The Nemesis

A Project Proposal and Feasibility Study

Engineering 339/340
Calvin College 2016 Senior Design Team 25

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Executive Summary

Nerf is a toy line known for its blasters. However, unlike its competitors, Nerf has not significantly diversified its products with more novel projectile systems. Team 25 feels that due to this lack of diversity, Nerf is lacking in dynamic forms of play offered by other product lines. Therefore, it has become the team's overarching guideline to "change the way the game of Nerf is played." This change will come about by providing the market with a stationary, single-volley, mass projectile toy designed to tag a large group of players at once that can be remotely triggered by the user. From market and precedent research, safety analysis, and rapid prototyping, Team 25 has come to the conclusion that this is a feasible project worth pursuing, and has developed a preliminary system to meet this goal through analysis of spring driven launch systems, pressure vessels, electronic controls, and user interface. *The Nemesis* currently utilizes a piston valve for energy storage and projectile launching, with safety and deployment controlled by a series of Arduino boards and associated sensors. The following proposal details the evolution towards these systems over the course of the fall semester, and where the team will take these systems moving forward into the spring semester.

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Introduction

Disclaimer

Due to the product nature of Nerf toys and, therefore, the nature of this project, language that draws upon firearm and ammunition technology will be used throughout this report. This terminology is meant to simply and easily convey operation and deployment means. It must be noted outright that Team 25's project and the real world product line it represents are non-lethal and meant for play.

The Narrative (Example of Play)

The only light in the long corridor came from the dim emergency light that had been triggered. Jimmy ducked behind a column, catching his breath. He clutched his rifle close to his chest, sporadically peering around the corner of his temporary shelter to gauge just how far the walking dead were behind him; a mob of shambling, moaning figures darkened the far end of the way he came, and the way he was going led to a dead end. He knew he didn't have enough rounds left in his clip to put down the herd chasing him. If Jimmy wanted to make it out of this death trap, he only had one option left.

Setting aside his rifle, he reached into his pack and removed what he hoped would be his savior; an explosive device he had been holding onto for a while. He looked over his shoulder; the zombies were halfway to him, now, the chorus of moans now distinctly calling for "Braaaaiiiiiins…" Jimmy wiped a bead of sweat from his forehead and opened the device's loading doors and dumped all the ammunition for it he had for it into the cavity. He slammed the trap door shut, primed the firing mechanism, and moved the switch on the side from "SAFE" to "FIRE." Eyes wide and heart racing, Jimmy dropped the charge in the corner he had hidden himself, grabbed his gun, and stumbled forward in a mad dash.

He couldn't go far, though, before his back was to the wall at the end of the corridor. The mass of dead were maybe ten meters in front of him, lurching ever closer, groaning louder as they closed in on their prey. Jimmy whispered a prayer as he pulled the remote detonator from his pocket, and, once the walkers were almost upon him, he pressed the button.

The device clicked, and with a loud bang, shrapnel flew through the air.

"Aw, man…" one of the zombies grumbled as he was tagged out.

"Where did that even come from?" another chimed in.

"I'm out, are you?"

"Yeah… Start counting."

Almost two thirds of the group that had been chasing Jimmy were tagged out of the game by the barrage of foam balls he triggered. Anyone else who was still standing were quickly tagged out by a NERF dart from his blaster. Jimmy laughed impishly as he gathered up as many of the darts and balls he could and shoved them back into his bag. He picked up the spring-loaded plastic box he had set in the corner, and quickly made his way down the cleared hallway to rejoin the other "uninfected" in this game of "Zombie Walk."

Goal (What Are We Doing, and Why Are We Doing It?)

Nerf, a brand of the Hasbro company, is ubiquitous with childhood play. For its history, the company's defining product has been its line of blasters; toy guns that shoot foam darts singularly or in rapid succession. Essentially, this beloved product has remained unchanged for twenty years.

Nerf's competitors, those who market to a more mature age demographic, have long since diversified their product lines. Games like airsoft and paintball offer not just guns, but landmines, grenades, and claymores. These games have also been incredibly team-oriented since their inception. It is these advantages in play to which Nerf has yet to fully catch up.

However, Nerf has begun to redefine its product lines. The *Rival* line of blasters is the most recent, and while it continues the long tradition of singular, handheld blasters, the main marketing push of this line is team-based play—red versus blue.

In addition to this shift, Nerf has also unveiled an unprecedented toy for Holiday 2016: the *Terrascout*, a tank-like drone with remote control and video streaming capabilities. The MSRP value for this new product is two hundred dollars USD with pre-release consumer reactions being universally positive. This shows that Nerf is not only now not afraid to diversify its products, but that it is willing to market at much higher price points than before.

Therefore, it is Team 25's goal to enter into this fledging sub-market and change the way the game of Nerf is played. The team desires to facilitate this newfound team-based organization found in the *Rival* line, and augment this toy line with more unconventional arms.

The Nemesis is being put forth as a claymore-like toy that appeals to both a pre-teen and young adult demographic. It is an easily transportable and deployable launcher able to rapidly fire a single volley of multiple projectiles from a stationary position. Team 25 has taken design cues from existing systems in other toys, along with developing novel ideas of its own, in order to develop this product.

The Team (Who Are We?)

Team 25 is comprised of four mechanical engineers with a wide range of talents and interests. The team was selected to provide a wide range of solution diversity in an attempt to mitigate risks in the project.

Scott Bokach's primary strengths include advanced CAD techniques and rapid prototyping knowledge, primarily associated with 3D printing technologies. He is able to quickly and efficiently bring designs from thought to reality. He perseveres through a problem and maintains focus until a task is complete. His deliverables provide a clear, physical model for the team to analyze and test.

Ian McClaskie's strengths lie in his deep knowledge of munition mechanisms and quality of work. Ian has a deep patience that, when he is tasked to build or learn something new, drives him to get it done right the first time. Though a mechanical engineer, Ian has a strong interest and aptitude in electronic systems, and has therefore tasked himself with managing the onboard electronic systems and coding.

Scott Stamper, while obtaining a degree in mechanical engineering, is also pursuing a biochemistry degree with a focus on pre-professional medicine. This double major dynamic brings with it a mind not just for the technical performance of the project, but the “human element” of the design, and safety precautions for both the potential user and the designers. With experience in research writing and journalistic methods, Scott brings his strengths to the documentation and communication functions of the group.

Nate Zylstra's strengths revolve around the theoretical side of this project, making predictive models and analyzing test data. He has a wide variety of skills that include machining skills and system construction, data recording and analysis, and web design. Nate is the team's webmaster and in charge of media presence; he quantifies the team’s progress and guides the testing phases forward in order to more fully and effectively develop the project.

Developments (What Have We Done?)

Communication

Constant communication is key to a successful team. Fortunately for the members of Team 25, all happen to reside in the same house off campus, which owes to an environment of free-flowing information and consistent updates. When everyone was not in one place, social media was a valuable tool for communication; Facebook and the group chat option it offers was key to keeping all members up to date, and its history could be referenced at any time for past communication.

Proximity of course not being enough, the team has taken meticulous notes in the form of meeting minutes since the outset of this project. The entirety of these minutes can be found in **Appendix I**.

Data records, documentation, and 3D CAD models were all stored on associated cloud servers: Google Drive was utilized to conveniently create and store word documents and data sheets, while *AutoDesk Fusion 360* offered a cloud-based storage system for designs and models that could be shared between users and accessed from any computer with the same software. Any changes to any file in either of these systems would be logged and able to be accessed by any team member at any time.

Financial records were also kept up to date in a shared document, letting each member know who purchased what, for what amount, and where it was obtained. These records were kept primarily as a parts list for future reference, and also for reimbursement records from the school for budgetary reasons.

Budget Plans

Calvin College allots an initial budget of five hundred dollars to each design team; the teams are free to seek further outside funding from sponsors and donors. Team 25 has elected to remain within this initial budget for the foreseeable future. The team feels comfortable with the allotted amount, since a small portion of needed materials for this project can be found in house; with the machine shop, wood shop, and electronics shop at the team’s disposal, several raw components and needed tools can be found on hand or readily provided by advisors: PVC piping, valves, basic sensors, wire, fixtures, et cetera. It was decided that approximately three hundred dollars of the budget would be focused into "research and development;" the building processes during the first semester. A larger portion of the budget would be spent on the rapid prototyping and development of ideas during the fall, in order to effectively develop ideas and workable models, testing their viability. The remaining two-fifths of the budget will be allocated for second semester, where refinement of the project would take place. Since the second semester is focused primarily on the refinement of one system developed in the first semester, the team plans on not having to spend nearly as much money on material costs; the major components will already be in place by then, and many of the remaining pieces from other developments have the potential to be reused.

Custom parts are also able to be made with both the engineering department's 3D printers, and the 3D printer of team member Scott Bokach; the availability and cost effectiveness of 3D printing technology has been an invaluable aid in the rapid prototyping process. A budget of printing costs for on-campus machine can be seen in **Appendix II**. Material and time for team member Scott Bokach's 3D printer were freely donated to the team.

At the time of this writing, the team has spent $194.00 on parts from various distributors like Lowe's, Home Depot, and Amazon, mostly being specific PVC fixtures and assorted electronic components. What parts could not be found in-house were purchased on an as-needed basis. Digital documentation of purchase records and physical receipts were kept for reimbursement purposes. This record can also be seen in **Appendix II**.

Along with the current status of the budget, a preliminary total system budget was created. This system can be seen in **Appendix II.**

Research

Market Precedence

As stated above, Nerf does not have the diversity of its competitors. Airsoft produces its own claymore-style device which uses a torsion spring system to catapult its payload. Paintball grenades have existed for some time now, where a player throws a small canister that, upon striking the ground, releases a wide spray of paint in every direction. The soon-to-be-released, as of this writing, *Terrascout* is the closest thing Nerf has produced to match these other armaments.

Nerf did, however, once produce a viral marketing campaign that at least appealed to the desire for such a product, if not fulfilling it. The Nerf *Nuke* was a 2014 April Fool's joke put out by ThinkGeek, advertised as a large, cartoonish missile that could be launched into the middle of a group. Upon striking the ground, a large payload of darts would fire in every direction, in the hopes of tagging out as many opposing team members as possible. To date, the video on YouTube has over ten million views, with commenters still asking, "Is this a real thing? Where can I get one?" This obviously shows that the Nerf community wants devices in Hasbro's product lines that perform similar to its competitors.

Safety

First and foremost, safety is the main concern of the team, which would be accomplished through the adoption of the same standards for safety as seen in existing Nerf product lines. Hasbro recommends using safety glasses during play; therefore, safety standards assumed by this team were set for the impact safety standard from the OSHA accepted ANSI Z87.1-2010 impact rated testing.

The requirements from ANSI outline two methods of tests: a high mass impact and a high velocity impact. A pair of safety glasses must pass both tests without failure, which is defined as: any piece fully fractures, device fracture, penetration of the rear surface, and/or the lens is not retained. Impact rated testing for the high velocity test dictates a 0.25-inch diameter steel ball that is fired at 150 feet per second at the lens, and the high mass impact requires a pointed projectile that weighs 500 grams be dropped from a height of 50 inches. The results of these tests were then adapted to a safety factor of four, and it was then determined that the maximum muzzle velocity for the product would be 464 ft/s. This is obviously much, faster than any product Nerf produces. Team 25's project will perform nowhere near this threshold (in fact, on the scale the team is building, this speed is unachievable, anyway). Because of this, there is a large margin for safety already inherent in the system; the Nerf Rival line operates at a muzzle velocity of 150 ft/s, and it is the team's goal to come within 15% of that value. The final test considerations can be seen in **Appendix VI**.

Target Market Ergonomics

Team 25's intent was to design a product for children ages ten and up that could be used comfortably and safely. Academic research was initially sought out in order to create clear specifications for ergonomic use and safety. After thorough research, no directly relevant studies were found. The following sources were used as a reference for the development of our specifications.

According to Nemours Health System, the average ten-year-old should carry no more than ten and a half pounds. This is given for a child carrying a standard school backpack. The maximum size of the product must be an appropriate for an average child. According to the CDC, the wingspan is 50 in. The ideal carrying width and depth of the product is to not exceed 25% of the average wingspan. The height of the object is to not exceed the normal claymore dimension of 8 in tall.

Specifications

The final requirements the team determined were created according to the SMART design model. SMART design specifications are ones which are specific, measurable, assignable, realistic, and timely.

1. Safety
    - 1.1. Eye protection: impact will not exceed 50% of the standard rating for impact on safety glasses
    - 1.2. No bruising from impact
    - 1.3. No pinch points greater than 1/8in
2. Light weight, less than 10 pounds
3. Portable, less than one cubic foot in volume
4. Repeatability, spread of fire will be 15 +/- 2 ft.
5. Spread will be 120 degrees +/- 30 degrees
6. Muzzle velocity (average) is 55 +/- 10 ft/s
7. Safety switch (on/off) emergency deactivation
8. 12 projectile minimum

The development of these specifications over time, with an outline of basic, desired, and reach goals the team considered can be found in **Appendix III**.

Brainstorming

The first major hurdle the team encountered in development was energy storage: how will the *Nemesis* be primed and fire its payload?

The initial design process for the project began with a team-driven creative brainstorming session. This was modelled on a method used by the engineering company, Disher. Disher is a product development company based out of Zeeland, Michigan, for whom Scott Bokach interned this past summer. The method used by the team was based on Disher's Whiteboard Wednesday (hereafter referred to as "WBW") sessions. In these structured brainstorming sessions, team members are given a set of boundaries and boosters, which help aid in the creative process. Every idea presented is valid and open for consideration, but never criticized. The aim of this process is pure, massive idea generation through the process of drawing and writing.

After the preliminary WBW session, the team moved forward by selecting the most promising ideas presented and moved to rapid iteration of proofs of concepts. The following proofs of concepts were deemed by the team as the most feasible options moving forward:

1. *Spring Action Pressurized Piston (Hasbro's Current Method)*. Resembling a bolt action lever, this system uses a spring mechanism to pressurize a single piston. When triggered, it fires a single projectile from the attached barrel. This is the system currently in use in every modern Nerf toy. The Nemesis would employ an array of these pistons, all primed and triggered simultaneously. This system would allow for uniform launching distance, speed, and density every deployment.
2. *Momentum Spring System.* This system would eschew the piston mechanism and simply use the force of a spring driven hammer to strike the projectile itself, imparting the stored energy directly to the projectile. This could be accomplished with an array of individual hammers for each projectile, or one single hammer used to propel a mass of projectiles.
3. *Torsion Spring with Sling.* This system is one present in airsoft and paintball applications of this design. The projectiles are packed into a sling, which is anchored at opposite ends to two torsion springs. Similar to a mousetrap, the spring mechanisms are triggered simultaneously, drawing the sling taught, and propelling its contents outward.
4. *Manually primed pressure tank.* This system would use a pressurized vessel that would be pumped by the user. Air pressure would then be rapidly released and used to launch the projectiles from their storage area. Nerf has used pressure vessels in their blasters in years past to varying degrees of success, so precedence for this system exists in the product line.

Risks and Rewards

It is here that one must stop and consider what may happen in undertaking this project. What risks are associated with the proposed ideas found above? First and foremost, none of them could work, and the project would be a failure. However, the fact that the proposed systems are already implemented in other markets begins to negate that specific concern for risk. For the team's purposes, however, these systems may not scale appropriately or transfer to the specific projectile desired to be used here: what works for paintball and airsoft may not necessarily work for Nerf projectiles.

Another major risk of this project has to do with cultural appropriateness. With past teams and current peers working on projects geared towards sustainability and renewability in order to further human flourishing, it is a very valid to question why this team would undertake a project that centers around a children's toy, let alone one that simulates violent combat.

This team admires and celebrates the other teams working with communities and companies to find solutions to resource usage, sustainable production, and environmental impact. Something that is just as important as these endeavors to human flourishing, though, is the concept of recreation; rest, relaxation, and entertainment are necessary to healthy living.

Team-based gameplay fosters healthy competition, community, and cooperation. Just one example is the semiannual game of "Zombies" hosted by members of the Calvin College Computer Sciences Department, a Nerf game involving teams of "survivors" and "zombies" spending the evening running and chasing each other through the science building, boosted by their imaginations and sharing an evening of fun, laughter, and competition.

Many Christians have argued against simulated violence, whether it be in toys, paintball, airsoft guns, or, more recently, video games. Many would argue that the virtual shooting of someone else only makes light of the violent act it represents: an actual gunshot. Yes, violence is a terrible and wicked thing, but, the depiction of violence, in and of itself, is not necessarily the same thing. Depictions of violence can be a matters-of-life representation; a portrayal of struggle, real or symbolic; or it can even be a call to action. It may be argued that games such as Nerf, paintball, or airsoft are merely more complex versions of tag or capture the flag. While this can be a contentious subject amongst the believing community, and a discourse on the condemnation or defense of such is too long and not necessarily relevant to this paper, it is this team's opinion that the game of Nerf and other similar concepts, as long as they are performed with a healthy attitude and respect for other players, are acceptable in which to engage for the Christian. Strategic thinking, team dynamics, and imagination all come into play when people come together in these games. To quote Dr. Renard Tubergen, the advisor of this team, "We model conflict so that we can model resolution."

In spite of these potential risks, the team feels that pursuing a testable system is worth the expenditure. The reward would be a new toy, a new product associated with the Nerf brand. Nerf is ubiquitous with play and being able to bring about a new, unique toy and product line would be a worthy endeavor in itself. The creation of the Nemesis will facilitate an understanding of energy storage and delivery in a small, mechanical projectile system. Even with the risks of failing, cultural insensitivity, and potential misuse, the reward of understanding, the creation of new product line, and the potential to positively influence and inspire children in play are reasons to pursue this project.

Prototyping

The team began researching into not only existing products, but literature associated with the mechanisms, as well. It was quickly discovered, however, that in order to fully understand what it was exactly the team was trying to accomplish, the above systems had to be immediately taken to the real-world; physical, testable models were quickly developed.

The first avenue explored involved the torsion spring system. In mimicking airsoft's claymore design, the team used standard mousetraps connected to a cloth sling to model the propulsion system; when the traps were triggered simultaneously with a lever arm, the cloth sling was snapped taught, launching the Nerf balls. This system had the benefit of being the potentially simplest and easiest to fire mechanism, however, it did not provide initial considerations for consistent launches: there was no control over launch distance or velocity of any given projectile.

The team moved on to the pressurized piston and momentum spring system. It is obvious from picking up any current Nerf product that the pressurized piston system works exceedingly well, so the team first delved into the momentum spring, since it is a very similar mechanic that simply removes the pressure vessel aspect and physically strikes the projectile with a plunger head, rather than using the plunger to prime a small air piston that then acts on the projectile. This proved promising at first; parts were easily created from PVC tubing, springs, and 3D printed parts. Complications arose when multiple firing mechanisms were chained together; pulling back one spring was easy enough, but the force to pull back four at the same time was far more considerable, almost impossible to do by hand, let alone for the desired twenty shots at a time. It was reasoned that the piston version would encounter similar priming issues, and the team moved on.

Next, the use of pressurized air was considered. Nerf has used air tanks in their blasters before, and continue to do so in their Super Soaker line, but it is a rare system in the dart blasters. The team found that attempting to manifold one small air tank into twenty separate barrels would result in substantial pressure loss throughout the system, and would not be able to perform up to specifications, so a more novel system had to be implemented.

Further research led the team to look into piston valves as a mechanism for storage and firing; this is a system common in potato guns and similar, larger projectile projects. Piston valves use a free-floating piston inside the pressure chamber to seal off the barrel containing the projectile, which interacts with pressure differentials created on either side of the piston to allow the pressurized air to escape the vessel and launch the projectile. Several configurations exist for this system, notably one using a chamber separate from the barrel, and one having the barrel mounted in line with the pressure chamber, the latter also known as a coaxial piston valve.

Below, **Figure 1** details the team's decision matrix when it came to evaluating the systems under consideration. As can be seen, many of the systems scored very close to one another; again, this can be contributed to the fact that these are already marketable solutions that exist in other applications; they work, and they work well in their given products. However, as is shown in the decision matrix, according to the team's criteria, the coaxial piston valve more consistently met the desired specifications and has therefore been the model pursued further in testing and analysis.

		Launch Mechanism				
Criteria	Weight of Importance	Torsion Sling	Spring Momentum	Spring Compressed Air	Compressed air tank pull valve	Compressed air tank piston valve
Weight	8	8	8	6	6	6
Ease of Loading	9	10	6	6	5	5
Failure Potential	8	1	6	4	4	7
Volume	6	6	8	8	6	4
Moving Parts	10	2	2	2	10	7
Total Potential Energy Storage	10	6	7	5	10	10
Ease of Priming	8	2	4	4	5	5
Safety of Design	10	3	3	3	7	7
Ease of Triggering	8	4	6	6	3	8
Hasbro Precedence	6	1	4	8	3	3
Ability to Manipulate Trajectory	7	1	5	5	5	5
Muzzel Velocity	8	7	5	3	8	8
Usable at Partial Capacity	9	9	9	9	5	5
	Final Desirability	506	594	550	657	679

Figure 1: Energy Storage System Decision Matrix

Progress

Mechanical

With a single mechanical firing mechanism now firmly established as a viable option, the team proceeded with testing and analysis. **Appendix IV** provides a brief illustrated example of how a coaxial piston valve with an internal, free floating piston works; this example is nearly identical to the inner workings of the team's built piston valve.

Now that the problem of energy storage has been feasibly solved, the team moved on to payload capacity. Clearly, the piston valve design works marvelously for one projectile in the barrel; as a firing mechanism for potato guns, this makes sense. A new problem arises as the goal of launching a single volley of twelve projectiles is considered: rather simply put, how does one launch twelve balls out of a barrel meant to hold one? Several options exist to overcome this. Most obviously, the team could simply chain several piston valves together that are all primed by a single input and fired simultaneously; however, building a device that contains twenty pressure vessels for twenty projectiles is, quite honestly, absurd, and destroys the team's other goals of transportability, size, weight, and ergonomic considerations. Manifolding the air from one piston valve into twenty separate barrels encounters the same problems considered with previously discussed pressure vessel designs: either dangerously high pressures are required to maintain projectile distance and velocity goals, or else a safe level of pressure simply cannot overcome the friction forces and loss in the system to fire all projectiles at once.

In order to overcome the shortcomings of each of these designs, the is in the process of developing a hybrid of the two: a system of a few piston valves (currently four) that each have a manifold at the end of the barrel capable of holding multiple projectiles (a muzzle attachment that bifurcates, with each of the new barrels capable of launching multiple projectiles, not just a single one). These modifications create almost a shotgun-shell-like effect, and also allow the team to divert a projectile's path by angling the muzzle attachments and controlling the degree of spread without significantly compromising muzzle velocity. Data collected analyzing the relationship between pressure in the piston valve and projectile velocity for single projectile can be seen in **Figures 2 and 3**.

Electrical

The mechanical system is controlled using an onboard electrical system to dictate safety features as well as a user interface. The electrical system can be triggered via a remote control or a pyroelectric infrared sensor, both methods have been extensively tested and shall lead to a smooth and reliable triggering system. Integrated in the electrical system is a variety of safety features to stop the device from firing and start the deactivation of the system (depressurizing). This system, or rather, the need for this system, developed over time with this project.

One of the goals laid out at the inception of this project was to have a motion detection device to trigger the firing mechanism. This goal evolved to also include a remote triggering option. It was initially thought that a basic motion sensor and RF receiver could be easily integrated into the firing mechanism.

These desires for an electrical based triggering control quickly grew into a system geared towards safety that has become just as vital, if not more so, than the physical, mechanical firing mechanism. An Arduino board is currently being coded to control not just the motion detection (a function performed by a PIR sensor), but communication with an IR remote that can trigger the system as well as de-arm it, operate a solenoid to fire the system, use an accelerometer to prevent misfiring while the product is being moved, power an onboard compressor and monitor the pressure in the system, monitor the battery life of the system, detect and report potential over-pressurization of the system and bleed the system in response by controlling a solenoid attached to the relief valve.

What started out as a desired feature for the final product became a necessary system in order to control and define safety parameters. The electrical components and the system controlling and monitoring has developed separately as its own entity in tandem with the mechanical firing system; essentially, the team has two separate working systems designed to work together, yet they have not been unified yet into one cohesive whole.

Future Considerations (What Are We Going to Do?)

Testing and Analysis

Once the coaxial piston valve was constructed, the team immediately began testing performance criteria. The primary consideration was system pressure, and how that affects projectile velocity. Nate Zylstra constructed a theoretical model in EES that took the input of final PSI in the system and provided a calculation of muzzle velocity through volume, pressure, and fluid dynamic equations.

In tandem with the theoretical calculations, the physical piston valve began to be tested. Time gates were used to measure the exit velocity of the Nerf dart after the system was pressurized at increasing values. **Figure 2** showcases averaged raw data of the system compared to the theoretical model produced in EES.

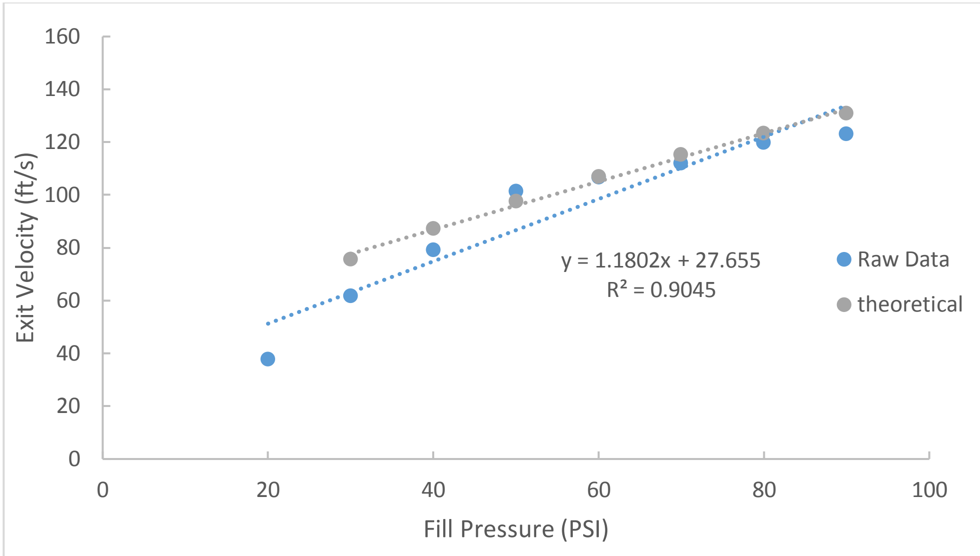

Figure 2: Average of Raw Data compared to the Theoretical Model

The experimental data corresponds well to the theoretical model; discrepancies can be contributed to a failure to fully consider losses due to friction in the physical apparatus, and also to human error. The latter is most likely the largest contributor to discrepancy in the data, since the release valve thus far has been turned by a team member every time, which contributes a lack of consistency to the speed at which the system depressurizes. It is for that reason the team has been developing an electronic triggering mechanism, to remove the human element in testing, as well as move towards a final product. This has been initially accomplished by replacing the manually turned ball valve with a solenoid. **Figure 3** below shows the collected data using a solenoid in which the results highlighted the fact that the orifice of the solenoid acted as a velocity cap due to flow restriction through the orifice.

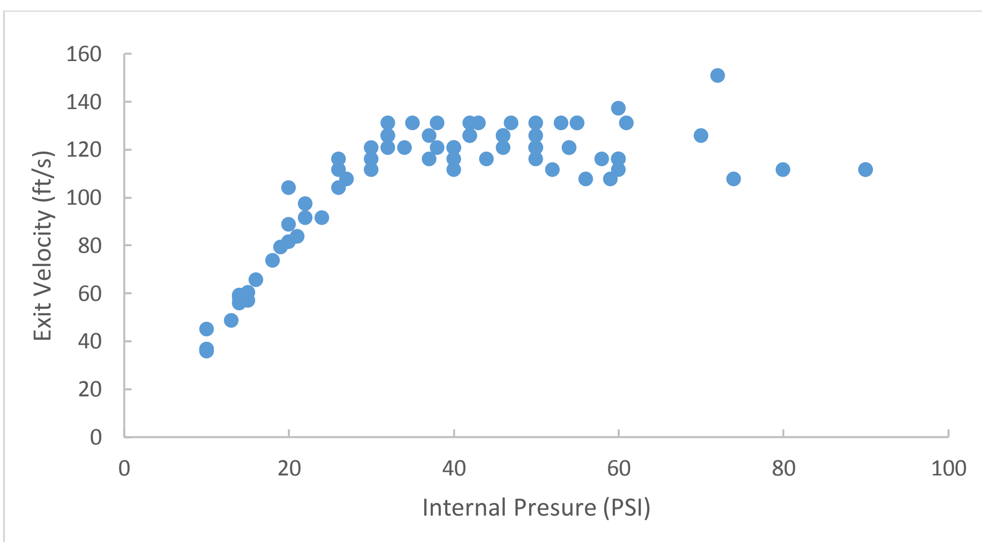

Figure 3: Exit Velocity as a Function of Internal Pressure

This data gives the team a good benchmark moving forward. In the coming semester, testing and analysis will obviously be a priority for the team. Continued studies of system performance as the team streamlines and modifies its prototype are a necessity in order to refine the device to meet the desired specifications. The team will analyze the effects of multiple barrels on pressure loss while firing, the effect of friction and loss of muzzle velocity when multiple projectiles are loaded in a single barrel, as well as final internal pressure levels that optimize system performance while also operating within safety standards.

System Unification

The team will also begin testing the integration of the electronic components into the operation of the mechanical system. As shown above by the discussion of **Figure 4**, the team has had preliminary success using a triggered solenoid to fire the piston valve. Moving forward, the team will further refine the electronic components and marry the two systems into one cohesive design. Once the mechanical firing system and electronic safety and control system are successfully fused, development of housing will begin, and the final design considerations for product development, ergonomics, and playability will be started.

FMEA

As the systems being developed for this project grow more complex, the potential for failure in any of these components also grow. Therefore, from a not just a documentation standpoint, but a safety standpoint, a Failure Mode and Effects Analysis has become one of the more pertinent aspects of this project. Since this project will be marketed as a toy, planning for any and all ways each component could fail is vitally important. The team has begun a preliminary analysis of failure modes now that the mechanical firing mechanism and electronic control system are becoming more robust. The team has already broken down the Nemesis subsystem by subsystem. The preliminary FMEA can be seen in Appendix V. Moving into next semester, when the team begins to unite these two operations into one cohesive design, the FMEA will also grow more robust. The team will further improve the FMEA to include failure modes for individual components in order to understand and plan for how each could and would fail, how to detect such a failure, how drastic that failure would be, and how to respond to that failure.

Spring Semester Schedule

The team is incredibly satisfied with the progress that has been made in the first semester. Not only does it have a working mechanical energy storage system, but a complex electronics system has evolved in tandem with it in a short time. These early developments cannot lull the team into slowing down as the project moves into the second semester, though; in fact, there is even more to do in the coming months. Below in **Table 1** can be found a list of tasks the team will complete in the coming semester, along with a Gantt Chart **(Figure 4)** schedule detailing a timeline for completion.

Table 1: Spring Semester Schedule

Task Name	Start	End	Duration (days)
System Testing	1/2/2017	1/28/2017	26
System Integration	1/28/2017	2/22/2017	25
Housing Creation	2/23/2017	3/27/2017	32
Housing Testing	3/10/2017	3/27/2017	17
Independent User Study	3/27/2017	3/29/2017	2
Analyze/Modify from User Study	3/29/2017	4/5/2017	7
Independent User Study 2.0	4/5/2017	4/7/2017	2
Analyze/Modify from User Study	4/7/2017	4/14/2017	7
DFM/QA/ Develop Back Up	4/12/2017	5/1/2017	19
Buffer Time	5/1/2017	5/8/2017	7
Seinor Design Night	5/7/2017	5/8/2017	1
FMEA Advanced Development	1/28/2017	2/22/2017	25
FMEA Completion	2/23/2017	2/24/2017	1
FINAL DELIVERABLE PAPER	1/28/2017	5/8/2017	100
Instruction Book Creation	3/1/2017	3/27/2017	26

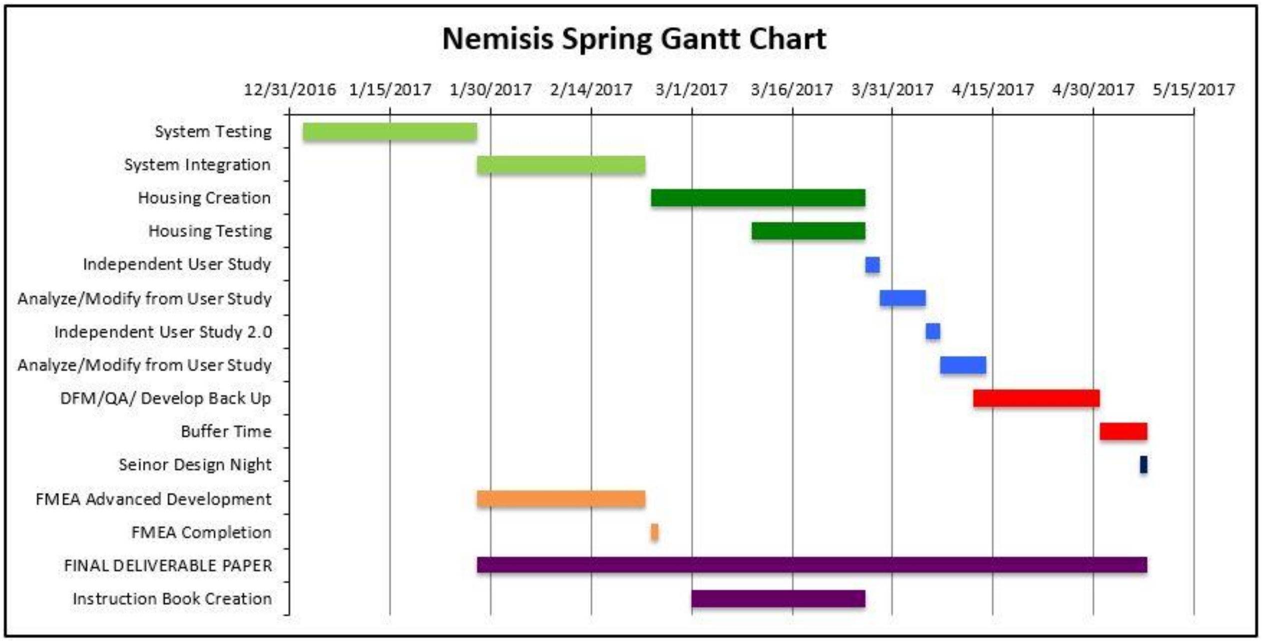

Figure 4: Spring Semester Gantt Chart

Appendices

Appendix I: Meeting Minutes

Team 25 Meeting – 1 October 2016

Location: Engineering Building Shop Floor

Meeting Called to Order at 11:45am by Scott Bokach

Members Present:
Scott Bokach
Ian McClaskie
Nate Zylstra

Members Absent:
Scott Stamper

Business:

- Digital documents were moved from Microsoft OneDrive to Google Drive for storage for the remainder of the project
- Members present began research impact safety requirements
- McClaskie and Zylstra ANSI specs
- Bokach Weight specs and target area per child in play field

Meeting adjourned at 12:45pm

Team 25 Meeting – 1 October 2016

Meeting called to Order at 2:45pm by Ian McClaskie

Members Present:
Ian McClaskie
Scott Stamper (Arrived at 3:30pm)
Nate Zylstra

Members Absent:
Scott Bokach

Business:

- McClaskie and Zylstra began high speed footage capture of darts fired from nerf guns owned by team members.
- Zylstra began spreadsheet for mass and velocity calculations.
- Formal documentation was begun (Stamper)

Meeting Adjourned at 4:15pm

Team 25 Meeting – 2 October 2016

Location: 1955 Radcliff Ave. SE

Meeting Called to Order at 11:00 pm by Ian McClaskie

Members Present:
Scott Bokach
Ian McClaskie
Scott Stamper
Nate Zylstra

Members Absent
None

Business:

- Research parameters were considered and deligated between members.
- Bokach will be researching child ergonomics, density statistics, and repeatability
- McClaskie will be researching ANSI safety specifications, density statistics, and pneumatic operation.
- Stamper will be researching precedent, prior design, and pneumatic operation of NERF devices
- Zylstra will be researching impact safety specifications triggering mechanisms

Meeting Adjourned at 11:24pm.

Team 25 Meeting – 3 October 2016

Location: EB Floor

Meeting Called to Order at 3:05pm by all

Members Present:
Scott Bokach
Ian McClaskie
Scott Stamper
Nate Zylstra

Members Absent
None

Business:

- How do we sell our story? Come up with a prose scenario describing playability and functionality in a real-world operating scenario (Team play, Rival games, Zombie Walk, etc.)
- Stamper will be in charge of this.
- Established a line of contact with Gaetan VanGyseghem in physics lab for time gates for use in velocity analysis and testing
- More consideration of tasks and planning, refining the delegations set out on 2 Oct 2016.
- A line of contact between group and the leadership of Calvin College's NERF/Zombie Walk club should be established for usability and playability features and considerations (target demographic).
- Establish a line of contact with Professor Nyhof about human pain thresholds and bruising for contact safety considerations
- More potential design options were considered and expounded upon

Meeting Adjourned at 4:55 pm

Team 25 Meetings – 4 October 2016

Location: HL 305

Meeting Called to Order at 4:30 pm by All

Members Present:
Scott Bokach
Ian McClaskie
Scott Stamper
Nate Zylstra

Members Absent
None

Business:

- Team met with David Malone to go over research procedures and recommendations using the Hekman Library.
- Calvin has resources available through ProQuest Engineering Collection.
- Google Scholar may be helpful, especially in our case.
- If an outside resource requires paid access, type, "lib-proxy.calvin.edu/login?url=" before the URL; the library may already have access to it under its proxy.
- Ustat, GPO Statistics, and the US Patent Office were also recommended.

Meeting Adjourned at 4:50 pm.

Team 25 Meeting – 4 October 2016

Location: HL 406C

Meeting Called to Order at 4:55 by Scott Stamper

Members Present:
Scott Bokach
Ian McClaskie
Scott Stamper
Nate Zylstra

Members Absent
None

Business:

- Initial outline for PPFS was discussed and drafted, to be turned in tomorrow.

Meeting Adjourned at 5:20 pm.

Team 25 Meeting – 5 October 2016

Location: EB Floor

Meeting Called to Order at 3:30 pm by Ian McClaskie

Members Present:
Scott Bokach
Ian McClaskie
Scott Stamper
Nate Zylstra

Members Absent
None

Business:

- Stamper's narrative of play scenario was reviewed and approved by group members and passed along to advisor Professor Tubergen
- Construction of website was begun
- Bokach continued proof of concept CAD work

Meeting Adjourned at 3:50 pm

Team 25 Meeting – 8 October 2016

Location: 1955 Radcliff Ave SE

Meeting Called to Order at 4:40pm by Nate Zylstra

Members Present:
Ian McClaskie
Nate Zylstra

Members Absent:
Scott Stamper
Scott Bokach

Business:
- Meeting with Nathan Coster, avid Zombie Walk/Nerf enthusiast
- Multiple Volleys
- Directional
- Not a 360 field, more of a 120 general directional
- Some upward angle- reach the pelvis
- 10ft max indoors average of 5ft
- Represent real forces of NERF so they feel this
- Reloading
- Make it simple and fast
- Not necessarily a speed reload
- Cartridge reload
- Some upward angle
- No trip wire (Safety and rule wise)
- Remote firing by person line of sight (preferred) or motion sensing (Selector)
- Wait until the third guy comes into the room (Time delay on motion sensing)
- Loaf of bread size not in your hand- physical strap to carry
- Non adjustable set it down and not worry about it- legs
- Durable to withstand a kick or drop
- Some part brightly colored to say hey this is safe
- Spring loaded piston- no pneumatics that you have to pump.
- Set within 10 seconds (cocking) brace foot against
- Not loud with noise when cocking
- How do you inactivate it so others can't use it (Master kill/Reset switch)
- $40 max
- Specific ammo- finding on the ground

Meeting Adjourned at 5:25pm

Team 25 Meeting – 10 October 2016

Location: EB Floor

Meeting Called to Order at 2:30pm by Ian McClaskie

Members Present:
Scott Bokach
Ian McClaskie
Scott Stamper (Arrived at 2:50pm)
Nate Zylstra (Arrived at 2:45pm)

Members Absent
None

Business:

- Narrative story was expounded upon based on critique from advisor Professor Tubergen
- Email was sent to VanGyseghem about borrowing physics equipment for testing
- More discussion of proof of concepts with regards to loading ammunition (clips that dump directly into device)

Meeting Adjourned at 3:45pm.

Formals meeting were held infrequently from this point on and personal daily trackers were implemented for each team member.

Appendix II: Budget

Table 2: 3D Printing Budget

Part Weight [g]	Material Cost [1/g]	Part Cost
112.0	$0.02321	$2.60
110.0	$0.02321	$2.55
34.0	$0.02321	$0.79
59.0	$0.02321	$1.37
50.0	$0.02321	$1.16
53.0	$0.02321	$1.23
12.0	$0.02321	$0.28
56.0	$0.02321	$1.30
29.0	$0.02321	$0.67
Total		$11.95

Table 3: Receipts/Fall Semester Budget

Date	Establishment	Number of Items	Store Transaction #	Price
10/15/16	Lowe's	1	76561518	$4.87
10/25/16	AutoZone	1	994433	$3.49
10/25/16	Lowe's	3	74416211	$9.86
10/30/16	Ebay	2	172150755621	$6.52
11/5/16	Lowe's	13	73365889	$17.42
11/7/16	The Home Depot	8	27150005617337	$1.02
11/7/16	Riders of Grand Rapids	1	MDJGH9XG81107	$16.95
11/7/16	O'Reilly Auto Parts	1	2353-254572	$1.79
11/10/16	Lowe's	1	75808952	$1.67
11/10/16	The Home Depot	9	27150005895966	$11.46
11/11/16	Radioshack	4	35000	$21.69
11/12/16	Lowe's	5	73976750	$4.75
11/17/16	Lowe's	9	75397168	$11.11
11/18/16	Lowe's	9	12494131	$14.10
11/19/16	Amazon	2	114-4197790-4089023	$21.04
11/27/16	Lowe's	2	73274534	$2.06
11/29/16	Lowes	8	12446378	$12.18
11/30/16	Amazon	1	106-5899942-4899465	$8.23
11/30/16	Lowe's	2	75535477	$3.56
11/30/16	Jo-Ann Fabric and Craft	1	5DA04916C1DD89C7	$1.05
12/1/16	O'Reilly Auto Parts	1	2353-256140	$1.69
12/1/16	Lowe's	13	74605106	$13.10
12/2/16	Lowe's	4	71716577	$4.39
12/4/16	Amazon	2	103-0479252-9952268	$28.21
12/4/16	Amazon	2	103-3489194-7363456	$11.78
12/5/16	GetFPV	1	100240919	$6.98
12/10/16	Lowe's	14	73400314	$25.76
12/10/16	Amazon	2	107-8626120-7545003	$23.38
Total				$290.11

Table 4: Proposed System Cost and Actual Cost for the Spring Build

Total Cost of System	284.81					
Actual Cost for Spring	$88.61					
System	Item	Quantity	Cost per piece	Up Front Cost	Reusable From Fall	Actual Cost
Air Storage	1.5" * 5' PVC	1	$2.50	$2.50	No	$2.50
Air Storage	.5" * 5 ' PVC	1	$2.50	$2.50	No	$2.50
Air Storage	1.5" PVC Male Threaded Coupler	8	$1.28	$10.24	No	$10.24
Air Storage	1.5" PVC Female Threaded Coupler	8	$1.32	$10.56	No	$10.56
Air Storage	1.5" to .5" Slip Bushing	8	$0.64	$5.12	No	$5.12
Air Storage	1.5"PVC Coupling	8	$0.85	$6.80	No	$6.80
Air Storage	1.5" to .5" Threaded Spigot Bushing	8	$0.92	$7.36	No	$7.36
Air Storage	PVC Cement	1	$5.00	$5.00	No	$5.00
Air Storage	Schrader Valve	1	$1.67	$1.67	Yes	$0.00
Air Redirection	."5 Threaded Tee Fitting	6	$1.67	$10.02	No	$10.02
Air Redirection	.5" Threaed 90 deg fittings	4	$0.98	$3.92	No	$3.92
Air Redirection	.5" * 1" Threaded nipples	7	$0.40	$2.80	No	$2.80
Firing Mechanism	Printed Piston	8	$0.10	$0.80	No	$0.80
Firing Mechanism	Felt Pad	1	$0.99	$0.99	No	$0.99
Firing Mechanism	RainBird Solinoid	2	$15.20	$30.40	Yes	$0.00
Electronic	Arduino	2	$21.00	$42.00	Yes	$0.00
Electronic	Pressure Sensor	1	$15.00	$15.00	Yes	$0.00
Electronic	PIR Sensor	1	$10.00	$10.00	Yes	$0.00
Electronic	LCD Display	1	$10.00	$10.00	Yes	$0.00
Electronic	LED Lights	2	$0.10	$0.20	Yes	$0.00
Electronic	Button Switches	2	$5.89	$11.78	Yes	$0.00
Electronic	General Wiring	1	$3.00	$3.00	Yes	$0.00
Electronic	Laser Pointers	4	$0.10	$0.40	Yes	$0.00
Electronic	RF Reciever and Controller	1	$13.00	$13.00	Yes	$0.00
Electronic	Accelerometer	1	$10.00	$10.00	Yes	$0.00
Electronic	2 Posistion Switch	2	$5.00	$10.00	Yes	$0.00
Electronic	3 Posistion Switch	1	$8.00	$8.00	Yes	$0.00
Electronic	BreadBoards	1	$10.00	$10.00	Yes	$0.00
Electronic	Piezo Buzzer	1	$4.00	$4.00	Yes	$0.00
Saftey Depressure	Water Solinoid	1	$8.75	$8.75	Yes	$0.00
Charging Mech.	Compressor	1	$8.00	$8.00	Yes	$0.00
Housing	Housing	1	$20.00	$20.00	No	$20.00

Appendix III: Initial Goals and Specifications

Required Features

The required category contains design features in the final product the team felt must be wholistically integrated into the design. All following design features are intended to be included in the final design of the Nemesis. The required design features are as follows:

- Safe (Does not exceed Hasbro's own guidelines)
- Must shoot something (Elite dart, Mega dart, Rival ball).
- Light and portable (< 5lbs.)
- Repeatability
- Uniform projectile velocity
- Single high volume discharge
- Pre-existing ammunition
- 6 projectile minimum
- Energy storage
- User friendly
- Time delay triggering
- Motion sensing

Desired Features

The desired category contains design features which the team feels are within scope of the project, but are secondary to the required design features. The desired design features are as follows:

- Omni-directional firing
- Light and portable
- (<3lbs.)
- Purely mechanical
- 15 projectile minimum
- Quiet
- Discrete (Not heavily realistic, but also not cartoonish)
- Simultaneous/rapid cascade triggering
- Stable mounting
- Uniform spread
- Compact
- Adjustability of projectile volume/Operation

Reach Features

The reach category is design features the team believes would allow the product to be of a higher intricacy, but are potentially outside the scope of the project. The reach design features are as follows:

- 35 Projectile Minimum
- Multi-surface mounting (Horizontal and Vertical)
- Motion sensing

- Camouflage
- Design for manufacturing
- Use of psychological gameplay (noisemakers)
- Elegance

Preliminary Product Specifications

By organizing our design features in the above categories, a clear framework was developed to aid in the creation of the products specifications. Using the design framework as guiderails, product specifications were created that adhere to the SMART design model. All specifications are specific, measurable, assignable, realistic, and time related. The final product specifications are as followed:

1. Safety
   1.1. Eye protection: impact will not exceed 50% of the standard rating for impact on safety glasses
   1.2. No bruising from impact
   1.3. No pinch points greater than 1/8in
2. Light weight, less than 5 lbs
3. Portable, less than 1 ft^3
4. Repeatability, spread of fire will be 15 +/- 2 ft.
5. Spread will be 120 degrees +/- 30 degrees
6. Life Cycle will be 5 hours of continuous dry fire
7. Muzzle velocity (average) is 32 +/- 2 ft/s
8. Safety switch (on/off)
9. 12 projectile minimum
10. Requires less than 5 lbs of force to prime the triggering mechanism.

Appendix IV: Piston Valve Operation

The following figures illustrate the priming and firing phases of a coaxial piston valve. These images were taken from an animation that can be found at this source[1].

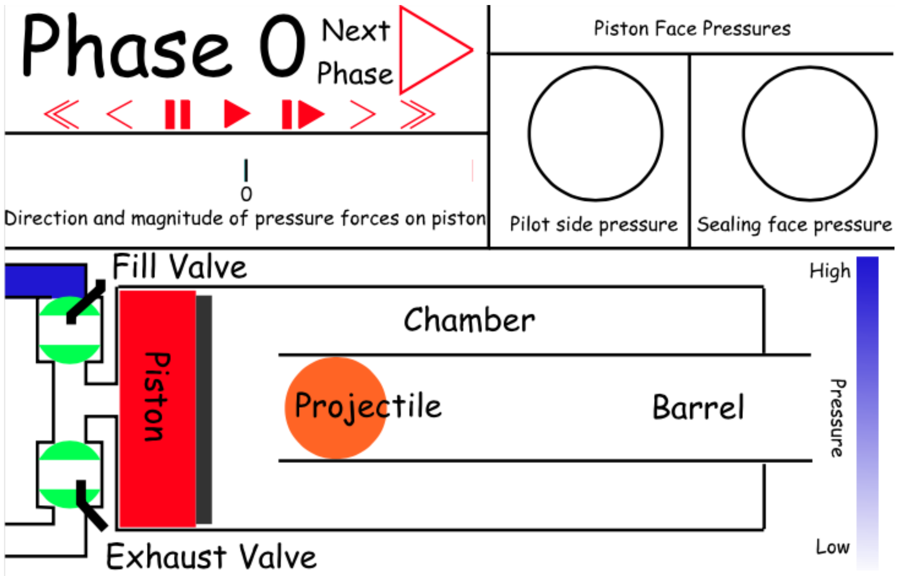

Figure 5: Phase Zero, The Neutral State of the Piston Valve

The projectile is loaded into the barrel before the fill valve is opened.

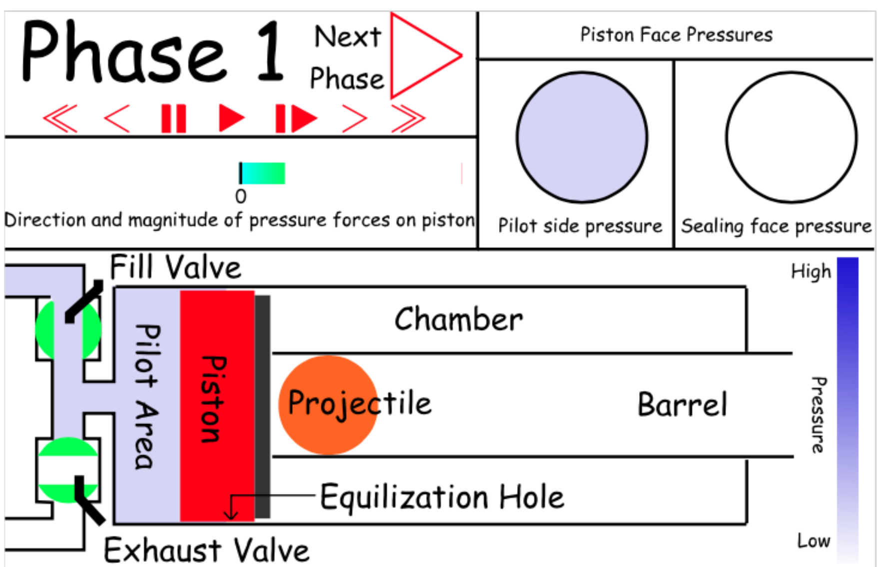

Figure 6: Phase One, When the Fill Valve is Opened

[1] Bell, Bryce. "Coaxial Piston Valve Concept." GBCannon, 6 Jan. 2009, gbcannon.com/concepts/coaxial.html.

The free floating piston is moved by the inflow of pressurized air that creates the pilot area and seals the piston against the interior opening of the barrel; air begins to flow through the equalization hole around the outside of the piston and fill the rest of the chamber.

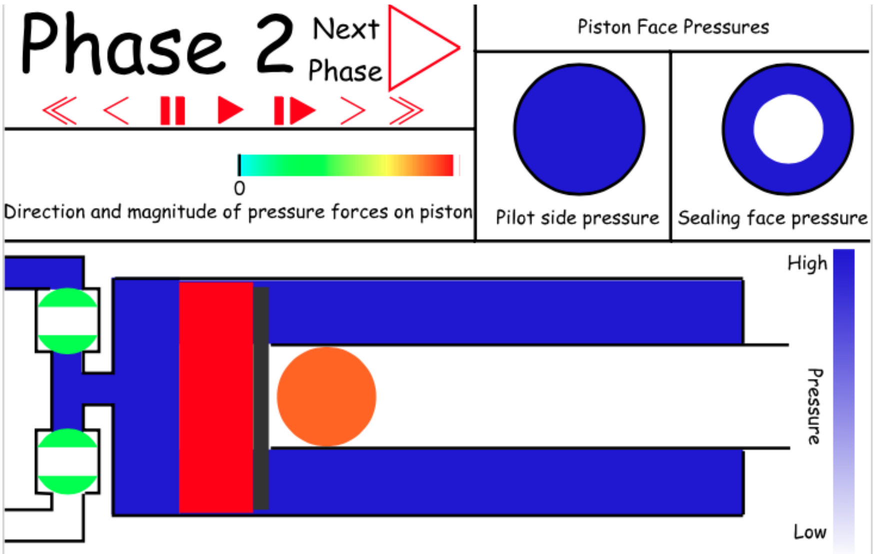

Figure 7: Phase Two, The Fully Primed System

The fill valve is closed when the chamber reaches the desired pressure.

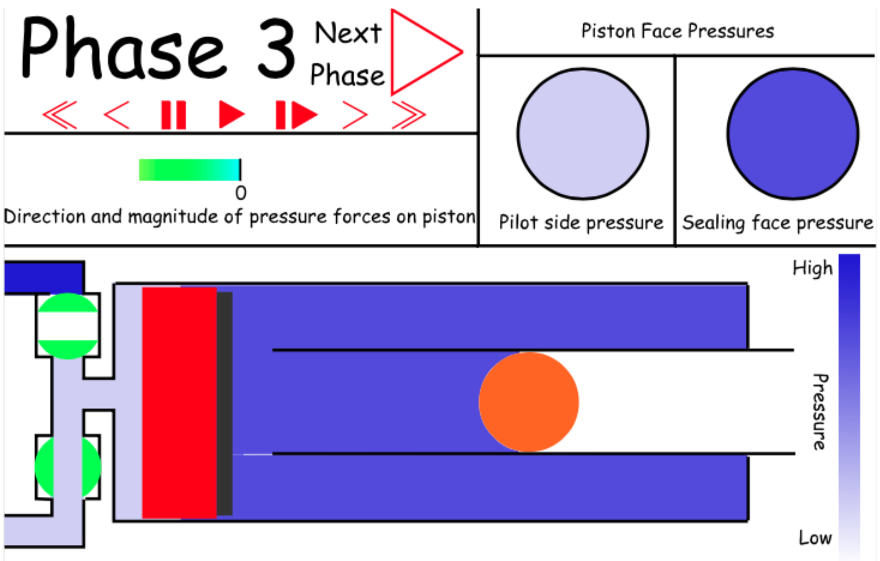

Figure 8: Phase Three, The Discharge of the System

When the exit valve is open, the pilot area initially created depressurizes first, creating a pressure differential that quickly sucks the piston away from the barrel and blocks the exit valve. The system then continues to depressurize through the barrel, launching the projectile.

Appendix V: Preliminary Subsystem FMEA

Table 5: FMEA Severity Rating Scale

Severity Rating Scale

Rating	Description	Definition (Severity of Effect)
10	Dangerously high	Failure could injure the customer or an employee.
9	Extremely high	Failure would create noncompliance with federal regulations.
8	Very high	Failure renders the unit inoperable or unfit for use.
7	High	Failure causes a high degree of customer dissatisfaction.
6	Moderate	Failure results in a subsystem or partial malfunction of the product.
5	Low	Failure creates enough of a performance loss to cause the customer to complain.
4	Very Low	Failure can be overcome with modifications to the customer's process or product, but there is minor performance loss.
3	Minor	Failure would create a minor nuisance to the customer, but the customer can overcome it without performance loss.
2	Very Minor	Failure may not be readily apparent to the customer, but would have minor effects on the customer's process or product.
1	None	Failure would not be noticeable to the customer and would not affect the customer's process or product.

Table 6: FMEA Detection Rating Scale

Detection Rating Scale

Rating	Description	Definition
10	Absolute Uncertainty	The product is not inspected or the defect caused by failure is not detectable.
9	Very Remote	Product is sampled, inspected, and released based on Acceptable Quality Level (AQL) sampling plans.
8	Remote	Product is accepted based on no defectives in a sample.
7	Very Low	Product is 100% manually inspected in the process.
6	Low	Product is 100% manually inspected using go/no-go or other mistake-proofing gages.
5	Moderate	Some Statistical Process Control (SPC) is used in process and product is final inspected off-line.
4	Moderately High	SPC is used and there is immediate reaction to out-of-control conditions.
3	High	An effective SPC program is in place with process capabilities (C_{pk}) greater than 1.33.
2	Very High	All product is 100% automatically inspected.
1	Almost Certain	The defect is obvious or there is 100% automatic inspection with regular calibration and preventive maintenance of the inspection equipment.

Table 7: FMEA Occurrence Rating Scale

Occurrence Rating Scale		
Rating	**Description**	**Potential Failure Rate**
10	Very High: Failure is almost inevitable.	More than one occurrence per day or a probability of more than three occurrences in 10 events ($C_{pk} < 0.33$).
9	High: Failures occur almost as often as not.	One occurrence every three to four days or a probability of three occurrences in 10 events ($Cpk \approx 0.33$).
8	High: Repeated failures.	One occurrence per week or a probability of 5 occurrences in 100 events ($C_{pk} \approx 0.67$).
7	High: Failures occur often.	One occurrence every month or one occurrence in 100 events ($C_{pk} \approx 0.83$).
6	Moderately High: Frequent failures.	One occurrence every three months or three occurrences in 1,000 events ($C_{pk} \approx 1.00$).
5	Moderate: Occasional failures.	One occurrence every six months to one year or five occurrences in 10,000 events ($C_{pk} \approx 1.17$).
4	Moderately Low: Infrequent failures.	One occurrence per year or six occurrences in 100,000 events ($C_{pk} \approx 1.33$).
3	Low: Relatively few failures.	One occurrence every one to three years or six occurrences in ten million events ($C_{pk} \approx 1.67$).
2	Low: Failures are few and far between.	One occurrence every three to five years or 2 occurrences in one billion events ($C_{pk} \approx 2.00$).
1	Remote: Failure is unlikely.	One occurrence in greater than five years or less than two occurrences in one billion events ($C_{pk} > 2.00$).

Table 8: Upper Barrel Subsystem FMEA

System	Upper barrel							
Cause	Occurance	Severity	Detection	Score		Solution	To be fixed by:	Aprrox Time to Fix:
Seal Failure Female Threads	6	5	5	150				Quick Fix
Seal Failure at 1.5" Slip	3	7	6	126				Quick Fix
Barrel Ejects	1	9	1	9				.5 Day
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				

Table 9: Main Barrel Subsystem FMEA

System	Main Air Tank Housing							
Cause	Occurance	Severity	Detection	Score		Solution	To be fixed by:	Aprrox Time to Fix:
Seal Failure at Male Thread Slip	6	5	5	150				1 Day
Seal Failure at PVC Coupling either End	3	7	6	126				1 Day
Seal Failure at .5"Threaded Spigot	6	5	5	150				1 Day
Any PVC Crack	1	10	9	90				2 Days
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				

Table 10: Piston Subsystem FMEA

System	Piston							
Cause	**Occurance**	**Severity**	**Detection**	**Score**		**Solution**	**To be fixed by:**	**Aprrox Time to Fix:**
Foam Comes Loose	4	10	2	80				Quick Fix
Piston Shatters	1	10	2	20				.5 Day
Chip in .5" Barrel cause leak	1	10	8	80				1 Day
Foam Chips/ Is cut cause leak	2	10	2	40				Quick Fix
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				

Table 11: Firing Mechanism Subsystem FMEA

System	Trigger Mechanism							
Cause	**Occurance**	**Severity**	**Detection**	**Score**		**Solution**	**To be fixed by:**	**Aprrox Time to Fix:**
Motor Dies	2	10	5	100				1 Day
Loose Wire	4	7	2	56				Quick Fix
Solinoid Jam	1	8	7	56				1 Day
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				

Table 12: Manifold Subsystem FMEA

System	Manifold Connectors							
Cause	**Occurance**	**Severity**	**Detection**	**Score**		**Solution**	**To be fixed by:**	**Aprrox Time to Fix:**
Seal Failure at any Joint	3	6	6	108				.5 Day
Seal Failure at Schrader Valve	3	6	6	108				1 Day
Seal Failure Pressure Gauge	3	6	6	108				.5 Day
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				
				0				

Table 13: Arduino Subsystem FMEA

System	Arduino							
Cause	**Occurance**	**Severity**	**Detection**	**Score**		**Solution**	**To be fixed by:**	**Aprrox Time to Fix:**
Fried Board	2	10	2	40				1 Day
Loose Wire	10	1	4	40				Quick Fix
				0				
				0				
				0				
				0				
				0				
				0				
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				0				
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				0				
				0				
				0				

Appendix VI: Initial Safety Testing

Table 14: Final Values of Initial Safety Considerations

	ABSI High Velocity Test	
Density [kg/m^3]	7850	
Velocity [m/s]	45.7	
Velocity [ft/s]	150	
Pressure [MPa]	8.20	
	Nerf Elite Dart	Nerf Rival Ball
Density	111	205
Pressure 25% [MPa]	2.05	2.05
Max Velocity [m/s]	193	141
Max Velocity [ft/s]	632	464