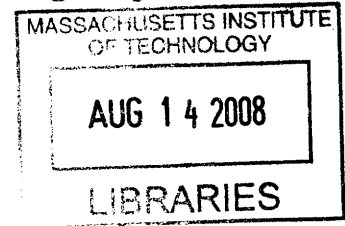


Design of Repeating Projectile Toy Based on Bistable Spring Propulsion

by

Matthew C. Blanco



SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2007

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Submitted to the Department of Mechanical Engineering on May 11, 2007
in partial fulfillment of the requirements for the Degree of
Bachelor of Science in Engineering
as recommended by the Department of Mechanical Engineering

ABSTRACT

Recently, bistable springs have been proven as a viable propulsion method for the standard 1.75” foam balls used in Nerf[®] projectile toys. This technology was developed at M.I.T. by William Fienup and Barry Kudrowitz, who designed a single-shot hand-popper that utilized a large bistable spring. The goal of this research was to design and develop a projectile toy capable of safely firing multiple foam balls in succession, using this novel propulsion. A structured design process was followed and this toy, the shot-popper, was brought to the alpha-prototype level. Largely this project was a success. Between the shot-popper, and the flat model that came before it, every module of the toy was shown to function as desired.

Thesis Supervisor: Dr. David Wallace
Title: Associate Professor of Mechanical Engineering

Acknowledgements

I would like to thank several people for their assistance and support with this project. Firstly, I owe much of the success of this project to my teammates, James Penn and Alan Skaggs. Secondly, Professor David Wallace has provided me with a great deal of guidance, both relating to this research and otherwise. Also, Hasbro[®] has been kind enough to offer the expertise of its employees, as well as funding throughout this process. Finally, the members of M.I.T.'s CADlab have helped to make this an incredibly enjoyable experience. Thank you all.

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1. Introduction

1.1 Background

Nerf[®] toys, created by Hasbro Inc.[®], are popular among children today. These toys fire soft foam projectiles, such as balls or darts, and are currently powered largely by plunger and spring launching mechanisms, and more recently by the Hasbro[®] Constant Pressure System (CPS). In the last few years, a new propulsion method for these toys has been developed at the Massachusetts Institute of Technology. William Fienup and Barry Kudrowitz, working in the M.I.T CADlab under the supervision of Dr. David Wallace, and in conjunction with Hasbro[®], have been using bistable springs to provide the force necessary to propel foam balls. These bistable springs are best described by looking at another toy commonly referred to as *Hopper Poppers*. These toys resemble hollow rubber balls, such as racquet balls, cut in half. They are called “bistable” because they have two stable modes, the first of which is the natural state (Figure 1-1a) and the second of which is the inverted state (Figure 1-1b). If an inverted popper is triggered it will release its stored energy and revert to its natural state. Triggering can be accomplished in many ways including squeezing, pushing on, or dropping the poppers. Larger, commercially available poppers have been shown to release enough energy to effectively and safely propel the standard 1.75 inch balls used in Nerf[®] toys [Fienup and Kudrowitz].

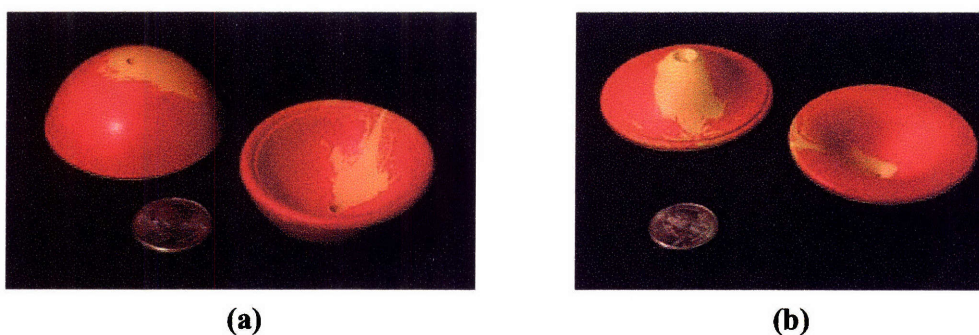


Figure 1-1: A Hopper Popper in its natural (a) and inverted state (b) [Fienup and Kudrowitz].

Hopper Popper propulsion has been used in multiple versions and iterations of hand-held, single-shot toys. The final design of Fienup and Kudrowitz is shown in Figure 1-2a. This was the first time that Hopper Popper propulsion had been used in projectile toys, and this design went through many iterations. In this version the popper is housed in a small plastic shell. It is loaded by pressing the device down onto a ball, and is fired by pressing the trigger button, which

in turn pushes on the side of the popper. This final version functioned well, and really showed the potential of this type of propulsion. It did, however, suffer from a few problems. The force required to load this toy could prove difficult for a young child to exert. Also, the triggering mechanism was somewhat unreliable.

More recently James Penn has developed a significantly different version of the hand-popper, which is shown in Figure 1-2b. This version was designed to address the loading force problem that was encountered by Fienup and Kudrowitz. The body was composed of a single-piece of compliant silicone rubber. This design resulted in no relative motion between the popper and its housing during loading, which greatly reduced frictional losses. Also, a piece was placed through the center of the popper which concentrated the loading force there. These design considerations effectively reduced the loading force by a factor of two over previous models (from 28.8lbs to 14lbs). Again, however, triggering reliability was a problem.

In late 2006 Hasbro[®] began selling a version of this toy, known as the Atom Blaster[™] (Figure 1-2c). This version takes the shape of a traditional gun. It implements a standard handle and trigger system, and like the first model, is loaded by pressing the device onto a ball. For this version Hasbro[®] developed a custom, non-latex popper and a trigger-locking system which prevents the toy from being fired without a ball present.

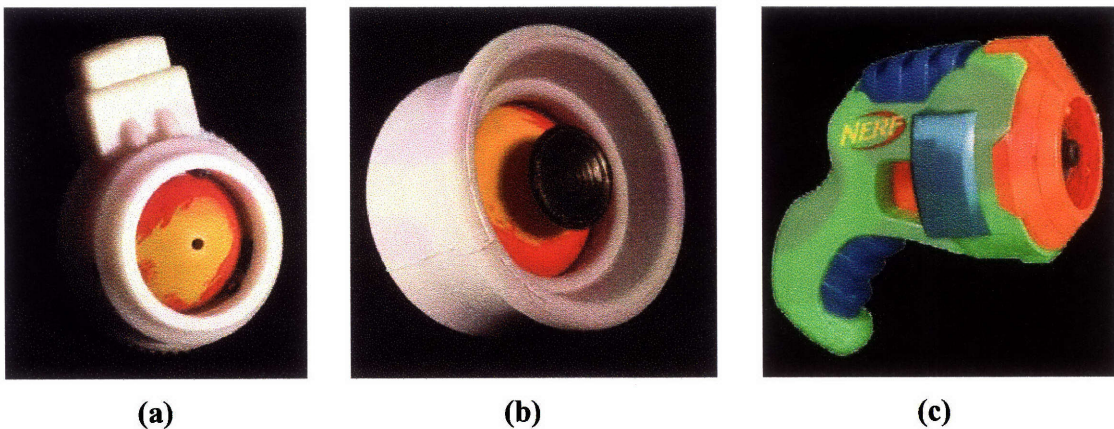


Figure 1-2: Hand poppers designed by Bill Fienup and Barry Kudrowitz (a) [Fienup and Kudrowitz], James Penn (b) [Photo courtesy James Penn], and Hasbro[®] (c) [Hasbro].

1.2 Objective

With a viable bistable spring propulsion mechanism, Hasbro[®] showed interest in expanding this technology to a more complex toy. The goal of this project was to design and develop a projectile toy capable of safely firing multiple 1.75 inch diameter foam balls in succession, using bistable spring propulsion. This concept will be referred to as the *shot-popper* from this point on. It was intended that this popper perform similarly to the state of the art, which in this case was most directly the Nerf[®] Ball Blaster[™] (Figure 1-3a), or more recently the Reactor[™] (Figure 1-3b). These guns can hold up to seven balls each, and are fired by simply pumping the front handle. They are both relatively low in cost and accuracy [Michal] [Hasbro].



(a)



(b)

Figure 1-3: State of the art repeating Nerf[®] ball-firing toys. Ball Blaster[™] - 1999 (a), and its redesign the Reactor[™] - 2006 (b) [Hasbro].

2. Design Process

The overall design approach to the shot-popper largely followed the structured method of product design presented by Karl Ulrich and Steven Eppinger in their text, “Product Design and Development” [Ulrich and Eppinger]. This approach is also used in multiple M.I.T. mechanical engineering courses, including *Product Engineering Processes* (course 2.009). A structured approach to product design aids in evaluating, making and documenting all important decisions. There were four major steps in the process used for this toy; they were planning, ideation, detailed design, and testing and refinement.

2.1 Planning

The planning stage involves all preliminary information gathering. This includes evaluation of the current marketplace and competition, patents, regulations, and customer needs. It is very important that this step be carried out carefully and thoroughly to minimize the risk of product failure. It is also important that any specifications defined in this stage be left as broad as possible, so as to not limit creative product solutions in the future.

In this case, the project idea came from Hasbro[®], and it was taken that they, as the experts, believed there was a market for this toy. Customer needs were fairly straightforward. It was specified that the gun should store and rapidly fire 1.75 inch foam balls using bistable spring propulsion. While achieving this goal it was imperative that the gun be both ergonomic and intuitive in its use. Also, it was obviously crucial that the cocking and triggering forces could be easily exerted by children, ages five years and older. Twenty pounds was set as the upper acceptable limit on these forces. Hasbro[®] representatives suggested that the toy hold between four and six balls.

Safety is always an important consideration when designing products, especially when these products are targeted at children. Hasbro[®] has a very explicit set of safety regulations regarding projectile toys entitled, “Corporate Quality Assurance, Safety and Reliability Specification, SRS-045, Projectiles.” This document provided some important restrictions for this product, and can be found in its entirety in Appendix A. The most important limitations placed on this particular project are that it must not be capable of firing projectiles other than the standard foam balls. Some common dangerous projectiles are pens, pen caps, markers, marker

caps, paper clips, pen refills, batteries, marbles, and pebbles. Also, the projectile kinetic energy density was not to exceed 1600 J/m^2 .

2.2 Ideation

The ideation stage generally involves generating a large number of ideas. In many cases at this stage design teams are brainstorming product ideas. In this case, however, the general product was previously defined. Ideation was used to generate different mechanisms and methods that could be used to accomplish the loading, cocking, and triggering challenges that firing multiple balls in succession posed. Once high potential ideas were identified they were tested through sketch model development and experimentation.

2.2.1 Early Models

Early in the design process there were several primitive models used to test certain aspects of the project quickly. One such prototype was created by James Penn and Alan Skaggs. The goal of this simple device was to test the effectiveness of using a mechanical advantage to reduce the force required to invert the popper, and to test cocking the popper from behind. All previous popper devices had been cocked from the front, using a ball directly.

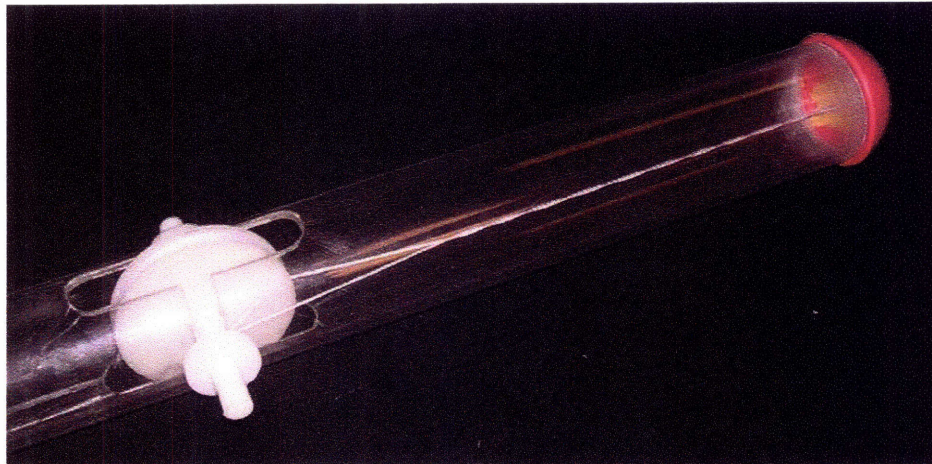


Figure 2-1: An early prototype used to test the idea of cocking the popper from behind, with a mechanical advantage [Photo courtesy James Penn].

This device consisted of a relatively large wheel which was coaxial to a thinner shaft, both of which rotated in an acrylic tube (see Figure 2-1). One end of a string was attached to the thin shaft, and the other to a bolt through the center of the popper. To cock this device the large

wheel was rotated by hand, until the string it wound pulled the popper to its inverted stable state. The ratio in shaft diameters produced a mechanical advantage of approximately four to one. This prototype was successful in showing that the popper can effectively be cocked from behind, and initiated the brainstorming of other mechanical advantage devices. This model did not directly address ball storage, loading or advancement.

2.2.2 Flat Model

The next prototype was quite a bit more complex and complete than any of the early models. This device was used to test chosen designs for cocking, storage and ball advancement, which would persist to the alpha prototype. The aspects not directly tested in this model were triggering and loading. This model will be referred to as the “flat model” from this point forward because of its orientation. As shown in Figure 2-2, this prototype consists largely of plastic parts mounted to sheet aluminum.

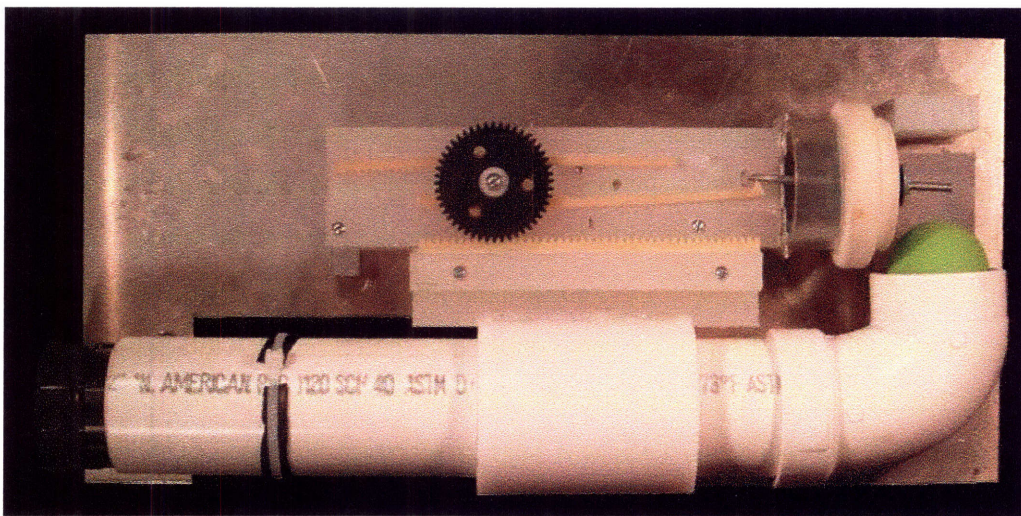


Figure 2-2: The “Flat model” which was used to test designs for cocking, storage and ball advancement [Photo courtesy James Penn].

The cocking in this model was accomplished using a coaxial set of gears, one with twelve teeth (hidden in Figure 2-2) and the other with forty-eight (black in Figure 2-2). The large gear was attached to the pumping mechanism by way of a rack, and the smaller gear was mated with two parallel racks. These racks would move in opposite directions as the gears moved, and they took turns engaging the popper bolt. The racks were positioned in such a way that in their starting/ending position there was clearance between their teeth and the teeth of the bolt. It was

necessary that the bolt move freely forward when the popper was triggered. In order for the racks to engage the bolt then they had to be directed inward. This was done by bending the lower rack and using rigid guides in the path of the upper rack, and it was dependent on the flexibility of the racks. Herein lays a very careful balance. The top rack had to be flexible enough to bend along its guides, but it also had to be stiff enough to return to its original shape when not guided. This stiffness was especially important because in the last few millimeters of cocking the second rack had to pull the popper to its stable state, disengage itself from the bolt, and move sufficiently far from the center to clear the path of the bolt's teeth. With this set up both the backward and forward motion of the pump accomplished half of the popper cocking motion, and the cocking force of the popper at the gears was reduced by a factor of four.

Ball storage in this prototype was handled using a two inch inner diameter polyvinyl chloride (PVC) pipe, positioned under the cocking mechanism. An elbow piece was used to move the balls from the horizontal storage tube to their correct vertical orientation in front of the popper. The advancement of balls along the storage tube was accomplished using a long spring, commonly found in Nerf[®] toys of this sort. The spring, when uncompressed, was slightly longer than the entire loading tube (including elbow) so that it could provide sufficient force to advance even the last ball. Another important part in the ball advancement was the metal bolt placed through the popper. This bolt protruded far enough from the front of the popper to rest on top of the next ball to be loaded. In this way it constrained the balls in the vertical direction when the gun was not cocked. As the popper was cocked this bolt followed the popper backward; it directed the ball below it in the same direction and ultimately positioned it correctly for firing. In the cocked state the ball to be fired was held in place by the force of the balls and spring below it, which pressed it against a stop positioned above the popper. Figure 2-3 is a conceptualization showing the balls and spring in the loading tube.

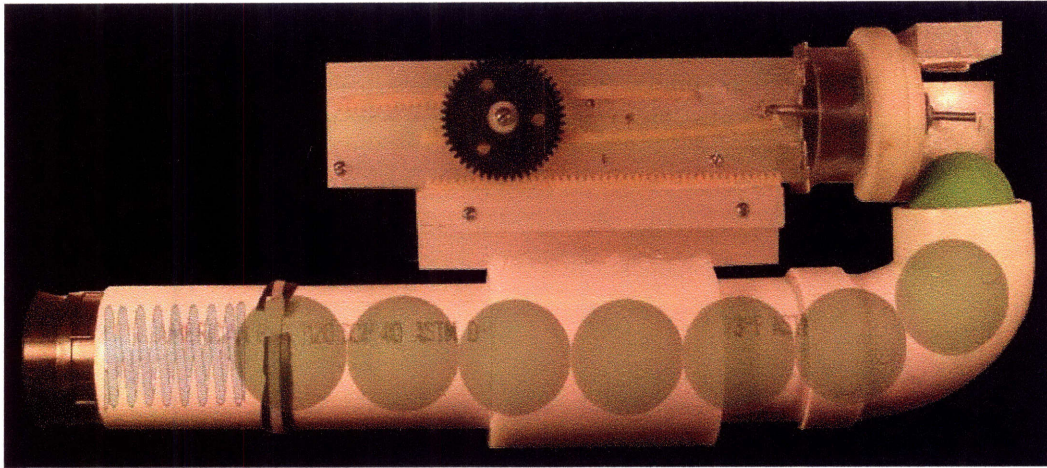


Figure 2-3: Conceptualization showing balls and the spring in the loading tube [Image courtesy James Penn].

This prototype was fired by pushing the bolt forward. Multiple options for a trigger were proposed, but retrofitting a trigger to this particular geometry was deemed to be more trouble than it was worth. Loading also was not finalized in this prototype, as balls were loaded by simply forcing them in the front of the gun as the bolt was displaced, which could prove both dangerous and cumbersome if a solid front barrel were adopted.

The flat model was extremely successful in proving both the function of the individual modules described above and also the idea of the shot-popper as a whole. It would serve as the basis for the detailed design of the alpha prototype.

2.3 Detailed Design

All major module decisions are made and tested in the ideation stage. In the detailed design stage they are carefully designed and integrated to produce a functional, ergonomic and aesthetically pleasing product. Prototyping techniques are then used to produce an alpha prototype, which is the first prototype that both looks and acts like the final product should.

2.3.1 Alpha Prototype

The alpha prototype was designed and modeled using SolidWorks[®] software. It was intentionally styled to resemble a standard shotgun, so that its use was readily apparent. The handle design was provided by Hasbro[®], and was based on their research regarding children's hands. Three dimensional computer models were turned into physical parts largely using stereo

lithography (SLA), which is an additive rapid prototyping technique. The assembled alpha prototype is shown in Figure 2-4, and the solid model can be found in Appendix B.

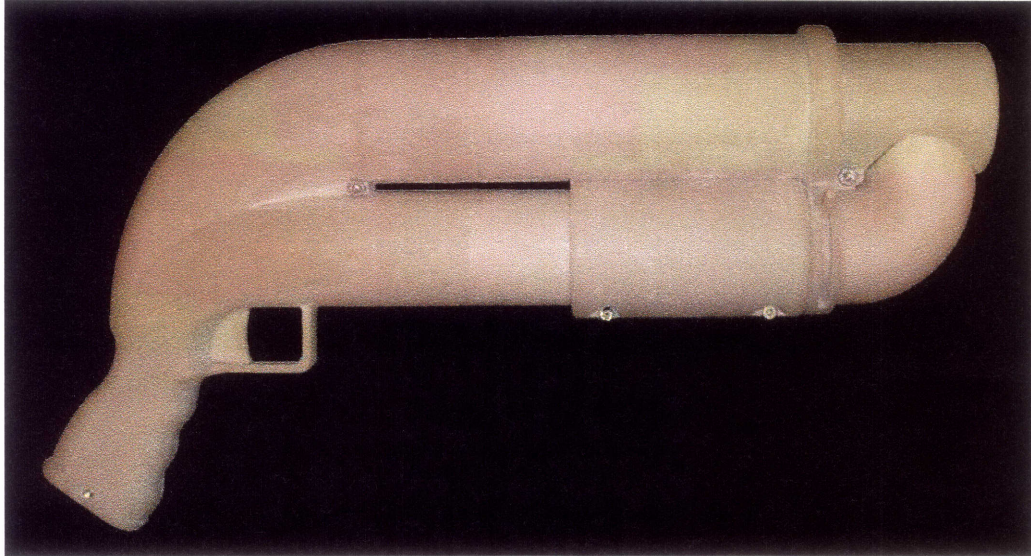


Figure 2-4: The assembled alpha prototype, which was created mostly using SLA.

The cocking mechanism for this version is essentially a more compact version of that used in the flat model (See Appendix B). The size was reduced by making the rack pieces much shorter than they were previously. This had several implications. Firstly, as intended shortening the racks made the entire cocking mechanism much more compact, which in turn reduced material use. However, it also increased the stiffness of the racks (beam stiffness is inversely proportional to its length cubed). This caused a slight problem because of the careful balance of flexibility and stiffness required in the racks, as described above. With some adjustment of the guide rails and the beam thickness this system was made to work consistently.

Ball storage and advancement in this prototype were also handled in the same way as they were in the flat model. Other methods were considered, but none were as simple, compact and practical as this lower tube and spring system. For the first time this prototype directly addressed ball loading. Balls are loaded by rotating the elbow piece away from the upper tube and forcing them, against the spring, into the lower tube. A small rod connected to the elbow is moved to accomplish this rotation, and is within reach of the user's pump hand. The loading mechanism is shown in Figure 2-5.

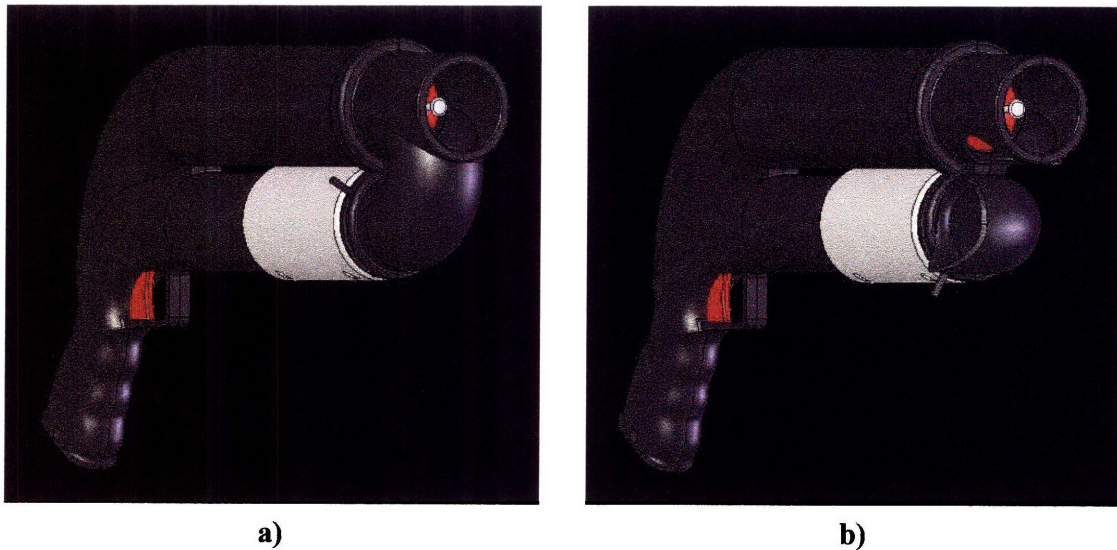


Figure 2-5: Loading of the alpha prototype is accomplished by rotating the elbow piece and placing balls in the lower tube.

This prototype was the first time a formal trigger was implemented. In an effort to make use as intuitive as possible, this trigger took the form of a standard gun trigger. The trigger mechanism consists of the trigger piece and a three piece linkage system. The first linkage is connected to the trigger. It acts as a lever, with a pivot point near its center, and converts the pull of the trigger toward the user's body into a push away from the body on the popper. The bottom of this linkage is constrained horizontally by the trigger, so its vertical orientation changes as the trigger is pulled backwards. For this reason pivoting is accomplished with a slot cut in this linkage, which has a sliding contact with the rod around which the linkage rotates. The second linkage simply converts the motion of the free end of the first linkage, which has a horizontal and vertical component, into a solely horizontal motion for the third linkage to apply to the back of the popper. A spring is used to return the system to its natural state after triggering. The horizontal displacement required to trigger the popper in its cocked state is between roughly one-quarter and one-half of an inch, depending on how tightly the popper is held and some other factors. To ensure consistent triggering a throw of about three-quarters of an inch was designed. This resulted in a comfortable one inch trigger pull. The force required to trigger is determined by the popper, and can easily be applied by a small child. Figure 2-6 shows the triggering mechanism.

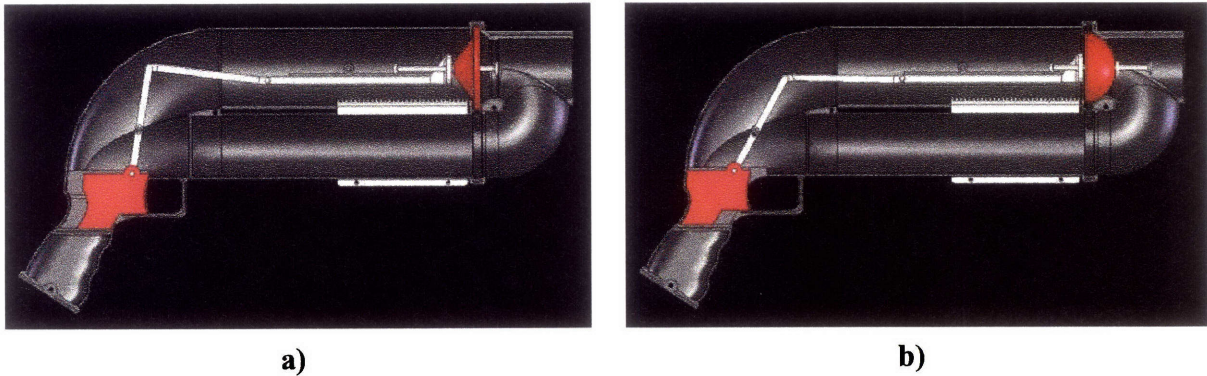


Figure 2-6: The triggering mechanism in its natural (a) and triggered (b) states.

Overall, the alpha prototype is quite successful, with some qualifications. All of the modules function independently, and can be made to work together. The one module which is not functioning as well as intended is the ball advancement. Balls frequently get jammed in the elbow because the inside diameter of this piece and of the bottom tube are slightly too small. Also, the rapid prototyping process used resulted in a relatively high-friction surface. This module was made to work by placing smooth tape and baby powder on the inside of the elbow, to reduce friction, and by preloading the advancement spring, to increase the force it exerted. This problem does not warrant much concern because the module functioned well in the flat model, which used a much smoother and larger PVC elbow.

The assembly of the alpha prototype is less than ideal. In order to assemble it one must completely understand the process, and follow a very specific order. Even with an experienced assembler there is a good deal of adjusting and luck involved in the final step of fitting the two halves together. Explicit solutions to both the ball advancement and the assembly problems are discussed in the *Future Work* section.

2.4 Testing and Refinement

Once the alpha prototype is made it is tested in the testing and refinement stage. In some cases only minor adjustments are needed before the product can go into production. In other cases extensive redesign leads to one or more high level prototypes following the alpha. Specific suggestions for future work on the shot-popper will be discussed in the next section.

3. Conclusion

Largely, this project was a success. The combination of the flat model and the alpha prototype function well as a proof of concept for a repeating shotgun-style toy based on bistable spring propulsion. Between these two versions every important module was proven to work, including those for cocking, triggering, ball loading, storage and advancement. The alpha prototype can hold up to six 1.75 inch foam balls. It resembles a standard shotgun, and thus is intuitive in use. Also, the ball exit velocity is sufficient to produce a fun experience, while at the same time remaining extremely safe. There are a few areas that could use improvement, and so there is certainly room for future work on this project. Hasbro® has expressed a desire for a fully-functional beta prototype.

3.1 Future Work

There were some problems with the alpha prototype that should be addressed in future models. One of these problems was major, and prevented the alpha prototype from working as intended, and some of them were relatively minor, and would slightly improve an aspect of the gun if implemented.

The major problem, as described above, was ball advancement. An overly tight internal diameter of the loading tube and the elbow, combined with a high friction surface there made advancing multiple balls difficult. In the next model it is suggested that this diameter be increased from 1.80" to 2.00", and that a material with a smoother surface be used. These specifications are the same as in the flat model, which functioned very well.

Another important consideration for future models is assembly. One major improvement is easily accomplished. By reversing the orientation of the halves of the slide pieces it is possible that all the gears and racks that have to interact will be assembled on the same side. This eliminates the need to align the large gear and the rack of the slide, which are currently on different sides of the gun, when assembling it. For a prototype, difficult assembly is not a huge deal, but this would cause major problems during mass production.

Some minor changes could include holding the trigger more tightly between the two halves of the gun, possibly by deepening its guide grooves. Also, ergonomics could be slightly improved by aligning the pump with the back of the handle. Currently, there is a torque created when cocking the gun, because the user's trigger-hand is below his pumping-hand.

Finally, there are a few simple steps that could be taken to improve the ease of testing this toy. Firstly, it is very difficult to troubleshoot the cocking and triggering mechanisms, because, when the gun is assembled, these modules are completely enclosed in the plastic housing. Testing can be done with the gun open, but is cumbersome because only half of the popper is constrained. A simple piece that can be used to complete the popper housing, when in this open testing mode would be extremely helpful. An example of what this piece might look like is shown in Figure 3-1. Another possible solution is to design a window into one side of the gun, so that these modules can be observed when the gun is fully assembled.

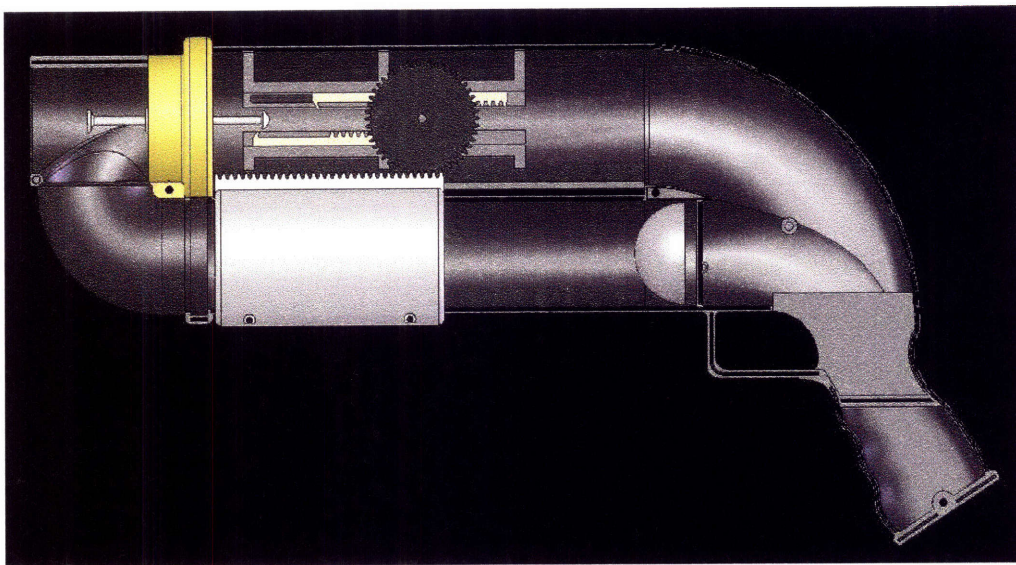


Figure 3-1: A special piece could be made which would complete the popper holder, so that the cocking mechanism can be observed in this open state, for troubleshooting.

A: Hasbro Inc. Corporate Quality Assurance Safety and Reliability Specification, Projectiles

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 3 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:** are 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. Sauter K800).
- 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:

$$\text{kinetic energy} = 1/2 mv^2$$

where: m = mass of projectile (Kg) and,

v = velocity of the projectile (meter/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

$v \text{ (meters/seconds)} = \text{mph} \times .447142$. 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.
- e) Examine whether or not the foil diaphragm ruptured, as specified in 5.2.3
- f) 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.
- g) 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.
- h) 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 shows, 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 conditional 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, life, 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:

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DIMENSIONS OF IMPROVISED PROJECTILES

(All measurements in inches)

A) Correction Pen Cap

Dimensions

- | | |
|---|---|
| 1) Pentel Opaquing Fluid Correction Pen
Oil-Based Quick Dry
18 ml. ZLC1-W
Manufacturer: Pentel Co. Ltd.
Made in Japan | A1) total length-1.10 inches
maximum diameter - 0.57 inch
minimum diameter - .53 inch |
|---|---|

B) Marker

Dimensions

- | | |
|--|--|
| 1) Pentel Marker
F50
Made in Japan | 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 |
|--|--|

C) Marker Caps

Dimensions

- | | |
|---|--|
| 1) Fluorescent Pen Cap
Zebra Pen 2
Thin Size Cap | C1) length - 0.93 inch
max. diameter - 0.35 inch
min. diameter - 0.23 inch |
| 2) Fluorescent Pen Cap
Zebra Pen 2
Thin Size Cap | C2) length - 1.82 inches
max. diameter - 0.58 inch
min. diameter - 0.28 inch |
| 3) Fiber Tip Permanent Marker Cap
Artline 70 High Performance
Xylene Free EK-70
Manufacturer: Shachihata Product
Made in Japan | C3) length - 1.71 inches
max. diameter - 0.66 inch
min. diameter - 0.51 inch |
| 4) Fiber Tip Permanent Marker Cap
Artline 70 High Performance
Xylene Free EK-700
Manufacturer: Shachihata Product
Made in Japan | C4) length - 1.52 inches
max. diameter - 0.70 inch
min. diameter - 0.69 inch |

D) Paper Clip

Dimensions

- 1) Trigonal Clip
Elephant Trigonal
Art. No. PM121
Made in China

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

E) Pen

Dimensions

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

- 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

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

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

- 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

- 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

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

F) Pen Refill

Dimensions

- 1) Bic #C-B-19

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

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

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

<u>G) Battery</u>	<u>Dimensions</u>
1) "Energizer" AA	G1) length - 1.74 inches diameter - 0.41 inch
2) "Energizer" AAA	G2) length - 1.97 length diameter - 0.52 inch
3) "Energizer" C Size	G3) length - 1.95 inches diameter - 0.99 inch

<u>H) Marble & Pebble</u>	<u>Dimensions</u>
1) Diameter 1"	H1) diameter - 1 inch
2) Diameter 0.635"	H2) diameter - 0.635 inch
3) Diameter 0.642"	H3) diameter - 0.642

Hazard evaluation of launched improvised projectiles shall include (but is not limited to) the following: Tip radii 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 Supplemental 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.

Also, reasonably foreseeable and normally expected handling or carrying the toy must not activate the discharge mechanism. In addition, the projectile should discharge within a reasonable time period after activation. (see 6.8)

5.8 Projectile Kinetic Energy Density

The projectile kinetic energy density must be determined on all projectiles with a kinetic energy greater than .08joule. 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, firing it at a suitable surface 1 foot away and measuring the area of the residual impression. Area is determined by the following:

$$\begin{aligned} \text{Radius in meters: Area} &= \pi r^2 \\ \text{Radius in inches: Area} &= .0006452 \pi r^2 \end{aligned}$$

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 lbs. (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 "fishhook" effect. (See 5.6).
- 6.3 No projectile fired from a toy shall have a tip radius less than 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 MINIMUM ALLOWABLE TIP RADIUS

up to .025 joule	2 mm
from .025 to .05 joule	3 mm
from .05 to .10 joule	4 mm
from .10 to .15 joule	5 mm
from .15 to .20 joule	6 mm

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

Projectile Type	Tip Radii (Section 6.3)	Resilient Tip* (6.4)	K.E.D. (6.9)	Foil Test (6.10)
Rigid	Yes	Yes	No	Yes**
Stored energy	Yes	Yes	Yes*	Yes**
No stored energy	Yes	Yes	Yes*	No

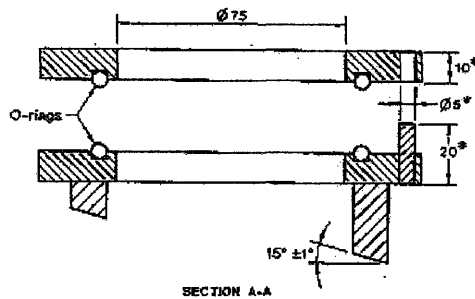
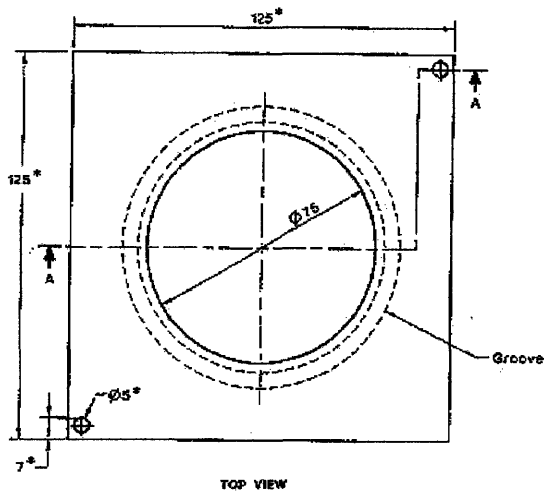
*Applies only if K.E. is > .08 joule

**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 Reporter, 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), Constructional Requirements", Section 7.15, Appendix K and Appendix DD.

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NOTES:

- 1 The dimensions marked * shall be within a tolerance of ± 1 mm.
- 2 The dimensions not marked * shall be within a tolerance of ± 0.3 mm.

DIMENSIONS IN MILLIMETRES

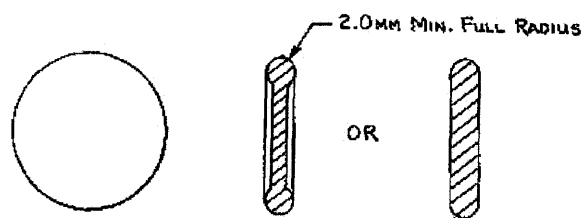
FIGURE 1

FIGURE DD1 PLAN VIEW OF CLAMPING FRAME

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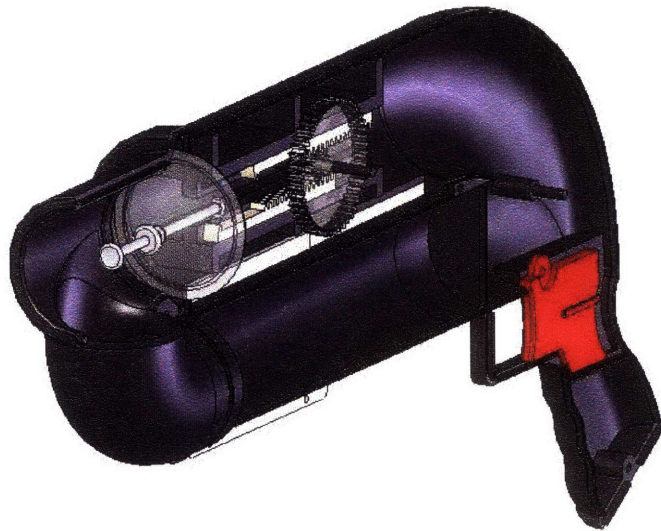
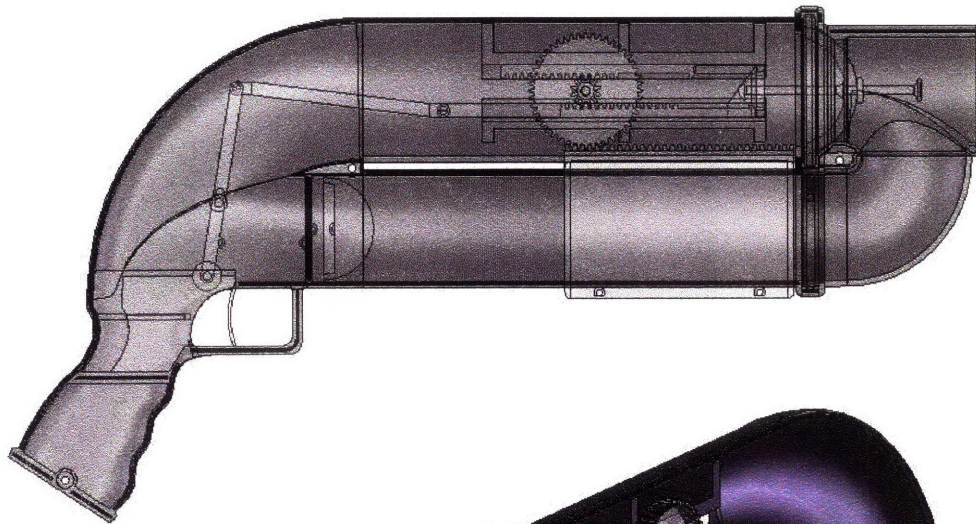
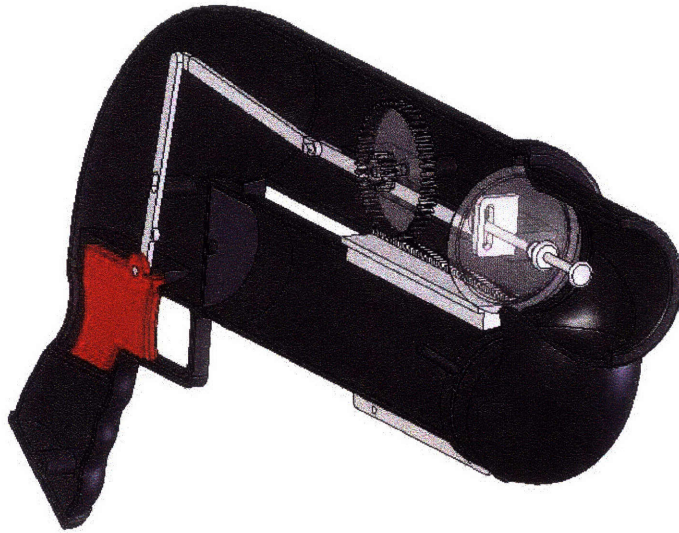
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FIGURE 2

DISK PROJECTILES



B: Alpha Prototype Solid Model





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