Design and Manufacture <u>of</u> **Tennis Ball Retriever**

By

PHILIP HURST

A Senior Project submitted in partial fulfillment of the requirements for the degree of **Bachelors of Science is Manufacturing Engineering**

California Polytechnic State University

San Luis Obispo

Graded By:_____ Date of Submission:_____

Table of Contents

Abstract		Page4
List of Fig	ures	Page 5
List of Tał	bles	Page 6
Chapter 1:	: Introduction (Problem Statement)	Page 7
Chapter 2:	Background	Page 9
	Similar Products	
	Pertinent Information from a Previous Senior Project	
	Target Markets and the Benefit to Humanity	
	Product and Mold Design	
Chapter 3	: Design Development	Page 18
	Design Version 1	
	Design Version 2	
	Final Design	
Chapter 5:	The Injection Mold	Page 22
	Sprue Half	
	Stripper Plate	
	Ejector Half	
Chapter 6	Considerations for Injection Molding	Page 28
Chapter 7	: Cost Analysis	Page 30
Chapter 8:	Problems Encountered	Page 32
Chapter 9	Conclusions and Recommendations	Page 34
Chapter 1): Work Cited	Page 35
Appendix	A: Final Drawings	Page 37

Appendix B: Bill of Materials

Page 45

Abstract

This report gives a, design summary, manufacturing report, testing report, conclusions and recommendations for an injection molded tennis ball retriever. The goal of this senior project was to design, build, and test an innovative racket-mounted tennis ball retriever. This new product was designed to be affordable, user friendly, manufacturable, and unobtrusive to the game. Imperfections were worked out, product features were redesigned, prototypes were tested, machining mistakes were corrected, and parts of the mold were made. During the prototyping process the biggest problem encountered in the design of the product was keeping the retaining straps wrapped around the racket. This problem was solved by creating mushroom shaped nubs to hold the straps to the body. During the manufacturing of the mold, costly mistakes were made, but these errors were corrected prior to machining the rest of the mold. There was not enough time to finish the mold, but it will be finished before the school year is over. The report will chronicle the different prototypes, design of the injection mold, and manufacture of the three parts of the injection mold.

List of Figures

Figure #1.	Patent # 6652397	Page 9
Figure #2.	Patent # 6719651	Page 9
Figure #3.	Patent # 5333854	Page 10
Figure #4.	Patent # 4210327	Page 10
Figure #5.	Patent # 3874666	Page 11
Figure #6.	Patent # 5383661	Page 11
Figure #7.	Patent # 7112153	Page 12
Figure #8.	Drawing of product in action	Page 13
Figure #9.	Prototype 1 and wax mold	Page 18
Figure #10.	Prototype 2 and wax mold	Page 20
Figure #11.	Prototype 3	Page 21
Figure #12.	Three part wax mold for prototype 3	Page 22
Figure #13.	Explanation of how the mold and stripper plate function	Page 23
Figure #14.	Photo of sprue plate	Page 24
Figure #15.	CAD image of sprue plate	Page 24
Figure #16.	CAD image of stripper plate	Page 25
Figure #17.	CAD image of internal features of the stripper plate	Page 26
Figure #18.	CAD image of ejector plate	Page 26
Figure #19.	Photo of ejector plate	Page 27
Figure #20.	Image of how cooling channels work in a mold	Page 29

List of Tables

Table #1.	Cost Per Part	Page 29
Table #2.	Bill of Material	Page 45

Chapter 1: Introduction

Picking up dropped tennis balls has burdened tennis players since the beginning of tennis. Some players (the elderly mostly) may have difficulty bending or crouching down to pick up dropped tennis balls. There are tennis ball picker-uppers on the market, but they are cumbersome and disrupt the flow of a game in process. The goal of this project is to design a semi-permanent attachment to the stringed end of the racket to solve the problem of picking up dropped tennis balls in mid play.

The concept of attaching tennis ball retrieval devices to tennis rackets is not completely unheard of, many patents exist for such devices, but no design has ever been brought to the consumer market. My design differs from previous designs, was conceived with no influence of the other designs, and is going to be produced and marketed.

The major requirements of this product are:

- One-size-fits-all rackets
- Must be removable for racket restringing
- Deforming the racket was not an option
- Must not detract from the appearance of the racket
- Using Velcro (the hooked side) to grip a tennis ball
- Must not effect the player's game

Some designs (as you will see later in the report) require adhesives or screws to be put in to the racket, this may damage the racket, or provide a poorly secured device. Some devices look like they would interfere with the player's (operator) ability to play the game. Other devices are uncomfortable for the player to use when attempting to pick up tennis balls. This product will have none of the previously mentioned problems, and be simple and affordable.

Perfecting the product design required testing prototypes and making alterations to their shape and weight. After the product design was been finalized, an injection mold

designed and made. The final design of the injection mold is compatible with large scale molding machines found in industry. The appropriate material (polymer) was selected. The finished mold will eventually be used to make a large quantity of tennis ball retrieving devices. The report will document: research performed, prototypes and testing, making the mold, problems encountered, cost analysis, and conclusions.

Chapter 2: Background and Lit Review

Many sources of media were sampled in the pursuit to find information about tennis ball retrieving devices, injection mold design, and plastic part design. In a strict sense, injection molding and tennis ball retrievers don't have much to do with each other, so research was some what divided. Information came from different sources. The best resources of all turned out to be the on-line patent database, books from the library, Lee Smith from Santa Maria Mold and Container Co. (injection mold design/machinist), and Rene Hale (injection molding expert at Prince LionHeart). It was surprising to see the

numerous tennis ball retrieval devices people had patented over the years. Even more surprising was that none of these inventors ever took their designs to market. Here is a sample of the most relevant designs.

Similar Patented Products

Patent # 6652397 "Adhesive ball retrieval and guard system for sports equipment"

A strip of hook Velcro attached, using double-sided tape, to the stringed end of a racket (as seen in figure #1). The player rubs the end of the racket on a dropped tennis ball to activate the Velcro, and pick up the ball. This is a permanent fixture, and will leave a sticky mess is it ever needs to be removed.

Patent # 6719651 "Tennis ball retrieval device"

This device is a gripping device for attachment to the

bottom of a tennis racket to retrieve tennis balls. The





gripping device is made of an old tennis ball that has been cut to form fingers (as seen in figure #2). These fingers can slide around a tennis ball on the ground and pick it up. The cut tennis ball is screwed in to the butt of the racket. This installation damages the butt plate.

Patent # 5333854 "Tennis ball retriever and racquet"

On the end of the handle goes a cap with teeth/pins extending inwardly inside a recessed area (as seen in figure #3). The pins are for grasping the fuzzy surface of the tennis ball. The cap is made of a



foamy material to aid in the connection with the round surface of the tennis ball. Pressing the recessed area to the ball makes the pins bite the ball. This product is attached by unwrapping the handle, removing the butt plate, and replacing it with this product then rewrapping to handle.

Patent # 4210327 "Racket-mounted tennis ball retriever"

For this design the butt plate of the handle is made concave and coated with the hook side of Velcro. The butt of the racket is pressed to a tennis ball and the concave Velcro conforms to the tennis ball and



grasps it (as seen in figure #4). Some kind of glue is used to permanently attach this product to the butt of the racked.

The drawback to the handle mounted designs is that the player must let go of the handle to pick up the ball. This motion is inconvenient, and holding the racket by the stringed end is uncomfortable and awkward. Another possible problem with handle mounted products is that they are attached (screwed in to) the handle of the racket, most modern racket handles are hollow, so it is questionable how securely attached they really are. Furthermore, handle mounted products may get in the way of the player's grip during play, and will need to be removed when the racket is going to be stored in its cover/case.

Patent # 3874666 "Tennis racket having incorporated ball retrieval means"

Basically a patch of hooked Velcro is attached to some kind of concave base plate with a matching plate on the other side. The two base plates are bolted together through the strings in the upper portion of the racket (as seen in figure #5). The product can be unbolted from the racket in maintenance or re-stringing

can be unbolted from the racket in maintenance or re-stringing Figure #5 is necessary. It seems like the product would get in the way during play, and is now very well positioned for retrieving tennis balls off the ground.

Patent # 5383661 "Apparatus to retrieve tennis balls"

This design uses a bracket consisting of a pair of arms positioned between sidewalls. These sidewalls are affixed to an attached base, and the base is held to the racket by zip ties. The arms open to form an opening slightly smaller than a tennis ball. The arms are pressed around a tennis ball on the ground, and the ball is





wedged between them (as seen in figure #6), and can then be picked up. The arms are retractable so they won't get destroyed during regular play.

Patent # 7112153 "Retrieval device"

The retrieval device includes an elongated retrieval member having a stationary section connected to the racket via an attached assembly. The moveable section slides along the fixed guides of the attached assembly, and the attached assembly is held to the racket using built in straps. The elongated member has a storage configuration and retrieval configuration. In the retrieval position the ball is wedged between the elongated member and the head of the racket (as seen in figure #7).



Pertinent Information from a Previous Senior Project

Another topic of interest was how Velcro worked and performed during use. A senior project gave the answer. "Velcro is composed of two mutual surfaces consisting of hooks and loops. When mated the hooks penetrate into the opposing bed of loops and grab a loop there by holding the two surfaces together." (Young, 1986) The senior project tested the force needed to separate Velcro at varying speeds. They found that the faster it was separated the more force was needed. This is interesting information that could be applied to keeping tennis balls attaches to the strip of Velcro while traveling from the ground to the player's hand.

Target Markets and the Benefit to Humanity

Tennis offers health benefits to all who play it, especially the elderly. An article about Nehemiah Atkinson, 83 year old competitor in the international tennis circuit for senior tennis and winner of four golden balls, summarizes his life by explaining the man's love of the sport and the health benefits of playing it. Nehemiah Atkinson explains, "Tennis keeps you young. It stimulates your heart, keeps your body in shape and your eyes sharp." (Miller, 2001) More elderly people might pick up the sport and get healthier, if they had a tennis ball retrieving device. Tennis popularity has been declining over the last twenty years according to an article in Parks and Recreation (Caldwell, 2003). One reason for the decline is people don't have time to play tennis in their busy schedules. Popularity might possibly be restored to the sport if the chore if picking up dropped tennis balls was eliminated and lengthy recovery times from injuries (from this action) were a thing of the past.

Product and Mold Design

On a more technical note, if this product is to succeed the material, mold, and design must be carefully considered. The product must meet the requirements of the manufacturer and consumer. There will always be compromises in design due to limitations with to mold, and there will always be tradeoffs when selecting one material over another. Most likely a thermoplastic elastomer will be used for the tennis ball retriever. This material is analogous to a rubbery shoe sole. They combine the

properties of rubber with the speedy processing time of conventional



thermoplastics. (Osswald, 2002) Prince Lionheart runs a thermoplastic elastomer (40 shor hardness) in their small machine that will be ideal for this project. Thermoplastic elastomers can be injected in to aluminum molds, which is necessary because the material the mold will be made out of is aluminum. The mold will be kept as simple as possible. Ideally all the features, excluding the sprue, would be on one half of the mold, but the final part design prevents such a simple mold. The problematic (yet crucial) feature is a mushroom shaped post. The mushroom heads are important because they allow the strap to form a strong connection around the end of the racket. The first and second prototypes did not have this feature, and they did a poor job of holding on to the racket. The problem with the mushroom shaped post is that it requires the parting line of the part to be in the middle, and not on the outer edge. Thus the mold must have features cut in to both sides, and use a stripper plate design. The basic design is shown in figure 8. Located on the stringed end of the racket, the flexible/elastic arms wrap in between the strings and around the edge of the racket. The arms fit into the body, and a strip of Velcro holds the arms to the body, and holds the part on the racket.

Traditional Design Approach

The design process for new part (my part) and its respective injection mold should follow these steps. (p466 Osswald)

1. Data collection:

•Collect information about customer and product.

At a sporting goods store down town measurements of various tennis rackets were taken. •Develop specifications based on data.

Rough dimensional requirements were established from the averages of the

measurements taken.

•Determine starting/ending dates.

A rough time line of goals to meet was drawn up early in the first quarter.

2. Projecting Plan:

•A set of guidelines that help keep the project on track, and accomplish design and time

objectives.

As the first quarter progressed the time line of events was revised. Goals (like the

finishing of prototypes for example) were met on a weekly basis.

3. Time table for tasks:

•Allocate resource (personnel, equipment, technology, money).

I worked my busy schedule around the open lab hours. In the lab the milling machines

and CAD software were used to make prototypes and the final mold.

•Order long lead-time items early on.

Materials, such as the aluminum blocks for the mold, were ordered and paid for early on

in the design process.

4. Preliminary Design:

•Develop sketches of a variety of design options.

With every prototype the design was refined, and a working design was eventually

delivered.

•Review the viability of the various options, and take in to account manufacturability,

cost, and risk. Consulting with Rene and Lee during the design process brought new ideas

to light. Their expertise kept the prototypes realistic and manufacturable.

•Anticipate part requirements (structural, environmental, cosmetic, etc).

•Break up the part design in to separate sessions to allow for new ideas and view points.

5. Material Selection:

•An initial material selection must be made early on in the design before more detailed

designing can be done.

Drastic changes in material mid-way in the design process can lead to expensive design

changes later on. Fortunately Prince Lionheart's thermoplastic elastomer will work

perfectly for this part.

6. Develop Detailed Design:

•Finalize the design with the best function. The third prototype has all the desired

functions.

•Test the structural performance with software

•Review process for manufacture.

The design and machining processes of the mold were approved by Lee (an expert in

injection mold making).

•Develop detailed dimensioned drawings.

Dimensioned drawings were used to design the mold.

7. Testing/Prototyping:

•Testing the part design before production is sometimes necessary. Prototype can be

made from substitute materials such as wood, plastic, or wax. Rapid prototyping might

have also been a viable option, but machining wax molds gave a more realistic prototype.

8. Review design and Commit:

•Review all assumptions

•Avoid running out of resources and taking on too many jobs simultaneously.

Since Prince Loinheart already runs the needed material in their injection molder, and keeps a supply of it on hand, there shouldn't be a danger of running out of material during production.

Chapter 3: Design Development

Design Version 1

Designed purely from my imagination, prototype 1 was a crude proof-of-concept, but pointed the project in the right direction. The problems were: too heavy, large unnecessary rubber ends, the base was too tall and narrow (3/4"), and the straps did not fit into the body very securely. Figure #8 depicts prototype 1 and the problematic features. It was clear that the size of the part needed to be reduced. Reducing the size of the part would reduce the amount of material per part needed, and thus lower the material cost. The molds for the prototypes were made from machineable wax blocks. Wax was used because it is much cheaper than aluminum, and it can be machined quickly and easily. When the wax molds were finished being machined, silicone was poured in (at room temperature), and allowed to harden. The silicone prototypes were intended to have similar characteristics to the final injection molded parts.



Figure #9

Design Version 2

Taking the perceived benefits of prototype 1, version 2 improved some areas, but also presented a host of new problems. Reducing the overall weight was achieved by making the body thinner, and shrinking the rubber ends. The shape and thickness of the straps was changed. The circular ends were enlarged in the hopes they would grip the body better, and increase the adhesive surface for the Velcro. The effect turned out to be much less desirable. When the strap was stretched around the end of the racket the body of the part would deform. The arms were too thick. This deformation of the body caused the circular ends of the straps to not lay flush in their recessed areas. The straps wouldn't hold because the recessed areas in the body were no longer round. If the body is distorted, the fit between round end (of the strap) and the body is poor, the Velcro will not have a secure surface to stick to, and the product will look unattractive and come apart. While testing the function of the two prototypes it was discovered that the adhesive Velcro did not stick to the silicone very well. Most certainly not well enough to hold the product to the end of the racket, but the addition of super-glue between the Velcro and the silicone made for a strong bond. Perhaps including a tube of super glue in the package of the final product will be necessary.



Description of Final Design

The final prototype combined functionality and manufacturability to meet all the design requirements. The weight is lower than the previous designs. The straps are thinner and don't distort the body. The corners have been rounded to improve moldability. (p59 Campbell) The shape of the part is roughly uniform thickness. Parts of uniform thickness are easier to fill and have a more predictable setting time. (p67 Campbell)



Figure #11

The biggest difference in this design is the mushroom head. The mushroom head make an "interference fit" with the strap. This means the mushroom heads hold the strap to the body of the part. The mushroom head is the best interference fit option for this part. This is because of the flexible nature of the material. The other alternatives would be straight posts or small hooks, but these would fail. The flexibility of the material would make the posts and hooks bend and deform under the pulling force of the strap, and the strap would release. The mushroom heads are also advantageous, because they have flat tops, which provide additional surface area for the adhesive Velcro to stick to.



This final prototype required a more complicated wax mold. A thin plate of wax, with features cut into it, went between the two larger halves of the mold. The thin plate (in figure 12) was the only way to machine the mushroom heads in wax.

Chapter 5: The Injection Mold

The mold design was devised by Lee Smith (master injection mold machinist). He saw that using a two piece mold with ejector pins would not work. The ejector pins would shear off the mushroom heads upon injection, so he recommended a three piece mold. Using a core pins and a spring loaded stripper plate, the mold could produce the part without destroying the mushroom heads. The three parts of the mold can be seen in figure 12. The three parts of the mold are the sprue half, stripper plate, and ejector half.



<u>Sprue Plate</u>

The top (sprue) half of the mold has the sprue, the straps, and the body of the part.



The sprue is the channel in the center of the plate that melted plastic flows through to fill the mold cavity. The sprue was cut with a specialty tapered end mill.

Stripper Plate

The middle part of the mold is called the stripper plate. It contains the mushroom heads and the remaining features of the part body.



It is bolted to the bottom half of the mold with four stripper plate bolts. The bolts screw into the plate, and slide back and forth in the bottom plate. The stripper plate is held off the bottom plate by 4 springs. When compressed the combined force of the springs is 600 lbs. When the part is cooled and the mold opens, the springs push the stripper plate out .100" away from the bottom half of the mold. This movement moves the mushroom heads away from the core pins, that penetrate the stripper plate, and creates a small gap

above the mushroom heads. This makes it possible for the mushroom heads to flex and be removed from the mold. The final feature in the stripper plate is the sprue puller. The sprue puller is located directly in line with the sprue. The sprue puller feature in the mold is a cylinder with a ridge around the middle. The sprue puller can be seen in middle of figure 16. It is similar to the mushroom heads, just bigger.



When the mold opens the sprue puller keeps the part attached to the stripper plate, and removes the sprue from the top of the mold. Without a sprue puller the part would be ripped in half when the mold opened.

Ejector Half

The bottom (ejector half) of the mold contains the stripper bolts, core pins, and springs. In each corner is a ½ inch diameter through hole. Each hole is for a stripper bolt. The holes are reamed so the stripper bolts can slide smoothly as the mold is opened and closed. Next to each corner



is a pocket for a spring. In the middle of the mold is a 3/8 diameter core pin used for the sprue puller. See figure 18.



There are 12 more core pins, one for each mushroom head, and all of them press-fit into the mold. (p88 PYE) Core pins are hardened steel rods, they have a circular base, and are precision ground to length and diameter. They come in a wide variety of lengths and diameters. The 12 core pins in the ejector half of the mold are 3/16" diameter and 3" long when purchased. They will be ground to length by Lee Smith after being purchased. Consult the bill-of-materials for more information on the quantity and prices of the mold components. The finished mold will be polished by hand with diamond dust cutting oil. (p140 Campbell) This will improve the surface finish and allow easier part removal.

Chapter 6: Considerations for Injection Molding

When it comes time to make parts at Prince Lionheart, they have several sizes of injection molding machines. Any of the machines could accept my mold, but it is more cost effective to match part size to machine size. Using too large a machine is a wasteful (p133 Campbell), so the smaller 85 ton Engel injection molding machine will be optimal. The color of the part will be black to match the Velcro. Furthermore Prince Lionheart already runs a black thermo plastic elastomer (with a 40 shor A hardness) in their machine, so the machine will not need to be purged, saving time and money. To optimize production a mold should make as many parts per cycle as possible. The number of cavities (parts) is restricted by the size of the mold being used; in this case there is only room for one cavity. The cavity will need draft angles (1-3 degrees) on as many surfaces as possible. Draft angles allow for easier ejection/removal of the part from the mold cavity. After the heated plastic in mold cools it may shrink. The shrink rate for most plastics is between .000" and .050". (p26 Bryce) This tennis part does not need to hold any critical tolerances, so minor distortions from shrinkage are not a concern. Temperature settings are also critical to producing quality parts. If the temperature is too high, the plastic will thermally degrade. If the temperature is too low the mold cavity may not fill completely. (p64 Osswald) Mold cooling is provided by cooling channels cut in to the mold. Water or coolant is pumped through both sides of the mold. The temperature must be kept cold enough to allow the plastic to solidify after injection, but not during injection. (p155 PYE) Figure 20 shows a possible coolant pathway layout.



The mold will use a cold runner system. A cold runner system ejects the cooled sprue with the finished part. (p13 Osswald) Cold runners make the mold simpler and cheaper. An operator removes the finished part from the open mold by hand. The sprue and sprue puller is trimmed later.

It is good practice to provide vents in the mold to allow air to escape. Vents are usually added after the mold has been tested. Testing is the best way to find the optimal locations for the vents. Vents are usually .002" by .125" slots. The core pins will act like vents for the mushroom heads, but the straps may need vents. Parts furthest from the sprue might require a vent. (p154 PYE)

Normally the mold halves and stripper plate are made of hardened steel, this allows the mold to last for many thousands of parts. My mold is made out of aluminum, because aluminum is cheap, easy to machine, and high volumes of parts are not needed. The projected production run will be approximately 500 parts. (p318 PYE)

Chapter 7: Cost Analysis

Since injection molds require such high tolerances and attention to detail they are expensive to make. High volumes of injection molded parts are needed to recoup the high cost of the injection mold and costs of operation. The costs for the manufacture of the mold and injection molding can be calculated three ways. If I paid myself \$17/hour to design and manufacture the mold, and paid Prince Lionheart to produce the parts, these would be called "Theoretical Costs." If I was working on this mold for free (un-paid), and Prince LionHeart was not going charge me to produce parts, this would be "My Costs." The last way to calculate costs is "Real World." In this final scenario Lee Smith (Santa Maria Mold) would be paid to make the mold, and Prince Lion heart would be paid to produce the parts. The second scenario is what will happen when the mold is finished; Prince Lionheart will do a production run of around 500 parts for free.

	Theoretical Costs	My costs	Real World			
Mold						
Materials	\$233	\$233	\$233			
Labor	\$1,445	\$0	\$2,300	85 hours of work at \$17/h		7/hour
Mud Bace	\$400	\$0	\$400			
Total	\$2,078	\$233	\$2,933			
Production run of 500	parts					
Electricity	\$20	\$0	\$20	3 hours at \$6.70/hour		
Material	\$200	\$0	\$200	100lbs at \$2/lb		
operator	\$48	\$0	\$48	3hr at \$16/hour		
Supervisor	\$100	\$0	\$100	3hr at \$33/hour		
Setup	\$200	\$0	\$200	2hr at \$100/hour		
Total	\$568	\$0	\$568			
Grand Total	\$2,646	\$233	\$3,501			
Cost/Part for 500 parts	\$5.29	\$0.47	\$7			
Cost/Part for 5000 parts	\$1.19	\$0.05	\$1.36			1

Table #1

The numbers in the table are assuming that there will be no defective parts, and that the mold will last for a production run of 5000 parts.

Chapter 8: Problems Encountered

With any project there will be setbacks and mistakes, and this senior project was no different. The mistakes made during the machining were both frustrating and expensive. They can be categorized into five areas.

G code

Making the ejector half of the mold required reaming the holes for the stripper bolts. The oversized half inch ream was in the tool 10 slot. For some reason the tool-offset for tool 10 was incorrect. Tool 1 (center drill) offset was specified instead. When it came time to ream the first bolt hole, the reamer went straight through the hole in the part, and I had to hit the feed hold before it crashed into the table. The machine was stopped, the code was inspected, and corrected. It was rerun successfully.

Part Orientation

Injection mold making demands high tolerance (less than .001" if possible). The first time the ejector half of the mold was machined, the vice was .015" off square, so the part was ruined. That was a \$55 block. The vice was promptly squared before any more parts were made on that machine. Another problem arose while machining the ejector half. The work off set in the Y direction was off .100 inch. This was on account of not zeroing the edge finder properly. The effect was that the stripper bolts were too close to the edge on one side of the mold. Furthermore the bolts would not fit into the mold, because the holes were not properly aligned with the pockets.

Tool Path

The Sprue half of the mold was the simplest part of the mold to machine, however a problem arose from using a tapered end mill. The code to machine out the cavity for the arms and body of the part called for a left to right movement of the tool. Then a profile

32

cut finished the perimeter. When the code was finished the right and left sides of the cavity were scalloped. The problem was that the top of the end mill was wider than the base (because it was tapered) and the right to left pattern was over cutting in to the cavity walls, and the profile pass was too shallow. The solution was to rewrite the profile pass to take a deeper cut. The deeper profile pass cleaned up the sides of the cavity.

Tool Selection

The ejector half of the mold has four pockets in it, one for each spring. The packets need to be ¹/₂" in diameter, and .7" deep. The code specified a 3/8" end mill. When the first block was finished, the spring pockets were several thousandths too small, and the springs wouldn't fit. Apparently the end mill wasn't exactly 3/8" in diameter, so for the machining of the final block, the end mill was changed for one the correct size.

Machine Availability

By the end of the second quarter everyone's senior projects were in full swing and the CNC machines were frequently occupied by other people's projects. Scheduling a CNC machine in between work and classes was sometimes difficult. Another thing that caused delays was the limited open hours for the lab. Sometimes it would take so long to get the code correct and the tools loaded into the machine, that there wouldn't be time to run the part before the lab closed. Some of the machining was beyond my skill level, so help from the lab techs or other students was required. Occasionally progress was delayed due to their unavailability.

Chapter 9: Conclusions and Recommendations

A substantial amount of progress has been made in the last two quarters. Many sources of information were consulted. Three molds were cut out of wax, and three prototypes were made from these molds. A proper injection mold was designed in CAD software. Injection mold components were selected and ordered off the internet. The sprue half of the mold was machined with minimal difficulty. The ejector half of the mold was machined incorrectly the first time, and this mistake cost \$55 in material and 4 hours of valuable setup/machining time. A second attempt using a wood block also failed. The problems were solved by changing the G-code, and the next aluminum block used for the ejector half was successfully machined. It seems very likely that the mold will be finished by the end of the quarter. The remaining work includes: making the stripper plate, grinding the core pins, and pressing the core pins in to the ejector plate. From consulting with Rene Hale, Lee Smith, the lab techs, and the library, I have learned volumes about injection molding. The production run at Prince Lionheart is scheduled for this summer break. If the mold was correctly designed and manufactured it should last about 500 parts. Once the tennis ball retrievers have been made they must be packaged for sale. After being packaged the next step will be to take the finished product to Tennis Warehouse. Tennis Warehouse is the world's largest tennis product distributor. The hope is that they will sell the tennis ball retrievers on their web site.

Chapter 10: Work Cited

Beck, Andrew. "Apparatus to Retrieve Tennis Balls." <u>Free Patent Online United States</u> <u>Patent US5383661</u> 26 July 1993 Feb. 2010 <<u>http://www.freepatentsonline.com/5383661.pdf</u>>

Beu, Jose. "Retrieval Device." <u>Patent Online United States Patent US7112153</u> 4 Apr 2005 Feb. 2010 <<u>http://www.freepatentsonline.com/7112153.pdf</u>>

Bryce, Douglas. Plastic Injection Molding. USA: Society of Manufacturing Engineers, 1999.

Caldwell, Dale. "Net More Adults." <u>Parks & Recreation</u> Vol. 38. Issue 6 (Jun2003) p60. <u>Academic Search Elite</u>. Cal Poly Library, 16 Feb 2010 < <http://xerxes.calstate.edu/slo/metasearch/record?group=002783&resultSet=047698&star tRecord=1>

Campbell, Paul. Plastic Component Design. New York: Industrial Press Inc., 1996.

Kalpakjian, Serope, and Schmid, Steven. Manufacturing Engineering and Technology. New Jersey: Prentice Hall, 2001.

Lamson, William. "Adhesive Ball Retrieval and Guard System for Sports Equipment." <u>Free Patent Online United States Patent US6652397</u> 17 May 2002. Feb. 2010 <<u>http://www.freepatentsonline.com/6652397.pdf</u>>

Miller, Robert. "Elderly Tennis Phenom Nehemiah Atkinson Spends His Golden Years on the World's Tennis Courts." <u>Black Collegian</u> Vol. 31. Issue 3 (Apr2001) p108. <u>Academic Search Elite</u>. Cal Poly Library, 16 Feb 2010 <http://xerxes.calstate.edu/slo/metasearch/record?group=002708&resultSet=047321&star tRecord=1>

Newey, James. "Tennis Ball Retrieval Device." <u>Free Patent Online United States Patent</u> <u>US6719651</u> 2 Apr 2003. Feb. 2010 <<u>http://www.freepatentsonline.com/6719651.pdf</u>>

Osswald, Tim, and Lih-Sheng, Tom, and Gramann, Paul. Injection Molding Handbook. Cincinnati: Hanser Gardner Publications, Inc., 2002.

R.G.W. PYE. Injection Mould Design. Great Britain: George Godwin Limited, 1978.

Ross, Peter. "Tennis Racket Having Incorporated Ball Retrieval Means." <u>Free Patent</u> <u>Online United States Patent US3874666</u> 11 Oct 1972 Feb. 2010 <<u>http://www.freepatentsonline.com/3874666.pdf</u>>

Schubert, Steven. "Racket-Mounted Tennis Ball Retriever." <u>Free Patent Online United</u> <u>States Patent US4210327</u> 15 May 1978 Feb. 2010 <<u>http://www.freepatentsonline.com/4210327.pdf</u>> Woollard, Howard. "Tennis Ball Retriever and Racquet." <u>Free Patent Online United</u> <u>States Patent US5333854</u> 2 Aug 1993 Feb. 2010 <<u>http://www.freepatentsonline.com/5333854.pdf</u>>

Young, Timothy. "Velcro Peel Test Project." Senior Project. Cal Poly, 1986

Appendix A: Final Drawings

















Appendix C: Bill of Materials

A complete list of materials and components purchased to complete the injection mold. The first category lists the components that make up the finished mold. The second category lists the extra mold components, practice mold blocks made of wood and aluminum, and an aluminum mold block that was made

Bill of Materials	-				
	Used in the mold				
		Item	Quantity	Price/Item	Total
		5.5x6.5x1.5 Aluminum block	2	\$55	\$110
		1/2x1" Heavy Duty Spring	4	\$2	\$8
		1/2x1" Stripper bolt	4	\$1.88	\$7.52
		C 13 M3 Core Pin	12	\$2.75	\$33
		C 21 M3 Core Pin	1	\$3.75	\$3.75
	Extra parts				
		5.5x6.5x1.5 Aluminum block	1	\$55	\$55
		5.5x6.5x1.5 Wood block	1	\$0	\$0
		5.5x6.5x1 Aluminum block	1	\$0	\$0
		C 13 M3 Core Pin	3	\$2.75	\$8.25
		C 21 M3 Core Pin	2	\$3.75	\$7.25
	Grand Total				\$233

Table #2