Design and Development of a Multi-Shot Foam Projectile Toy

by

Alan M. Skaggs

B.S., Mechanical Engineering (2005)

B.S., Mathematics (2005)

Southern Methodist University

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Signature of Author

Department of Mechanical Engineering
May 23, 2007

Certified by

David Wallace
Associate Professor of Mechanical Engineering, MacVicar Fellow
Thesis Supervisor

Accepted by

Lallit Anand
Chairman, Department Committee on Graduate Students
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Abstract

The goal of this research was to design and develop a working prototype of a new toy for Hasbro®'s Nerf® line of foam projectile toys. Several years ago, Hasbro approached the MIT CADlab about developing a new method for firing Nerf® foam balls. The hope was that a new approach would be generated from which a new platform of products could be developed. The result of the initial work was the development of Hopper Popper Activation™, which uses a bistable rubber spring to fire Nerf foam balls.

Due to its novel nature and the simplicity of its design, Hopper Popper Activation has since been integrated into a single projectile toy named the Atom Blaster™, which reached the market in early 2007. Following the success of this project, Hasbro requested that a multi-shot projectile toy be developed that makes use of Hopper Popper Activation™, so that it may extend the platform of toys which use this new firing mechanism.

This thesis follows the product design process that led to the development of the Multi-Shot Popper™, which incorporates Hopper Popper Activation™ into a toy blaster capable of storing and rapidly firing multiple foam ball projectiles. In addition to using Hopper Popper Activation™, the Multi-Shot Popper™ was required to fulfill several other requirements, including specific safety and performance specifications, while still remaining a fun and enjoyable toy.

The design team created a series of iterative sketch models to test different mechanisms and methods of accomplishing the stated functional requirements. At each stage of the process, the successes and shortcomings of the current model were assessed and small scale brainstorming sessions were held to generate new concepts. These new concepts were combined with the successful features of the previous models until a final alpha-prototype was created which meets the customer and user requirements.

Thesis Supervisor: David Wallace
Title: Associate Professor of Mechanical Engineering
MacVicar Fellow, Co-Director MIT CADlab
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# Table of Contents

1 Introduction ............................................................................................................. 11
   1.1 Objective ......................................................................................................... 11
   1.2 Outcome ......................................................................................................... 11
   1.3 About this Thesis .......................................................................................... 12

2 Planning ................................................................................................................... 13
   2.1 Customer Needs .......................................................................................... 13
   2.2 Standards and Safety ................................................................................... 15
   2.3 State of the Art ............................................................................................ 16

3 Concept Development ............................................................................................. 19
   3.1 Introduction/Ideation ..................................................................................... 19
   3.2 Background .................................................................................................... 19
      3.2.1 Hopper Popper Activation ..................................................................... 20
   3.3 Model Progression ........................................................................................ 23
      3.3.1 Wooden Model ....................................................................................... 24
         3.3.1.1 Popper Inversion ........................................................................... 24
         3.3.1.2 Storage/Loading ........................................................................... 26
         3.3.1.3 Triggering .................................................................................... 27
      3.3.2 Metal Model ........................................................................................... 27
         3.3.2.1 Popper Inversion ........................................................................... 28
         3.3.2.2 Storage/Loading ........................................................................... 31
         3.3.2.3 Triggering .................................................................................... 32
      3.3.3 Rapid Prototyped (RP) Model ................................................................. 32
         3.3.3.1 Popper Inversion ........................................................................... 33
         3.3.3.2 Storage/Loading ........................................................................... 34
         3.3.3.3 Triggering .................................................................................... 36

4 Conclusion ............................................................................................................... 41
   4.1 Summary ......................................................................................................... 41
   4.2 Future Work .................................................................................................... 41

Appendix A ..................................................................................................................... 43
   A.1 Hasbro Inc Corporate Quality Assurance Safety and Reliability Specification 43
A.2 Final Shot Popper CAD Model

56
List of Figures

1-1: Final Multi-Shot Popper Iteration Multi-Shot Popper\textsuperscript{TM} ........................................................................ 11
2-1: Nerf\textsuperscript{R} Atom Blaster\textsuperscript{TM} ........................................................................ 17
2-2: Nerf\textsuperscript{R} Ball-Blaster\textsuperscript{TM} and Reactor\textsuperscript{TM} ................................................. 18
3-1: Popper in Inverted and Natural States ...................................................... 20
3-2: Inverted Popper with Nerf\textsuperscript{R} foam ball ...................................................... 21
3-3: Direction of resistance preventing full popper inversion ................................. 21
3-4: Cross Section of Popper Holder ............................................................ 22
3-5: Popper Holder with and without popper ................................................... 22
3-6: Wooden Model ................................................................................. 24
3-7: Eye-bolt through popper ...................................................................... 25
3-8: Top view of Wooden Model showing eye-bolt through popper ....................... 25
3-9: Metal Model .................................................................................... 28
3-10: Exchange of bolt during popper inversion ................................................ 30
3-11: Visualization of foam balls in storage chamber ........................................ 31
3-12: Primary ball pinned against bolt .......................................................... 31
3-13: Primary ball in fully loaded position ...................................................... 32
3-14: Fully assembled RP model ................................................................. 33
3-15: Rack and pinion system .................................................................... 33
3-16: Elbow Joint closed and open to allow loading .......................................... 35
3-17: Handle and trigger ........................................................................... 36
3-18: Triggering Assembly ........................................................................ 37
3-19: Trigger ............................................................................................ 37
3-20: CAD Model displaying motion of trigger assembly during triggering ............. 39
3-21: Initial and refined head piece of pusher .................................................. 40
Chapter 1

Introduction

1.1 Objective

The goal of this research was to design and develop a projectile toy able to store and fire multiple standard-size Nerf® balls using the Hopper Popper Activation™ technology previously developed in the MIT CADlab [1]. The developed product was required to comply with all applicable safety standards provided by the sponsor company Hasbro® Incorporated, while at the same time satisfying all stated and implied customer needs, and maintaining the requisite level of fun for the user.

1.2 Outcome

After several model and design iterations, a working final prototype of the Multi-Shot Popper™ was implemented, meeting the customer needs, as they are understood, while also satisfying the applicable safety standards. The Multi-Shot Popper™ is unique amongst projectile toys in that it is the only toy that is able to store and fire multiple projectiles using Hopper Popper Activation™ system as the firing mechanism.

Figure 1-1: Final Multi-Shot Popper™ Iteration
1.3 About this Thesis

A structured method of product design, as described in Ulrich and Eppinger's text Product Design and Development [4], was used by the design team throughout the development of the Multi-Shot Popper™. It is beneficial to the development of any successful product to use a structured design method, to reduce the risk of proceeding with a flawed design. This thesis provides documentation of the sketch models that were developed, and shows how the design of key modules progressed from one stage to the next. This approach should allow the reader to follow the development of the Multi-Shot Popper™ design from start to finish and thereby gain a fuller understanding of not only how it works, but why it was designed to work in the way that it does.
Chapter 2

Planning

The planning phase involved all work done before the actual design of the product began. It was a necessary first step in the product design process, as it was the stage during which the key design considerations were defined, including:

- Specifications to be met by the product
- Limitations (safety or otherwise) to be placed on the product
- Target market for the product
- Existing competitors (state of the art)

Keeping these considerations in mind as the product design process progressed made it easier for the design team to stay focused on feasible ideas and prevented the team from exploring the development of a design that was clearly deficient in any of these areas, which would have rendered it unacceptable in the final analysis.

2.1 Customer Needs

Before any drawings were made or parts were sketched, it was necessary to identify the users of the product and determine their needs. In the case of this project, the sponsor and the end-user were different, each with their own set of needs, which both had to be taken into account.

The sponsor, Hasbro, presented the design team with several specifications to be met, encompassing the functionality as well as the safety of the product. The safety needs will be detailed in the Standards and Safety section. The functional specifications for the product were broad enough to allow for the design team to work with a relatively large amount of freedom, encouraging the exploration of a variety of design approaches to meet the customer needs.

The key sponsor needs were as follows:

- The product is a projectile toy that can accommodate standard Nerf® balls
- The product uses the Hopper Popper Activation™ system as the discharge mechanism
- The product can store multiple balls, and once loaded, can fire these balls in rapid succession
- The product is not overly complex, either in its design or its use
- The product makes use of a familiar “pump-action” style of motion
- The product is safe and meets all applicable safety specifications as listed in the Standards and Safety section

An additional sponsor requirement was that the product be fun, though this is subjective and difficult to quantify. While it was an important requirement to keep in mind, it is not listed above since the team decided that this would be achieved as a natural consequence of meeting the other specifications.

In addition to the needs of the sponsor, it was important to consider the specific needs of the actual end-user, or customer. Before beginning any work on the design of the product, it was essential to know who the actual end-user would be and what his/her needs were as they related to the product. The type of customer being targeted will, in most cases, greatly affect the direction of the design process, as the customer needs will vary across different segments of the population. For this project, the target user was defined to be children over the age of 5. Accordingly, the following customer needs were taken into account:

- The product is simple to use and does not require complicated instructions
- The required loading force is within the customer’s limits (< 20 lb-f)

Using these sponsor and customer needs, the design team moved forward with the following mission statement to define the design task:

To design and develop a safe, fun, multi-projectile toy that makes use of the Hopper Popper Activation™ system to fire Nerf® foam balls.
2.2 Standards and Safety

Anytime a product is being designed, it is necessary to make safety a priority. The possibility for injury must be kept to a minimum through careful consideration of the need for safety throughout the design process. At the same time, a careful balance between safety and performance must be struck so as to ensure that this emphasis on safety does not detract from the enjoyment of the product by the user.

Safety is especially important when designing a product intended for use by children. As a general rule, children (and perhaps even adults!) can not be relied upon to read written safety warnings, or expected to truly appreciate the risks involved in not obeying these warnings. Therefore, it was incumbent upon the design team to create a product with a sufficiently high level of safety that a parent would feel comfortable buying this toy for his/her child.

In addition to the special safety risks presented by a product geared towards children, a toy that fires projectiles bears added risk for injury (especially eye injury). With this in mind, Hasbro® applies their own set of safety standards for projectiles, detailed in a document entitled, “Corporate Quality Assurance, Safety and Reliability Specification, SRS-045, Projectiles” [2]. The document can be found in its entirety in Appendix A.1.

From the beginning of the design process, it was known that the Multi-Shot Popper™ would use stored energy to fire projectiles. This meant that the projectiles (Nerf® foam balls) were propelled by a discharge mechanism (Hopper Popper Activation™) capable of storing and releasing energy under the control of the user. In other words, the toy itself, and not the user, would define the amount of energy imparted to the projectiles. This is in contrast to projectiles without stored energy, such as a Frisbee, boomerang, or football, which are propelled solely by the energy imparted by the user.

Listed below are synapses of the sections of this document that applied to the Multi-Shot Popper™. Since the type of projectile was defined to be the standard Nerf® foam ball, any sections relating only to the features of the projectile itself were assumed to be satisfied.

Impact Test for Projectiles

Projectiles shall be propelled by their discharge mechanism six times into a concrete block wall (or equivalent surface) at a distance of one foot plus the length of the
projectile from the front end of the discharge mechanism while the discharge mechanism is aimed perpendicular to the wall. This test assures that the integrity of the projectiles will not be compromised upon impact.

**Improvised Projectile Testing**

The discharge mechanism must not be capable of discharging projectiles other than the projectile specifically designed for use with the discharge mechanism. Some of the more common improvised projectiles include: pens, pen caps, markers, marker caps, paper clips, pen refills, batteries, marbles, and pebbles.

**Unexpected Discharging of Projectiles**

The discharge mechanism must not discharge projectiles in an unexpected or inordinately delayed fashion. During normal use, only the activating button, lever or switch must be capable of discharging the projectile. The projectile must be discharged within four seconds of launch activation.

**Kinetic Energy and Kinetic Energy Density**

Any projectile fired from a toy that has a kinetic energy above 0.08 Joules must have an impact surface made of a resilient material. If the projectile kinetic energy exceeds 0.08 Joules, the projectile Kinetic Energy Density must be determined by dividing the kinetic energy of the projectile by its contact area. This Kinetic Energy Density must not exceed 1600 J/m².

### 2.3 State of the Art

The roots of this project were found in the previous work done in the CADlab to develop a novel line of projectile toys, resulting in the development of the Hopper Popper Activation™ system. Documentation of related work done in the CADlab can be found in the theses of Barry Kudrowitz and Bill Fienup [1], Matt Blanco [7], and Andrew Greenhut [8].

In their text *Product Design and Development* [4], Ulrich and Eppinger define the four types of product development projects as follows:
- New product platforms involve creating a new family of products based on a common platform.
- Derivatives of existing product platforms extend an existing product platform to address different needs.
- Incremental improvements to existing products are slight changes to enhance or eliminate flaws.
- Fundamentally new products are radically different products or production technologies to address new or unfamiliar markets, usually at a high risk.

At the time this multi-projectile project was proposed, the Hopper Popper Activation™ system had not yet reached the market in any form, so there were no directly comparable products to the Multi-Shot Popper™. In the intervening time period, the Nerf® Atom Blaster™ reached the market, becoming the first consumer product to use Hopper Popper Activation™ in this way. However, the Atom Blaster™ was designed to hold and fire only a single Nerf® ball, and was aimed at younger customers, so it could not be seen as a direct competitor to the Multi-Shot Popper™. Rather, these two products were part of the same family of products based on a common platform. Thus, the development of the Multi-Shot Popper™ fell under the category of derivatives of existing product platforms, as it extended the Nerf® and Hopper Popper Activation™ product platforms to cover the storage and firing of multiple projectiles.

Figure 2-1: Nerf® Atom Blaster™
For the purpose of comparison, the design team deemed that the closest competitors, which would comprise the state of the art technology, would be any products able to store and fire multiple Nerf® balls without the use of an electric motor. The two products which best fit this description were the Nerf® Ball Blaster, released in 1999, and its 2006 redesign, the Nerf® Reactor, both shown in Figure 2-2. While these products used stored air pressure as the discharge mechanism, the overall function was the same, allowing for a straightforward comparison.

Figure 2-2: Nerf® Ball Blaster (a) and Reactor (b)
Chapter 3

Concept Development

3.1 Introduction/Ideation

The customer needs defined several aspects of the design, such as the use of pump action, ability to store multiple balls, and use of Hopper Popper Activation™ as the firing mechanism. These elements created a general framework for what the finished product should look like and be able to accomplish. Equipped with this general definition, the design team was able to bypass the initial brainstorming session that often serves as the first stage of the product design process.

Instead, the design team conducted smaller scale brainstorming sessions on a modular level throughout the course of the design process. These sessions were used to develop different concepts for mechanisms or methods to perform a specific function or meet a certain need. The most promising concepts were then integrated into sketch models to test their feasibility, before a final prototype model was created, encompassing all of the necessary design elements.

3.2 Background

One feature that was guaranteed to be a part of the finished design was Hopper Popper Activation™ as the firing mechanism, meaning that the rest of the design was generated around this one element. It was therefore necessary for the design team to become familiar with Hopper Popper Activation™. Understanding its capabilities, limitations, strengths and weaknesses made it easier for the design team to know how best to integrate this element into the rest of the design. To accomplish this, the design team used several different methods, including experimenting with Hopper Popper Activation™ and consulting with Barry Kudrowitz, one of the primary developers of Hopper Popper Activation™. The theses of both Andrew Greenhut [8] and Barry...
Kudrowitz and Bill Fienup [1] served as excellent resources, as they contained an in-depth explanation of the development and behavior of Hopper Popper Activation™.

3.2.1 Hopper Popper Activation

The most important part of Hopper Popper Activation™, and the part that supplied the actual ‘pop’, was an injection molded bi-stable rubber toy called a “hopper popper,” or “dropper popper.” These toys will henceforth be referred to as “poppers.”

When in its natural, non-inverted state, the popper resembled half of a hollow rubber sphere (similar to a cereal bowl), as shown in Figure 3-1a. However, the key to the popper was that it was capable of storing energy when inverted, as shown in Figure 3-1b.

![Figure 3-1: Poppers in the Natural (a) and Inverted (b) States [1]](image)

The traditional intent for the popper was to make use of its own stored energy to launch itself, rather than to fire independent projectiles. When inverted and then dropped onto the ground or other surface, the popper would convert its stored energy into kinetic energy, launching itself into the air. In essence, the popper acted as both the projectile and the firing mechanism. However, if the popper was held in place when its stored energy was released, that energy could instead be transferred into the kinetic energy of a projectile. This was the realization that led to the development of Hopper Popper Activation™. To accommodate standard Nerf® foam balls, a popper with a diameter of 2.2 inches in its natural state was used, allowing a Nerf® foam ball to rest in the inverted popper, as shown in Figure 3-2.
Since the popper had never before been used in this manner, it was necessary to design a device to perform this function. Several considerations had to be taken into account during this process. The device, or popper holder, had to allow the popper to freely invert and return to its natural position while keeping the popper firmly in place. However, it could not provide excessive resistance, which would decrease the amount of energy capable of being transferred to the projectile.

Additionally, when the popper was inverted, its rim diameter increased 0.4 inches radially [1], which had to be accounted for in the design of the popper holder. If this increased diameter was not accommodated, the popper would have been prevented from reaching its fully inverted state due to the restrictions of the holder, applying forces in the horizontal direction as shown in Figure 3-3.

![Figure 3-3: Direction of resistance preventing full popper inversion](image)

This presented multiple problems. If the popper never became fully inverted, it would never reach its second stable position, and the ball would be ejected as soon as it
was released by the user. Since all projectiles must be released in a controlled manner, allowing the popper to become fully inverted was essential. Furthermore, fully inverting the popper allowed it to store the most energy, increasing the firing distance of the projectile. Finally, the added resistance made it much harder to invert the popper, making inverting forces too high for a young user.

The final iteration of the popper holder incorporated a tight internal geometry to prevent unnecessary motion of the popper, while still allowing the popper to invert freely. Small rubber gasket segments were added at three points around the rim to keep the ball in place once loaded. Figure 3-4 illustrates a cross sectional view of the securing device with the popper itself appearing in blue as it fit inside the device. Figure 3-5 shows a SLS (selective laser sintering) prototyped version of the final iteration.
3.3 Model Progression

As a natural consequence of the design process, the design team created several iterative sketch models of the Multi-Shot Popper™, each serving to illustrate and test different aspects of the design. After each model was produced, the positive and negative aspects were discussed and documented, and design improvements were suggested based on the performance of the model.

To help the design process proceed in an orderly manner, and to ensure that the end result would fulfill all necessary requirements, the major functions of the design were divided into three categories: Storage/Loading, Popper Inversion and Triggering. These categories represented all of the actions that the Multi-Shot Popper™ needed to perform.

While safety was one of the most highly ranked customer needs, it was not classified as a distinct category because it was not possible to separate safety from the other components of the design in that way. Listing safety as its own category would imply that it was not a factor in the other categories, allowing for the development of unsafe design elements. Attempting to go back and retroactively account for safety in inherently unsafe designs was not an efficient method for product design. Therefore, the design team was mindful of the safety requirements in each facet of the design.

What follows is a description of the models that were created, arranged in chronological order, along with how each model addressed the three major functional requirements listed above. By examining the design process through the progression of the whole models, and not merely the functional modules, it is easier to conceptualize how the modules worked together and how the design of the Multi-Shot Popper™ evolved. Reading about the process in true chronological order also makes it easier to follow the changes and progression made along the way, as each model acted as a step along the path of the product design process.
3.3.1 Wooden Model

The first significant model iteration will be referred to as the “wooden model,” a sketch of which can be seen in figure 3-6. Though simple in appearance, this model addressed several functional issues, teaching the design team important lessons.

![Figure 3-6: Sketch of Wooden Model](image)

3.3.1.1 Popper Inversion

Prior to building the first model, the design team theorized different methods by which the popper could be inverted, while also fitting into the shape of a traditional blaster. The three most feasible possibilities were: Holding the Popper Holder stationary and pulling on the popper from behind; Holding the Popper Holder stationary and pushing a foam ball into the popper from the front with enough force to invert it; Holding a foam ball stationary and forcing the popper to invert around the ball by pushing the Popper Holder forward. Of these three methods, the first was selected as the most promising. With the second and third approaches, some of the energy exerted to invert the popper would have been lost by pushing into the foam ball, which would have deformed and absorbed energy.

The main purpose of this model was to test the feasibility of inverting the popper by pulling on it from behind while holding the Popper Holder stationary. Applying force to the popper from behind required a linkage connecting to the popper, which could be
accomplished either by rigid or flexible attachment, which was the second aspect of Popper Inversion being tested with this model. The design team chose to test string, a flexible attachment, as the linkage.

To make the attachment to the popper, the design team placed an eye-bolt through the hole in the center of the popper with the eye in back, fixing the bolt in place with a nut on either side of the popper. The string was tied to the eye of the bolt in back of the popper and then affixed in two locations to a shaft located farther back on the body of the model. This shaft was press fit through the center of a larger wheel, to which the inversion force could be applied. When the wheel was rotated, the shaft would rotate as well, winding the string around the shaft and pulling back on the popper.

Several rubber bands were placed around the circumference of the wheel, which provided a high-friction surface to more easily apply force without slipping. To invert the popper, a small block of wood was pressed down upon the top of the wheel and
pulled backwards, using the desired pump action, and winding the string until enough force had been applied to invert the popper.

This model provided several key insights into the area of Popper Inversion. Most importantly, it showed that it was indeed possible to invert the popper from behind. Also, by using a large wheel on a smaller shaft to translate force to the popper, the user was able to gain a mechanical advantage, reducing the required input force.

However, it also revealed the shortcomings of using string as the linkage material. When the string was being wound, it would stretch, absorbing energy and increasing the amount of energy required to invert the popper. Additionally, when the blaster was fired, the popper had to unwind some length of string, thus rotating the shaft and wheel, as it returned to its natural position, resisting the motion of the popper and decreasing the amount of energy imparted to the ball. This caused the balls to be discharged with a lower velocity.

An unexpected benefit of this approach was that the eye-bolt provided a solution to one of the major safety concerns. Having the front of the bolt extend through the front of the popper served two purposes. The first was to center the force of the popper in the middle of the ball when it was launched, and the second was to make it much more difficult to fire improvised projectiles. Most perceived improvised projectiles were small and would need to rest in the center of the popper to be fired at any appreciable velocity. Since the bolt occupied this position, any improvised projectiles would be restricted to the edge of the popper, where they would receive only a fraction of the converted kinetic energy from the discharging of the popper.

3.3.1.2 Storage/Loading

The secondary purpose of the model was to examine the suitability of a vertically oriented loading/storage enclosure. The storage device was a plastic tube held by hand in a vertical orientation above the firing platform. The tube could hold six foam balls, and contained a compression spring to force the balls out of the tube. In this orientation, while a single ball was in the firing position (from now on referred to as the “primary ball”) and ready to be discharged by the popper, the remaining stored balls were resting
on top of one another, with the second ball to be fired ("secondary ball") resting on the primary ball.

Testing confirmed that it was possible to fire a ball in this configuration without a significant loss in velocity. This presented two benefits. First, the stored balls held the primary ball in place, keeping it from moving out of the firing position as the orientation of the blaster was changed. Second, using the stored balls to perform this task eliminated the need for a separate mechanism, simplifying the design.

Despite its useful lessons, the vertically oriented storage/loading tube was not seen as an appealing permanent option, as its appearance was obtrusive and it gave the blaster a clunky feel, reducing the perceived play value.

### 3.3.1.3 Triggering

The triggering in this model was performed simply by hand. The design team observed, as was discovered in previous work by Barry Kudrowitz and Will Fienup, that the closer to the center of the popper the force was applied, the less force was required to fire the popper. While no mechanical triggering mechanism was put in place, this knowledge aided in future development of a triggering mechanism.

### 3.3.2 Metal Model

The metal model iteration represented a big leap forward from previous models in many respects and introduced for the first time several key design features which were present in the final design of the Multi-Shot Popper™.
3.3.2.1 Popper Inversion

The method of popper inversion for this model drew from the lessons learned in the previous model while also including several new design features. The approach of inverting the popper from behind was retained, but the linkage mechanism was changed significantly.

A multi-gear rack and pinion system was implemented that linked the popper to a sliding pump mechanism. The sliding pump was connected to the primary gear with a nylon rack, which will be referred to as the "main rack". A secondary, smaller gear was attached to the primary gear, and the two gears rotated together. The tooth ratio of the two gears was 4:1, generating a mechanical advantage of 4:1. This secondary gear was, in turn, connected to two separate racks which each had a single grabbing tooth at the front. To distinguish them from the main rack, these racks will be referred to as the upper and lower "grabbers." The popper was mounted at the front and had a bolt through it which played a role in both popper inversion and loading/storage.

Inversion of the popper involved two stages: the backward stroke and the forward stroke of the pump mechanism. As the pump was moved backward during the initial stage of the backstroke, the main rack rotated the primary gear, in turn rotating the secondary gear. This drew the lower grabber backwards, causing it to hook onto the back of the bolt attached to the popper. At the same time, the upper grabber moved forward. A small inclined nub was placed on the track of the upper grabber and acted as a ramp,
causing the grabber to move downward into the path of the bolt as it moved across the nub. As the pump reached the end of its backstroke, the grabbers met and exchanged the bolt.

During the forward return stroke, the top grabber moved backwards, pulling the bolt along with it. At the end of the return stroke, the bolt had been pulled back far enough to invert the popper. The sliding pump and the racks had returned to their original position, and when the popper inverted, the bolt was released by the upper grabber and the popper was ready to fire.

This system allowed for both the forward and backward motions of the pump action to contribute to the inversion of the popper. By harnessing energy in both directions, the necessary travel distance of the pump was reduced, allowing the blaster to be more compact. Additionally, the use of a 4:1 gear ratio reduced the amount of force required to invert the popper by a factor of 4, making the process easier.

Figure 3-10 illustrates the interaction between the grabbers and the bolt during a single popper inversion cycle. To make the process easier to follow, the point of contact between the bolt and grabber(s) has been indicated by a circle. Figures 3-10 (a) and (f) represent the beginning and end, respectively, of the inversion cycle, at which points the bolt is not in contact with either grabber.
Figure 3-10 (a)-(f): Exchange of bolt during Popper Inversion

(a) Initial State
(b) Contact with lower grabber
(c) Backstroke continues
(d) Bolt Exchange
(e) Return stroke
(f) Fully Inverted
3.3.2.2 Storage/Loading

In this model the storage enclosure for balls was moved to the interior of the blaster, contributing to a more compact design. A length of PVC tubing with a compression spring in the back was used to store up to 7 balls. This tube also served as the guide for the sliding pump used in the inversion process. An elbow joint at the front of the tube directed the balls into the firing position in front of the popper. This elbow joint could be rotated 90° to allow the balls to be loaded.

![Figure 3-11: Visualization of balls in storage chamber](image)

Loading of the balls happened simultaneously with inverting. As the bolt was pulled back out of the way, the first ball was pushed into the firing position by the spring in the back of the storage tube. Prior to inverting the popper, the secondary ball applied an upward force on the primary ball, pinning it against the bolt, as shown in Figure 3-12.

![Figure 3-12: Primary ball pinned against bolt](image)
As the bolt was drawn back, it pulled the ball back slightly, coming to rest slightly behind where it began, but now centered in front of the popper. The secondary ball still provided some force on the primary ball, pushing it against the top wall of the firing area, and keeping it in the proper firing position. As the design team learned in the previous model, the primary ball could still be fired with sufficient velocity while being held in place by the secondary ball.

![Image](image.jpg)

Figure 3-13: Foam ball in fully loaded position

### 3.3.2.3 Triggering

Triggering was again performed by hand for this model. A small force applied on the back of the bolt was sufficient to discharge the popper, as long as the bolt was pushed straight ahead. If the bolt was twisted or the force was not applied parallel to the motion of the racks, a much higher triggering force was required. This discovery helped to shape the development of a mechanical triggering mechanism in the next model.

### 3.3.3 Rapid Prototyped (RP) Model

This final model was an approximation to not only a “works-like” model but also a possible “looks-like” model. While retaining many of the mechanical elements integrated into the Metal Model, the RP Model also took on a sleeker, more finished shape. The body was fully enclosed, hiding all of the mechanical elements from the user. Hasbro provided the design for a commonly used handle, which was incorporated into the
model. The overall design of the blaster was reminiscent of a traditional shotgun, with the sliding pump, large firing barrel and trigger location.

This model was designed in SolidWorks and rapid prototyped by Hasbro using stereo lithography (SLA). A set of CAD drawings can be found in Appendix A.2.

![Figure 3-14: Fully Assembled RP Model](image)

### 3.3.3.1 Popper Inversion

The RP Model used the same mechanism for popper inversion as the Metal Model. Once again a rack and pinion system was used to invert the popper, with the main rack produced as a part of the top of the sliding pump. A new gear and set of racks was fabricated, but due to inaccuracies in the production of the parts, the same gears, and shorter versions of the same racks from the Metal Model were used.

![Figure 3-15: Rack and pinion system](image)
A new problem that was encountered with this model was having the front gripping tooth on the grabber racks break off due to excessive stress on this single tooth. The actual source of the problem was hard to identify because the model could only be operated while it was completely assembled. This meant that the inner workings were fully enclosed, so the grabber (and the source of the problem) could not be seen.

One possible explanation for this problem was the poor meshing of the primary gear and the main rack. There was a very tight fit between the teeth of the primary gear and those of the main rack, meaning that the primary gear did not rotate smoothly as the pump was moved backward, instead often moving in short bursts and possibly causing the grabbing tooth to break.

Another problem was the roughness of the material used to produce the model. By design, the fit between the sliding pump and the storage barrel was tight; however, the friction between these pieces was larger than expected, requiring more force than anticipated to overcome this resistance. By sanding the outside surface of the storage barrel and the inside surface of the sliding pump, the friction was reduced by a small amount. The amount of sanding that could be performed was limited by the thickness of the walls of the model. If too much surface material was removed, the walls would have become too thin and might have cracked or broken.

A final step taken to combat the dry friction was the addition of Johnson’s Baby Powder. This acted as a solid lubricant and allowed the pump to slide much more easily, in turn allowing the primary gear to rotate more smoothly. However, the baby powder had to be reapplied often to continue to be effective and was not a good long term solution.

### 3.3.3.2 Storage/Loading

The storage and loading aspects of this model were very similar to the previous model. The cylindrical storage chamber running from the back to the front of the blaster was long enough to store 6 balls, and housed a compression spring at its rear to push the balls out of the front of the chamber and into the firing position. A semi-spherical guide piece
was attached to the front of the spring to mimic the shape of a foam ball and to help push the balls forward through the elbow joint and into the firing position.

The elbow joint leading from the front of the storage chamber to the firing chamber was rotated 90° to allow for loading. To ensure that the elbow would not over-rotate in either direction, a small guide post was placed on the side of the joint. This post was designed to fit into a guide channel cut into the side of the blaster, which prevented the elbow joint from rotating beyond 90° and from going beyond the correct firing position.

![Figure 3-16: Elbow Joint closed (a) and open (b) to allow loading](image)

After the balls were loaded, the primary ball was lightly pinned between the secondary ball and the bolt extending out of the popper. When the popper was inverted, the bolt would draw the primary ball backwards and into the firing position, with the secondary ball pinning the primary ball against the roof of the firing chamber.

As the model was tested, two major factors were identified that sometimes combined to prevent the balls from reliably moving into the proper firing position. First, the unexpectedly high friction of the production material resisted the motion of the balls through the storage chamber and the elbow joint. Secondly, the inside diameter of the loading chamber and the elbow joint did not have sufficient clearance space for the balls.

Due to the high friction, the balls were unable to slide (translating without rotating) across the surface of the storage chamber as they were pushed forward by the spring, instead being forced to roll along the surface. This became a problem as the balls attempted to roll through the elbow joint. Because of the lack of extra clearance, one ball would sometime roll up the side of the ball in front of it, trapping both balls in the elbow.
The inside of the storage chamber and elbow was sanded extensively in an attempt to reduce the friction and provide more clearance, but this did not have any noticeable effect. Baby powder was added inside the elbow to act as a solid lubricant and did result in improved performance, but had to be reapplied often.

After sanding failed to provide any noticeable improvement, the design team attempted to overcome these problems by increasing the force supplied by the spring. It was theorized that with more force, the balls might be successfully pushed through the elbow despite the high friction and tight clearance.

A spacer was placed behind the spring at the back of the storage chamber, which moved the spring forward. This increased the compression of the spring when the chamber was loaded, causing the spring to supply a greater force to the balls. However, this increased force failed to improve the performance. A second spacer was added, further increasing the force, but this also yielded the same results.

3.3.3.3 Triggering

This model included a mechanical trigger, located in the contoured handle, which was based on a common blaster handle design provided by Hasbro. This handle and the trigger can be seen in Figure 3-17.

![Figure 3-17: Handle and Trigger](image)

The trigger was located near the back of the blaster, in the same position it would occupy in a traditional shotgun. This traditional location, along with the familiar pump action, allowed the user to intuitively understand how to operate the Multi-Shot...
Popper™. This instant familiarity was viewed as a benefit to any toy marketed to children, who may lose interest in a toy that was extremely complicated to operate.

The triggering mechanism itself involved several components, as shown in Figure 3-18. These components were necessary to translate the force applied to the trigger at the back of the blaster into a force on the popper at the front of the blaster.

![Figure 3-18: Triggering Assembly](image)

The part of the trigger visible to the user comprised only about one third of the entire trigger. The section of the trigger that was hidden had a raised key on one side, which fit into a keyway inside of the handle. This ensured that the trigger would move in only a single plane and would not twist or rotate.

![Figure 3-19: Trigger](image)
The trigger was directly connected to the lower linkage, which was held in place by a pin through a hole in the middle of the linkage. Near the connection to the trigger, this linkage was attached to a fixed point in the blaster with a spring, so that after being displaced, both the linkage and trigger would return to their normal position. As the user pulled back on the trigger, the lower linkage would rotate about the pin. This rotation resulted in horizontal movement at the top of this linkage, which in turn translated into horizontal motion of the upper linkage attached to the top of the lower linkage.

This upper linkage was then connected to the “pusher”, which was the final piece of the triggering assembly, and was the piece that actually made contact with the popper, causing it to invert and discharge the projectile. The pusher fit into a horizontal channel behind the racks and gears, which restricted its motion to a single plane, harnessing only the horizontal displacement of the upper linkage.

Figure 3-20 shows the location of the triggering assembly both before and after triggering occurs. In Figure 3-20(a) the popper inversion stage has been completed and the popper is ready to discharge a projectile. Figure 3-20(b) shows the triggering assembly after the trigger has been pulled back, and the stored energy of the popper has been discharged.
The head piece of the pusher was designed to contact the popper as close to its center as possible to keep the triggering force to a minimum, ensuring that the popper would discharge reliably. However, since this head piece was located directly behind the popper, it had to be designed to allow the bolt to pass through it freely. The first iteration of the head piece allowed the bolt to fit through it, but a problem arose during popper inversion.

As the bolt was pulled back by the grabbers, its vertical orientation remained fixed, but it would jostle horizontally from side to side a small amount. This side to side motion brought the bolt into contact with the sides of the head piece, and the threads on the bolt
would sometimes get caught on the head piece. The bolt would then become stuck and could not be pulled back by the grabber, preventing the popper from fully inverting. This was also another likely cause of the front tooth breaking off of the grabber during inversion — a problem cited above in the Popper Inversion section. By redesigning the head piece to allow for more side to side motion, and using smooth electrical tape to cover the rough metal edges where contact with the bolt would occur, as shown in Figure 3-21, this problem was solved.

![Image](image_url)

(a)  (b)

Figure 3-21: Initial (a) and refined (b) head piece of pusher

A final shortcoming of this trigger design was that there was very little safeguard against unexpected discharge of projectiles. By its nature, the popper would be stable once it had been inverted, requiring some outside force to cause a projectile to discharge. However, it was possible that if the blaster was dropped or bumped against a rigid object, the jarring effect would cause the popper to return to its natural position and discharge a projectile unexpectedly. Due to the fragility of this model, the design team chose not to test this scenario extensively.
Chapter 4

Conclusion

4.1 Summary

The design team began this project with the goal of designing a safe and fun toy, which used Hopper Popper Activation™ to fire multiple Nerf® foam balls. Through the product design process a series of iterative models were produced, from which the team was able to learn which concepts worked well and where problems were found, learning valuable lessons to be used as the design process progressed.

The final iteration of the Multi-Shot Popper™ had some functional limitations but was sufficient to illustrate that all of the key customer needs were likely to be satisfied by the proposed solutions. It was capable of storing 6 standard Nerf® balls, used Hopper Popper Activation™ as its discharge mechanism, was simple to operate, used pump action and took safety into account. While the final implementation of the loading system was not completely reliable, the design itself was shown to work in a previous model, and the popper inversion and triggering system both perform well.

The Multi-Shot Popper™'s ability to shoot multiple foam balls using Hopper Popper Activation™ was something that no other toy could match. Additionally, it had a sleek appearance, was relatively compact, simple to operate, and used a fun pump-action style of motion. These features, along with its novelty, are intended to give the Multi-Shot Popper™ a unique place within its intended market.

4.2 Future Work

Future work on the Multi-Shot Popper™ could include implementing more stringent safety measures to prevent unexpected discharge of projectiles. In the retail version of the Nerf® Atom Blaster™, a safety mechanism was implemented that locked the popper in place once it was inverted, and prevented it from being discharged unless a ball was properly seated in the firing position. This safety mechanism guarded against firing
improvised projectiles and might be a good candidate for use with the Multi-Shot Popper™. The addition of a dry lubricant improved the reliability of the loading process in the final prototype, but a permanent solution should be pursued. Suggested solutions include increasing the diameter and/or decreasing the sharpness of the curve of the elbow joint, or using a different production material with lower friction. The trigger could be raised so that it is in line with the sliding pump, preventing a torque from being created around the handle as the user operates the toy. The loading procedure could be refined by adding a small catch at the end of the elbow joint to hold the balls in place as the elbow joint is rotated back to the firing position.
Appendix A

A.1 Hasbro Inc Corporate Quality Assurance Safety and Reliability Specification [3]

HASBRO INC.

CORPORATE QUALITY ASSURANCE
SAFETY AND RELIABILITY SPECIFICATION

SRS - 045
TITLE: PROJECTILES

BY: C. FISCHER
DATE: JUNE 16, 1999

APPROVAL:
REVISION: G

1.0. PURPOSE

To establish specifications for the various structural characteristics and kinetic parameters of projectiles used on Hasbro, Inc. products. The intent of these specifications is to minimize any potential for injury (especially eye injury) to children while simultaneously maintaining the traditional play value represented by projectiles at an acceptable, but under reasonably foreseeable conditions of use and abuse, safe level. Conformance to the requirements of this specification will also ensure compliance to global requirements for projectiles.

2.0. SCOPE

This specification applies to both toys A) that are intended to launch projectiles into free flight by means of a discharge mechanism in which the kinetic energy of the projectile is determined by the toy and not by the user and B) certain projectile toys without stored energy. (i.e. arrows and darts intended to be thrown, helicopter rotors, propeller blades, bows and arrows and other items intended to be thrown, but not intended to be caught).

This specification does not apply to discharge mechanisms intended to propel a ground based vehicular toy along a track or other surface, nor when a projectile is inaccessible to a child when it leaves the discharge mechanism (e.g. a pin ball machine).

Projectiles without stored energy are acceptable only for toys with a minimum age grade of 3 years and up.

Projectiles are acceptable only for toys with a minimum age grade of 4 years and up)

Projectile guns and bows and arrows are acceptable only for toys with a minimum age grade of 5 years and up.

Helicopter-type projectiles that are intended for vertical discharges are only acceptable for toys with a minimum age grade of 6 years and up.

3.0 DEFINITIONS

3.1 PROJECTILE WITH STORED ENERGY: an object propelled by means of a discharge mechanism capable of storing and releasing energy under the control of the operator.
3.2 PROJECTILE WITHOUT STORED ENERGY: An object propelled solely by the energy imparted by a child.

3.3 DISCHARGE MECHANISM: An inanimate system for releasing and propelling projectiles.

3.4 PROJECTILE TIP - Any portion of a projectile that can reasonably be expected to contact an impact surface (e.g. an eye) during flight. A tip end or leading edge of a projectile is not the only possible “tip”. On disc or saucer like projectiles, the “edge” of the disc is considered as the tip. On rotor-type projectiles that have a ring around the perimeter, all exposed surfaces of the ring should be considered “tips”.

Note: The requirements of 6.3 apply to all “tips”.

See Figure 2 for a pictorial depiction of the proper radii on a disc-type projectile.

3.5 PROTECTIVE TIP: A component that is attached to the impacting end of a projectile to minimize injury if it should impact on the body and also to prevent damage to the projectile on striking a target, or prevent damage to inanimate objects.

3.6 RESILIENT TIP: A tip on impact surface of a projectile that has a Shore A durometer not greater than 55 (as measured on the impact surface of the tip).

3.7 RIGID PROJECTILES: Projectiles with an impact tip that has a Shore A durometer that is greater than 55.

3.8 PROJECTILE GUNS AND BOWS AND ARROWS: Hand-held projectile launchers that are comparable in scale to a real firearm or bow and arrow. For purposes of this specification, small projectile launchers scaled to the size of toy figures (e.g. G.I. Joe) are not “projectile guns”.

4.0 TEST EQUIPMENT

4.1 A radar gun capable of measuring a small projectile (larger than Hasbro small part gage) traveling at a high speed (e.g. 11 miles/hour).

4.2 Hasbro small parts cylinder (per SRS-001, figure 2).

4.3 Laboratory balance with an accuracy of +/- 0.1 gram. (i.e. Santer KD50).

4.4 Aluminum foil complying with the requirements of 5.2.

4.5 A steel ball having a nominal diameter of 15 mm and a mass of 14.00 +/- 0.05 grams.

4.6 Clamps to uniformly clamp the diaphragm in the supporting frame - See Figure 1.
5.0 TEST PROCEDURE

5.1 KINETIC ENERGY DETERMINATION

5.1.1 The kinetic energy (in joules, J) of a projectile shall be determined from the following equation:

\[ \text{kinetic energy} = \frac{1}{2} mv^2 \]

where: \( m \) = mass of projectile (Kg) and,
\( v \) = velocity of the projectile (meters/sec.)

Conversion factor: Meters/sec. = 447142 x miles/hour

5.1.2 The mass of projectile (kg) shall be determined by weighing a sample on a laboratory balance. A sufficient sample size (at least 30) of projectiles shall be weighed to determine the average weight plus 3 standard deviations. This upper limit weight in Kg is used for "m".

5.1.3 The velocity of a projectile (v) shall be determined by firing a sample from the discharge mechanism of the toy projected out in front of the radar gun. Recording m.p.h.). The velocity of the projectile shall be calculated from the expression

\[ v \text{ (meters/seconds)} = \frac{\text{mph x } 447142}{\text{conversion factor}} \]

The value of \( v \) in the equation is the average of five measurements of a given projectile.

5.2 Test for Penetration of Toy Projectiles with Stored Energy

5.2.1 Foil

From a roll of aluminum foil, cut out twenty samples measuring 105 mm x 105 mm. Ensure that each sample is free from obvious imperfections including creases or wrinkles. Ten samples of aluminum foil are required to verify the quality of the aluminum foil and ten samples are required to test the toy.

5.2.2 Foil Verification.

a) The quality of the foil should be verified as follows:

b) Place one of the samples of foil between the two O-rings of the clamping frame and clamp the foil between the clamps so that the foil diaphragm is evenly tensioned with no creases or wrinkles.

c) Place the clamping frame on a substantially horizontal surface so that the foil diaphragm makes an angle between 15 degrees and 20 degrees relative to the horizontal.
d) Position the steel ball so that when the ball is released, it would fall freely through a vertical distance of 300 mm to strike the central 25 mm diameter area of the foil diaphragm.

c) Examine whether or not the foil diaphragm ruptured, as specified in 5.2.3.

d) If the steel ball does not cause the foil diaphragm to rupture, repeat steps b) to d) a further four times, provided that each time the foil diaphragm does not rupture.

e) If all five of the foil diaphragms do not rupture, repeat steps b) to d), but this time, drop the steel ball through a height of 500 mm.

b) If the ball causes the foil diaphragm to rupture, as specified in 5.2.3, repeat steps b) to d) a further four times, provided that each time the foil diaphragm does rupture.

5.2.3 Interpretation

The foil diaphragm shall be considered as not ruptured if the foil shows, without magnification, no split or hole. A mere dent shall not be considered as a rupture.

The foil diaphragm shall be considered as ruptured if the foils show, without magnification, a split or hole.

The ten remaining foil samples that are to be used to test the toy shall be considered as verified as being of a suitable quality if all five samples that were subjected to the ball drop height of 500 mm did rupture.

5.2.4 Test Specimen

The toy submitted for this test shall be representative of the normal population and shall not have been subjected to any normal use and reasonably foreseeable abuse tests prior to penetration testing the toy.

5.2.5 Procedure

The procedure shall be carried out in a conditioned environment as follows:

a) Place one of the verified foil samples between the two O-rings of the clamping frame and clamp the foil using the clamps so that the foil diaphragm is evenly tensioned with no crease or wrinkles.

b) Place the clamping frame such that the foil diaphragm lies in a substantially vertical plane.

c) Load the projectile into the discharge mechanism.
d) Position the toy so that:

1) The end of the toy, that is, the end of the projectile or the end of the discharge mechanism whichever protrudes furthest, is 150 mm from the foil diaphragm; and

2) When the projectile is ejected, the flight path of the projectile would be substantially normal relative to the foil diaphragm and the projectile would strike the foil's center as possible.

e) Eject the projectile.

f) Observe whether or not the projectile ruptures the foil diaphragm as specified in 5.2.3.

g) Repeat steps a) to f) a further nine times using the other nine verified foil samples.

5.2.6 Report

The report shall state the number of times the projectile ruptured the foil diaphragm when the toy was tested in accordance with 5.2.5.

5.3 Impact Test For Projectiles

Projectiles shall be propelled by their discharge mechanism six times into a concrete block wall (or equivalent surface) located at a distance 1 foot (300 mm) plus the length of the projectile from the front end of the discharge mechanism. The discharge mechanism shall be aimed perpendicular to the wall.

5.4 Use and Abuse Testing

Perform all pertinent use, abuse, lift, and environmental testing on the projectile per the appropriate test plan for its parent product.

5.5 Improvised Projectile Test

Determine through experimentation if discharge mechanism is capable of discharging projectiles other than the projectile specifically designed for use with the discharge mechanism. Testing of improvised projectiles shall include, but is not limited to, the following objects:
(All measurements in inches)

A) Correction Pen Cap

1) Pentel Opaquing Fluid Correction Pen
   Oil-Based Quick Dry
   18 ml. ZLC1-W
   Manufacturer: Pentel Co. Ltd.
   Made in Japan

B) Marker

1) Pentel Marker
   F50
   Made in Japan

C) Marker Caps

1) Fluorescent Pen Cap
   Zebra Pen 2 Thin Size Cap

2) Fluorescent Pen Cap
   Zebra Pen 2 Thin Size Cap

3) Fiber Tip Permanent Marker Cap
   Artline 70 High Performance
   Xylene Free EK-70
   Manufacturer: Shachihata Product
   Made in Japan

4) Fiber Tip Permanent Marker Cap
   Artline 70 High Performance
   Xylene Free EK-700
   Manufacturer: Shachihata Product
   Made in Japan

Dimensions

A1) total length - 1.10 inches
    maximum diameter - 0.57 inch
    minimum diameter - .53 inch

B1) total length - 3.3 inches
    diameter - 0.91 inch

Tip: length - 0.28; width - 0.18 inch
Tip Body: length - 0.70 inch
max. diameter - 0.65 inch
min. diameter - 0.36 inch

C1) length - 0.93 inch
    max. diameter - 0.35 inch
    min. diameter - 0.23 inch

C2) length - 1.82 inches
    max. diameter - 0.58 inch
    min. diameter - 0.28 inch

C3) length - 1.71 inches
    max. diameter - 0.66 inch
    min. diameter - 0.51 inch

C4) length - 1.52 inches
    max. diameter - 0.70 inch
    min. diameter - 0.69 inch
D) Paper Clip

1) Triangular Clip
   # Elephant Triangular
   Art. No. PM121
   Made in China

Dimensions
D1) length - 1.19 inches
     max. diameter - 0.37 inch
     min. diameter - 0.15
     diameter of wire - 0.04 inch

E) Pen

1) Ball Pen Body
   Zebra - New Crystal
   N-5000
   Made in Japan

Dimensions
E1) length - 4.56 inches
     max. diameter - 0.32 inch
     min. diameter - 0.200 inch

2) Ball Pen Body
   Zebra - Hard-Crystal
   N-5100
   Made in Japan

Dimensions
E2) length - 4.83 inches
     max. diameter - 0.31 inch
     min. diameter - 0.21 inch

3) Ball Pen Body
   Bic #C-B-19

Dimensions
E3) length - 5.32 inches
     max. diameter - 0.29 inch
     min. diameter - 0.24 inch

4) Ball Pen Cap
   Zebra N-5000
   Made in Japan

Dimensions
E4) length - 2.32 inches
     max. diameter - 0.47 inch
     min. diameter - 0.25 inch

5) Ball Pen Metal Nozzle
   Zebra - Hard Crystal
   N-5100

Dimensions
E5) length - 0.46 inch
     max. diameter - 0.22 inch
     min. diameter - 0.13 inch

F) Pen Refill

1) Bic #C-B-19

Dimensions
F1) length - 5.17 inches
     max. diameter - 0.19 inch
     min. diameter - 0.12 inch

2) Zebra Ballpoint Pen Refill BR-6A-H-BK

Dimensions
F2) length 5.48 inches
     max. diameter - 0.12 inch
     min. diameter - 0.09 inch
G) Battery

<table>
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H) Marble & Pebble

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<th>2) Diameter 0.635”</th>
<th>3) Diameter 0.642”</th>
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<td>0.635 inch</td>
<td>0.642 inch</td>
</tr>
</tbody>
</table>

Hazard evaluation of launched improvised projectiles shall include (but is not limited to) the following: Tip radius relative to kinetic energy; for rigid projectiles, the kinetic energy; for non-rigid or resilient tipped projectiles, the kinetic energy density.

5.6 Projectile Configuration Evaluation

Projectiles must not have projections (i.e. ribs, missiles, fins, etc.) that protrude from the main body of the projectile and have the potential to generate a “fishhook” effect. Generally, projections that extend 3/16” or more from the body of the projectile and subtend an angle of 30-90 degrees from the body and are not “blended” to the body will be considered as having the potential to generate a “fishhook” effect and are not acceptable for use on the Hasbro, Inc., products. However, projectiles of a size and/or shape such that they don’t penetrate to the full depth of the Hasbro Suplemental Test Fixture (see SRS-004, Figure 2) in their normal flight orientation shall be considered acceptable regardless of configuration. The configuration of all projectiles must be approved by Quality Assurance.

5.7 Unexpected Discharging Of Projectiles

Determine through experimentation if the discharge mechanism is capable of discharging projectiles in an unforeseeable, unexpected, or inordinately delayed fashion. When the projectile is in its normal launching position only the activating button, lever or switch must be capable of discharging the projectile. The actions and movements of the toy during all of its reasonably foreseeable normal play modes must not activate the discharge mechanism.
5.8 Projectile Kinetic Energy Density

The projectile kinetic energy density must be determined on all projectiles with a kinetic energy greater than .09 joule. The Projectile Kinetic Energy Density is the kinetic energy of the projectile divided by its contact area. On non-rigid (i.e. including resilient tipped) projectiles the contact area is measured by applying a suitable staining agent (e.g. Prussian Blue) to the projectile, fixing it at a suitable surface 1 foot away and measuring the area of the residual impression. Area is determined by the following:

Radius in meters: Area = \( \pi r^2 \)
Radius in inches: Area = 0.006452 \( \pi r^2 \)

The kinetic energy density is expressed as joules/area.

5.9 Arrows, Darts and Other “Thrown” Items and Bows

The kinetic energy of arrows, darts and other projectiles intended to be thrown shall be imparted to the projectile by a adult throwing the projectile with the highest reasonably foreseeable velocity. To determine the highest reasonably foreseeable velocity, child testing with children of the highest age for which the toy is intended may be required.

For bows, use an arrow intended for the bow and stretch the bow string, using a maximum force of 8.0 lb. (35.6 newton), as far as the arrow allows, but to a 28 inch maximum (71 cm).

6.0 SPECIFICATIONS

6.1 No projectile intended to be fired from the toy shall have sharp edges per SRS-003, sharp points per SRS-002, or parts that fit without compression (i.e. the 1 lb. weight is NOT used) into the Hasbro cylinder per SRS-001. (NOTE: pieces that detach as a result of abuse test and cannot be launched by the discharge mechanism are not projectiles).

6.2 No projectile shall have a configuration that generates a "fisheye" effect. (See 5.6).

6.3 No projectile fired from a toy shall have a tip radius less then 2 mm (.08 in.). The minimum allowable tip radius increases in direct proportion to the kinetic energy of the projectile per the table below:
### Projectile Energy Level vs. Minimum Allowable Tip Radius

<table>
<thead>
<tr>
<th>Energy Level</th>
<th>Tip Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to .025 joule</td>
<td>2 mm</td>
</tr>
<tr>
<td>From .025 to .05</td>
<td>3 mm</td>
</tr>
<tr>
<td>From .05 to .10</td>
<td>4 mm</td>
</tr>
<tr>
<td>From .10 to .15</td>
<td>5 mm</td>
</tr>
<tr>
<td>From .15 to .20</td>
<td>6 mm</td>
</tr>
</tbody>
</table>

**NOTE:** Any projectile with an energy level of .25 joule or greater must be reviewed and approved by Senior Vice President, Hasbro Quality Assurance.

Projectiles in the form of arrows or darts or other missile-shaped objects that are intended to be thrown by the user must have resilient tips with an impact area of at least 4 cm² (.620 in²).

Helicopter rotors and single propellers intended to be powered into vertical or nearly vertical flight by a spring mechanism or similar device must have a ring around the perimeter that complies with all the radii requirements of this section.

6.4 Any projectile fired from the toy that has a kinetic energy that exceeds .08 joule (as determined by section 5.1) shall have an impact surface(s) of a resilient material.

**NOTE:** If the flight characteristics of the projectile are such that it tumbles or turns around in flight when the kinetic energy exceeds .08 joule, then all profile surfaces are to be treated as impact surfaces.

6.5 Discharge mechanisms must be unable to discharge hazardous improvised projectiles.

6.6 All projectiles must withstand the impact test for projectiles (5.3 above) without the generation of a hazardous condition.

6.7 A protective tip shall not be detached from the projectile when subjected to torque/tension test per SRS-006 (i.e. 8 in-lbs torque/20.5 lbs tension) and shall not detach or produce or reveal hazardous points or edges when fired into a solid object according to test procedure described in 5.3 above.

6.8 Projectiles must not be discharged in an unexpected fashion. Projectiles must discharge within 4 seconds after launch activation (unless there is ample warning in the form of lights, sounds, etc.).

6.9 The Kinetic Energy Density of projectiles must not exceed 1600 joules/m³. (See section 5.8).

**NOTE:** Kinetic Energy Density determination is not required for projectiles with an energy level less than .08 joule.
6.10 A toy, when tested in accordance with 5.2, shall not eject a stored energy projectile that results in the rupturing of more than two out of the ten foil diaphragms.

6.11 Any subject toy capable of discharging a projectile with a kinetic energy greater than 0.08 joule must carry a cautionary statement on the toy (see SRS-070 - Section 4.8).

6.12 All projectiles must meet above specifications both before and after all pertinent use, abuse, life and environmental testing per the appropriate test plan.

6.13 Summary of Selected Requirements

<table>
<thead>
<tr>
<th>Projectile Type</th>
<th>Tip Radii (Section 6.3)</th>
<th>Resilient Tip* (6.4)</th>
<th>K.E.D. (6.5)</th>
<th>Foil Test (6.10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes**</td>
</tr>
<tr>
<td>Stored energy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes*</td>
<td>Yes**</td>
</tr>
<tr>
<td>No stored energy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes*</td>
<td>No</td>
</tr>
</tbody>
</table>

* Applies only if K.E. is > .08 joule
** Does not apply to disc or saucer type projectiles.

7.0 REFERENCES

7.1 F963 (ASTM), sections 4.20 and 8.15

7.2 Product Safety and Liability Report, 8/21/81, pp 645-646

7.3 NBS report No. 10-893 "Ocular injury potential of projectile-type toys, 8/1/72"

7.4 EN71-1: 1998, Sections 4.17 and 8.25

7.5 "Guidelines for relating children's ages to toy characteristics", CPSC, 10/7/85, Page 181.

7.6 Australian Standard 1647.2-1992, "Children's Toys (Safety Requirements), Constructual Requirements", Section 7.15, Appendix K and Appendix DD.
DISK PROJECTILES

2.0 mm Min. Full Radius

OR
A.2 Final Shot Popper CAD Model [6]
Bibliography


