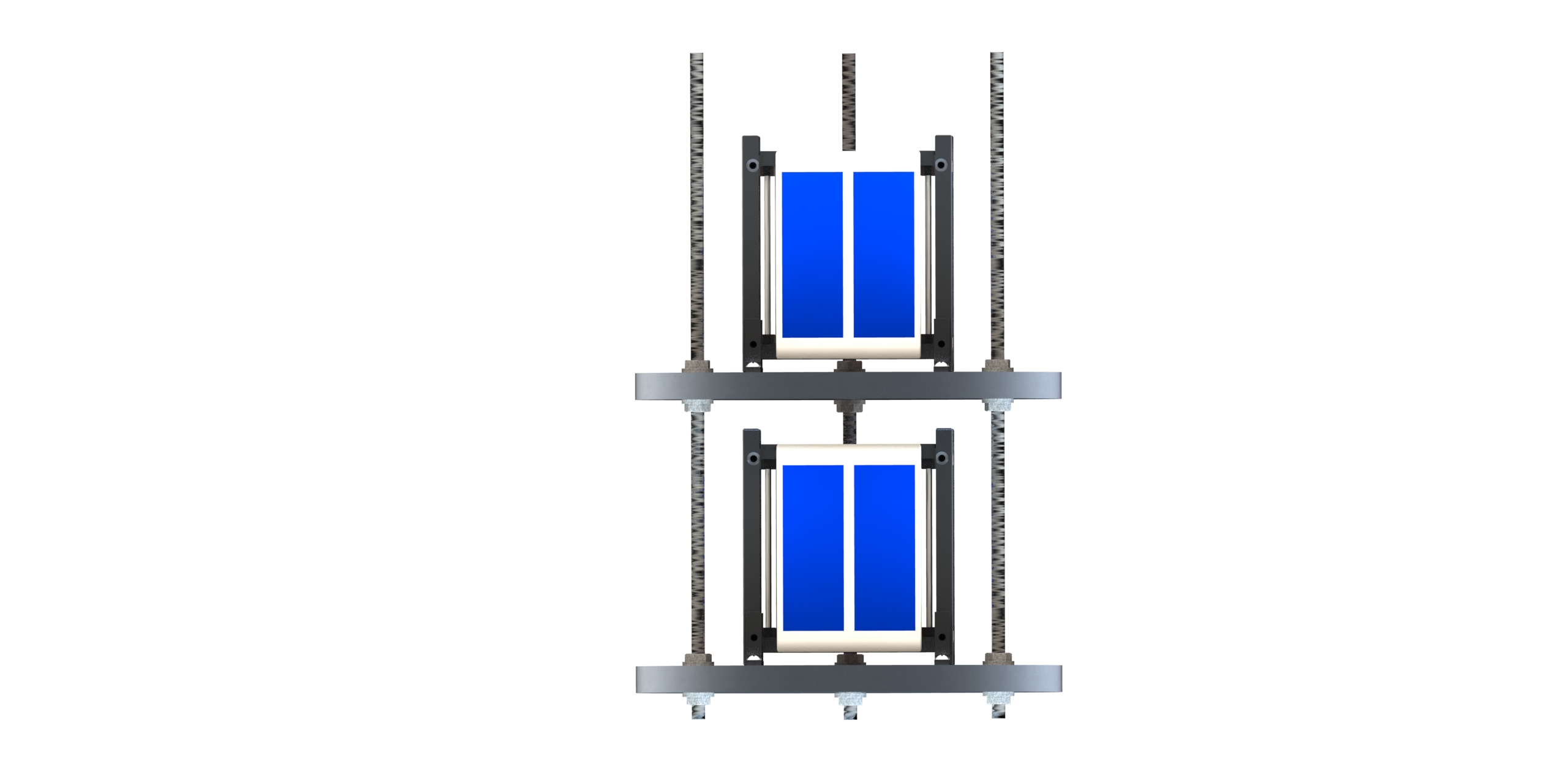


Figure 1.5. Payload Mounting Bay CAD Model

The payload bay is physically similar to the to the avionics bay, consisting of two horizontal platforms connected by three all through bolts with lock nuts on either side. Its dimensions are eleven inches in height and 8 inches in diameter. Two major differences are noted however: there are no vertical boards, instead the satellites will rest directly on top of the horizontal boards in their place. The other major change is to the horizontal boards. Instead of wood they will be milled from aluminum to increase the weight. This will also lend support to the satellites whose delicate components can be easily damaged. The satellites will be secured to the aluminum by four brackets which will screw directly into the satellites.