High Altitude Rocket Team
Project Document

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1.1. Executive Summary

The project we are working on is the OSU AIAA High Altitude Rocketry Team's (HART) avionics system. HART's goal is to reach an altitude of 150,000 feet with a two-stage solid fuel rocket during a collegiate rocketry competition at the end of the school year. The system that we will be creating will include both a wireless launch box and displays for live readouts of telemetry information from the rocket as it is in flight, including data such as altitude, acceleration, velocity, and angle of attack. HART would like to add functionality to the new launch box design and create a more streamlined device that simplifies procedures and shortens setup time.

Our goal with the launch box is to have a well documented, accessible, and rugged wireless launch control box that also displays live telemetry by interfacing with the TeleDongle, a product sold in conjunction with the flight computer that HART uses, the TeleMega. The development process will occur in two parts, first focusing on the wireless launch box functionality and then moving on to the live telemetry displays. The project will be defined by discrete blocks within these two parts. Each block will have rigorous definitions which dictate how these blocks will be made and function.

The phased approach of this project will be key for delivering a functional launch box that can be used in the numerous test launches that will occur throughout the school year, before focusing on the more ambitious aspects of the project that will be most useful in later, more ambitious launches. In doing this work we hope that the new systems we build will aid HART in reaching their goal and bring new and useful data to the launch for teams in years to come.

1.2 Team Communication Standards

Member	Cell-Phone	Email	Role/Responsibilities
Timothy Englehart	(408) 398-1242	englehat@oregonstate.edu	Team Mediator, HAM License, Design Lead
Joshua Muir	(503) 943-9039	muirjo@oregonstate.edu	Media Coordinator, Presentation Lead
Kenton Bender	(425) 892-5576	benderke@oregonstate.edu	Scheduling Coordinator, Integration Lead,
Leif Miller	(541) 990-0364	millerle@oregonstate.edu	ECE Subteam Lead, HAM License

1.2.1 Channels

For the purpose of ease of communication, the methods of contact between team members, partners, etc. have been divided into separate channels. The main method of contact between the ECE capstone team members should be done over the Discord channel. It will be used for general team updates, requests, dialogue, and any other non-urgent communication. However for more urgent situations (i.e. requiring quick responses) texting should be used instead. Notifications for this chat should always be on in case of emergencies. For contacting the project partners unless otherwise specified, well formatted emails should be used through our designated primary contact team member who will send all emails with the other members CC'd.

1.2.1.1 Primary communication: Discord

-For updates on progress, general requests, questions, dialogue

1.2.1.2 Backup: Texting

-For urgent requests, updates, or questions

1.2.1.3 Tertiary: Email

-Method of contact for partners/advisors

1.2.2 Communication Analysis

Project Partner	Category	Description
Nick Miller	Email	milleni7@oregonstate.edu
	Interest	HART Member
	Role	Avionics/Recovery Team Lead
	Level of Technical Knowledge	Mechanical Engineering Senior
	Prefered Communication	Primary: HART Discord Secondary: Email
	May Report To	Dr. David Blunck
Josh Edenfield	Email	edenfelj@oregonstate.edu
	Interest	HART ME Capstone Member
	Role	Avionics/Recovery Subteam Lead
	Level of Technical Knowledge	Mechanical Engineering Senior
	Prefered Communication	Primary: HART Discord Secondary: Email
	May Report To	Dr. Blunck
Dr. David Blunck	Email	david.blunck@oregonstate.edu
	Interest	HART Facility Sponsor
	Profession	Oregon State University Associate Professor of Mechanical Engineering
	Level of Technical Knowledge	Ph.D. Mechanical Engineering
	Prefered Communication	Primary: Team/Subteam Lead Meeting

1.2.3 Meetings

The ECE capstone team will have at least four meetings each week; three happening regularly every week with one or more on a case by case basis. First, the general HART meeting occurs weekly every monday with updates to the entire club on the overall state of the club and a report from each sub-team including the ECE capstone team. Additionally the weekly avionics sub-team meeting occurs weekly, the ECE capstone project's team is a subdivision of said team. Both these meetings are mandatory for the ECE capstone team, given urgent situations notwithstanding. Finally there will be a weekly ECE team meeting over zoom/in-person depending on the situation and with a rolling date determined on a week by week basis.

Weekly:

1.2.3.1 ECE Project team meeting.

General meeting

-Over Discord

-For documentation work and updates

In person meetings

-For hardware work, when the situation requires it

1.2.3.2 HART General Meeting

Team wide update meeting

Date: Mondays: 7:00PM PST

1.2.3.3 HART Avionics Sub-Team meeting

-In person

Date: Wednesdays: 6:00PM PST

1.2.4 Protocols

Protocol	**Description**	**Action**
Absences	An unexpected or soon to occur absence from project work Examples: Family/personal emergency Illness Injury	• Inform team of the amount of time you will be unavailable and what work will need to be covered ASAP over texting channel
Known Event	A planned event taking place in the future or on a regular schedule that will impede project progress: Examples: Vacation plan Job/internship commitment Club activities	• Inform team of timeframe of unavailability at least 1 week prior to occurrence over Discord chat • Complete as much work as possible before hand • Inform team of incomplete work that still needs to be done prior to departure
Updates	Weekly update on individual team member progress	• Posted to general Discord chat • Include current state of assigned section, any questions regarding it, • Requests for aid (if required), and expected completion time

Disagreements	When team members disagree on next steps or over quality of work	● If an argument occurs other members have to step in to defuse ● If a resolution is not readily available contact third party service
Timeliness	For each portion the project, timeframe for when work should be completed	● Individual portions due 24 hours prior to due date to allow for team review and feedback beforehand

1.3 Gap Analysis

Our project exists because the AIAA HART project needs a wireless launch-box for safety and ease of use, as well as a live data readout for in-flight monitoring of the rocket. In previous years HART has not had a way of tracking the flight data live. This means that data recovery has depended on a successful recovery of the avionics equipment within the rocket, which means that any destructive failures are very hard to diagnose. Aside from the new functionality that we are introducing to the HART team's launch box setup, we also need to ensure that the new launch box incorporates all the features of the one that was previously in use, including all the safety features such as arming keys on both the launch and pad boxes and secure, long-range wireless communications that don't interfere with other launch box systems.

The main stakeholders of our project are current and future members of the HART team at OSU. Since the members of this team are mostly mechanical engineering students, we must take care to design it to be operated and maintained in a way that does not require any type of specialized electrical, computer programming, or debugging skills. This means that the final product should be as simple to turn on and operate as possible, with as few wires and accessories to plug in before use as possible and a thorough yet easy to read manual for operation.

1.4 Timeline

The proposed project timelines, Figure 1.4.1 to Figure 1.4.3, contains both course milestones as well as High Altitude Rocket Team milestones. The course timeline for the project includes design, implementation, and presentation phases. These phases do not meet the expected timeline for HART. The fall term contains multiple launches of rockets that would ideally contain prototypes of the project. This term is scheduled to be the design phase of the project and producing a prototype before a design is not a good practice. The timeline for the initial prototype is short and the team will strive to meet the second launch deadline in the beginning of december.

Project objectives are the responsibility of the team as a whole and subsections of each milestone will be delegated to individual members of the team. HART objectives are the responsibility of the HART and as members of the avionics team we are partially responsible for these deadlines as well.

One critical piece of the timeline will be component acquisition. Covid-19 rendered the semiconductor supply chain backlogged due to closures. Other component manufacturers may also be seeing shipping delays and shortages. It will be crucial to order components as soon as they are incorporated into the design to ensure adequate shipping time to meet implementation goals.

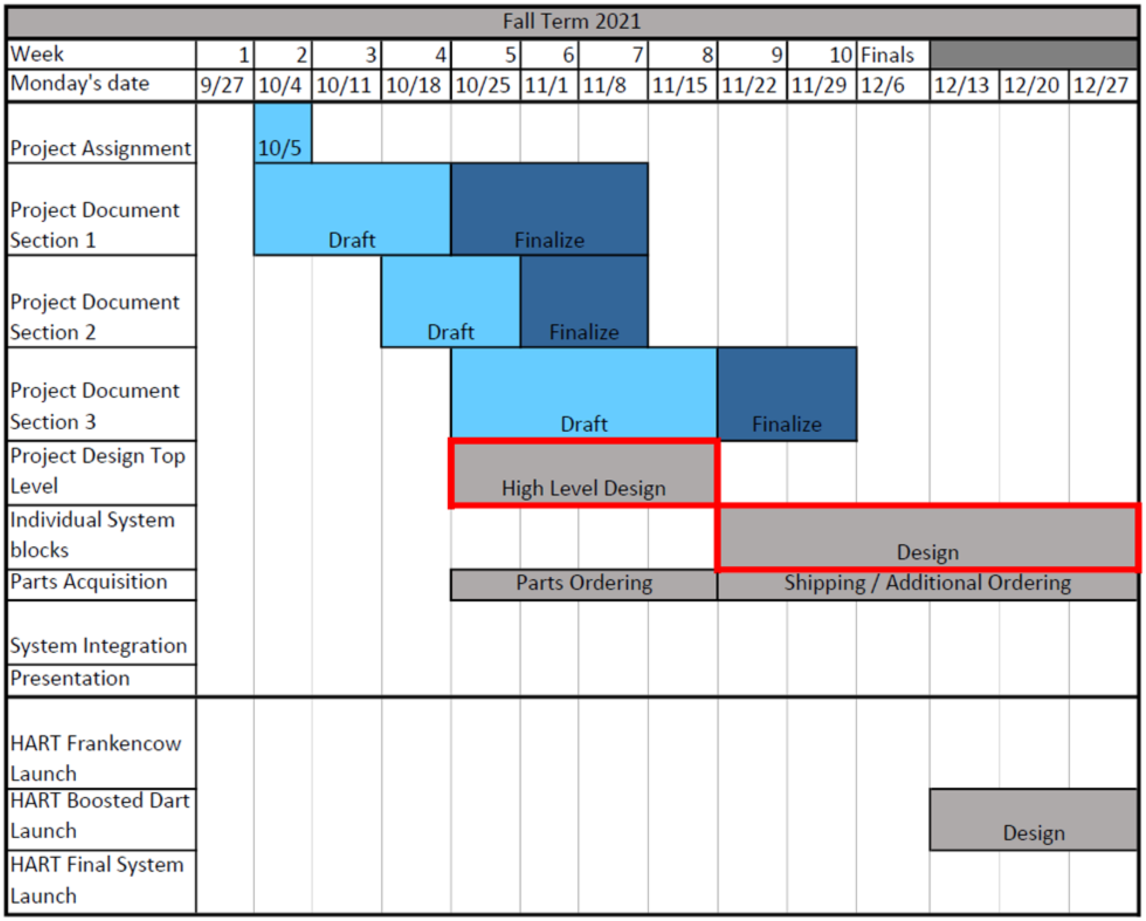


Figure 1.4.1: Fall term schedule critical path outlined in red.

Winter Term 2022											
Week	11	12	13	14	15	16	17	18	19	20	Finals
Monday's date	1/3	1/10	1/17	1/24	1/31	2/7	2/14	2/21	2/28	3/7	3/14
Project Assignment											
Project Document Section 1											
Project Document Section 2											
Project Document Section 3											
Project Design Top Level											
Individual System blocks	Block Construction					Block Testing					
Parts Acquisition	Shipping										
System Integration						System Integration			System Testing		
Presentation											
HART Frankencow Launch											
HART Boosted Dart Launch	Construction, Design, System Integration										
HART Final System Launch											

Figure 1.4.2: Winter term schedule critical path outlined in red.

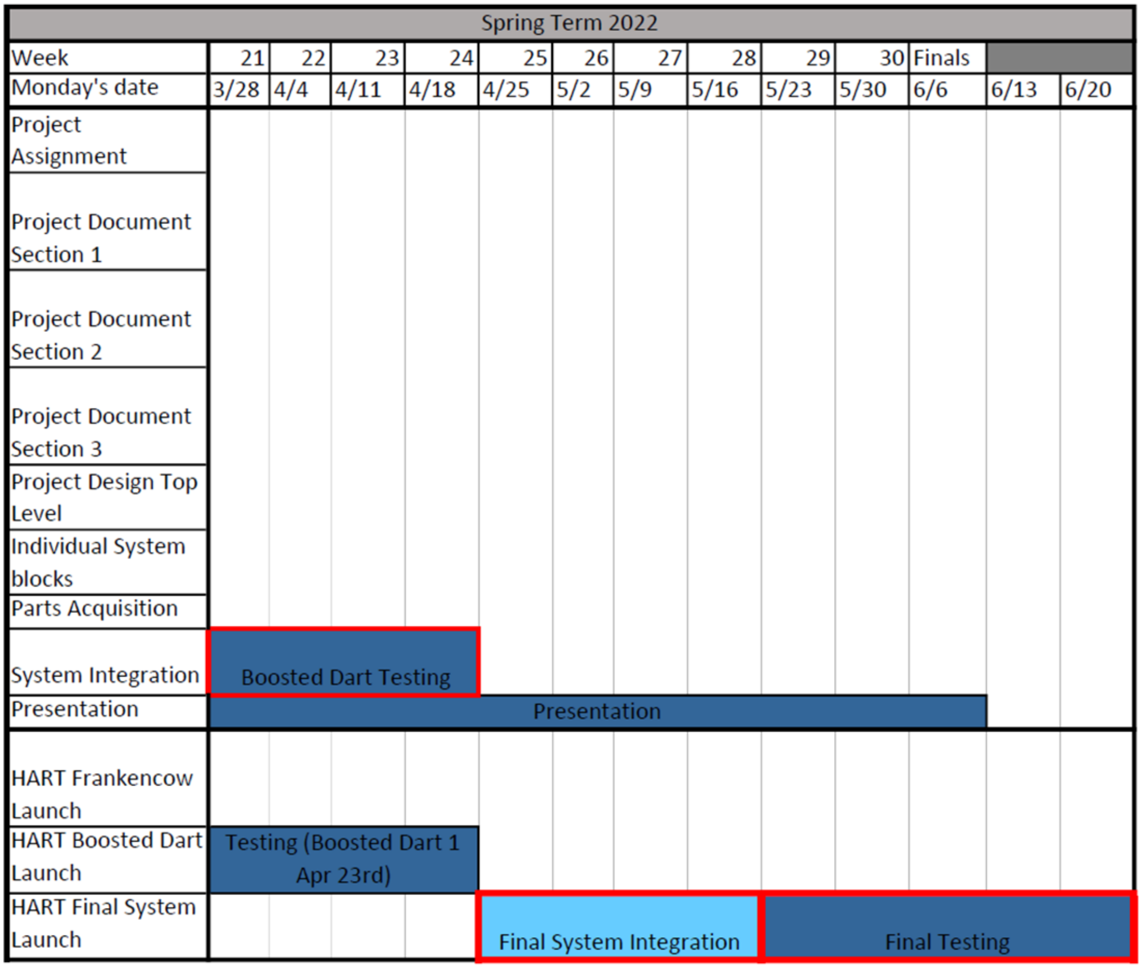


Figure 1.4.3: Spring term schedule critical path outlined in red.

1.5 References and File Links

1.5.1 References

1.5.2 Links

Project Timeline Spreadsheet

1.6 Revision Table

Date	Revision Number	Description	Author
12/2/2021	Rev 6	Grammar and capitalization fixes. Updated Timeline coloring.	Leif Miller
12/2/2021	Rev 6	Updated executive summary and gap analysis based on peer review feedback	Joshua Muir
11/19/2021	Rev 5	Added communication analysis table 1.2.2. Revised project timeline and indicated critical path. Added roles and responsibilities to 1.2. Reformatted table 1.2.4.	Leif Miller
11/19/2021	Rev 5	Updates to protocol section 1.2.4, changing to table format.	Tim Englehart
11/11/2021	Rev 4	Table of contents that links to sections created.	Leif Miller
11/11/2021	Rev 4	Updated timeline images for format. Turned Figure 1.4.1 into 1.4.1, 1.4.2 and 1.4.3. Added subteam lead to project partner contact table.	Leif Miller
11/8/2021	Rev 3	1.3: Incorporated instructor and peer review feedback into gap analysis. 1.1: Incorporated instructor feedback into executive summary	Joshua Muir
10/29/2021	Rev 2	Section 1.2: Updated wording on Communication 1.2.2, added contact information tables, added sections for protocols on disagreements	Tim Englehart
10/22/2021	Rev 1	Initial draft of section 1.1	Kenton Bender
10/22/2021	Rev 1	Initial draft of section 1.2	Tim Englehart
10/22/2021	Rev 1	Initial draft of section 1.3	Joshua Muir
10/22/2021	Rev 1	Initial draft of section 1.4	Leif Miller

2.1 Requirements

Project Partner Requirement (PPR)
Engineering Requirement (ER)

2.1.1 Long Range

PPR: Launch box must be long-range.

ER: Launch box will communicate wirelessly with the pad box from a range of at least 2500 feet.

Verification:

1. Find a flat field or road with minimal obstructions for at least half a mile.
2. Turn on the launch box and pad box right next to each other.
3. Ensure that the launch box and pad box are properly communicating, this is signified by the periodic beeps and green LEDs being illuminated.
4. Walk the pad box along the flat field or road up to a distance of 2500ft, ensuring that radio connection is maintained the entire way.
5. If the launch box is still beeping and the green LEDs are still illuminated at a distance of over 2500ft, the requirement is verified.

2.1.2 Live Telemetry

PPR: Launch box must display flight information.

ER: The launch box will connect to the Telemega flight computer and display telemetry information using the associated ALTOS application.

Verification:

1. Attach Teledongle and Antenna to Launch Box.
2. Turn on the Telemega flight computer.
3. Turn on the Launch Box.
4. Connect to the Telemega using the Teledongle.
5. Verify Teledongle and launch box are communicating with callsign ‘KK7BXH’. (This is the callsign for the test Telemega.)
6. Verify that battery voltage is displayed on the launch page.
7. Verify that the ascent page displays within 2m of 0 height.
8. Verify the age of the information in ALTOS is less than 5 seconds.

2.1.3 Safety Key

PPR: Launch box system must include a safety key that enables launch.

ER: Launch box must include a mechanical safety switch that can only be actuated with a key that prevents the transmission signal from being sent.

Verification:

1. Program the launch hardware.
2. Turn on the launch hardware.
3. Ensure that the safety keyswitch is in the SAFE position.
4. Press the firing button and observe that the igniter does not fire.
5. Turn the safety keyswitch to the ARMED position.
6. Press the firing button and observe the igniter being ignited.
7. If behavior is consistent with the check steps above, the system has passed.

2.1.4 Quick Ignition

PPR: Launch box must ignite rocket quickly.

ER: Launch box must ignite e-match within three seconds of pressing launch.

Verification:

1. Install an igniter in the output terminals of the Pad Box.
2. Turn on and arm Pad Box, then move to a safe distance of at least 10 feet away.
3. At a safe distance from the Pad Box, turn on the Launch Box.
4. Once the Launch Box operator has confirmed that the Pad Box operator has armed the Pad Box and stepped away, arm the Launch Box.
5. Press the launch button on the Launch Box and start a stopwatch at the same time.
6. Monitor the igniter for ignition and stop the stopwatch when it ignites.
7. If the stopwatch reads under 3 seconds, the requirement is passed.

2.1.5 Portable

PPR: Launch box system must be portable.

ER: Each launch box system enclosure must be smaller than 12in x 12in x 12in and have a weight of less than 10 pounds.

Verification:

1. Set up a baking scale and ensure it reads zero on activation.
2. Set the launch box on scale and weigh to ensure it is less than 10 pounds.
3. Remove the launch box from the scale and repeat step 1.
4. Set the pad box on scale and weigh to ensure it is less than 10 pounds.
5. Confirm both boxes are less than 10lbs then continue to step 6
6. Measure the launch box assembly using a ruler to ensure it is within limits of 12”x12”x12”
7. Measure the pad box assembly using a ruler to ensure it is within limits of 12"x12"x12"
8. If both boxes fall within the designated measurements then the requirement is passed.

2.1.6 Battery Life

PPR: Launch box system and pad box must operate on battery power for at least 2 hours.

ER: Launch box and pad box must be able to be powered on for 2 hours and still fire an e-match after this time.

Verification:

1. Set up both the pad box and launch box in the same room within 10 feet of each other.
2. Power up both the pad and launch box.
3. Install an e-match in the pad box terminals.
4. Prepare to fire e-match.
5. With the system is a armed ready to fire state wait 30 minutes.

6. After the 30 minutes has elapsed, press the fire button to ignite the e-match.
7. Safe both boxes without removing power.
8. Repeat steps 3, 4, 5, and 6 three more times.
9. The system has passed if all e-matches fired correctly.

2.1.7 Arming Status

PPR: Launch box system must have visual and audio indication of box status.

ER: The launch box must use four unique visual indications and two unique audio indications representing the status of the system. The visual statuses are power, igniter continuity, pad/launch box armed, and the audible statuses are system idle and system armed. The pad box will have three unique visual and two unique audio indications of system status. Visual statuses will indicate power on, igniter continuity, and system armed, and audio statuses will indicate system idle and system armed/continuous. All audible and visual state cues will update within 1 second of state change.

Verification:
1. Power on the launch box. Check that the power light is on.
2. Power on the pad box. Check that the power light is on.
3. Connect the terminals on the pad box to achieve continuity. Check that the continuity light on both pad and launch box turn on.
4. Arm the pad box. Check that the pad box arming light is on for both the pad and launch box and the pad box speaker is indicating armed status.
5. Arm the launch box. Check that the launch box arming light is on for the launch box and that the launch box speaker is indicating armed status. If all checks have passed, the system has passed verification.

2.1.8 Ease of use

PPR: Launch box system must be well documented and easy to use.

ER: A user manual will be created for the launch box system that an operator without extensive electrical and computer knowledge is able to follow. The manual will include set-up, operation, and troubleshooting sections and must allow the user to set up the system within 30 minutes.

Verification:
1. Give the launch box, pad box, and manual to a HART member unfamiliar with the system.
2. Instruct the HART member to assemble the system according to the manual.
3. Set a timer for 30 minutes.
4. If and when the assembly is complete within the time limit, check to see if the system will fire an e-match as assembled.
5. Repeat this test until 3 members have tested the system. If at least 2/3 tests are successful, then the system has passed.

2.2 Design Impact Statement

2.2.1 Public Health, Safety, and Welfare Impacts

Although it would make sense that an activity that involves powerful explosives and aerodynamic projectiles would be dangerous, "model rocketry is not dangerous if done in accordance with established and tested safety rules," according to Stine [1] in a report prepared for the National Association of Rocketry in 1997. It is important to note the potential biases of this report, as the support for its creation came from the National Association of Rocketry, who would be highly unlikely to want to disparage their own practices and safety guidelines. Despite this assertion, high powered model rocketry is not without its risks. While specific training and certifications are required to be involved in launches at the scale of the rocket that we will be launching as part of our project, accidents still do occur. Enough accidents in fact, that a group of doctors were compelled to publish a paper titled "Model rocket engine burn injuries: The need for stricter regulation." While the paper is written from a pediatric medicine point of view, it is still a valuable counter-point to the assertion of Stine. "From 1975 to 1992, the Consumer Product Safety Commission's National Electronic Injury Surveillance System database received reports of 18 burn injuries caused by model rocketry sets and their engines," Lynch *et al.* [2]. The authors go on to say that "the current regulations appear to be inadequate and need to be altered" [2].

To address some of the risks to public safety and welfare, especially that of the club members that will be operating our project, significant concern and effort was given to the safety features of the boxes. This started with the requirements we defined for our project, including a safety key and arming status displays. The two main elements of these safety features are preventing unintentional ignitions and ensuring that anyone in the vicinity is aware of the status of the boxes. On top of adhering to these requirements, thorough calculations and design work went into making sure that the ignition system is incapable of firing an ignitor without the arming switches on both the pad box and launch box being activated.

2.2.2 Cultural and Social Impacts

Rocketry contains some negative and some positive impacts when looked at from a cultural and social perspective. One of the primary negative impacts would likely be as a consequence of failures in model rocketry. Failures within the hobby and community, particularly those that lead to loss of property and injury to life, often cast a very negative light upon model rocketry. Though these sorts of failures are few and far between given how well the National Association of Rocketry (NAR) has laid out guidelines and rules, they still have serious impact within local communities. Some parks and other potential launch sites have ordinances banning rocket launches and deny use permits for those aiming to launch based on the fact that failures can occur and cause harm to others, making it necessary to check for this before launch [3]. Failures on this project could contribute to a decreasing of availability of rocket test sites, which could be a greater negative than at first glance as it could negate the positive effects to be discussed.

Other social impacts are, for the most part, positive. Society generally views model rocketry in a positive light, as model rocketry can encourage spectators to get into spaceflight and engineering in general [4]. Increasing the number of people interested in Science, Technology, Engineering, and Math (STEM) fields is the goal of many major organizations within the United States and abroad, and model rocketry is a great implement to achieve these goals. Model rocketry can help those who are from disadvantaged communities learn about and become inspired to pursue STEM, as it can be a low-cost hobby if practiced right. As such, this project is more likely than not to be seen in a more positive light socially.

This impact can be boosted by a well-organized social media campaign encouraging people to follow along with the HART program and possibly build their own rockets. Generating high-quality media with a positive message through demonstrating the success of the HART project could bring on a good return for the rocketry community at large.

Overall, the social and cultural impacts of this project are likely to be low, but positive. Showing off the positive aspects of rocketry by maintaining a safe launch and emphasizing the educational value and spreading media from the launch and design of the project would be a good step for furthering positive impacts. HART is an interesting project for all skill levels of people interested in aerospace, but it is still necessary to be mindful of the negative social impacts that failures could have. Keeping the project safe to avoid having to deal with relocating to a different launch site and/or getting in trouble with local and national authorities is of high importance.

2.2.3 Environmental Impacts

While it could be considered minimal it is important to consider the potential environmental impacts of our project. These range from the manufacturing stage to actual operation. The first comparison is the general pollution of our rocket during operation, while the study of emissions is fairly low when considering model rockets, many studies have been done regarding full scale rocket emissions. While it is far beyond the league of the HART rocket, a key piece of information stood out regarding them. Although they are not launched very often and emit a decent portion of their emissions into the vacuum of space, a large amount of emissions are trapped in the upper atmosphere causing damage. “Ross, a senior project engineer for civil and commercial launch projects at The Aerospace Corporation in El Segundo, California, told Space.com. "But with respect to ozone, we now understand that the climate and ozone impacts of rocket exhaust are completely intertwined." Rocket soot accumulates in the upper stratosphere, where the particles absorb sunlight, Ross said. This accumulation heats the upper stratosphere, changing chemical reaction rates and likely leading to ozone loss”. [5] Emissions at such high altitudes don’t simply disappear, the bris they leave behind in the form of soot can get trapped in the upper stratosphere leading to the degradation of the ozone layer and potentially more than that. There is currently a minor amount of resources devoted to such research but is still an incredibly important subject especially with rocket launches increasing and predicted to continue. This may seem out of scale in comparison to our rocket, but even a minor amount of emissions in the upper levels of the atmosphere could have an impact and should be taken seriously.

However it is also important to consider the effectiveness of the rocket's design at not adding to the pollution of plastics and electronics material during operation. The system is designed as a two stage rocket with a multi-stage recovery system including global positioning and ocular tracking. There is a lot of documentation relating to this subject due to its importance for both model rockets as well as full scale ones. The necessity of recovery can not be underestimated and as part of the Avionics and Recovery subteam of HART we hope to contribute to this. Due to a rise in high-power rockets being lost after operation a GPS system was devised to prevent that and is implemented within HART's rocket. Keeping track of these rockets post operation by utilizing such systems keeps the rocket from contributing to the already staggering amount of electronics pollution "About 60 chemical elements can be found in various complex electronics, including lead, cadmium, chromium, mercury, copper, manganese, nickel, arsenic, zinc, iron, and aluminum, many of which are potentially, or known to be, hazardous (Grant et al. 2013). These metals are used in products such as circuit boards, semiconductor chips, cathode ray tubes, coatings, and batteries."[6] through the recovery of all related parts, our systems electronic components and the rocket itself will not contribute to these staggering figures.

To limit the amount of environmental damage of the rocket a few points can be considered. First during operation ensure the airspace is clear in the flight trajectory of the rocket to avoid accidental wildlife injury. This will be completed by the operators and the rocket should only launch when the airspace has been confirmed clear within a safe radius of the launch site. Second, which directly relates to the design of our project is making sure the GPS system for recovery is functional. This will ensure all components of the rocket that can be hazardous to the environment if left unchecked can be retrieved.

2.2.4 Economic Impacts

To analyse the impacts of the project from a economic standpoint it was decided to evaluate rocketry in general as opposed to model rocketry which is a much smaller subfield. The economics of space programs and rocketry on the world stage is interesting and our project could be viewed as a stepping stone towards the larger field.

The 1960's were known for the governmentally funded space race [7]. Today the field is experiencing commercialization and private sector funds are flowing into the industry. To being, in 2016 the commercial space industry counted for 2.0% of the United States of America Gross Domestic Product [7]. This is equivalent to $38 billion dollars [7]. More interested parties in the space industry means more jobs to support new projects. A 2017 report concluded that the commercial space industry should see continuous 7% growth annually [7]. The outlook for careers in the space industry is positive and engineers should be conscious of this impact.

South Korea is considered a late arriver to the space industry and yet is already showing the positive economic feasibility of their satellite program [8]. The first satellite South Korea launched was the KITSAT-1 in 1992. Since then, the program has already grown to a benefit cost ratio of 1.24 [8]. This illustrates the economic impacts of the space industry as for every South Korean won spent 1.24 won is returned. There are certain disadvantages of being a late adopter of the space industry. The benefit cost ratio is 47% lower than a European Union program called Copernicus [8]. This shows that the longer entities are involved in the space industry the more benefits are seen.

Economically the transition to a commercial industry is showing benefits but it comes with its own set of issues. At the end of the day these commercial companies are for profit and will make industry decisions with profits in mind. This can incentivize the wrong types of innovations and suppress innovations that are low return. It will be crucial for engineers in these companies to keep the other impacts areas in mind and ensure that the industry doesn't increase negative impacts in the pursuit of money.

The cost barrier of entry into the space industry is large. This prevents the positive economic impacts of a space program from being seen by lower economic status entities. HART can put emphasis on cost and longevity into the design of their project and allow more people to get started in the subfield of model rocketry. The more people that are involved the more economic savings will be seen. This will all serve to grow the industry and open it up to those with tighter budgets.

2.3 Risks

Risk ID	Risk Description	Risk Category	Risk Probability	Risk Impact	Performance Indicator	Responsible Party	Action Plan
R1	Semiconductor devices are delayed due to global chip shortage	Timeline	50%	M	Estimated time of delivery	Joshua Muir	Finalize component selection and device design ASAP so that parts can be ordered to reduce the risk of parts arriving late.
R2	Broken components due to stresses associated with field use.	Technical /Cost	10%	H	If any components break or are damaged.	Joshua Muir	Include spare parts in the BOM to maintain the flexibility for repair in the field and avoid long shipping times for replacements. Reduce the likelihood of part breaking by having a rugged enclosure.
R3	Increase of component prices	Cost	20%	M	If BOM price increases	Tim Englehart	Avoid choosing parts with extra functionality or additional features that are not required and keep a low total unit cost.
R4	HART timeline variance from class timeline creates conflicts.	Timeline	30%	L	Project is not prepared for HART milestones when they arise.	Kenton	Request updated HART timeline every two weeks to reduce risk of schedule differences and avoid conflicts created from said differences.
R5	Team member illness (Covid 19 or other) interfering with project deadlines.	Timeline	50%	H	Absences from meetings, classes, and events.	Leif Miller	Stay on top of group work and have every team member familiar with teammates responsibilities to transfer these responsibilities to another individual if needed.

2.4 Reference and File Links

2.4.1 References

[1] G. Stine, “Forty Years of Model Rocketry: A Safety Report,” National Association of Rocketry, 1979. Accessed: Oct. 29, 2021. [Online]. Available: https://www.apogeerockets.com/education/downloads/40years.pdf

[2] M. Smith, K. Bellian, R. Edlich, H. Himel, “Model rocket engine burn injuries: The need for stricter regulation,” in *The Journal of Emergency Medicine*, vol. 12, iss. 3, pp. 325-330, May 1994. Accessed: Oct. 29, 2021. [Online] Available: https://www.jem-journal.com/article/0736-4679(94)90274-7/pdf

[3] Northern Illinois Rocketry Association “Frequently Asked Questions.” nirarocketry.org. https://www.nirarocketry.org/faq.html (Accessed October 28, 2021).

[4] N. P. Lang, “The Effectiveness of Model Rocketry to Teach Science and Quantitative Content to Students in a Non-Science Majors Course at the College Level: An Example from a Planetary Geology Course.” Open Journal of Statistics, vol. 10, no. 1, pp. 139-154, Feb. 2020, doi: 10.4236/ojs.2020.101011 (Accessed October 28, 2021).

[5] M. Heacock *et al.*, “E-Waste and Harm to Vulnerable Populations: A Growing Global Problem,” *Environmental Health Perspectives*, vol. 124, no. 5, pp. 550–555, May 2016, doi: 10.1289/ehp.1509699.

[6] M. G. Attinasi *et al.*, “The semiconductor shortage and its implication for euro area trade, production and prices,” *www.ecb.europa.eu*, Jun. 2021, [Online]. Available: https://www.ecb.europa.eu/pub/economic-bulletin/focus/2021/html/ecb.ebbox202104_06~780de2a8fb.en.html.

[7] K. Whealan George, “The Economic Impacts of the Commercial Space Industry,” *Space Policy*, vol. 47, pp. 181–186, Feb. 2019, doi: 10.1016/j.spacepol.2018.12.003.

[8] J. H. Park, H. Jung, C. H. Lim, and T. Chang, “The economic impact analysis of satellite development and its application in Korea,” *Acta Astronautica*, vol. 177, pp. 9–14, Dec. 2020, doi: 10.1016/j.actaastro.2020.06.031.

2.4.2 File Links

2.5 Revision Table

Date	Revision Number	Description	Author
5/6/2022	Rev 10	Filled section 2.2.4 and updates section 2.4 with references. Consolidating formatting.	Leif Miller
5/6/2022	Rev 10	Filled in section 2.2.2 with updated information regarding the cultural and social impacts of our project.	Kenton Bender

5/5/2022	Rev 9	Filled in section 2.2.3 with updated information regarding the potential environmental impacts of our project.	Tim Englehart
5/5/2022	Rev 8	Filled in section 2.2.1 with updated perspectives on the health and safety impacts of our project.	Joshua Muir
4/21/2022	Rev 7	Updated sections 2.1.3 and 2.1.7 to properly reflect the current state of the project and to have easier to read verification steps.	Kenton Bender
4/21/2021	Rev 7	Updated 2.1.5 and 2.1.6 to improve format, detail, and readability by streamlining the testing procedure and removing/combining redundant testing steps	Tim Englehart
12/2/2021	Rev 6	Updated 2.1.2 to include angle from vertical as requested by project partner during document review.	Leif Miller
12/2/2021	Rev 6	Updated requirements based on instructor and peer reviews. Included adding simple names to headers and incorporating project partner feedback.	Joshua Muir
11/19/2021	Rev 5	Wrote verification requirement for 2.1.2 and added accuracies. Revised table 2.3 risks.	Leif Miller
11/19/2021	Rev 5	Rewrote Verification processes as step by step instructions. Addresses PD 1 & 2 instructor comments in requirements.	Josh Muir
11/19/2021	Rev 5	Changed verifications to be in steps. Removed requirement 2.1.3 and adjusted following requirement numbers.	Kenton Bender
11/11/2021	Rev 4	Adjusted risks R5 and R6. Reformatted requirements sections.	Leif Miller
11/11/2021	Rev 3	Removed requirement 2.1.5, set other requirements to right numbers.	Kenton Bender
11/11/2021	Rev 3	Commented on requirements with suggested revision to ER and Verification Processes. Updated Revision table to Author column instead of reviewed by per instructor comment. Updated requirements 2.1.4 and 2.1.9. Need team review.	Leif Miller
11/11/2021	Rev 3	Revised wording on all project requirements. Further consolidated two requirements.	Tim Englehart

11/8/2021	Rev 2	Expanded upon requirements 2.1.1, 2.1.5, and 2.1.6, brought to new standards.	Kenton Bender
11/8/2021	Rev 2	Revised project requirements 2.1.2, 2.1.5, and 2.1.6 to new standards sent in announcement	Joshua Muir
10/29/2021	Rev 1	Draft of requirements 2.1.2, and 2.1.4. Draft of Risk R1 and R2.	Joshua Muir
10/29/2021	Rev 1	Draft of requirements 2.1.1, and 2.1.7.	Kenton Bender
10/29/2021	Rev 1	Draft of requirements 2.1.8, 2.1.9, and 2.1.10. Draft of Risk R5 and R6.	Leif Miller
10/29/2021	Rev 1	Draft of requirements 2.1.6, 2.1.3. Draft of Risk R3 and R4	Tim Englehart

3.1 Block Diagram

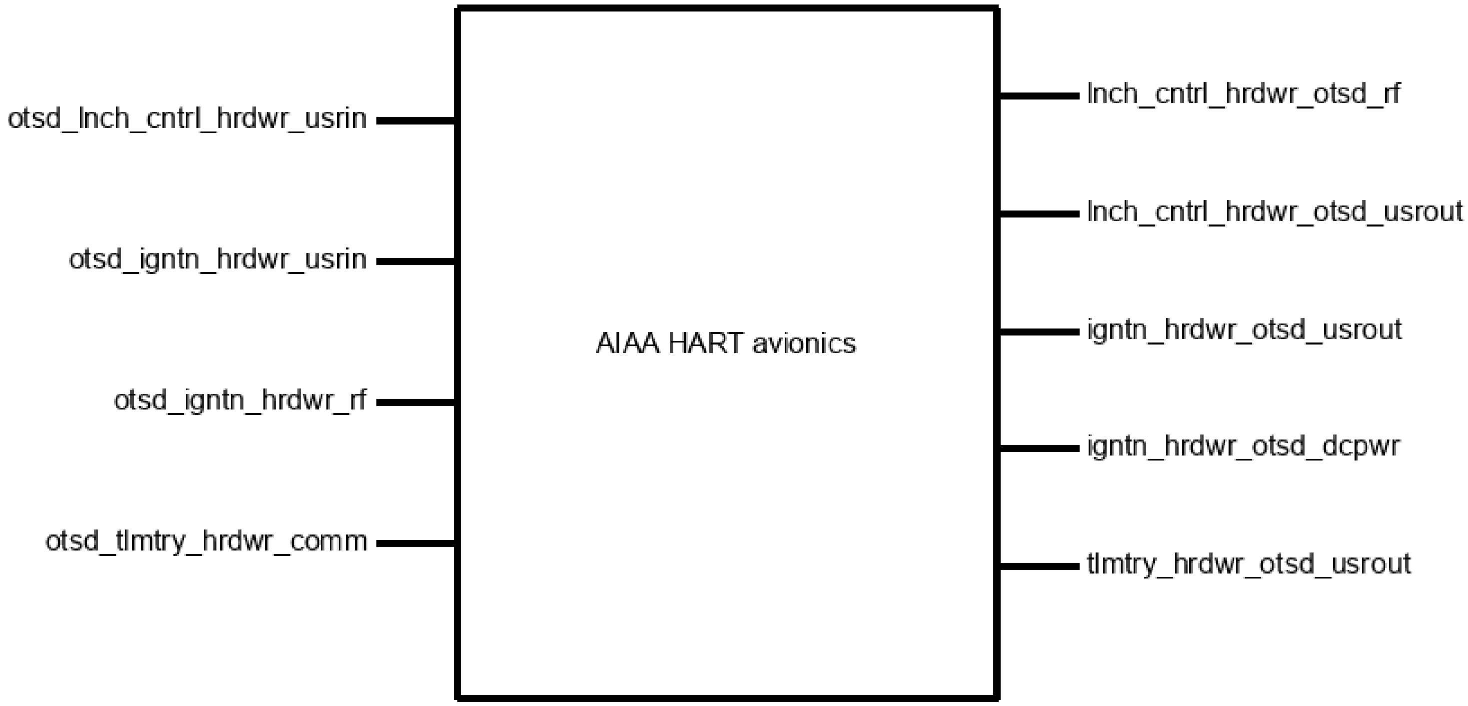


Figure 3.1.1 Black Box Diagram

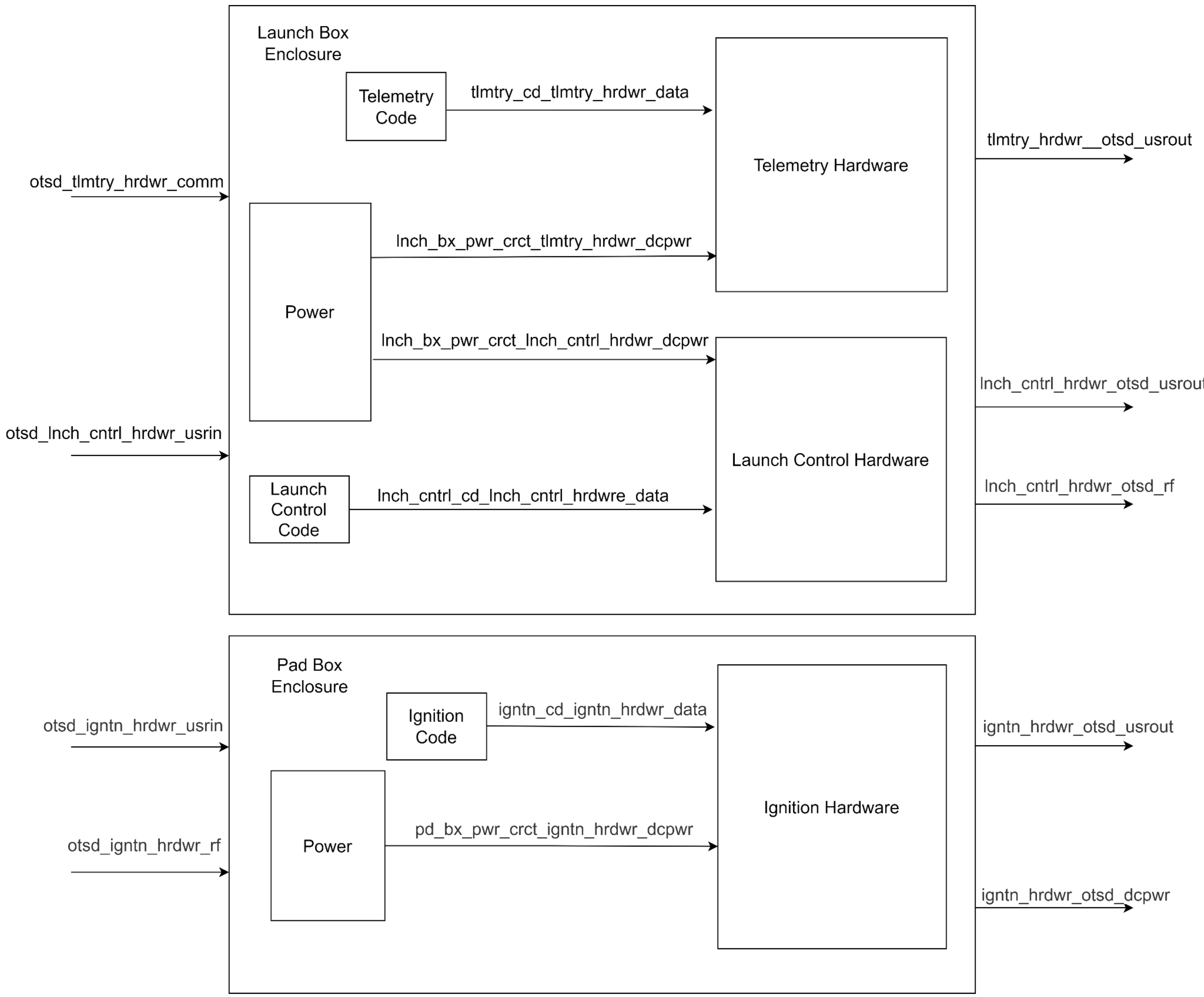


Figure 3.1.2 System Block Diagram

3.2 Block Descriptions

Name	Description
Pad Box Enclosure Champion: Timothy Englehart	This enclosure contains the PCB and circuitry comprising the pad box system. It will be 8in x 8in x 8in at maximum but will be within said dimensions. This block exists to provide a sturdy protective enclosure for the electronics inside, and extra care must be taken to design it to withstand dust and blasts from the rocket launching nearby.
Launch Box Enclosure Champion: Timothy Englehart	This enclosure contains the PCBs and circuitry comprising the launch control and telemetry display systems. It will be 8in x 8in x 8in at maximum but will be within said dimensions. This block exists to provide a sturdy protective enclosure for the electronics inside, as well as an intuitive layout for all elements of the outside interface, such as buttons, switches, status lights, ports, and telemetry displays.
Launch Box Power Circuit Champion: Timothy Englehart	This circuit is essentially the battery which provides power to the circuit which is distributed to each component. Without this block no power would exist within the circuit. The block will function through a power connection to the CPU with the ground connection fed through the On/Arming circuit so when the button is activated the circuit completes and the power flows through the Launch Box.
Pad Box Power Circuit Champion: Timothy Englehart	This circuit is essentially the battery which provides power to the circuit which is distributed to each component. Without this block no power would exist within the circuit. The block will function through a power connection to the CPU with the ground connection fed through the On/Arming circuit so when the button is activated the circuit completes and the power flows through the Pad Box.
Ignition Hardware Champion: Josh Muir	This block consists of the PCB, CPU, transceiver, on/arming switches, power MOSFET, and status display lights/speaker that comprise the ignition system. The CPU, transceiver, power MOSFET, and display lights/speaker will all be soldered to the PCB, and there will be pin-based connectors for the on/arming switches, and power connections.
Ignition Code Champion: Josh Muir	This block contains all the code that runs on the ignition circuit CPU. It is responsible for listening to the transceiver for a launch command, monitoring the arming switch status, monitoring the continuity of the igniter, and controlling the visual/auditory alerts, and turning the power MOSFET on to ignite the e-match.
Telemetry Hardware Champion: Leif Miller	This block represents the processing circuitry that will display the rocket's telemetry information on the launch box system. Telemetry is flight information like vehicle speed, altitude, acceleration, and the angle from vertical. The High Altitude Rocket Team utilizes Altus Metrum products for flight computers and ground stations. The Teledongle is a wireless communication ground station that connects to the rocket's onboard flight computer. The Teledongle is a USB device and connects to a Raspberry Pi. The Raspberry Pi processes the data from the ground station for display.
Telemetry Code Champion: Leif Miller	This code block is the entirety of the launch box systems telemetry software. This software enables USB communication through the Telemetry Hardware. The Altus Metrum Teledongle ground station that is used by HART generates a data packet that contains telemetry information. This block will process the data packet from the

	ground station. Data processing includes reading the data packet, selecting the relevant information, and sending the information to user output hardware.
Launch Control Code Champion: Kenton Bender	This block contains the code for the Launch Control Hardware. It manages the signals to be sent out to the Ignition Hardware to launch the rocket. It also manages which lights should display on the Launch Control Hardware for the status of the box.
Launch Control Hardware Champion: Kenton Bender	This is the hardware to control authorization and launch of the rocket from a distance. It contains a microcontroller, buttons, LEDs, transceiver, and a PCB connecting all of these. It receives power from the power circuit block and has its own set of code to run for operation in another block.

3.3 Interface Definitions

Name	Properties
otsd_lnch_cntrl_hrdwr_usrin	• **Type:** Arming key • **Type:** Pushbutton • **Usability:** Key requires simple 90 degree turn • **Usability:** Button requires at least 1lb of force to depress
otsd_igntn_hrdwr_usrin	• **Type:** Wired Ignition Signal Input • **Type:** On Switch • **Type:** Wireless/Wired Select Switch • **Type:** Arming Switch
otsd_igntn_hrdwr_rf	• **Messages:** Launch Command to Pad Box • **Messages:** Igniter Continuity Signal to Launch Control • **Protocol:** 2.4GHz
otsd_pd_bx_pwr_crct_acpwr	• **Inominal:** 300 mA • **Ipeak:** 1000 mA • **Vmax:** 7.5 V • **Vmin:** 7 V
otsd_tlmtry_hrdwr_comm	• **Datarate:** 12 Mbps • **Protocol:** USB • **Vnominal:** 5 V

lnch_cntrl_hrdwr_otsd_usrout	• **Type:** Audio • **Type:** Visual • **Usability:** LEDs visible from 25 feet away in daylight by an observer • **Usability:** Sound audible from 25 feet away by an observer
lnch_cntrl_hrdwr_otsd_rf	• **Messages:** Igniter continuity signal from pad box • **Messages:** Launch Authorization to pad box • **Protocol:** 2.4GHz band
pd_bx_nclsr_igntn_hrdwr_mech	• **Fasteners:** 4 M2 screws • **Pulling Force:** 2 lbs • **Shear Force:** 2 lbs
pd_bx_nclsr_igntn_hrdwr_mech	• **Fasteners:** Nut • **Pulling Force:** 3 lbs • **Shear Force:** 3 lbs
lnch_bx_nclsr_lnch_cntrl_hrdwr_mech	• **Fasteners:** 4 - M3 Screws • **Other:** PCB between 1/4 and 1 inch off of inside of enclosure surface • **Pulling Force:** 20 pounds
igntn_hrdwr_otsd_usrout	• **Type:** Visual • **Type:** Audio • **Usability:** Sound audible from 25 feet away by an observer • **Usability:** LEDs visible from 25 feet away in daylight by an observer
pd_bx_pwr_crct_igntn_hrdwr_dcpwr	• **Inominal:** 300 mA • **Ipeak:** 550 mA • **Vmax:** 5.2 V • **Vmin:** 4.8 V

pd_bx_pwr_crct_igntn_hrdwr_dcpwr	• **Inominal:** 2.2 A • **Ipeak:** 3.3 A • **Vmax:** 8.4 V • **Vmin:** 6.0 V
pd_bx_pwr_crct_igntn_hrdwr_dcpwr	• **Inominal:** 100 mA • **Ipeak:** 200 mA • **Vmax:** 3.5 V • **Vmin:** 3.1 V
lnch_bx_pwr_crct_lnch_cntrl_hrdwr_dcpwr	• **Inominal:** .5 A • **Ipeak:** 1 A • **Vmax:** 5.25 V • **Vmin:** 4.4 V
lnch_bx_pwr_crct_lnch_cntrl_hrdwr_dcpwr	• **Inominal:** 600 mA • **Ipeak:** 800 mA • **Vmax:** 3.5 V • **Vmin:** 3.1 V
lnch_bx_pwr_crct_tlmtry_hrdwr_dcpwr	• **Inominal:** .5 A • **Ipeak:** 1 A • **Vmax:** 5.25 V • **Vmin:** 4.4 V
lnch_bx_pwr_crct_tlmtry_hrdwr_dcpwr	• **Inominal:** 600 mA • **Ipeak:** 800 mA • **Vmax:** 3.5 V • **Vmin:** 3.1 V
tlmtry_hrdwr_otsd_usrout	• **Other:** Displays Acceleration • **Other:** Displays Altitude • **Other:** Displays Angle from Vertical • **Other:** Displays Speed • **Type:** Visual

igntn_cd_igntn_hrdwr_data	● **Messages:** Armed/Continuity signals to transceiver ● **Messages:** Binary signals sent to piezoelectric speaker ● **Messages:** Ignition command from transceiver ● **Messages:** Binary signals sent to power MOSFET ● **Messages:** Binary signals sent to LED status lights ● **Protocol:** Programmed with USB to TTL programmer
tlmtry_cd_tlmtry_hrdwr_data	● **Messages:** Output digital LCD control. ● **Messages:** Input serial data. ● **Protocol:** Firmware will be written in Python
lnch_cntrl_cd_lnch_cntrl_hrdwr_data	● **Messages:** Audio Control ● **Messages:** Binary signals to LED status lights ● **Messages:** Arming status ● **Protocol:** Coded in C or C-like software

3.4 References and File Links

3.4.1 References

3.4.2 File Links

3.5 Revision Table

Date	Revision Number	Description	Author
12/3/2021	Rev 2	Updated ignitor hardware and ignitor code blocks descriptions and interface definitions.	Joshua Muir
12/3/2021	Rev 2	Updated telemetry hardware and code blocks. Updated descriptions and interface definitions.	Leif Miller
12/3/2021	Rev 2	Revised descriptions and interface definitions for my blocks. Added and formatted updated block descriptions table.	Timothy Englehart

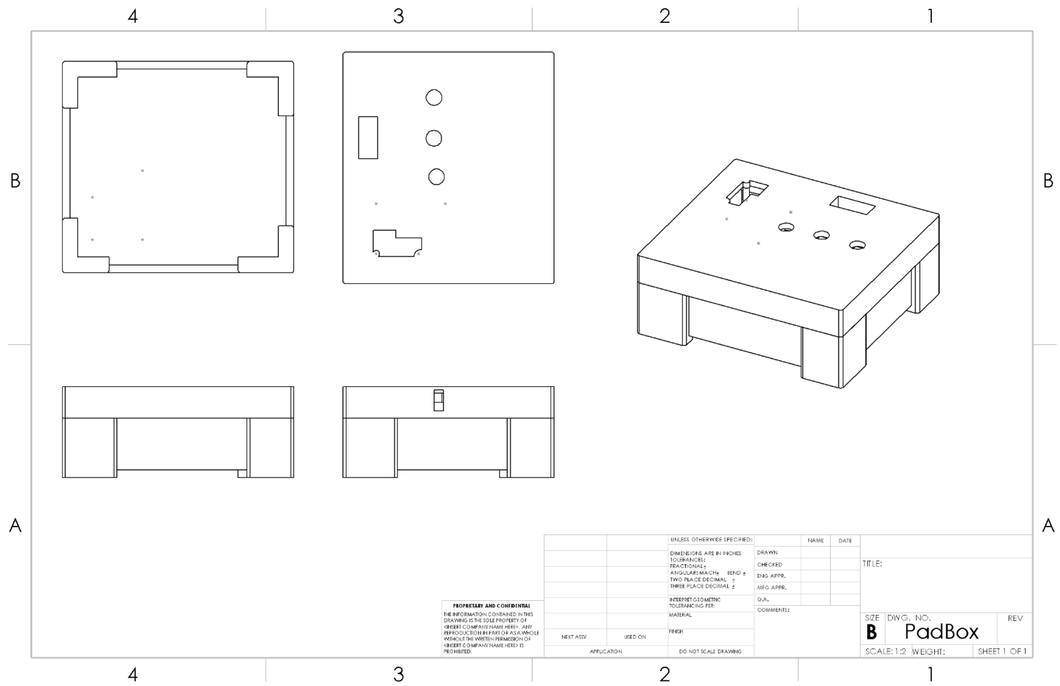
12/3/2021	Rev 2	Added revised black box diagram, block diagram, block definition, and interface definitions for my blocks	Kenton Bender
11/19/2021	Rev 1	Drafted block descriptions and interface definitions for my blocks. Updated block diagram. Reviewed section before submittal.	Leif Miller
11/19/2021	Rev 1	Drafted block descriptions and interface definitions for my blocks. Updated block diagram.	Josh Muir
11/19/2021	Rev 1	Inserted interface definitions and block descriptions. Drafted block descriptions and interface definitions for my blocks. Block diagram updates and formatting.	Kenton Bender
11/19/2021	Rev 1	Generated draft descriptions and interfaces for the Power Circuit, On/Arming Circuit, and Transceiver Circuit for the Pad Box and Launch Box respectively.	Tim Englehart

4.1 Pad Box Enclosure

4.1.1 Description

This enclosure contains the PCB and circuitry comprising the pad box system. It will be 8in x 8in x 8in at maximum but will be within said dimensions. This block exists to provide a sturdy protective enclosure for the electronics inside, and extra care must be taken to design it to withstand dust and blasts from the rocket launching nearby along with potential moisture damage.

4.1.2 Design



4.1.3 General Validation

The purpose of this particular enclosure is to hold the launch hardware required for the pad box. The pad box being the device left next to the rocket which will receive the launch signal and start the ignition process. As such the design will have to incorporate several features to ensure safety of the operators as well as ensuring operation in various conditions as it will be mostly standalone after activation.

The first facet of the design is its ability to operate at long distance without access to an external power source. This will work in tandem with a switch that will double as a charging port when the switch is in its off state. Both features will require adequate space within the enclosure so now that a battery and switch have been decided on the box lid will have to have a hole in the top that will fit the switch that will seal up after insertion to also allow for device charging. This is tested by sealing the enclosure and affixing the charger to the external port and observing the charging state LED. IF it shows charging and eventually fully charged this function will be shown as complete.

The launch hardware, accompanying PCB and power distribution circuits will also require sections of space within the box and will be given slots accordingly to also ensure they do not slide around when placed. These spaces will have added screw holes that will match up with the PCB design files provided by the rest of the team to allow secure mounting. All these mounting points will be tested by attaching said mountable components and their corresponding fasteners and testing them with pull/shear force to ensure the components are affixed and won't be easily removed from the enclosure.

Another feature that will be incorporated into the design is an ability to resist the elements, meaning shielded against sudden clouds of dust during launch, and securing every external port and the lid with water-resistant seals. This will also double as dust and wind protection of internal components. These features will be tested post assembly directly on the sealed areas using liquids to ensure a tight seal and observing if any was able to enter the box.

4.1.4 Interface Validation

Interface Name	Properties
pd_bx_nclsr_igntn_hrdwr_mech	• Fasteners: Nut • Pulling Force: 3 lbs • Shear Force: 3 lbs
pd_bx_nclsr_igntn_hrdwr_mech	• Fasteners: 4 M2 screws • Pulling Force: 2 lbs • Shear Force: 2 lbs

4.1.5 Verification Plan

Testing process for pad box:

Water/Dust seal test

1) Cover external ports in duct tape on the inside and outside of the box
2) Seal the lid closed along the watertight gasket seal
3) Fill a 5 gallon bucket with water
4) Submerge the box in water
5) Hold for at least 60 seconds
6) Remove the box
7) Unseal the lid
8) Inspect for water
9) The test passes if less than a quarter inch of water has entered the box

Solidity test #1

1) Seal the lid on the enclosure
2) Lift the box off solid ground (i.e hardwood floor, cement, pavement, etc.) to a height of 3 feet
3) Drop the box and allow it to hit the ground
4) Retrieve box
5) Perform inspection steps below

Solidity test #2

1) Seal the lid on the enclosure
2) Place on stable surface such as a worktable
3) Place a 20lb disk weight on top of the box so as the weight is not concentrated on one spot
4) Allow to rest for at least 60 seconds
5) Perform inspection steps below

Inspection steps:

1) Inspect for external fissures

2) Open the lid of the box
3) Inspect lid for fissures
4) Inspect the inside of the box for internal wall fissures
5) Inspect segment separation walls for fissures or signs of detachment
6) If no signs have been seen the box passes the test

4.1.6 References

4.1.7 Revision Table

Date	Revision Number	Description	Author
2/25/22	5	Added all current documentation	Timothy Englehart
2/25/22	4	Re-designed 3D model of box and lid and updated design image	Timothy Englehart
2/17/22	3	Added Figure 3; 3D model of box design. Updated general validation section.	Timothy Englehart
2/4/22	2	Edited Block description and general validation. Drafted block testing process	Timothy Englehart
2/3/22	1	Drafted Sections: Block description and general validation	Timothy Englehart

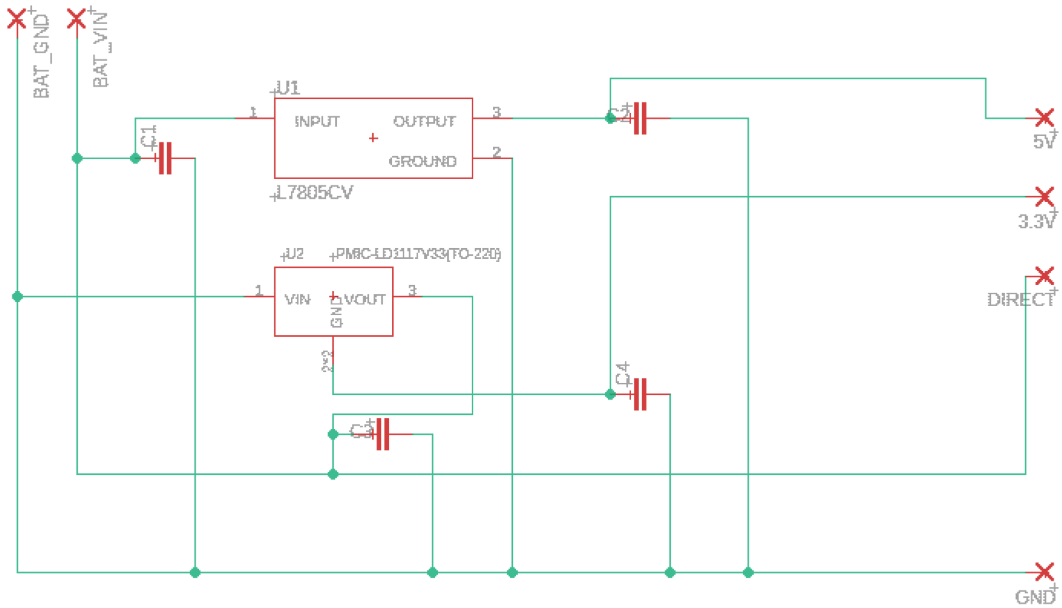
4.2 Launch Box Power Circuit

4.2.1 Description

This circuit is essentially the battery which provides power to the circuit which is distributed to each component. Without this block no power would exist within the circuit. The block will function through a power connection to the CPU with the ground connection fed through the On/Arming circuit so when the button is activated the circuit completes and the power flows through the Launch Box.

This block will be made of three power busses, one through a 5V regulator, another through a 3.3V regulator, and a direct connection to the battery. All three paths will share a common ground. The battery will also have a connection set up to the charger to allow external attachment.

4.2.2 Design



4.2.3 General Validation

The general purpose of this block is to supply ample power to the system for a period long enough unplugged to suit our design requirements. To do this the voltage and current output must match up with the other block/s in the system, the overall battery capacity must be sufficient in relation to the design requirements, and the additional features also described in the requirements must be implemented as well. The block I have designed and the components I have chosen meet these requirements when assembled together and in terms of supply, cost, and availability are all well within the margins of safety. The main part of the circuit is comprised of our Lithium-Ion (Li-on) battery. As shown in the Block Interface Validation table below, the power circuit will have to output a voltage value of around 5V and 1 A nominally, with some margin of minimum and maximum ratings. However, the battery in question as it is a two-cell battery exceeds this rating by a couple volts. The Tenergy 7.4V Li-ion 2200mAh Rechargeable Battery Module with PCB has a voltage 7.2V (peak at 8.4V), Capacity: 2200mAh, Dimensions: 2.69 x 1.45 x 0.7 inch, and a max discharge current of 3.3A. The capacity in question works perfectly for our pad box as it will need to operate wirelessly for a long period of time, with this capacity rating during constant operation the battery could last up to 2 hours. However, as the box will often be idling in standby it can be reasonably assumed it could last far longer during use.

The other addition to this block is its ability to recharge, this will be done utilizing two different items. The first being a simple smart charger specifically designed for Li-ion batteries to ensure safe charging without risking battery health. This will be used in tandem with a battery arming switch to ensure the battery is not connected to the circuit during charging. Both will be incorporated into the enclosure and accessed externally. Each of these parts according to distributers is well in stock and in no current danger of running out. Each component including the battery is relatively small in relation to the project requirements enclosure sizing including the potential size of the required PCB's to build the regulator circuit. While some of the components are more expensive, the pricing for the high capacity battery along with the coinciding charger which is required to ensure safe charging without potentially overcharging or damaging the battery is well worth the cost.

4.2.4 Interface Validation

Interface: otsd_pd_bx_pwr_crct_acpwr : Input

Inominal: 1 A	This value is based on the rated draw of the smart charger that will be connected to the AC outlet	The smart charger specification rates the charger for a 1 A draw, given the standard potential output of a US AC power outlet is well above 10 A it more than provides enough current to operate the device.
Ipeak: 1.5 A	This is the highest rated output of the smart charger before safety cutoffs occur	The smart charger specification rates the charger for a 1 A draw, given the standard potential output of a US AC power outlet is well above 10 A it more than provides enough current to operate the device. If the current input exceeds 1.5A the safety system is activated and the charger ceases function.
Vmax: 120 V	The maximum output voltage of standard US Wall outlets	US wall outlets are rated for a maximum output of 120V, given the voltage input of the smart charger is rated to be between 100-240V its is well within operable parameters.
Vmin: 110 V	Minimum output of US wall outlets considering standard +/10V variance.	US wall outlets are rated for a maximum output of 120V, given the voltage input of the smart charger is rated to be between 100-240V its is well within operable parameters.

Interface: pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Output

Inominal: 2.2 A	This value was found based around the expected current needs of the other system blocks.	This value is based on the max output of the battery, as much current as possible is required for the igniter the max output of the battery is taken as the nominal draw
Vmax: 8.4 V	This is the highest voltage we expect on our Li-ion battery	This value is based on the maximum output voltage of the battery. For a direct connection there will be little to no resistance besides the native resistance of the material it will be attempting to ignite.
Ipeak: 3.3 A	This is based on the expected needs of the control hardware	Utilizing the battery specifications the highest output current of the battery is 3.3 A
Vmin: 7.4 V	The value is based on the expected needs of the control hardware	The standard operating output of the battery is rated at 7.4V and will be considered the minimum draw as it will be a direct connection with the physical igniter

Interface: pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Output

Inominal: 100 mA	This is roughly what the ATmega328p and INA169 current sensor should draw when some LEDs are being driven.	The circuit will be designed with thick enough traces where it needs them to handle this current.
Ipeak: 200 mA	This is roughly the maximum current that the ATmega328p and INA169 current sensor should draw when all the LEDs and piezoelectric speaker are being driven.	The circuit will be designed with thick enough traces where it needs them to handle this current.

Vmax: 5.2 V	This is the value given voltage variation of the provided regulator output typical variation	Output voltage as shown in the L7805 datasheet the output of the regulator will be 5V slight variation of less than 0.3V. This coincides with the control hardware data sheet which shows a draw of 1.8V to 5.5V. Vin can range from 8-20V
Vmin: 4.8 V	This is the value given voltage variation of the provided regulator output typical variation	Output voltage as shown in the L7805 datasheet the output of the regulator will be 5V with slight variation of less than 0.3V. This coincides with the control hardware data sheet which shows a draw of 1.8V to 5.5V. Vin can range from 8-20V

Interface: pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Output

Inominal: 100 mA	The value is based on the expected draw of the control hardware	The NRF24L01+ transceiver module draws approximately 20 mA when in receiving mode, given the maximum output of the regulator is 800mA this is well within safety margins
Ipeak: 300 mA	The value is based on the expected draw of the control hardware	The NRF24L01+ transceiver module draws approximately 150 mA when in sending mode. given the maximum output of the regulator is 800mA this is well within safety margins
Vmax: 3.5 V	This is the value given voltage variation of the provided regulator output typical variation	Output voltage as shown in the LD1117V33 datasheet the output of the regulator will be 5V slight variation of less than 0.3V. This coincides with the control hardware data sheet which shows a draw of 1.8V to 5.5V. Vin can range from 8-20V

Vmin: 3.1 V	This is the value given voltage variation of the provided regulator output typical variation	Output voltage as shown in the LD1117V33 datasheet the output of the regulator will be 5V slight variation of less than 0.3V. This coincides with the control hardware data sheet which shows a draw of 1.8V to 5.5V. Vin can range from 8-20V

4.2.5 Verification Plan

Testing process for pd_bx_pwr_crct_igntn_hrdwr_dcpwr:
This process will be the same for all three busses
Testing Ipeak and Inominal:

1. Connect voltage regulator to breadboard positive and negative leads.
2. Using 2 jumper wires connect one to the positive bar and one to the negative with the other ends free.
3. Attach the battery to the corresponding bus circuit.
4. Using a multimeter branch the two wires.
5. Measure current.

Testing Inominal

1. Connect the voltage regulator to a breadboard that is connected to the launch control hardware circuit.
2. In between the regulator and the hardware attach two jumper wires along the same path with the leads remaining unattached to the circuit.
3. Attach the battery to the regulator circuit.
4. Using a multimeter branch the two free ends of jumper wires from step 2.
5. Measure current.

Testing Vmax and Vmin:

1. Connect voltage to breadboard positive and negative leads.
2. Affix a 220 ohm resistor to a point on the breadboard.
3. Using two jumper wires connect them to either side of said resistor.
4. Using a multimeter measure the voltage over the resistor by touching the positive and negative probes to opposite metal connectors coming out of the resistor.

4.2.6 References

Links:

L7805 data sheet
ATMega324P data sheet
LD1117V33 data sheet
Smart Charger specifications
NTE2987 datasheet

4.2.7 Revision Table

Date	Revision Number	Description	Author
3/6/22	5	Added all current documentation to the Project Document	Timothy Englehart
1/21/22	4	Revised year on revision table dates. Completed interface validation table.	Timothy Englehart
1/18/22	3	Edited block description and updated testing process. Added circuit diagram. Added LD1117V33 3.3V regulator circuit, example test sheet, and description.	Timothy Englehart
1/8/22	2	Edited Block description and general validation. Drafted block interface validation and block testing process	Timothy Englehart
1/7/22	1	Drafted Sections: Block description and general validation	Timothy Englehart

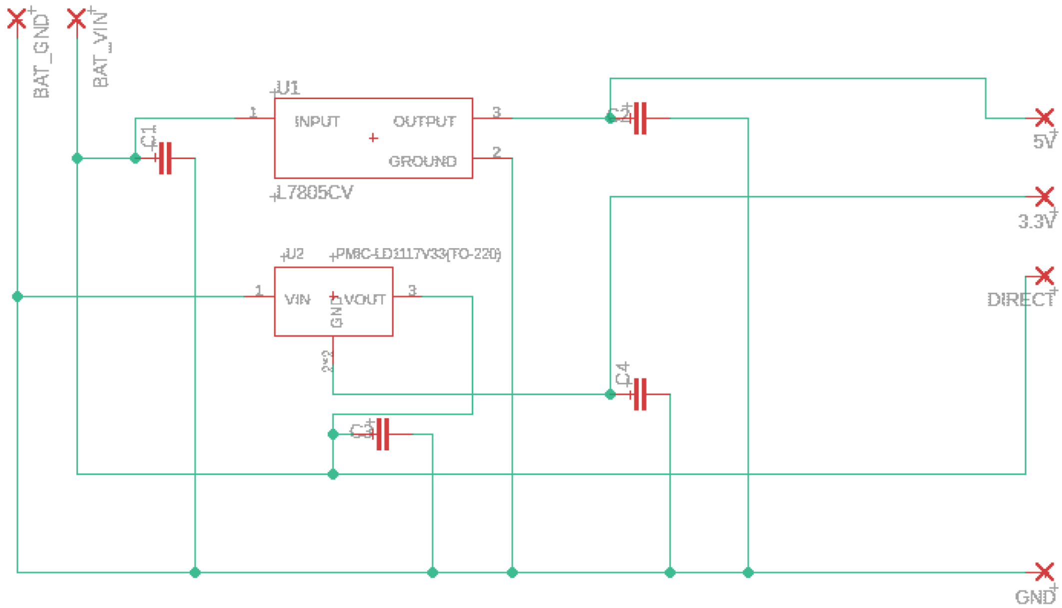
4.3 Pad Box Power Circuit

4.3.1 Description

This circuit is essentially the battery which provides power to the circuit which is distributed to each component. Without this block no power would exist within the circuit. There is a port for the purpose of recharging using a standard US AC outlet using the accompanying battery smart charger. The block will function through a power connection to the CPU with the ground connection fed through the button/switch security system so when the button is activated the circuit completes and the power flows through the Pad Box.

This block will be made of three power busses, one through a 5V regulator, another through a 3.3V regulator, and a direct connection to the battery. All three paths will share a common ground. The battery will also have a connection set up to the charger to allow external attachment. This will use the same PCB model as the Pad Box.

4.3.2 Design



4.3.3 General Validation

The general purpose of this block is to supply ample power to the system for a period long enough unplugged to suit our design requirements. To do this the voltage and current output must match up with the other block/s in the system, the overall battery capacity must be sufficient in relation to the design requirements, and the additional features also described in the requirements must be implemented as well. The block I have designed and the components I have chosen meet these requirements when assembled together and in terms of supply, cost, and availability are all well within the margins of safety. The main part of the circuit is comprised of our Lithium-Ion (Li-on) battery. As shown in the Block Interface Validation table below, the power circuit will have to output a voltage value of around 5V and 1 A nominally, with some margin of minimum and maximum ratings. However, the battery in question as it is a two-cell battery exceeds this rating by a couple volts. The Tenergy 7.4V Li-ion 2200mAh Rechargeable Battery Module with PCB has a voltage 7.2V (peak at 8.4V), Capacity: 2200mAh, Dimensions: 2.69 x 1.45 x 0.7 inch, and a max discharge current of 3.3A. The capacity in question works perfectly for our pad box as it will need to operate wirelessly for a long period of time, with this capacity rating during constant operation the battery could last up to 2 hours. However, as the box will often be idling in standby it can be reasonably assumed it could last far longer during use.

The other addition to this block is its ability to recharge, this will be done utilizing two different items. The first being a simple smart charger specifically designed for Li-ion batteries to ensure safe charging without risking battery health. This will be used in tandem with a battery arming switch to ensure the battery is not connected to the circuit during charging. Both will be incorporated into the enclosure and accessed externally. Each of these parts according to distributers is well in stock and in no current danger of running out. Each component including the battery is relatively small in relation to the project requirements enclosure sizing including the potential size of the required PCB's to build the regulator circuit. While some of the components are more expensive, the pricing for the high capacity battery along with the coinciding charger which is required to ensure safe charging without potentially overcharging or damaging the battery is well worth the cost.

4.3.4 Interface Validation

Interface: otsd_pd_bx_pwr_crct_acpwr : Input

Inominal: 1 A	This value is based on the rated draw of the smart charger that will be connected to the AC outlet	The smart charger specification rates the charger for a 1 A draw, given the standard potential output of a US AC power outlet is well above 10 A it more than provides enough current to operate the device.
Ipeak: 1.5 A	This is the highest rated output of the smart charger before safety cutoffs occur	The smart charger specification rates the charger for a 1 A draw, given the standard potential output of a US AC power outlet is well above 10 A it more than provides enough current to operate the device. If the current input exceeds 1.5A the safety system is activated and the charger ceases function.
Vmax: 120 V	The maximum output voltage of standard US Wall outlets	US wall outlets are rated for a maximum output of 120V, given the voltage input of the smart charger is rated to be between 100-240V its is well within operable parameters.
Vmin: 110 V	Minimum output of US wall outlets considering standard +/10V variance.	US wall outlets are rated for a maximum output of 120V, given the voltage input of the smart charger is rated to be between 100-240V its is well within operable parameters.

Interface: pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Output

Inominal: 2.2 A	This value was found based around the expected current needs of the other system blocks.	This value is based on the max output of the battery, as much current as possible is required for the igniter the max output of the battery is taken as the nominal draw
Vmax: 8.4 V	This is the highest voltage we expect on our Li-ion battery	This value is based on the maximum output voltage of the battery. For a direct connection there will be little to no resistance besides the native resistance of the material it will be attempting to ignite.
Ipeak: 3.3 A	This is based on the expected needs of the control hardware	Utilizing the battery specifications the highest output current of the battery is 3.3 A
Vmin: 7.4 V	The value is based on the expected needs of the control hardware	The standard operating output of the battery is rated at 7.4V and will be considered the minimum draw as it will be a direct connection with the physical igniter

Interface: pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Output

Inominal: 100 mA	This is roughly what the ATmega328p and INA169 current sensor should draw when some LEDs are being driven.	The circuit will be designed with thick enough traces where it needs them to handle this current.
Ipeak: 200 mA	This is roughly the maximum current that the ATmega328p and INA169 current sensor should draw when all the LEDs and piezoelectric speaker are being driven.	The circuit will be designed with thick enough traces where it needs them to handle this current.

Vmax: 5.2 V	This is the value given voltage variation of the provided regulator output typical variation	Output voltage as shown in the L7805 datasheet the output of the regulator will be 5V slight variation of less than 0.3V. This coincides with the control hardware data sheet which shows a draw of 1.8V to 5.5V. Vin can range from 8-20V
Vmin: 4.8 V	This is the value given voltage variation of the provided regulator output typical variation	Output voltage as shown in the L7805 datasheet the output of the regulator will be 5V with slight variation of less than 0.3V. This coincides with the control hardware data sheet which shows a draw of 1.8V to 5.5V. Vin can range from 8-20V

Interface: pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Output

Inominal: 100 mA	The value is based on the expected draw of the control hardware	The NRF24L01+ transceiver module draws approximately 20 mA when in receiving mode, given the maximum output of the regulator is 800mA this is well within safety margins
Ipeak: 300 mA	The value is based on the expected draw of the control hardware	The NRF24L01+ transceiver module draws approximately 150 mA when in sending mode. given the maximum output of the regulator is 800mA this is well within safety margins
Vmax: 3.5 V	This is the value given voltage variation of the provided regulator output typical variation	Output voltage as shown in the LD1117V33 datasheet the output of the regulator will be 5V slight variation of less than 0.3V. This coincides with the control hardware data sheet which shows a draw of 1.8V to 5.5V. Vin can range from 8-20V

Vmin: 3.1 V	This is the value given voltage variation of the provided regulator output typical variation	Output voltage as shown in the LD1117V33 datasheet the output of the regulator will be 5V slight variation of less than 0.3V. This coincides with the control hardware data sheet which shows a draw of 1.8V to 5.5V. Vin can range from 8-20V

4.3.5 Verification Plan

Testing process for pd_bx_pwr_crct_igntn_hrdwr_dcpwr:
This process will be the same for all three busses
Testing Ipeak and Inominal:

1. Connect voltage regulator to breadboard positive and negative leads.
2. Using 2 jumper wires connect one to the positive bar and one to the negative with the other ends free.
3. Attach the battery to the corresponding bus circuit.
4. Using a multimeter branch the two wires.
5. Measure current.

Testing Inominal

1. Connect the voltage regulator to a breadboard that is connected to the launch control hardware circuit.
2. In between the regulator and the hardware attach two jumper wires along the same path with the leads remaining unattached to the circuit.
3. Attach the battery to the regulator circuit.
4. Using a multimeter branch the two free ends of jumper wires from step 2.
5. Measure current.

Testing Vmax and Vmin:

1. Connect voltage to breadboard positive and negative leads.
2. Affix a 220 ohm resistor to a point on the breadboard.
3. Using two jumper wires connect them to either side of said resistor.
4. Using a multimeter measure the voltage over the resistor by touching the positive and negative probes to opposite metal connectors coming out of the resistor.

4.3.6 References

Links:

L7805 data sheet
ATMega324P data sheet
LD1117V33 data sheet
Smart Charger specifications
NTE2987 datasheet

4.3.7 Revision Table

Date	Revision Number	Description	Author
3/6/22	5	Added all current documentation to the	Timothy Englehart

		Project Document	
1/21/22	4	Revised year on revision table dates. Completed interface validation table.	Timothy Englehart
1/18/22	3	Edited block description and updated testing process. Added circuit diagram. Added LD1117V33 3.3V regulator circuit, example test sheet, and description.	Timothy Englehart
1/8/22	2	Edited Block description and general validation. Drafted block interface validation and block testing process	Timothy Englehart
1/7/22	1	Drafted Sections: Block description and general validation	Timothy Englehart

4.4 Ignition Hardware

4.4.1 Description

This block consists of the PCB, CPU, transceiver, on/arming/wired-select switches, power MOSFET, and status display lights/speakers that comprise the ignition system. The CPU, transceiver, and power MOSFET will all be soldered to the PCB, and there will be pin-based connectors for the on/arming switches, power connection, and status display lights/speakers.

4.4.2 Design

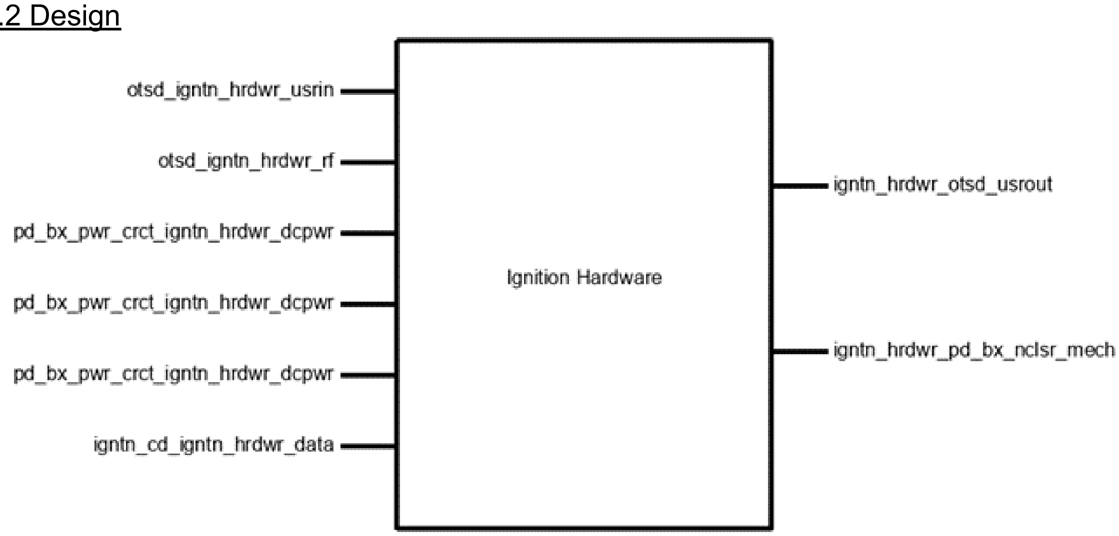


Figure 4.4.2.1: Black Box Diagram

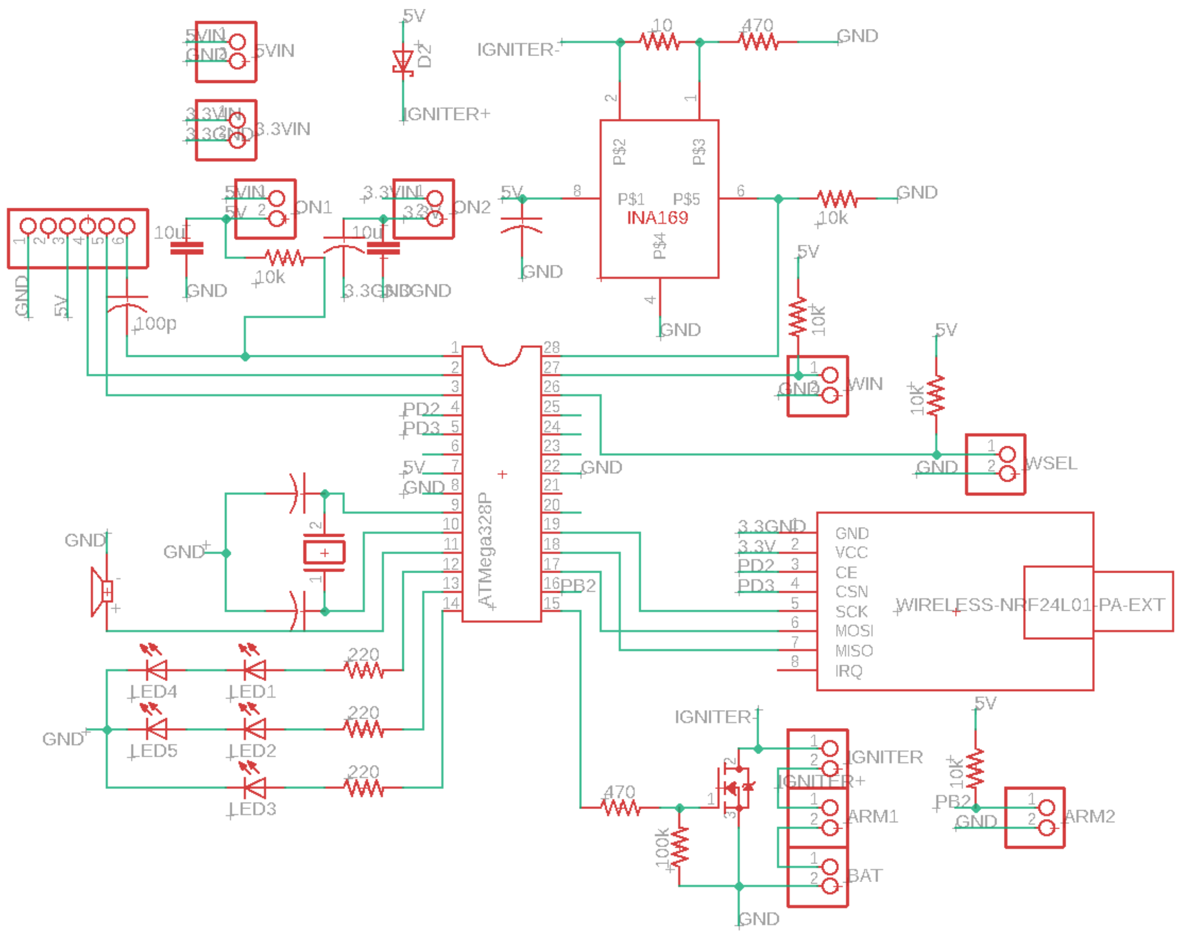


Figure 4.4.2.1: Schematic

4.4.3 General Validation

The block design presented above meets all the requirements that it covers in the general system requirements outlined in the project document. It contains a wireless transceiver that can receive a wireless launch signal from 2500 feet away, switches that turn the box on, block the battery path to the MOSFET, and select between wireless and wired connection, and LEDs and a piezoelectric speaker for clearly communicating the arming status of the device. The wireless transceiver operates at 2.4Ghz and is capable of sending and receiving data to/from a second transceiver located in the launch box. The continuity check is performed by the INA169 current sensor by sending a small amount of current through the igniter below the minimum ignition current. There is a 6-pin female header to program the microcontroller with a USB to TTL adapter. The DC power interfaces have all been specified within the expected operating power draws of the various devices that they are connected to. Finally, the components all have low idle power draw and are small and light.

4.4.4 Interface Validation

Interface Property	Why is this interface this value?	Why do you know that your design details <u>for this block</u> above meet or exceed each property?

otsd_igntn_hrdwr_usrin : Input

Type: On switch	The ignition hardware needs a way to turn it on.	My block design includes an on switch that is between the power supply and the whole circuit.
Type: Wireless/Wired Select Switch	The ignition hardware needs a way to switch between wired and wireless launch signal communications.	My block design includes a switch to select wired or wireless operation.
Type: Arming key	The ignition hardware needs a way to be turned on but unable to fire the igniter.	My block design includes an arming key that is between the power supply and the MOSFET.

otsd_igntn_hrdwr_rf : Input

Messages: Launch Command to Pad Box	The launch box must send the launch command to the pad box.	My block design includes the NRF24L01+, which is capable of receiving these messages.
Messages: Igniter Continuity Signal to Launch Control	The pad box must send the igniter continuity status to the launch box.	My block design includes the NRF24L01+, which is capable of sending these messages.
Protocol: 2.4GHz	The NRF24L01+ transceiver that we will be using uses this wireless protocol.	My block design includes the NRF24L01+, which uses this protocol.

igntn_hrdwr_otsd_usrout : Output

Type: Audio	There needs to be an audible warning that the device is on and armed so that people know to avoid the launch pad.	My block design includes a piezoelectric speaker that can be driven by a pin on the microcontroller to produce sounds.
Type: Visual	There needs to be a visual warning that the device is on, armed, and has continuity through the e-match so that people know to avoid the launch pad.	My block design includes 3 different LEDs to show the 3 different necessary pieces of information.
Usability: LEDs visible from 25 feet away in daylight by an observer	Anyone approaching the pad must be able to know the status of the box before getting too close for safety reasons.	The LED lights selected will be bright enough to be seen from this far away.

Usability: Sound audible from 25 feet away by an observer	Anyone approaching the pad must be able to know the status of the box before getting too close for safety reasons.	The piezoelectric speaker selected will be loud enough to be heard from this far away.

igntn_hrdwr_pd_bx_nclsr_mech : Output

Fasteners: 4 - M2 screws	The mounting holes on the enclosure and PCB must be coordinated to ensure that they fit together.	The PCB will be designed with 4 M2 screw holes.
Other: PCB between 1/4 and 1 inch off the inside enclosure surface	There must be adequate room between the PCB and the enclosure to provide airflow for cooling and to prevent shorts or unintended problems.	This is a definition that the enclosure design will incorporate.
Pulling Force: 20 pounds	There must be an adequate restraint mechanism to keep the PCB in place in case the ignition box gets dropped.	This is a definition that the enclosure design will incorporate.

pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Input

Inominal: 20 mA	The NRF24L01+ transceiver module draws approximately 20 mA when in receiving mode.	This is a definition that the power supply block will incorporate. The traces on the PCB will be thick enough to handle this current.
Ipeak: 150 mA	The NRF24L01+ transceiver module draws approximately 150 mA when in sending mode.	This is a definition that the power supply block will incorporate. The traces on the PCB will be thick enough to handle this current.
Vmax: 3.5 V	The NRF24L01+ transceiver module can take up to 3.6V as VCC. This value provides enough cushion to never go over this.	This is a definition that the power supply block will incorporate.
Vmin: 3.1 V	The NRF24L01+ transceiver module needs 1.9V minimum as VCC. This value provides enough cushion to never go under this.	This is a definition that the power supply block will incorporate.

pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Input

Inominal: 2.2 A	This is a sufficient amount of current to light most igniters.	The PCB traces will be thick enough to handle this amount of current and the MOSFET selected will also be able to handle it.
Ipeak: 3.3 A	This should be a sufficient amount of current to light any igniter.	The PCB traces will be thick enough to handle this amount of current and the MOSFET selected will also be able to handle it.
Vmax: 8.4 V	The voltage must high enough to drive the required current given the resistance in this circuit.	This is a definition that the power supply block will incorporate.
Vmin: 7.4 V	The voltage must high enough to drive the required current given the resistance in this circuit.	This is a definition that the power supply block will incorporate.

pd_bx_pwr_crct_igntn_hrdwr_dcpwr : Input

Inominal: 100 mA	This is roughly what the ATmega328p and INA169 current sensor should draw when some LEDs are being driven.	The circuit will be designed with thick enough traces where it needs them to handle this current.
Ipeak: 200 mA	This is roughly the maximum current that the ATmega328p and INA169 current sensor should draw when all the LEDs and piezoelectric speaker are being driven.	The circuit will be designed with thick enough traces where it needs them to handle this current.
Vmax: 5.2 V	The ATmega328p can take up to 6V as VCC. This value provides enough cushion to never go over this.	This is a definition that the power supply block will incorporate.
Vmin: 4.8 V	The ATmega328p needs 4.5V minimum as VCC. This value provides enough cushion to never go under this.	This is a definition that the power supply block will incorporate.

igntn_cd_igntn_hrdwr_data : Input

Messages: PWM audio signal sent to speaker	The piezoelectric speaker must be controlled by a PWM signal from a pwm output pin on the ATmega328p.	The piezoelectric speaker doesn't require much power, so it will be able to be driven by a 5V PWM signal from the Arduino.
Messages: Ignition command from transceiver	The ATmega328p must receive the ignition command from the transceiver to then turn the MOSFET on.	The Arduino will receive the ignition command from the transceiver via the SPI protocol.
Messages: Binary signals sent to power MOSFET	The MOSFET must be controlled by a digital output pin on the ATmega328p.	The MOSFET is logic level, meaning it can be driven by a 5V binary signal from the Arduino.
Messages: Binary signals sent to LED status lights	The LEDs must be controlled by digital output pins on the ATmega328p.	The LEDs don't require much power, so they will be able to be fully illuminated by a 5V binary signal from the Arduino.
Protocol: Programmed with USB to TTL programmer	The ATmega328p chip must be able to be programmed once installed on the PCB.	The PCB will contain 6 female pins to plug in a TTL programmer to the board.

4.4.5 Verification Plan

1. Create a test program that can be loaded onto the Arduino that will step through every function of the system to test, including the binary signals sent to the MOSFET and LEDs, and PWM signal sent to the piezoelectric speaker. Perform the LED and sound tests from 25 feet away to verify the distance requirement.
2. Verify that the MOSFET is capable of delivering enough current to an e-match by either attaching a small resistor and an ammeter in series or simply attaching an e-match and attempting to light it with the circuit and test program.
3. Create another test program that can be loaded onto the Arduino that will test the inputs to the block and display their values on the serial monitor.
4. Create a second Arduino/NRF24L01 pair with a program that sends a short test message to the ignition block Arduino/NRF24L01 pair.
5. Run the test programs on both systems and use the serial monitor to confirm the test message was received.
6. Verify that the other digital and analog inputs used for the device arming detection and continuity detection can detect signals using the serial monitor.
7. Verify that the DC inputs can handle the specified voltage and current ranges by attaching a DC power supply to each terminal and testing the range of values while ensuring continued functionality of the block.

4.4.6 References

[1] "NTE2987 Datasheet." https://www.nteinc.com/specs/2900to2999/pdf/nte2987.pdf (accessed Mar. 06, 2022).
[2] "INA169 Datasheet." https://www.ti.com/general/docs/suppproductinfo.tsp?distId=10&gotoUrl=https%3A%2F%2Fwww.ti.com%2Flit%2Fgpn%2Fina139-q1 (accessed Mar. 06, 2022).

[3] “ATmega328p Datasheet.” https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf (accessed Mar. 06, 2022).
[4] “NRF24L01+ Datasheet.” https://www.sparkfun.com/datasheets/Components/SMD/nRF24L01Pluss_Preliminary_Product_Specification_v1_0.pdf (accessed Mar. 06, 2022).

4.4.7 Revision Table

Date	Revision Number	Description	Author
1/21/2022	Rev 4	Updated general validation and references	Joshua Muir
1/20/2022	Rev 3	Updated interface validation table	Joshua Muir
1/6/2022	Rev 2	Initial draft of interface validation section.	Joshua Muir
1/5/2022	Rev 1	Initial draft of design and general validation sections.	Joshua Muir

4.5 Ignition Code

4.5.1 Description

This block contains all the code that runs on the ignition circuit CPU. It is responsible for listening to the transceiver for a launch command, monitoring the arming switch/continuity status and sending them over the transceiver, controlling the visual/auditory alerts, and turning the power MOSFET on to ignite the e-match. The operation of these various elements of the hardware block must be completely bug-free and well tested to ensure that all the safety features function properly 100% of the time considering the high-powered rocket motor that will be on the other end of the igniter that is directly controlled by this code.

4.5.2 Design

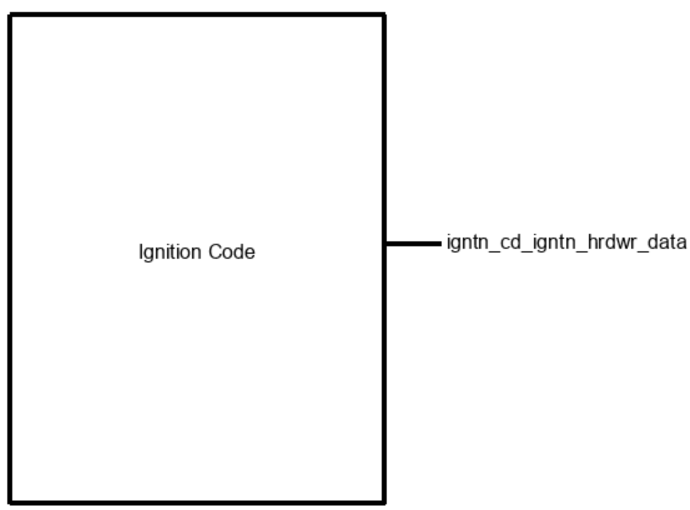


Figure 4.5.2.1: Black Box Diagram

```
Setup
    Establish radio settings
    Initialize all LEDs, buzzers, and MOSFET outputs to 0
Loop
    Check arming switch
        If armed
            Light armed LED and play tone on piezoelectric speaker
            Send armed signal to launch control box
            Check wired/wireless select switch
            If wired signal selected
                Check wired input
                If wired input = launch, turn on MOSFET
            If wireless signal selected
                Check ignition signal
                If ignition signal = launch, turn on MOSFET
        Else
            Send not-armed signal to launch control box
        If continuity detected
            Light continuity LED
            Send continuity signal to launch control box
        Else
            Turn off continuity LED
            Send discontinuity signal to launch control box
```

Figure 4.5.2.2: Pseudocode

4.5.3 General Validation

This block can accomplish all the tasks required of it because it uses well documented software tools. The ATMega328p used in the hardware block is the same processor used in an Arduino Nano, and so the Arduino IDE and libraries can be used. One such library is the RF24 library used to control the NRF24L01 radio over SPI. This will enable communication to and from the launch box with the launch command and arming/continuity signals. All other hardware features of the ignition box can be controlled with simple binary signals, which are easily generated within loops and based on conditions that will be checked by the code block. Finally, since the ATMega328p comes preloaded with the Arduino bootloader and there wiring for a USB-TTL programmer built into the hardware, the code can be easily uploaded to the hardware for testing throughout development and final deployment.

4.5.4 Interface Validation

Interface Property	**Why is this interface this value?**	**Why do you know that your design details for this block above meet or exceed each property?**
igntn_cd_igntn_hrdwr_data : Output		

Messages: Binary signals sent to power MOSFET	The code block must be able to precisely control when it turns on or off the MOSFET to either direct current through the igniter or not. This is accomplished by a binary signal.	Individual digital I/O pins on the ATMega328p are easily controlled within the Arduino C++ that will be used.
Messages: Binary signals sent to LED status lights	The code block must be able to control the LED status lights in the hardware block to alert the users when it is on/armed/has continuity across the igniter. This is accomplished with binary signals.	Individual digital I/O pins on the ATMega328p are easily controlled within the Arduino C++ that will be used.
Messages: Armed/Continuity signals to transceiver	The code block must be able to transmit messages to the launch box alerting it of the current arming status and continuity status for display on the launch box so the users know this information without needing to approach the pad.	The code block will use the RF24 library to communicate with the transceiver over SPI. This is capable of sending any type of data message to the NRF24L01 chip for transmission over RF.
Messages: Binary signals sent to piezoelectric speaker	The code block must be able to control the piezoelectric speaker in the hardware block to alert the users when it is on/armed. This is accomplished with a binary signal because the piezoelectric speaker has a set frequency that it plays.	Individual digital I/O pins on the ATMega328p are easily controlled within the Arduino C++ that will be used.
Messages: Ignition command from transceiver	The code block must be able to interpret the ignition command received by the transceiver from the launch control box to light the igniter when the users press the launch button.	The code block will use the RF24 library to communicate with the transceiver over SPI. This is capable of receiving any type of data message from the NRF24L01 chip received over RF. [1]

Protocol: Programmed with USB to TTL programmer	The code must be able to be easily programmed and iterated upon during development and testing. Also adding future functionality to the code in the future may be important depending on feedback from the users.	The hardware block has been designed with a 6-pin header connection for the USB to TTL programmer and this is compatible with the standard Arduino IDE programmer.

4.5.5 Verification Plan

1. Upload final code to the completed hardware block
2. If the launch command box is completed as well, use this to test the ignition command and armed/continuity signals. If not, create a mock launch command box with an Arduino nano and NRF24L01 transceiver module to simulate the messages using a test program and the serial monitor.
3. Repeat the previous step with the following combinations of switches flipped and igniters connected/disconnected to verify proper actuation of lights, piezoelectric speaker, and MOSFET.

- Igniter connected, wireless selected, device armed: All lights and speaker should be on and igniter should light when launch signal is sent
- Igniter disconnected, wireless selected, device armed: On and armed lights and speaker should be on and continuity light should be off, nothing will happen when launch signal is sent
- Igniter connected, wireless selected, device not armed: On and continuity lights should be on and armed light and speaker should be off, nothing will happen when launch signal is sent
- All of the above but with wired selected instead of wireless: All behavior should be the same, but nothing should happen if wireless launch signal is sent and instead wired signal should trigger igniter if armed and continuous

4.5.6 References

[1] “Optimized high speed nRF24L01+ driver class documentation.”
https://nrf24.github.io/RF24/ (accessed Mar. 06, 2022).

4.5.7 Revision Table

Date	Revision Number	Description	Author
2/15/2022	Rev 2	Updated description and verification plan sections.	Joshua Muir
2/3/2022	Rev 1	Initial draft of design and general validation sections.	Joshua Muir

4.6 Telemetry Hardware

4.6.1 Description

This block represents the processing circuitry that will display the rocket's telemetry information on the launch box system. Telemetry is flight information like vehicle speed, altitude, acceleration, and the angle from vertical. The High Altitude Rocket Team utilizes Altus Metrum products for flight computers and ground stations. The Teledongle is a wireless communication ground station that connects to the rocket's onboard flight computer. The Teledongle is a USB device and connects to a Raspberry Pi. The Raspberry Pi processes the data from the ground station for display.

4.6.2 Design

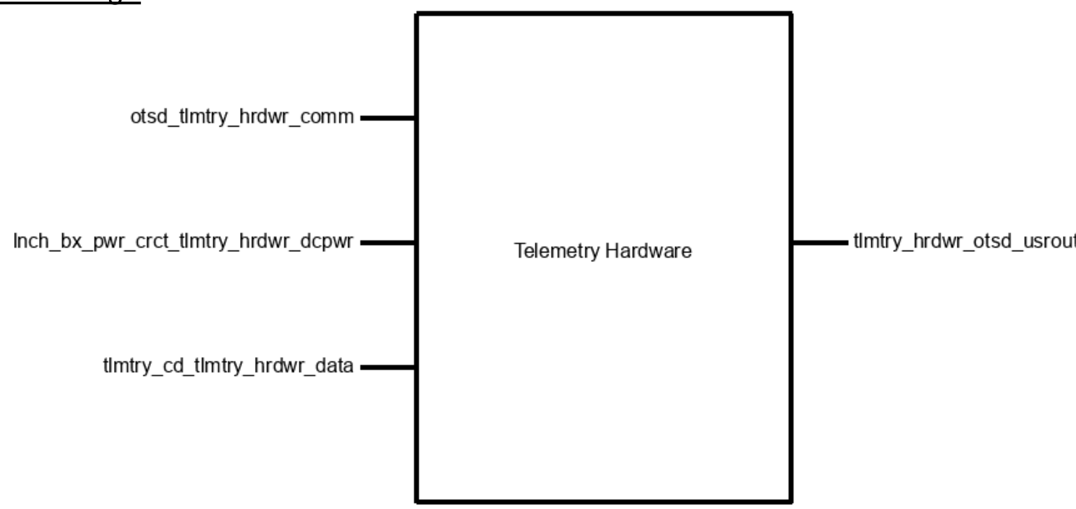


Figure 4.6 Black box diagram of the telemetry hardware block.

Components:

- Raspberry Pi 3b
- 2 20x4 Character LCDs
- USB 2.0 female connector

4.6.3 General Validation

The Raspberry Pi utilizes the Linux based operating system called Raspberry Pi OS. This enables native USB host operations which are needed for the Teledongle. The Raspberry Pi contains 4 full speed USB 2.0 ports. The Raspberry Pi also has GPIO pins associated with an I2C bus. This is used for communicating with the LCDs. The operating system allows for installation of the Altus Metrum AltOS which is the open source software associated with Altus Metrum products like the Teledongle and Telemega.

4.6.4 Interface Validation

otsd_tlmtry_hrdwr_comm : Input

Datarate: 12 Mbps	The Altus Metrum Teledongle used by HART utilizes a full speed (12 Mbps) USB 2.0 connection [2][3] [4].	The ATSAMD21 supports full speed USB 2.0 [1].
Protocol: USB	The Altus Metrum Teledongle used by HART utilizes a full speed (12 Mbps) USB 2.0 connection [2] [3] [4].	The ATSAMD21 supports full speed USB 2.0 [1].

Vnominal: 5 V	USB 2.0 uses a 5 V voltage bus [3].	The USB connector has a 5 V voltage bus.

lnch_bx_pwr_crct_tlmtry_hrdwr_dcpwr : Input

Inominal: .5 A	This is an overestimate of the current required by the block from the 5 V bus.	Current carrying conductors will be sized accordingly.
Ipeak: 1 A	This is the maximum current that the power block can provide from the 5 V bus to the Telemetry hardware block.	Current carrying conductors will be sized accordingly.
Vmax: 5.25 V	This voltage max protects the devices connected to the 5 V bus.	The power supply block defined this value and all components on the 5 V bus are sized to handle this voltage.
Vmin: 4.4 V	This voltage min ensures that devices on the 5 V bus can function properly.	The power supply block defined this value and all components on the 5 V bus are sized to handle this voltage.

tlmtry_hrdwr_otsd_usrout : Output

Other: Displays Acceleration	This is a telemetry value required by the project [5].	The Teledongle ground station provides this information to the microcontroller and the LCDs are capable of displaying characters [6].
Other: Displays Altitude	This is a telemetry value required by the project [5].	The Teledongle ground station provides this information to the microcontroller and the LCDs are capable of displaying characters [6].
Other: Displays Angle from Vertical	This is a telemetry value required by the project [5].	The Teledongle ground station provides this information to the microcontroller and the LCDs are capable of displaying characters [6].
Other: Displays Speed	This is a telemetry value required by the project [5].	The Teledongle ground station provides this information to the microcontroller and the LCDs are capable of displaying characters [6].

Type: Visual	This indicates that the user of the project will be able to see the listed telemetry values.	The LCDs are capable of displaying characters.

tlmtry_hrdwr_lnch_bx_nclsr_mech : Output

Fasteners: 4 - M3 screws	This is a generic fasten set. This is subject to change as other blocks develop more.	The enclosure and PCB will be designed with this fastener size in mind.
Other: PCB between 1/4 and 1 inch off the inside enclosure surface.	This provides mounting dimensions for the hardware inside the enclosure. This will be adjusted as the enclosure block is developed.	The enclosure will be designed with this in mind. .
Pulling Force: 20 pounds	This pulling for was selected to ensure rugged design of the mechanical connections.	M3 fasteners are listed at 1130 N proof load (254 lbs-force) [7].

tlmtry_cd_tlmtry_hrdwr_data : Input

Messages: Output digital LCD control.	This describes the software requirements that will be programmed to the microcontroller. The LCD screens will require coded outputs from the microcontroller.	The ATSAMD21 supports SERCOM instances capable of I2C communication [1].
Messages: Input serial data from Teledongle.	The Teledongle generates a serial packet that is communicated over USB. This serial packet contains a single line of text that contains information from the flight computer [6].	The ATSAMD21 supports USB device/host capabilities [1].
Protocol: Firmware will be written in C++, C, or Assembly.	This was selected because these are the file types supported in Atmel Studio [8]. Atmel Studio is the IDE that will be used to program and debug the ATSAMD21.	Atmel Studio supports C/C++, and assembly files using the GCC compiler [8].

4.6.5 Verification Plan

1. Connect display, keyboard, and mouse to Raspberry Pi.
2. Open ALTOS application.
3. Connect Teledongle to Raspberry Po.
4. Start up flight computer.
5. Connect to flight computer using the Teledongle and Raspberry Pi.
6. Verify Communication is established.

4.6.6 References

[1] “AltOS Telemetry.” https://altusmetrum.org/AltOS/doc/telemetry.html (accessed Mar. 06, 2022).

[2] “Raspberry Pi Documentation - Raspberry Pi OS.” https://www.raspberrypi.com/documentation/computers/os.html (accessed Mar. 06, 2022).

4.6.7 Revision Table

Date	Revision Number	Description	Author
3/6/2022	Rev 1	Initial Draft	Leif Miller

4.7 Telemetry Code

4.7.1 Description

This code block is the entirety of the launch box systems telemetry software. This software enables USB communication through the Telemetry Hardware. The Altus Metrum Teledongle ground station that is used by HART generates a data packet that contains telemetry information. This block will process the data packet from the ground station. Data processing includes reading the data packet, selecting the relevant information, and sending the information to user output hardware.

4.7.2 Design

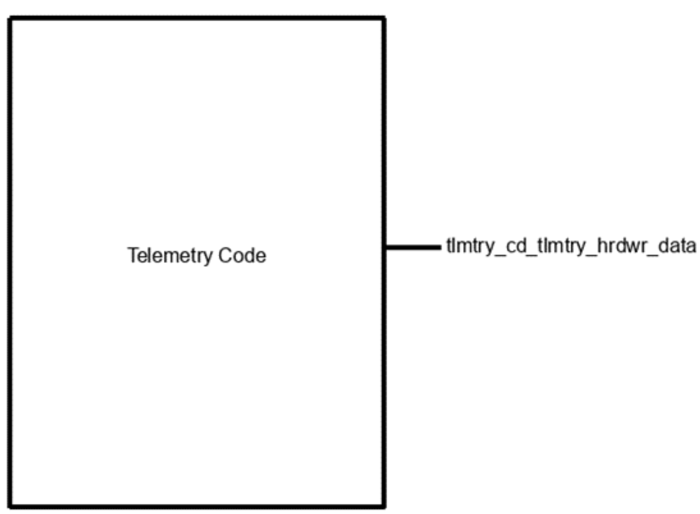


Figure 4.7 Black box diagram for telemetry code block.

Libraries:

PyUSB - a python USB library used for connecting to the Teledongle.
I2C_LCD_driver - a python library for sending LCD commands over an I2C bus.

Pseudocode:

```
Initialize USB connection
Initialize I2C bus
Initialize serial connection to Teledogle
while(serial link == true){
        read serial text
        copy relevant data
        send data to LCD
}
```

4.7.3 General Validation

The goal of this block is to read, interpret, and display rocket telemetry information to the user. The PyUSB library provides a framework for controlling USB ports of the Raspberry Pi. This allows a python program to be written to read the serial information from the Teledongle. The I2C_LCD_driver library provides the framework for controlling LCD displays over the I2C bus of the Raspberry Pi.

4.7.4 Interface Validation

tlmtry_cd_tlmtry_hrdwr_data : Output

Messages: Input serial data.	The input serial data property is required because of the Teledongle used by the team. The Teledongle is a USB device that communicates with the rocket's flight computer. This is how the required information from the rocket is received. [1]	The PyUSB is a python library capable of supporting USB operations. [2]
Messages: Output digital LCD control.	The overall goal of the telemetry system on the launch box is to display flight telemetry to the user. This property is based on the selection of I2C controlled 20x4 character LCDs..	The I2C_LCD_driver is a python library capable of controlling LCDs over I2C. [3]
Protocol: Firmware will be written in the Python	This was selected to ensure software compatibility.	A python IDE comes standard with the Raspberry Pi OS. [4]

4.7.5 Verification Plan

1. Power the Raspberry Pi with 5V DC.
2. Power the Altus Metrum Telemega flight computer with associated battery.
3. Connect Altus Metrum Teledongle to Raspberry Pi through USB.
4. Initiate serial radio communication between Teledongle and Telemega using the Raspberry Pi.
5. Verify telemetry information is displayed on the LCD.

4.7.6 References

[1] “AltOS Telemetry.” https://altusmetrum.org/AltOS/doc/telemetry.html (accessed Mar. 06, 2022).

[2] *PyUSB 1.0 - Easy USB access from Python*. PyUSB, 2022. Accessed: Mar. 06, 2022. [Online]. Available: https://github.com/pyusb/pyusb/blob/1caac015d1d62d4097eac00aa3ce244a01ebe5c3/docs/tutorial.rst

[3] S. C. | R. Pi | 92, “How to Setup an I2C LCD on the Raspberry Pi,” *Circuit Basics*, Mar. 25, 2016. https://www.circuitbasics.com/raspberry-pi-i2c-lcd-set-up-and-programming/ (accessed Mar. 06, 2022).

[4] “Raspberry Pi Documentation - Raspberry Pi OS.” https://www.raspberrypi.com/documentation/computers/os.html (accessed Mar. 06, 2022).

4.7.7 Revision Table

Date	Revision Number	Description	Author
3/6/2022	Rev 1	Initial Draft	Leif Miller

4.8 Launch Control Code

4.8.1 Description

This block contains the code for the Launch Control Hardware. It manages the signals to be sent out to the Ignition Hardware to launch the rocket. It also manages which lights should display on the Launch Control Hardware for the status of the box.

4.8.2 Design

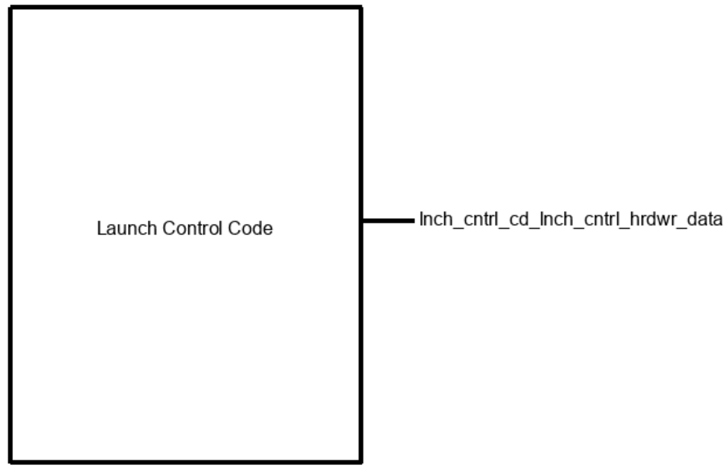


Figure 4.8.2.1: Launch Control Code black box diagram.

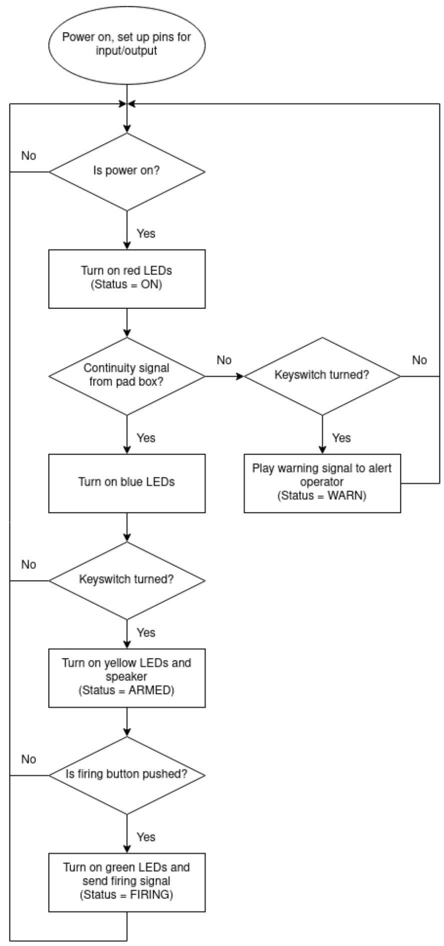


Figure 4.8.2.2: Launch Control Code pseudocode flowchart

4.8.3 General Validation

This code allows the ATMega328p to function as the launch controller and to communicate with the operator and pad box. By interpreting user input through buttons and switches and pad box feedback, the launch controller can tell what state the box is in and the code will allow the launch box to behave appropriately. This state is then communicated to the operator through the launch box hardware. If the box is in the FIRING state, the command to fire the igniter using the pad box hardware is sent to the pad box. This will allow function of the block as the ATMega328p at the heart of the launch box hardware will not achieve these functions on its own.

4.8.4 Interface Validation

Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
lnch_cntrl_cd_lnch_cntrl_hrdwr_data: Output		

Messages: Audio Control	The code must control the piezoelectric speaker to serve as a warning to the user.	PT-4175PQ Datasheet. ATMega328p general IO pins can output the voltage input to V_{dd}. This means that the pin will output 5V in this design, enough to drive the speaker.
Messages: Binary signals to LED status lights	The code must control the LED status lights to indicate what arming state the system is in and if there is continuity at the pad box.	ATMega328p Datasheet. ATMega328p general IO pins can be configured to be digital output of either binary HI or LO signals.
Messages: Arming status	The status of the system must be represented to the user in order to maintain safety of the launch site.	ATMega328p Datasheet. The ATMega328p is very versatile in its functions and will be able to be coded to handle the IO requirements of a signaling system such as this.
Protocol: Coded in C or C-like software	Familiarity with C-like languages makes implementing the code in C much easier than it may be in other languages.	Arduino Introduction Page - "...and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based."

4.8.5 Verification Plan

1. Assemble the launch control hardware and set up a laptop with the Arduino IDE and code.
2. Display the code to show that it is written in a C-like language, then program the hardware with said code.
3. Display the various states of the hardware and show that they behave according to the flowchart shown above.
4. Show that the code can receive a continuity signal and transmit a firing signal through the hardware.
5. If all the above tests succeed, the verfication is complete.

4.8.6 References

PT-4175Q Datasheet
ATMega328p Datasheet
Arduino Introduction

4.8.7 Revision Table

Date	Revision Number	Description	Author

02/18/2021	Rev 1	Created Block 2 Validation form. Imported skeleton from online tool. Details filled out.	Kenton Bender

4.9 Launch Control Hardware

4.9.1 Description

This is the hardware to control authorization and launch of the rocket from a distance. It contains a microcontroller, buttons, LEDs, and transceiver. It receives power from the power circuit block and has its own set of code to run for operation in another block.

4.9.2 Design

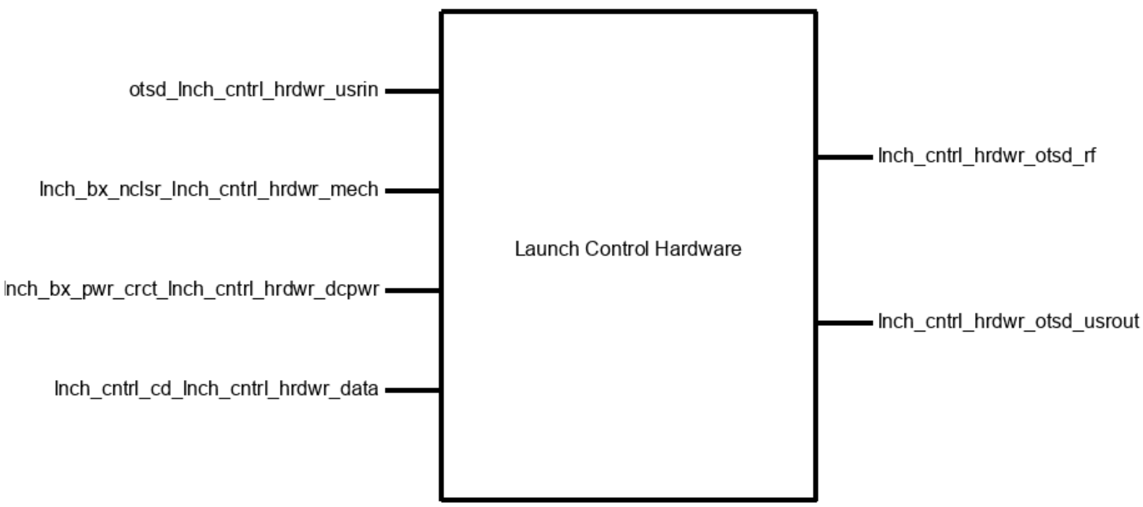


Figure 4.9.2.1: Launch Control Hardware black box diagram

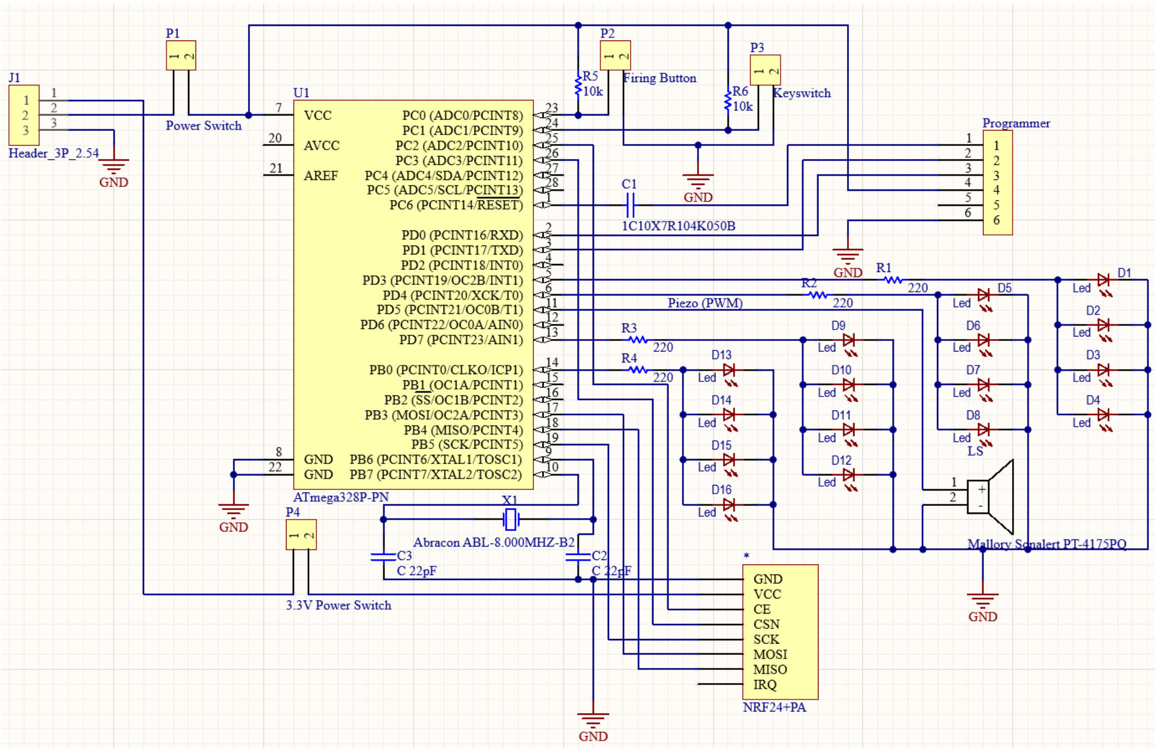


Figure 4.9.2.2: Launch Control Hardware Schematic

4.9.3 General Validation

The block's design is mostly ensuring the function of communication between the two major components of the system and allowing the human operation of the system. By choosing simple mechanisms such as key switches, push buttons, and obvious audiovisual feedback, the status and operation is conveyed in a simple fashion. The ATMega324p allows for the simple conversion through code of authorization signals into coded messages to be sent to the pad box to fire the motors. By transmitting over 2.4GHz, we also have an available band that can be operated by anyone, not just those with a HAM license. The simplicity of the block's function allows for the PCB which will connect components to also be simple, removing points of failure that might arise due to complexity of the design.

4.9.4 Interface Validation

Interface Property	Why is this interface this value?	Why do you know that your design details for this block above meet or exceed each property?
otsd_lnch_cntrl_hrdwr_usrin: Input		
Type: Arming key	The system will need a safe way of only allowing authorized users to arm and fire the rocket motors.	[KO Series switch datasheet.]()

Type: Pushbutton	By keeping the arming system simple, it allows for the use of the box to be relatively self-explanatory.	PLP16 Datasheet.
Usability: Key requires simple 90 degree turn	Like the arming key, the firing button should be self-explanatory and simple for anyone to pick up and understand the function.	See above. Datasheet details a simple 90 degree turn to actuate the switch.
Usability: Button requires at least 1lb of force to depress	The button should not be able to be pressed without purpose, such as by accidentally brushing a hand along it. There must be a decent minimum force to operate the firing mechanism.	See above. Datasheet details an operating force of 3.0.

lnch_cntrl_hrdwr_otsd_rf: Output

Messages: Igniter continuity signal from pad box	The system must show when the igniter is connected for safety reasons.	The ATMega324p is able to be coded to receive data from the NRF24L01 and then send the signal out to the indicator lights.
Messages: Launch Authorization to pad box	An authorization code is necessary to ensure that garbage signals and noise do not trigger a launch on accident.	The ATMega324p is able to be coded to receive digital input from the switches and then send the signal out to the NRF24L01 transmitter.
Protocol: 2.4GHz band	The transceiver in both the launch box and pad box will operate on the 2.4GHz band.	NRF24L01 Datasheet. This chip allows transmission at 2.4 to 2.5GHz.

lnch_cntrl_hrdwr_otsd_usrout: Output

Type: Visual	The user must be able to read the current status of the launch system to maintain a safe launch environment.	LED indicator datasheet.
Type: Audio	The status of the launch should be evident so that safety protocols can be easily maintained by both the operator and others.	PT-4175PQ Datasheet.

Usability: Sound audible from 25 feet away by an observer	The alarm will sound to alert the operator that the system is armed and ready to fire to make double sure that the operator knows they are one press away from launching.	[PT-4175PQ Datasheet.](#) [PT-4175PQ application guide.](#)
Usability: LEDs visible from 25 feet away in daylight by an observer	Same reasoning as audio. Must maintain ability for operator and others to assess safety. Without visual on the system.	[LED indicator datasheet.](#)

lnch_bx_nclsr_lnch_cntrl_hrdwr_mech: Input

Fasteners: 4 - M3 Screws	Our screws are standardized for compatibility and to make assembly and disassembly easy.	
Other: PCB between 1/4 and 1 inch off of inside of enclosure surface	In order to provide space for components within the box, this dimension was chosen.	
Pulling Force: 20 pounds	A 3D printed enclosure should be able to handle 20 pounds of force and it is a reasonable drop force to handle.	

lnch_bx_pwr_crct_lnch_cntrl_hrdwr_dcpwr: Input

Inominal: 100mA	Expected power draw of the ATMega324p is low, even at 1MHz and 5.5V. LEDs typically max out at 20mA, and the piezo speakers are generally low power devices.	[ATMega324P datasheet.](#) [LED indicator datasheet.](#)
Ipeak: 300mA	Same as above.	[ATMega324P datasheet.](#)
Vmax: 5.25 V	ATMega324p can take 5V power, this is within specs.	[ATMega324P datasheet.](#)
Vmin: 4.4 V	Same as above.	[ATMega324P datasheet.](#)

lnch_bx_pwr_crct_lnch_cntrl_hrdwr_dcpwr: Input

Inominal: 10 mA	The NRF24L01 is a very low power device. It should not take much power to utilize the device.	[NRF24L01 datasheet](#)

Ipeak: 20 mA	Same as above.	NRF24L01 datasheet.
Vmax: 3.5 V	Power supply range for the NRF24L01 is from 1.9V to 3.6V. This is within spec.	NRF24L01 datasheet.
Vmin: 3.1 V	Same as above.	NRF24L01 datasheet.

lnch_cntrl_cd_lnch_cntrl_hrdwr_data: Input

Messages: Arming status	The ATMega324p must inform the operator that the system is armed and on standby.	ATMega324P datasheet.
Messages: PWM Audio	The ATMega324p must control the signaling to the piezoelectric speaker to inform the operator the system is ready to fire.	ATMega324P datasheet.
Messages: Binary signals to LED status lights	The ATMega324p must control indicators informing the operator of continuity status and system status.	ATMega324P datasheet.
Protocol: Coded in C or C-like software	All members of the team are familiar with C and can code competently within this language. In addition, AVR microcontrollers can be coded in AVR C.	ATMega324P datasheet.

4.9.5 Verification Plan

otsd_lnch_cntrl_hrdwr_usrin:

1. Inspect the system. Ensure that button and key switch are present.
2. Insert key and test key switch to see that a 90° turn is the activation method.
3. Take a 1lb weight and set it on top of the button. If it does not actuate, then the interface has passed verification.

lnch_cntrl_hrdwr_otsd_rf:

1. In code, ensure that a clear launch authorization message is being sent when appropriate and a continuity message is being checked for.
2. Using an oscilloscope on the antenna of the NRF24L01, ensure that the signal is 2.4GHz. If it is, the interface has passed verification.

lnch_cntrl_hrdwr_otsd_usrout:

1. Inspect the system. Ensure that the piezoelectric speaker and four LED indicator lights are present.
2. Set up a 100Ω resistor in series with a parallel network of four LED indicators. Apply 5V across the resistor-LED network. Ensure indicators are visible from 25 feet away.
3. Using a square wave generator, apply a 750Hz square wave across the piezoelectric speaker. If this is audible from 25 feet away, then the interface passes verification.

lnch_bx_nclsr_lnch_cntrl_hrdwr_mech

1. Ensure the block attaches to the enclosure using 4 M3 screws.
2. Using a ruler, measure the standoffs the block uses to attach to the enclosure. Ensure these measure no less than ¼ inch and no more than 1 inch.
3. Attach a 20lb weight to the enclosure. Using a spare unbuilt PCB to minimize risk to functional parts, lift the enclosure by the PCB. If the enclosure does not break off, the interface passes verification.

lnch_bx_pwr_crct_lnch_cntrl_hrdwr_dcpwr

1. Attach the power circuit to the block. Turn on the ATMega324p and one set of LEDs. Ensure the current draw is 100mA ± 10%.
2. Turn on all lights and piezoelectric speaker. Ensure the current draw is 300mA ± 10%.
3. Measure the voltage output of the power circuit for one minute each in all states: standby, armed, ready to fire, and firing. If the voltage does not go above 5.25V or below 4.4V, the interface passes verification.

lnch_bx_pwr_crct_lnch_cntrl_hrdwr_dcpwr

1. Attach the second power circuit interface to the block. Turn on the ATMega324p and the NRF24L01.
2. Transmit a signal using the NRF24L01 for one minute. If the average current draw is 10mA ±10%, the peak current draw is 20mA ± 10%, the maximum voltage does not exceed 3.5V, and the minimum voltage does not go below 3.1V, the interface passes verification.

lnch_cntrl_cd_lnch_cntrl_hrdwr_data

1. Open the code.
2. Inspect to ensure that a state exists for each of the following: standby, armed, ready to fire, and firing.
3. Ensure that a continuity signal indication control code exists.
4. Ensure that a PWM control signal of 750Hz exists.
5. Ensure the code is in a C or C-like language. If so, the interface passes verification.

4.9.6 References

NRF24L01 Datasheet
ATMega328p Datasheet
PT-4175Q Application Guide
PT-4175Q Datasheet
LED Datasheet
KO Series Switch Datasheet
PLP16 Pushbutton Datasheet

4.9.7 Revision Table

Date	Revision Number	Description	Author
1/21/2021	2	Updated to use pre-formatted document. Added verification plan, revision table, and references section. Filled out details for interface validations.	Kenton Bender
1/14/2021	1	Initial document creation.	Kenton Bender

5.1 Universal Constraints

5.1.1 Breadboard

The ignition, launch control, power, and telemetry electronics do not utilize breadboards in their implementation. The ignition, launch control, and power subsystems contain custom PCBs alongside module boards. The telemetry system utilizes a Raspberry Pi and LCD modules.

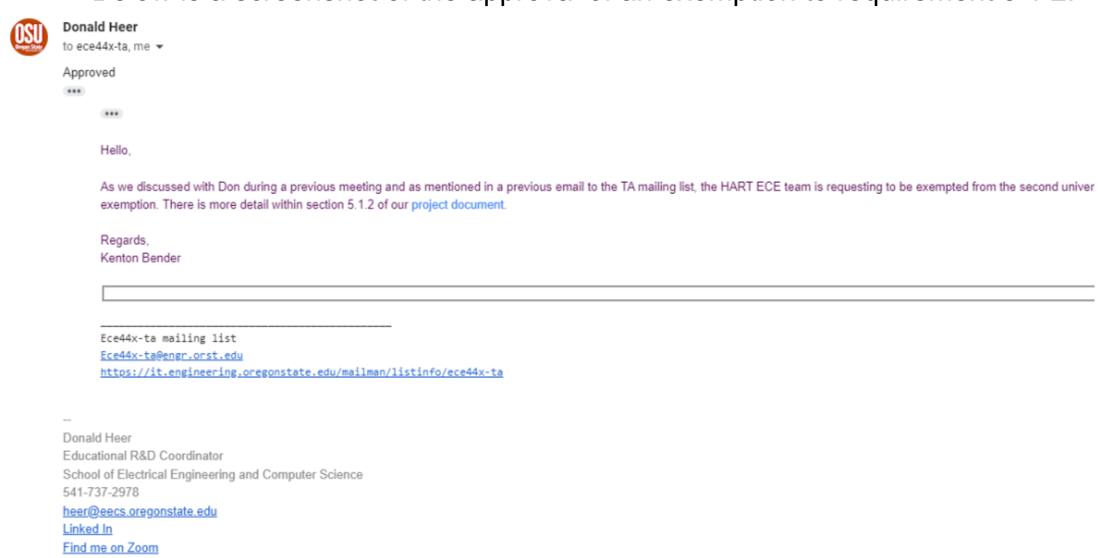
5.1.2 PCB/Application

The requirements set by the project partner have the team designing 3 custom PCBs. We believe that the application universal constraint is not compatible with project goals. HART is invested in using an open source flight computer called the Altus Metrum Telemega. This flight computer performs telemetry data logging that can be retrieved after recovery. The flight computer also has the ability to wirelessly transmit this information to a laptop running AltOS.

The project partner desired that the launch box be a self contained unit that does not require a laptop. The goal of the telemetry display is to utilize the wireless transmission performed by the Telemega but display critical information on the launch box itself. This would allow the team to conduct launches with nothing other than a rocket and the launch box system. The launch box is not required to do any data logging. Previous launch box designs have utilized applications alongside laptops which has at times been an issue. The applications were not compatible on everyone's computers and there is a large amount of software required for team members already.

The team's current plan is to not write a custom PC/Android/Cloud application. This will help to eliminate the need for a laptop at a launch site and reduce the amount of software downloads required of team members. This plan was discussed with Don during the section 3 review session. Don mentioned to draft this section with our reasons as a reminder. We also emailed this section to the TA mailing list to ensure that this plan is fine.

Below is a screenshot of the approval of an exemption to requirement 5.1.2:


Donald Heer
to ece44x-ta, me

Approved

Hello,

As we discussed with Don during a previous meeting and as mentioned in a previous email to the TA mailing list, the HART ECE team is requesting to be exempted from the second univer
exemption. There is more detail within section 5.1.2 of our project document.

Regards,
Kenton Bender

Ece44x-ta mailing list
Ece44x-ta@engr.orst.edu
https://it.engineering.oregonstate.edu/mailman/listinfo/ece44x-ta

--
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5.1.3 Rugged Enclosure

The purpose of the enclosure is to safely hold all the electronic components and as requested from the project partner said the enclosure must also be resistant to dust and minor amounts of water. While all launches must occur during good weather conditions rain is not to be expected but remnants of previous snow falls, morning dew, or fog can cause a build up of water and the box should be able to at the very least prevent that from intruding and damaging the components. The resistance to dust is due to the proximity of the pad box to the rocket itself, with large amounts of smoke and dust kicked up during any launch the box should be able to withstand that as well. The box must also generally be able to withstand simple falls and weight to allow for storage/transportation without extra need to carefully store or protect the box

The launch box will also be devised to accommodate all electronic components with specified slots along with screw holes where applicable. These measurements and slots are based on the size specifications of the other blocks and as such require the size specifications of other related boxes to be completed before the design is completed.

5.1.4 Connectors

Connections outside of the enclosure include USB, ignitors, and coax. The USB connection through enclosure is accomplished by mounting a female USB 2.0 connector through the side of the enclosure. This allows the ground station to be plugged into the enclosure. The ignitors use a similar method but instead contain two screw terminals for the exposed conductors of the ignitor to be screwed into. The screw terminal connector is mounted through the side of the enclosure. The coax connectors are attached to the LoRa modules. These modules and the PCBs they are attached to are mounted inside the enclosure to ensure the antennas extend outside the enclosure.

5.1.5 Power Supply Efficiency

The power supply is based on a battery system that must be at least 65% efficient which relates to the input voltage and current from the battery as compared to the drawn voltage and current of the various electronics. Meaning there will be different efficiency ratings depending on the connections and which voltage rail is being used, however as during a redesign the express need for the 3.3V rail was removed to a degree, it will not be tested alongside the 5V rail utilizing a simulated load. The other rail utilized is the direct connection, as it is a direct line to the battery it is considered 100% efficient. Based on basic calculations utilizing the current and voltage output to the various components measured during operation of the 5V rail to the hardware and the measurements at the input of the circuit a simple power calculation can be used to determine the efficiency.Testing the circuit we found an input voltage of 7 ~ 7.1 V and 30 ~ 31 mA and an output to the hardware of 28 ~ 29 mA and 5 ~ 5.01 V which results in an efficiency of about 67% satisfying the requirement.

5.1.6 Purchased Modules

The purchased modules within the system are as follows: two LoRas - one within both the pad and launch box, a Raspberry Pi, an LCD screen, and a power module for the Raspberry Pi. This is five modules. The student-designed modules are as follows: the launch box PCB, pad box PCB, launch box code, pad box code, launch box circuitry, pad box circuitry, power module PCB, power module circuitry, and pad box enclosure. This is nine modules. Thus, our purchased modules make up much less than 50% of the total number of modules, meaning we fulfill this universal constraint.

5.2 Long Range

5.2.1 Requirement

Launch box will communicate wirelessly with the pad box from a range of at least 2500 feet.

5.2.2 Testing Processes

1. Find a flat field or road with minimal obstructions for at least half a mile.
2. Turn on the launch box and pad box right next to each other.
3. Ensure that the launch box and pad box are properly communicating, this is signified by the periodic beeps and green LEDs being illuminated.
4. Walk the pad box along the flat field or road up to a distance of 2500ft, ensuring that radio connection is maintained the entire way.
5. If the launch box is still beeping and the green LEDs are still illuminated at a distance of over 2500ft, the requirement is verified.

5.2.3 Testing Evidence

VIDEO LINK

5.3 Live Telemetry

5.3.1 Requirement

The launch box will connect to the Telemega flight computer and display telemetry information using the associated ALTOS application.

5.3.2 Testing Processes

1. Attach Teledongle and Antenna to Launch Box.
2. Turn on the Telemega flight computer.
3. Turn on the Launch Box.
4. Connect to the Telemega using the Teledongle.
5. Verify Teledongle and launch box are communicating with callsign 'KK7BXH'. (This is the callsign for the test Telemega.)
6. Verify that battery voltage is displayed on the launch page.
7. Verify that the ascent page displays within 2m of 0 height.
8. Verify the age of the information in ALTOS is less than 5 seconds.

5.3.3 Testing Evidence

VIDEO LINK

5.4 Safety Key

5.4.1 Requirement

Launch box must include a mechanical safety switch that can only be actuated with a key that prevents the transmission signal from being sent.

5.4.2 Testing Processes

1. Program the launch hardware.
2. Turn on the launch hardware.
3. Ensure that the safety keyswitch is in the SAFE position.
4. Press the firing button and observe that the igniter does not fire.
5. Turn the safety keyswitch to the ARMED position.
6. Press the firing button and observe the igniter being ignited.
7. If behavior is consistent with the check steps above, the system has passed.

5.4.3 Testing Evidence

VIDEO LINK

5.5 Quick Ignition

5.5.1 Requirement

Pad box must ignite e-match within three seconds of pressing the launch button on the launch box.

5.5.2 Testing Processes

1. Install an igniter in the output terminals of the Pad Box.

2. Turn on and arm Pad Box, then move to a safe distance of at least 10 feet away.
3. At a safe distance from the Pad Box, turn on the Launch Box.
4. Once the Launch Box operator has confirmed that the Pad Box operator has armed the Pad Box and stepped away, arm the Launch Box.
5. Press the launch button on the Launch Box and start a stopwatch at the same time.
6. Monitor the igniter for ignition and stop the stopwatch when it ignites.
7. If the stopwatch reads under 3 seconds, the requirement is passed.

5.5.3 Testing Evidence

VIDEO LINK

5.6 Portable

5.6.1 Requirement

Each launch box system enclosure must be smaller than 12in x 12in x 12in and have a weight of less than 10 pounds.

5.6.2 Testing Processes

1. Set up a scale and ensure it reads zero on activation.
2. Set the launch box on scale and weigh to ensure it is less than 10 pounds.
3. Remove the launch box from the scale and repeat step 1.
4. Set the pad box on scale and weigh to ensure it is less than 10 pounds.
5. Confirm both boxes are less than 10lbs then continue to step 6
6. Measure the launch box assembly using a ruler to ensure it is within limits of 12”x12”x12”
7. Measure the pad box assembly using a ruler to ensure it is within limits of 12"x12"x12"
8. If both boxes fall within the designated measurements then the requirement is passed.

5.6.3 Testing Evidence

VIDEO LINK

5.7 Battery Life

5.7.1 Requirement

Launch box and pad box must be able to be powered on for 2 hours and still fire an e-match after this time.

5.7.2 Testing Procedure

1. Set up both the pad box and launch box in the same room within 10 feet of each other.
2. Power up both the pad and launch box.
3. Install an e-match in the pad box terminals.
4. Prepare to fire e-match.
5. With the system is a armed ready to fire state wait 30 minutes.
6. After the 30 minutes has elapsed, press the fire button to ignite the e-match.
7. Safe both boxes without removing power.
8. Repeat steps 3, 4, 5, and 6 three more times.
9. The system has passed if all e-matches fired correctly.

5.7.3 Testing Evidence

VIDEO LINK

5.8 Arming Status

5.8.1 Requirement

The launch box must use four unique visual indications and two unique audio indications representing the status of the system. The visual statuses are power, igniter continuity, pad/launch box armed, and the audible statuses are system idle and system armed. The pad box will have three unique visual and two unique audio indications of system status.

Visual statuses will indicate power on, igniter continuity, and system armed, and audio statuses will indicate system idle and system armed/continuous. All audible and visual state cues will update within 1 second of state change.

5.8.2 Testing Processes

1. Power on the launch box. Check that the power light is on.
2. Power on the pad box. Check that the power light is on.
3. Connect the terminals on the pad box to achieve continuity. Check that the continuity light on both pad and launch box turn on.
4. Arm the pad box. Check that the pad box arming light is on for both the pad and launch box and the pad box speaker is indicating armed status.
5. Arm the launch box. Check that the launch box arming light is on for the launch box and that the launch box speaker is indicating armed status. If all checks have passed, the system has passed verification.

5.8.3 Testing Evidence

VIDEO LINK

5.9 Ease of Use

5.9.1 Requirement

A user manual will be created for the launch box system that an operator without extensive electrical and computer knowledge is able to follow. The manual will include set-up, operation, and troubleshooting sections and must allow the user to set up the system within 30 minutes

5.8.2 Testing Procedure

1. Give the launch box, pad box, and manual to a HART member unfamiliar with the system.
2. Instruct the HART member to assemble the system according to the manual.
3. Set a timer for 30 minutes.
4. If and when the assembly is complete within the time limit, check to see if the system will fire an e-match as assembled.
5. Repeat this test until 3 members have tested the system. If at least 2/3 tests are successful, then the system has passed.

5.8.3 Testing Evidence

Video Link

5.10 References and File Links

5.11 Revision Table

Date	Revision Number	Description	Author
5/2/2022	Rev 4	Updates Video Links to Verification Videos	Leif Miller
4/22/2022	Rev3	Updated sections 5.3 and 5.9.	Leif Miller
4/21/2022	Rev 3	Added sections 5.4 and 5.7 as well as subsections. Filled section with proper content.	Kenton Bender
4/21/2022	Rev 3	Updated section 5.3 testing instructions, added new hyperlink for testing evidence. Updated section 5.1.5 with exact measurements of	Timothy Englehart

		system and calculation result. Added Section 5.8 with corresponding 5.8.1, 5.8.2, and 5.8.3	
3/6/2022	Rev 2	Created and populated Section 5.2	Kenton Bender
3/6/2022	Rev 2	Created and populated Section 5.3	Joshua Muir
12/3/2021	Rev 1	Created Section 5.1.2 to discuss application constraint.	Leif Miller

6.1 Future Recommendations

6.1.1 Technical

6.1.1.1 Connectors

We recommend that future teams carefully consider the type of connectors used for connecting various components like PCBs and barrel jack plugs for ignitor terminals. We simply used standard male and female pins with no type of mechanical retention other than metal-to-metal friction, which are already starting to become slightly worn down. Repeated connecting and disconnecting of these connectors will further weaken them, causing them to potentially come loose during transport. Something like a JST connector would be better, as it provides better connection retention and is polarity sensitive, another potential problem with our current setup.

6.1.1.2 Wireless Modules

We recommend that future teams carefully consider the type of wireless communication modules that they use for wireless communication between boxes. In our initial designs, we used modules called the NRF24L01, which presented countless problems and were incredibly unreliable. This necessitated a last-minute switch to modules called the RFM95W, which were much better. While this solved our issues, the switch came after we had already ordered PCBs that were designed with the old wireless modules in mind, so making such a late change added extra cost and work that could have been avoided with better planning and more thorough research prior to component selection.

6.1.1.3 Telemetry Screen/ ALTOS Application

It is recommended that a solution be found to the application sizing inconvenience. Currently when the ALTOS application is opened on the 5 inch capacitive touch screen to monitor flight scrolling is required to see all information.This is due to the way the creators of ALTOS programmed the user interface. The user interface was not sized for such a small screen. One possible solution would be to select a larger screen that the application is already equipped to handle. This has some downsides as the larger screen would likely be more expensive and take up more space. Perhaps redesigning the enclosure to have the screen on the lid of the box as oppose to the faceplate might be possible. The other option is to build the application from the source files. Instructions for how to do this are on the Altus Metrum website. Building from source files allows you to alter the java files that make up the application. Someone with java UI experience could probably find the appropriate files and adjust values so that the UI sizes correctly on the smaller screen. The downside of this is the complexity of building from source files as well as understanding and alter the creators code. The ideal situation would be for the entire page of information is displayed all at once and only requiring the user to click to other pages of the application if required instead of scrolling.

6.1.1.4 Enclosure

Another recommendation is for future teams to improve the enclosure. Currently the system is only water and dust resistant with the lids of the boxes closed. The boxes must be open for operation and due to the remote and usually dusty nature of launch sites HART visits it would be beneficial to be dust resistant throughout operation. The faceplate could be redesigned to meet this requirement. This would include redesign of the speakers, LEDs, and antenna connections to prevent large holes in the faceplate that enable dust to enter the internal compartments. Also implementing a way to charge the batteries without removing the faceplate would help make the internal compartment more isolated. Water and dust incursion is considered likely due to the operating conditions of the product and we recommend an updated design to address this concern.

6.1.2 Global Impact

6.1.2.1 E-waste

We recommend that future teams carefully consider attempting to reduce the number of electronic components used within the design. Reducing the amount of components and thus the amount of waste produced by the project when components break would reduce the impact of the project. Making more efficient design choices in future revisions would aid in reducing e-waste and allowing for less toxic metals and plastics circulating within the ecosystem.

6.1.2.2 Price and Longevity

We recommend that while it may be more expensive financially to invest in stronger components in regards to connectors, switches, and the thickness of the plates used for the enclosures. This is for the purpose of longevity to ensure the boxes can last longer, be used more often in various situations and with lower risk of failure or accidental damage. As for example damage to the enclosure plates would constitute an entire 3D reprint which long term would cost more than to print them with stronger material and higher density infill. The same applies to all components, to effectively balance affordable yet always reliable parts as the cheaper options may end in more failure and require much more work or replacement than if one went with the more expensive yet reliable option for mass production.

6.1.3 Teamwork

6.1.3.1 Frequent Meetings

While it may seem like a pain to meet with your group more than one time per week, we recommend that you do. Having at least one or two short check-in meetings per week can be extremely beneficial, as it allows everyone to stay on the same page about the work that everyone else is doing. Furthermore, if a team member is struggling with a specific part of the project, more frequent check-ins will allow for them to get more support earlier, rather than struggling alone for a week or more before seeking help from a team member or instructor.

6.1.3.2 Open Communication
Allowing open communication for your group, especially around due dates, is critical. Having several lines to talk between the group with one that everyone monitors often will make getting critical information delivered to team members guaranteed. Furthermore, ensuring that that channel is not cluttered with extraneous details should also be a priority so that members do not mute these lines and miss important dates and deadlines.

6.2 Project Artifact Summary with Links

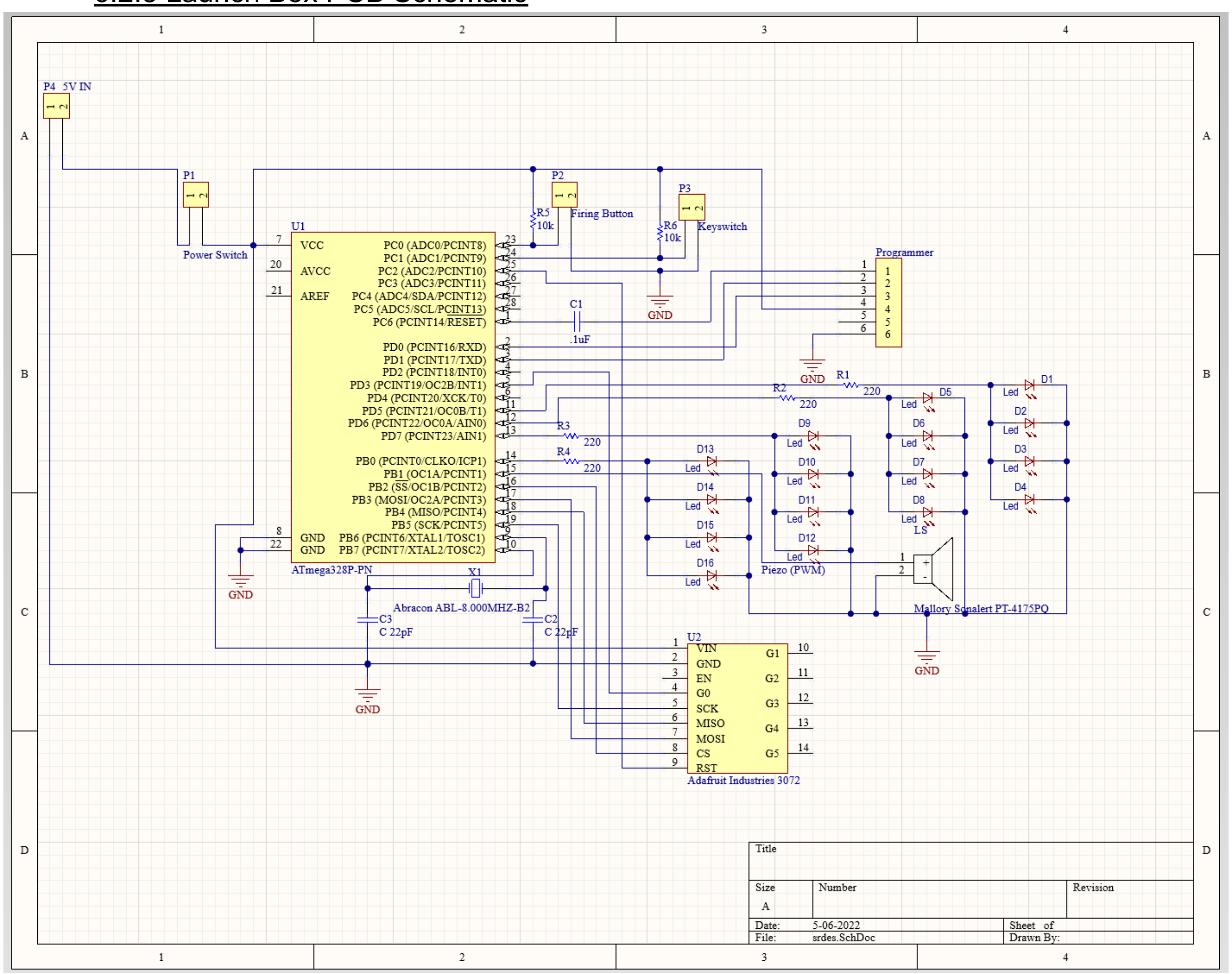
6.2.1 Launch Box Code

[Arduino .ino file]
[RadioHead Arduino Library]

6.2.2 Pad Box Code

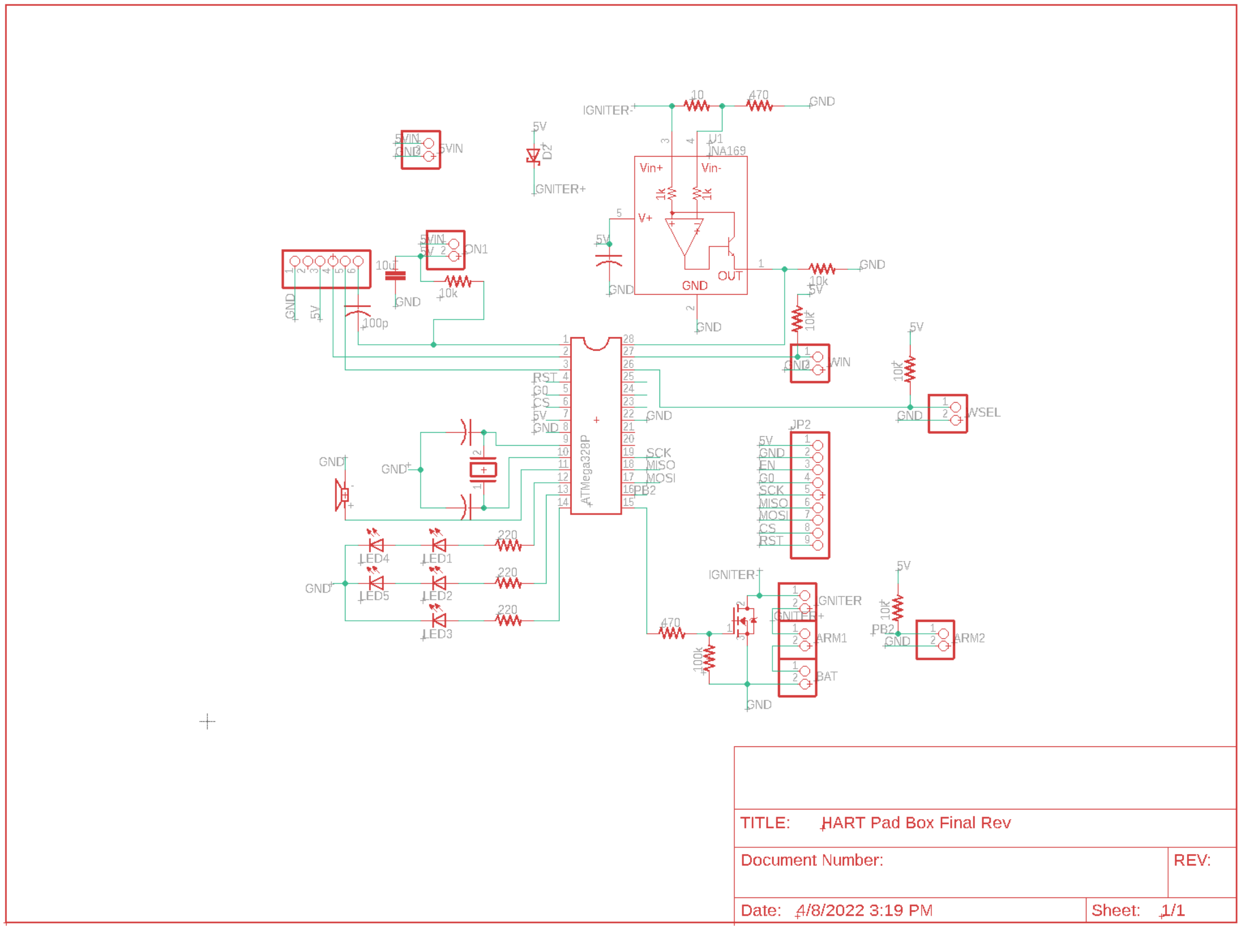
[Arduino .ino file]
[RadioHead Arduino Library]

6.2.3 Launch Box PCB Schematic



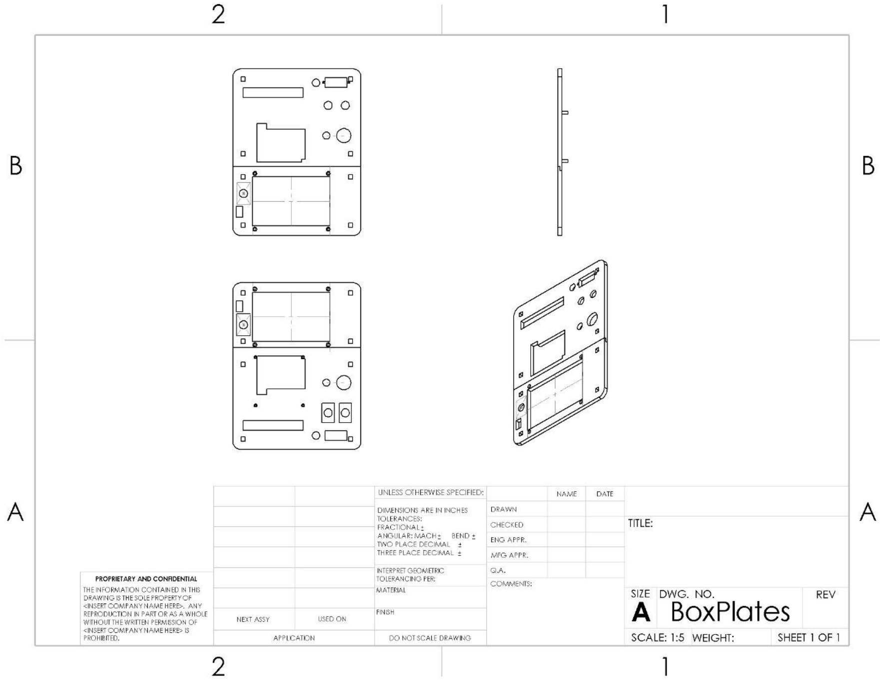
[(Launch Box Gerber Files)]

6.2.4 Pad Box PCB Schematic



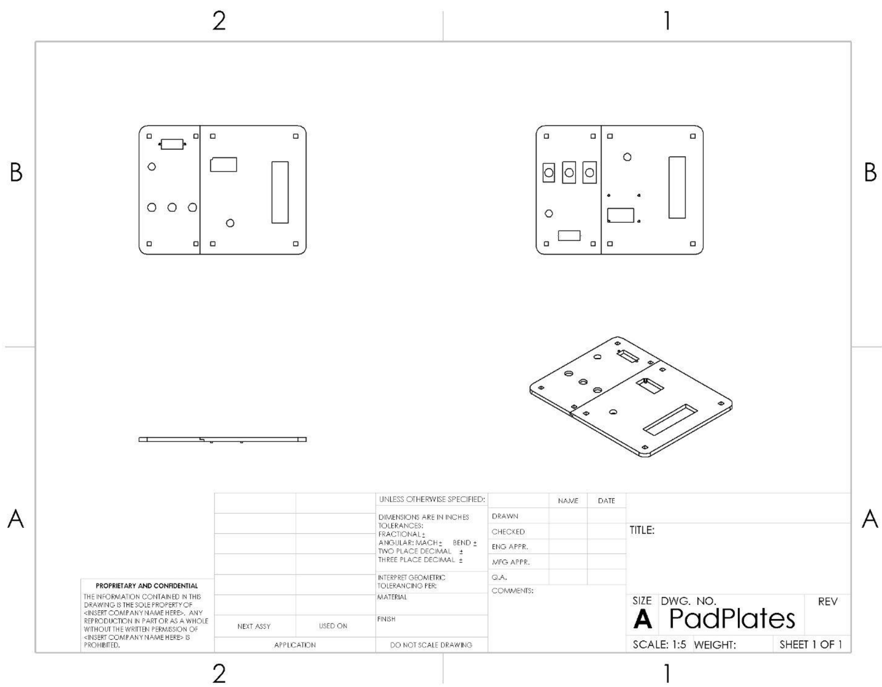
[(Pad Box Gerber Files)]

6.2.5 Launch Box Mechanical Drawings



[(Launch Box Model Files)]()

6.2.6 Pad Box Mechanical Drawings



[(Pad Box Model Files)]()

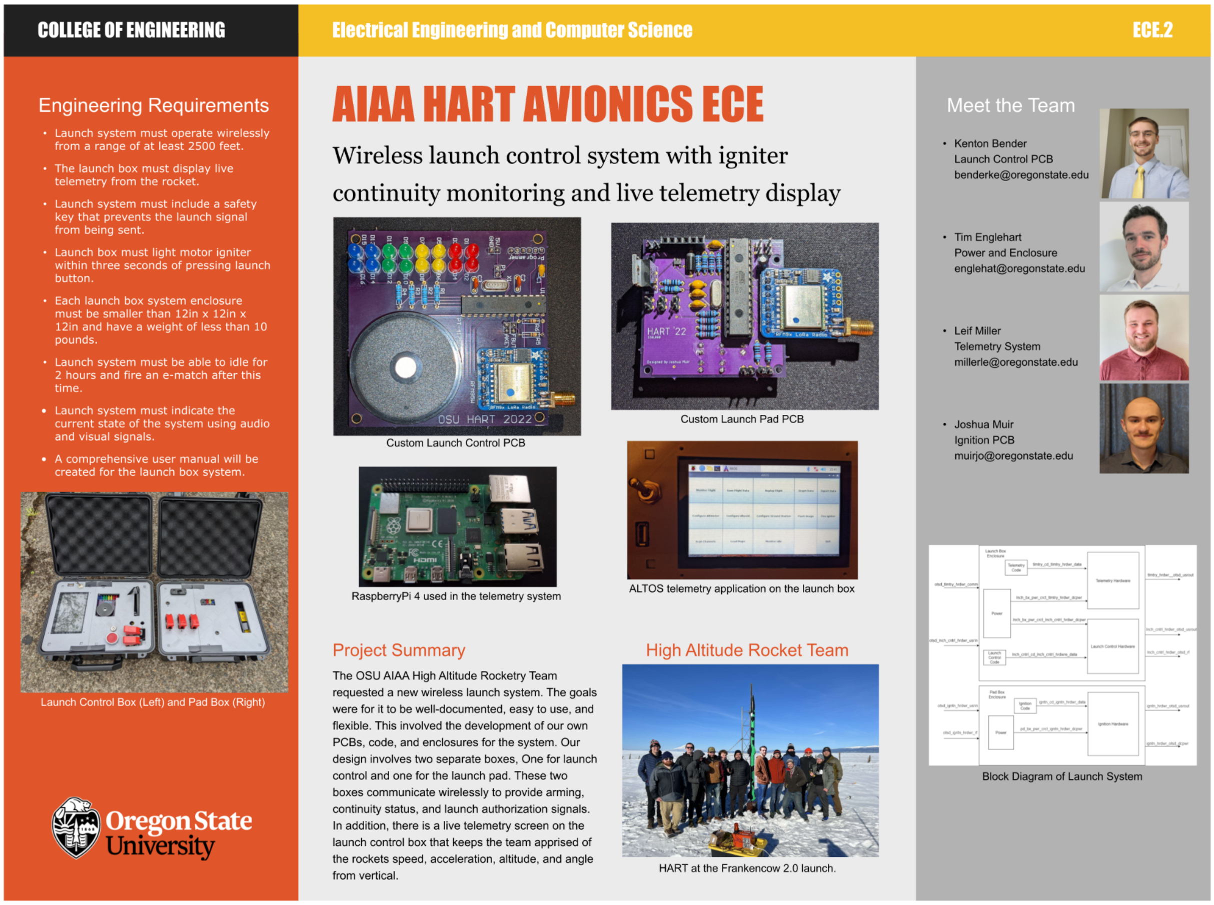
6.2.7 Debian and AltOS Installation Guide

[Raspberry Pi-Debain Sid and ALTOS Installation Guide]()

6.2.8 User Guide
User Guide

6.2.9 Power Supply PCB Schematic
Power Supply Board & Schematic Files

6.3 Presentation Materials



6.4 Revision Table

Date	Revision Number	Description	Author
5/6/2022	Rev 2	Added 6.2.5 and 6.2.6	
5/6/2022	Rev 2	Added 6.1.1.3, 6.1.1.4, and linked 6.2.7	Leif Miller
5/6/2022	Rev 2	Populated recommendation and artifact sections	Joshua Muir
3/6/2021	Rev 1	Outlined sections.	Leif Miller

Appendix