Putter Design - Kronos Golf

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Putter Design - Final Design Review

ME430 - Senior Design Project III

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2017
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Abstract
Gingham Golf, with the sponsorship of Kronos Golf, has developed three putter face inserts to act as a basis on which to innovate club design. Gingham Golf took a step back from traditional putter design and approached the putter through new aesthetic and engineering lenses. An extensive process of ideation and iteration, yielded three different face materials, aiming to test the feel and performance of the face inserts. A series of subjective and technical tests were constructed to weigh the face inserts against each other and industry competition. The results of the tests will be analyzed to select best putter face and integrate it in a final production design.
Chapter 1: Introduction

Golf putter design has been stifled and stagnated by strict regulation and a cultural reluctance to innovation. Kronos Golf is a putter design and manufacturing company that focuses on innovative club design through ultra precise, milled putters at a premium price point. In addition, Kronos is exploring emerging markets in Japan and Sweden. In an effort to bring fresh outlooks to the putter design space with a focus on the Swedish market, Kronos has employed three California Polytechnic State University Mechanical Engineering students to envision a new putter. This putter will be designed to be forgivable and appeal to a broad spectrum of golfers. The student team, Gingham Golf, will take a step back from traditional golf design and create a putter that will be proven through a series of technical and subjective tests.
Chapter 2: Background

History

Golf has been around for hundreds of years, and while the game has changed a lot since it was first invented, the fundamentals remain the same. The game is most simply broken down into two parts, the long game and the short game. The long game (driving and fairway shots) focuses on power and distance in order to get the ball close to the green. The short game (chipping and putting) puts an emphasis on finesse and accuracy to put the ball in the hole. When looking at a standard 18 hole course, and the typical two putts per hole, half of scoring par is directly from putting. This clearly shows how important putting is to the game of golf and how any innovations and improvements to putters are potentially game changing.

An important aspect to bring up, as it will be mentioned throughout the report, is putter forgiveness. We have defined forgiveness as the club’s ability to maintain both aim and distance control during an imperfect hit. An imperfect hit being when the ball is struck off center, either towards the toe or heel and the vertical location on the club face. One of the first and most influential innovations in putter technology was the Anser putter (Figure 1). Created by PING in 1966, the Anser was designed with heel and toe weighting and a center of gravity below the equator of the ball. These properties helped create a quick forward roll of the golf ball. This putter was rapidly adopted by pro and amateur golfers and remains a very popular putter today, over 50 years after its introduction.

![Figure 1: Putters identified as main competitors. From left to right: PING Anser, Odyssey 2-Ball, Happy Putter.](image)

While many small changes were seen after the Anser’s introduction to the market, the design remained much the same. When the patent for the putter expired in 1984, many other golf companies copied the Anser’s design. The next big change in putters happened in 2001 with the Odyssey 2-Ball putter (Figure 1), which had a unique club head shape. It was much longer than the typical blade putters and featured two golf-ball sized circles on the head; hence the name. This putter also implemented a softer more responsive insert into the face of the golf club. Players have reported significant improvements in forgiveness when compared to other models. The unique aesthetic design and insert technology led this putter to become one of the most popular clubs in the world.
One of the more recent developments of the United States Golf Association or USGA club regulations led to anchored putters being banned in January 2016. However, this does not forbid one from using a long putter, but changes the way it is used, as it now must be held away from the body. In response to this new regulation, Odyssey created the Tank putter in 2013. The Tank putter utilized a heavy head, grip and shaft in order to stabilize the club throughout the stroke. This putter became very popular for those transitioning from the anchored putter to the traditional putter. The aforementioned regulations from the USGA are one of the major reasons why innovation in the industry has been so slow.

Testing

Technical and subjective testing of the putters is critical to determining if a putter design is ready for production. Golf magazines and websites conduct thorough reviews on all clubs, which include quantifiable tests that can be used as a basis for our testing procedure. One of the more important metrics is the face aim test. This test looks at the putter during the address portion of the swing and determines if the face is square toward the target, or if not, how many degrees the aim is off. Because a square blade at address is a core fundamental of putting, this test is great for determining the forgiveness of a putter. The goal from this test is to have a putter that is consistently easy to address square and aim properly at the target.

The current industry benchmarks for putter design come from PING, Titleist (Scotty Cameron) and Odyssey. These putters have all received stellar user feedback regarding putter feel, balance, accuracy and aesthetics. It is important that the Gingham Golf final putter design competes with and exceeds the performance of these putters.

Within the designs, a couple of aspects of the putter will be emphasized for testing. The key aspects that will be tested are moment of inertia, club face, center of gravity, alignment, and loft angle. These are often highlighted by manufacturers as qualities that impact putting. All the final designs will explore at least one of these aspects to test their impact on putting forgiveness.

The moment of inertia (MOI) is how much of a torque must be applied to a body to change its angular momentum. In relation to golf, it is generally referring to how much the club rotates around its vertical axis when it is struck away from its center of gravity. Theoretically, the higher the moment of inertia, the less the club head with rotate on a hit that is not in line with the center of gravity. This results in a more forgiving clubface. Having a high MOI is becoming increasingly important for mallet style putter design. Scotty Cameron states that with their Futura series, the “high-MOI designs ... increase stability and forgiveness”. The TaylorMade Spider Tour Red has “perimeter weighting for added stability ... to help golfers drain more putts when they matter most.”

The club face is where the putter and ball connect. This aspect is an area where there are a lot of claims being made by manufacturers. A common design involves having an insert made of a different, generally softer, material in the club face. Another technique is applying different groove patterns on the club face. The Evnroll putter utilizes a grooved club face that has thicker and deeper grooves at the the center, that get progressively thinner and shallower at as the
grooves move out. This allegedly “imparts progressively more energy transfer on off-center hits to roll the ball a consistent distance with every stroke”. Ping putters have a similar design that “varies in depth and pitch across the face, which speeds up off-center impacts”.

The center of gravity is a geometric property of the club head. The location of the center of gravity is traditionally used to determine where the sweet spot of the club face is. Allegedly the father forward the center of gravity, the more control of the head is offered at the cost of stability. A lower launch angle, or angle the the ball leaves the club, is also a result of a lower center of gravity.

Putter alignment refers to the way the golfer lines up their shot. It incorporates both the biomechanics of the player and the physical design of the aiming mechanism. There are a variety of alignment strategies that attempt to help golfers better visualize where their ball is going to go. The Scotty Cameron Futura line has a variety of alignment options “including milled topline sight lines, new pop-through visual cues, rail alignment features and bright lines framing the sweet spot – provide added confidence at address.” The TaylorMade Spider Tour Red actually removes any alignment “to zero in the player's focus”. Compare this to the Cleveland 2135 Technology, which raise the alignment to the center of the ball so “regardless of whether you putt with your eyes behind, directly over, or well over the golf ball, [it] offers you perfect alignment.”

Loft angle is the angle from vertical that the club face is at. For a majority of clubs on the market currently, the loft is between 3 and 4 degrees, but lower loft putters are becoming increasingly popular.

Current Market

Building an adjustable putter will be critical to the project. Currently leading the adjustability market are two companies, Happy Putter (Figure 1) and Cure Putters. The Cure putter can adjust MOI, weight distribution and lie on some models. They adjust the mass properties by either securing weighted disks in two barrels located on the outside edges of the putter, or by inserting different weighted screws directly into the club head. The lie is adjusted with a simple joint on the putter head. Similarly, Happy Putters can adjust lie angle, loft angle, offset, and weight. Instead of infinite adjustability, Happy Putter has identified two to three different positions for each angle; adjustable by a simple torque wrench. Happy Putter also have interchangeable plates on the top of the putter which allow the user to customize their sighting guides. Generally, these putter are well received, but certainly leave room for improvement.

To understand the market we are designing for, a basic background of Swedish golf culture is necessary. The first Golf in Sweden was played on a private Estate in Ryfors. In 1888 an English architect, Edvard Milner, created a 6-hole course in the garden of the estate. A couple of years later his son changed the layout to a more conventional 9 holes. Since then the sport has quickly grown popular. In Sweden there are over 480 courses and more than 460,000 golf
club members. Sweden has been recognized as a golfing nation thanks to legend Annika Sörenstam and PGA players Henrik Stenson and Carl Pettersson. Sweden’s geography, with 15% of the country lying within the Arctic Circle, lends to an incredibly diverse golfing landscape ranging from rugged coastlines to giant forests.

The objective of Gingham Golf is to provide a new perspective on putting design and develop a new Kronos putter centered on forgiveness; targeted at the Swedish market. While Kronos has well established connections in the Japanese and American Markets, there has been limited interaction with the Swedish market. The Gingham Golf team is utilizing their experiences in Sweden to design a putter that would be fitting for further ventures into this emerging market. Specifically, one of the classes we took in Sweden was based around design products for pleasurable sensory experience. The class interrogated the theories of prominent Scandinavian designers and how to test their effectiveness. This knowledge will be applied heavily to the design of our putters.

Specifications

Kronos feels that to innovate in the putter industry, a fresh outside perspective is needed. Our group will provide an outsider’s perspective to an insular industry. While having a different outlook on design is important for success, there are a number of requirements and needs from Kronos and its customers that to have to be met. A Kronos putter is a precision milled instrument, and those expectations carry over to our team. When moving forward with our design process, we will be letting all of these requirements help guide our design. We have developed a Quality Function Deployment (QFD) matrix, which can be seen in Appendix A. Along with the QFD, Table 1 has a list of project specifications.

The QFD is a powerful tool that has helped the Gingham Golf team combine the engineering specifications and the customer requirements into a single matrix that we can use to see the relationships between requirements. Having a solid understanding of each individual part of the QFD is critical to understanding the matrix as a whole.

To begin using the matrix, you start with identifying your customers and what their requirements are. The customers are listed in the notes section while their requirements are listed in the left column. This is arguably the most important area of the matrix. If you are unable to properly identify the customer requirements or if you are unable to meet them, your product will be a failure. The customer requirements define what the customer wants or needs. The engineering specifications help define how these customer requirements will be accomplished. This section is in the middle of the matrix at the top. The engineering specifications will be measurable quantities that can assess if the customer requirements are achieved. This relationship is highlighted in the middle of the matrix where the customer requirements and the engineering specifications are given a relationship status, either strong, weak or unrelated. The correlations between the different engineering specifications can categorized as positive, negative or no correlation. This section is in the “roof” of the matrix, right above the engineering specifications.
Going down to the bottom of the matrix, the engineering specifications are quantitatively defined. The final section of the matrix is on the far right. This section is an evaluation of some existing products currently on the market. Once our design is finalized, its evaluation will be added to this section.

As far as specifications and testing goes, there are three main categories. The first category is specifications that are measurable constraints. The specifications that fall into this category are the Kronos Pure Balance standard, the USGA regulations for putters, cost, and weight. The putter must be designed to the Pure Balance standard of Kronos; meaning that the putter’s center of gravity must align on its sightline. This is a simple yes/no requirement, either the putter is balanced or it is not. The other yes/no requirement is the USGA regulations for putters. To be competition legal, the putter must meet all USGA regulations, outlined in Figure 1. The other two measurable quantities are the cost and weight of the putter. The target sale price for the putter is $300 wholesale cost which equates to approximately $30 production cost. This price is only achievable for a production series and not for a one off test design. The production cost will be estimated based off the costs of the initial manufacturing run. The weight of the putter specification is a range, from 200g to 600g, to not significantly limit possible designs.

The next area of specification is the quantifiable tests. We have to run our own tests for this section and define what a successful result will be. The two specifications in this section are the repeatability and forgiveness of the putter. The repeatability of the putter is how consistently the putter performs at various distances when the ball is struck. Forgiveness is how well the putter performs when the ball is struck imperfectly. For both of these requirements, what defines success has yet to be determined. Benchmark testing will have to be done with other industry clubs.

The final section for the requirements are the qualitative requirements for the putter. These are the aesthetics and the feel of the putter. While these specifications are the some of the hardest to design and measure, they are crucial to a successful putter design. In the world of golf, a player is unlikely to use a putter that they deem ugly or doesn’t feel good in their hands, despite its performance. In this section of testing, the prototypes will be put in the hands of actual golfers to see if they successfully meet the specifications.
Table 1: Gingham Golf Project Specifications.

<table>
<thead>
<tr>
<th>Spec #</th>
<th>Parameter Description</th>
<th>Requirement of Target (units)</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dimensions, USGA (see Figure 1.)</td>
<td>See Figure 1.</td>
<td>Maximum, Minimum</td>
<td>M</td>
<td>I,A</td>
</tr>
<tr>
<td>2</td>
<td>Loft, USGA</td>
<td>&lt;10</td>
<td>Maximum</td>
<td>L</td>
<td>I,A</td>
</tr>
<tr>
<td>3</td>
<td>Pure Balance</td>
<td>Y/N</td>
<td>-</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>4</td>
<td>Weight</td>
<td>200-600g</td>
<td>Range</td>
<td>L</td>
<td>A,T</td>
</tr>
<tr>
<td>5</td>
<td>Cost</td>
<td>&lt;$30 final manufacturing</td>
<td>Maximum</td>
<td>M</td>
<td>A</td>
</tr>
</tbody>
</table>

Figure 2: USGA Putter Dimensions.

Table 1 is a summary of the measurable design specifications. This table assesses the risk associated with each specification as as high (H), medium (M) or low (L). The table also includes the verification method for each specification, analysis (A), testing (T), similarity to existing designs (S), and inspection (I).
Chapter 3: Design Development

Initial Designs

Our initial design development culminated in three designs to test. The designs push the boundaries in both aesthetics and putter performance. They are each the brainchild of an individual group member, but have been approved and critiqued by the whole group. The chosen putters are designed to incorporate the multiple variables we plan to test. Each putter is unique in its approach to putting and designed to be different enough from the others to facilitate comparative testing. The putters presented below are our initial designs from our preliminary design review and have since been modified and expanded upon as seen in Chapter 4: Description of the final design. Our first design, called the Data (seen below in Figure 3) was created to test putter weighting with a strong focus on Scandinavian design theory.

![Figure 3: Preliminary Data Putter Design.](image)

The Data is characterized by the straight sections reminiscent of a bar graph. The main areas that this design hopes to explore during testing are aesthetics, alignment and moment of inertia. This design is exploring straight lines in the look. A majority of mallet putters in the market currently are curved in shape with rounded edges. The Data contrasts this stereotype with the a Scandinavian concept of straight, parallel lines. In Swedish design culture, there is an emphasis on contrasting the abstract with the natural. The Data explores the abstract conceptual side of Swedish Design. Having a series of lines perpendicular to the club face allows for the entire club head to help the golfer align their putt. Alignment is important in putting because it allows the golfer to consistently hit the ball on the correct section of the club face. The Data will also investigate the impact of a lower center of gravity and how that affects the forgiveness of the club. The high moment of inertia of the Data will stabilize the swing motion. The next putter, the HiCOG, contrasts parts of this concept.
As the name might imply, one of the main design specifications of the HiCOG putter (Figure 4) is a high center of gravity on the face of the club. This putter is designed towards testing how raising the center of gravity affects putter performance. Furthermore, the center of gravity is placed deeper into the club head to promote forgiveness by reducing the off-target launches during an off-center hit. A high moment of inertia is used to resist rotation during impact in order to improve consistency and distance control during the imperfect hits. In order to promote better putter alignment, the sight line on the putter is on two separate planes. These will lineup when square, allowing the user to easily tell if the putter is properly aimed. Aesthetically, this putter is designed to be simple and sleek; catering towards the understated elegance and minimalism of Swedish design. The next progression of this design will be the implementation of interchangeable putter faces; milled, grooved and insert styles. The different face styles will allow us to easily test how each type impacts the putters performance in terms of feel and distance control. The third design further expands on the customization of the putter.

The Double Rail putter (Figure 5) was designed for adjustability in all angles and mass properties. It draws its inspiration from the function-over-form ideologies of Swedish camera manufacturer Hasselblad and the Porsche 919 Hybrid race car. Each of the design cues are the best in their field for their ability to adapt to the user and provide unmatched performance in a wide array of conditions. This putter is is simplified and refined version of the Freud putter head, with the shaft design from the AHMOI. Changes were made after the initial sketches were analyzed, but the design concept remains the same. It is based on a basic blade with added features for adjustability.
The lie angle and shaft placement is adjustable by nut and slot running the width of the club face. The shaft location and angle can be adjusted to any point within the legal range for both right and left handed configurations. Simply loosening and tightening the nut will allow for both for these features to be adjusted. The next level of adjustability are two rails on the side of the putter. By locating simple disk weights on the rails, the MOI and weight distribution of the putter is extremely dynamic. Since the aluminum body is relatively light, the dense, mix-metal weights greatly affect the mass properties of the putter. The rails are threaded to allow light nuts to lock in the positions of the disk weights. This putter was designed with testing in mind. It would test the consumers desire for an adjustable putter. Secondly, it allows lie, loft, and shaft offsets to be tested to find their effects on swing mechanics, feel and forgiveness. Finally, the rail design allows us the vary the mass, heel-toe weighting, swing weight and Moment of Inertia during testing. Alternative to the other two putter designs, the Double Rail putter was envisioned primarily as a functional testing tool and forgoes a specific aesthetic effort.

All of the designs will be manufactured using the CNC milling equipment and shops available at Cal Poly. Specific to the Double Rail Putter, the rails will begin as simple metal rods that will be sized and press fit into the putter. The rails will then be cut using a die and appropriately sized disk weights and nuts will be applied. The shaft and grips will be sourced, relatively inexpensively, from online golf suppliers.

**Ideation**

An extensive ideation and narrowing process was undertaken to get final three designs. Using the information required in our background and the solidified goals in our QFD, we began our creative process. The ideation process focused on mass idea generation and creativity. Numerous ideas were presented. Ideas ranged from simple tweaks of modern putters to high-tech electronic precision tools. Every idea and concept was judged and narrowed into eight top designs. For our initial designs, the USGA regulations were largely ignored to promote creative solutions. Each of the the initial designs are shown below.
The Phoenix Putter design was highly centered around the aesthetic aspect of putter design. As the logo of Kronos golf, the goal behind this putter was to create a unique putter showcasing the aesthetic excellence associated with Kronos’ line of milled putters. Additionally, the design incorporated a focus on center of gravity depth and a large moment of inertia in order to make the most forgiving putter. This design was abandoned due to the lack of innovation in the engineering aspect, as well as difficulty in manufacturing.

The HiCOG putter, explained above, made it through the decision process. An early sketch of the idea can be seen below in Figure 7.

The Lumos (Figure 8) was aesthetically focused, inspired by layered curves often seen in Scandinavian design. It was designed mainly for aesthetics, but incorporates a higher mass and high center of gravity to improve ball roll. The Lumos had a relatively low MOI for its mass, making it relatively unstable, but maneuverable for its size.
Below in Figure 9 was the first iteration of the Data putter. There are a number of changes from the initial design to the final design. The most notable of the changes are to the height and length of the bars. The overall height of the putter was reduced along with the bars. The design was also trimmed to slim the club head.

Similar to the Data, the Open Air (Figure 10) was focused on the concept of straight lines. Aesthetically, the Open Air was more similar to a traditional putter. The MOI of the Open Air was much lower than the Data which eliminated the design.
The Crown Putter (Figure 11) was a Swedish focused aesthetic design; based on the crown in the Swedish Coat of Arms. Other aesthetic cues included logo inlays on the face and a flag design on the inside of the stem. The Crown featured minimal loft and a relatively high MOI, in line with the current direction of innovation. The putter was designed to have clean lines and a minimalist approach, drawing from Scandinavian design theory. While aesthetically stimulating, this design was extremely difficult to manufacture, and not innovative enough to qualify for the early testing process.

The Freud design, seen in Figure 12, started as a simple blade putter with rails used to adjust the MOI and weight distribution. From there, a light, sculpted wooden body was added for aesthetic and centering purposes. The raised ridges are intended to add a third dimension to the centering lines, ideally to eliminate non-horizontal strokes. Rails are added to the sides of the putter. The rails carry weighted disks which allow us to adjust the mass properties of the putter. The rail system from this design was carried into the final design as they were a very simple way to adjust the mass properties. However, some of the aesthetic body elements were
scrapped because it was unnecessary to the testing purposes of the putter and added time to the manufacturing process.

![Figure 12: The Frued putter.](image)

The AHMOI putter design (Figure 13) was a test tool for weight distribution and moment of inertia. A grid of raised pegs, loaded with disk weights allowed for a wide range of testing arrangements. Additionally, this design featured an interchangeable face to test hitting materials. It used a simple dove-tail design to lock in each insert. All shaft angles are adjusted with a series of locking joints and the loft is changed by adding shims directly behind the face. The shaft length is increased using a telescoping mechanism. This putter could be ideal because it allows us to test a wide array of putter fits, but is perhaps overly complex. However, the shaft adjustability concept was carried over into the final design.
From these eight designs, we narrowed down to a final three. The three designs may be outside of USGA regulations, but they have to incorporate realistic technology. Later in the process, the non-compliant ideas will either be scrapped or adapted to pass regulations. Prototypes of these designs will be made and used in an early testing phase. The designs do not need to be made to the precision or quality of the final product, but need to be useable for as much testing as possible. The discussion and concept selection was aided by the simplified version of a decision matrix, seen below in Table 2.

Table 2: Decision Matrix

<table>
<thead>
<tr>
<th></th>
<th>Open Air</th>
<th>Data</th>
<th>Lumos</th>
<th>Crown</th>
<th>MAP</th>
<th>Frued</th>
<th>Phenix</th>
<th>HICOG</th>
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</thead>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Manufacturing Feasability</td>
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<td>-1</td>
<td>-1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Since our putter designs were based on relatively subjective research, making a traditional decision matrix was difficult. Realizing this, our decision matrix was used primarily as a vehicle
for discussion, rather than a definitive tool to pick top designs. This decision matrix graded the putter on three categories, Aesthetics, Manufacturing Feasibility, and Innovation. The Aesthetics category was simply a “like”, “neutral” or “dislike” vote on the aesthetic design corresponding to 1, 0 and -1. Manufacturing Feasibility was created to judge each putter on its ability to be created. Especially for this initial design round, designing putters that can be manufactured and quickly sent out to test is essential to keeping our timeline. Finally, the Innovation category judged the putter on its deviation from the norm and its ability to test a certain aspects of putter design. A datum was chosen to be the PING Anser putter and each group member assigned a grade for each category. The grades were summed in the Total section. In our discussion for concept selection, we aimed to choose a set of putters that had aesthetic and performance potential plus fulfilled a goal for our testing. We chose putters that represented the breadth of our designs. For instance, the Double Rail putter will be a useful tool to test putter fit and the mass properties affect on swing, but does not challenge the design principle as much as the Data. Because of their significant design differences, pitting the two putters against each other in tests will yield more meaningful results.

Testing Planning

Simultaneous to the creation of the three prototype designs, a testing method was envisioned. This testing method will be used to grade the putter designs against each other and create a final design. Using the putting machine from a previous project, we will test the putter forgiveness as a performance metric. The plan is to use the machine to hit the ball at various locations on the club face and plot the resulting locations. Multiple trials of perfect and off-center hits will be run for each putter and compared to an “industry” control putter. We will collect data for the following metrics: location of the hit on face, distance of the hit, and precision of the putt. The hit location will be set for each trial. Distance is a simple ruler measurement. The precision will be determined by the total distance between a hit from the perfect center of the club and an off-center hit for the same putt parameters. The putters will be tested at different swing speeds to achieve the effect of putting at different distances.

Our next performance tests will look at repeatability. To test repeatability, we will run two tests. Both of these tests will be run with real golfers. In the first portion of the test, we will have a variety of real golfers use all our putters at various distances and plot/video where their putts end up. This would be on an actual putting green. This does introduce considerable outside variables that we have to control for but we feel like this is a necessary step to understanding how the putters work. The second test would be in a more controlled environment, indoors on a level surface. This would be run with less golfers but the environment would allow for more data to be collected.

The final performance test will be an analysis of how our putters impact the swing mechanics of the golfers using them. This test will be done in conjunction with the second repeatability test. We will use accelerometers, cameras or other data-collection devices to analyze the swing mechanics of each putter. We aim to design a putter where an excellent swing comes naturally.
Our clubs will be compared with the swing mechanics of our control clubs to see how the properties of the club effect the swing.

Additionally, we will run a series of active and passive tests on the experiential design of our putter. The final element of our testing procedure will be a set of surveys on observational data to help determine the user experience (UX) of each club. The surveys will include specific questions about each design and explanation of reasoning for their answers. Additionally, other design tools like semantic scales. As each participant putts and takes the tests, their actions will be observed. We will see which putters they tend to use first and the things they do as they interact with each putter. Along with the numerical data from the surveys, extensive noted evidence will be collected on the subconscious interactions. The data collected from these test will help narrow the design elements that are desired from a putter.

The data from the putter tests will be analyzed. Correlations relating design elements with performance or experiential trends will be highlighted. Additionally, the testing process itself will be edited and refined for the final putter. With the results of the testing phase for the three putters, a final design phase will take place. The best elements of all three putters will be combined to one design that is tailored to fit USGA regulation. In addition to the final design, a manufacturing plan will be created. The plan will detail the procedure and cost of every step of the process. Next, the final putter must be manufactured. A majority of manufacturing will take place through the facilities and staff at Cal Poly. In certain situations, outside parts will be sourced.

Once the club has been manufactured, the refined testing process will be run. The club will be compared to other benchmark clubs and the previous three designs. If necessary, small design modifications will be done as time permits. The results of our final testing procedure will determine the success level of the final product.

A summary of the project timeline can be found in the Gantt Chart in Appendix D. It includes estimated dates and times for the completion of the project. The dates, apart from design reviews, are subject to change and will likely be altered as the project develops.

Using input from the Preliminary Design Review, reflection on the PDR designs and input from manufacturing consultants, the three putter designs were modified and refined into a final design. The majority of design modifications were to improve manufacturability and simplify the designs. The details of the finals designs are seen in Chapter 4 below.

**CDR Designs**

In order for the putters to be manufactured quickly and sent out to test, each of the selected designs were modified. Using input from PDR, the shop technicians and other outside sources, the designs were modified as seen below.
HiCOG

The HiCOG Putter (Figure 14) was changed fairly significantly from the design originally proposed, but the idea behind the putter remained very much the same. The two main aspects of this design were a large moment of inertia and a high center of gravity, and both had a larger emphasis in order to determine if these features could be successful and should be carried over to the final design. A detailed drawing of this design can be found in Appendix B.

![Figure 14: HiCOG putter design.](image)

This iteration of the HiCOG would have been significantly easier to machine which will allow us to put the putter into testing faster. When looking at manufacturing the preliminary design, it became apparent that many of the curves and internal angles on the design were impossible for a mill to properly cut, and because of this many of the complex curves were simplified. The undercut portion was removed to further increase the putters center of gravity. The face grooving has also been removed. The hosel was also removed in favor of drilling into the putter head to insert the shaft, this makes the part both easier to manufacture as well as assemble. The fillets seen in the preliminary model were traded in favor of chamfers which fit the design language of the putter better while also reducing machining time. One of the most important parts of this design was the material selection, which was to be 303 stainless steel. This was chosen mostly for it’s increased density when compared to aluminum. The increased head mass creates a higher swingweight, which should help prevent the player’s hand from hinging during their stroke, in turn making the club more forgiving.

The putter head was to be manufactured in house at the Cal Poly facility by shop technicians. Once milled, we had planned to surface and polish the piece as necessary, then a hole was to
be drilled in the top of the putter where the shaft was to be mounted using epoxy. Once assembled the shaft was to be bent in order to create the correct lie angle and shaft offset. The full cost analysis is broken down in table 3 below.

Table 3: HiCOG Cost Analysis

<table>
<thead>
<tr>
<th>Part/Process</th>
<th>Cost</th>
<th>URL</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25&quot;x4&quot;x3&quot; 303 Stainless Steel</td>
<td>$37.69</td>
<td>midweststeelsupply.com</td>
<td></td>
</tr>
<tr>
<td>0.370&quot; Steel Putter Shaft</td>
<td>$0.00</td>
<td>-</td>
<td>Supplied From Kronos</td>
</tr>
<tr>
<td>COFFEE BEAN GRIP GOLD PHOENIX</td>
<td>$0.00</td>
<td>-</td>
<td>Supplied From Kronos</td>
</tr>
<tr>
<td>CNC Milling</td>
<td>$16/hr</td>
<td>Mustang 60 (Cal Poly)</td>
<td>Approx. 2 hours</td>
</tr>
<tr>
<td>Total Putter Cost</td>
<td>$69.69</td>
<td>-</td>
<td>One-off Design</td>
</tr>
</tbody>
</table>

Data

The Data putter was modified the least of any of the designs that are being tested. This was due to primary aspirations of the putter being to test the aesthetic aspect of the putter. The most significant design modification was the removal of the raised bar in the middle of the body of the club head this change can be seen in Figure 15.

![Figure 15: The Data Putter final design.](image)

Removing this raised section served two primary purposes. The first being the ability of the Data to contrast the HiCOG’s higher center of gravity. By removing this section, the center of gravity was lowered in the Data and the differences between the putters could have been more accurately understood. This change was made without significantly altering the aesthetic
qualities of the putter or reducing the high moment of inertia. The other changes that can be seen in this iteration of the Data putter were for primarily manufacturing purposes. The most noticeable of these manufacturing changes was the removal of the hosel. By removing the hosel, the amount material and time needed for machining the putter was significantly reduced. The shaft was inserted into a hole drilled into the top of the putter head at the proper angle. Fillets were added to the internal edges along with chamfers to the external edges. The bottom was also flattened to reduce the number of angles that need to be machined. The current iteration of the Data was CNC milled by Cal Poly technicians out of 6061 aluminum. This was different than the initially proposed 303 stainless steel. This is done to reduce machining time and costs for the initial prototype. This reduced the weight of the putter by approximately 50%. While this will change the swing properties, the aesthetics were the most important quality. Based off the analysis done by the Test putter, weighting was planned to be added into the base of the club head as testing continues. The club head was attached to the standard shaft and grip of all the initial testing designs. The lie angle, loft angle, and offset angle were planned to be adjusted by bending the shaft.

A cost analysis for the Data putter can be found below in Table 4.

Table 4: Data Cost Analysis

<table>
<thead>
<tr>
<th>Part/Process</th>
<th>Cost</th>
<th>URL</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75”x4”x12” 6061 Aluminum Bar Stock</td>
<td>$36.42</td>
<td><a href="http://www.onlinemetals.com">www.onlinemetals.com</a></td>
<td>Supplies 2 putters</td>
</tr>
<tr>
<td>0.370” Steel Putter Shaft</td>
<td>$0.00</td>
<td>-</td>
<td>Supplied From Kronos</td>
</tr>
<tr>
<td>COFFEE BEAN GRIP GOLD PHOENIX</td>
<td>$0.00</td>
<td>-</td>
<td>Supplied From Kronos</td>
</tr>
<tr>
<td>CNC Milling</td>
<td>$16/hr</td>
<td>Mustang 60 (Cal Poly)</td>
<td>Approx. 3 hours</td>
</tr>
<tr>
<td>Total/Putter</td>
<td>$42.21</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The production cost of $42.21 was higher than our final target production cost goal of $30 but there are some factors that must be considered for when the Data goes into a production run. The final putter was planned to be made out of 303 stainless steel which increases price but material would be used more effectively and the machining process would be more streamlined reducing the amount of hours needed per putter. A detailed drawing of the Data putter can be found in Appendix B.

Test (Double Rail v2)

The new Test putter maintained the same design philosophy and functional approach as the Double Rail. It still allows for some adjustment in fit, and improves the adjustment capabilities for mass properties. The loft was set at 0 degrees, but was adjustable up to 4 degrees by shaft bending. Modern putters are trending towards lower lofts (less than 4 degrees). The face was modified to the shape seen in Figure 16 and 17. The top of the face was lowered to move the COG closer to the center of the ball. The two upward extrusions (at the same height of the
The previous iteration allowed for vertical movement of the COG. To do this, the weighted shafts can now be located on 5 different vertical locations. One location on the center of mass, one below and three above added more dimensions to the mass properties. Additionally, the grooving on the front face was removed for ease of manufacturing.

Figure 16: Final Test Putter, Front Face

The second significant design modification was the removal of the adjustable hosel. In the final design, the shaft was located in a single 0.370” diameter hole in the head. This design allows for 4 different configurations for the shaft: right-handed side, right-handed middle, left-handed side, left-handed middle. The shaft was secured using a standard golf epoxy. Golf epoxy functions identically to a standard epoxy, but has a lower melting temperature, making shaft removal and re-fitting much easier. The epoxy is easily removed with heat, if a different shaft location is preferred, and an epoxy fit is significantly more stable than the previous wing nut design. The new three-hole design was justified for a few reasons. For one, the shaft mounting location added significant complexity and required trials to our testing procedure. Proceeding with a more traditional fit and focusing on mass-property testing more closely matched our goal of ultra-high forgiveness. The the wing-nut design had a high probability of slipping during testing and, due to its continuous slot, was difficult to consistently relocate. Since there are only 2 locations, center and side, for shaft mounting, the three hole design was effective and much more robust. Importantly, the new design was much easier to manufacture. Considering other unforeseen time barriers, a design that was streamlined to get ready to test as soon as possible was imperative.
6061 Aluminum was used to construct the Test Putter. It’s versatility in machining and favorable material properties made it ideal for this putter. Because 6061 is much softer than steel, it is easier to work on, but is more than strong enough to deal with the impacts of a golf ball. Secondly, its low density allows the steel weights to effect the mass properties more significantly. The detailed and layout drawings can be found in Appendix B.

In order to create the putter from aluminum stock, the following occurred: The initial profile of the test putter was cut using the Industrial Technologies water jet cutter. The stock will then be cut to the proper thickness of 0.75” using the band saw and milling equipment available in Mustang 60 Machine shop. Next, the holes were drilled and tapped (¼-20 only). The hard-plastic weighting shafts were replaced by steel shafts and were fitted by hand. Shaft mounting holes were drilled into the top of the putter, with a .005” clearance with the shaft. The shaft was bent to a 70 degree lie angle using the tube bending equipment in the shop. Finally, the shaft was mounted by hand and secured with the golf epoxy.
Table 5: Cost analysis of test putter.

<table>
<thead>
<tr>
<th>Part/Process</th>
<th>Cost</th>
<th>URL</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMCo 1 1/2 Inch 3&quot;x10&quot; 6061 Aluminum Bar Stock</td>
<td>$19.97</td>
<td><a href="http://www.amazon.com">www.amazon.com</a></td>
<td></td>
</tr>
<tr>
<td>0.370&quot; Steel Putter Shaft</td>
<td>$0.00</td>
<td>-</td>
<td>Supplied From Kronos</td>
</tr>
<tr>
<td>USP Nylon Threaded Rod 1/4-20 4'</td>
<td>$4.48</td>
<td><a href="http://www.usplastic.com">www.usplastic.com</a></td>
<td></td>
</tr>
<tr>
<td>COFFEE BEAN GRIP GOLD PHOENIX</td>
<td>$0.00</td>
<td>-</td>
<td>Supplied From Kronos</td>
</tr>
<tr>
<td>1/4&quot; Copper Washers (25) - 93744A130</td>
<td>$7.26</td>
<td><a href="http://www.mcmaster.com">www.mcmaster.com</a></td>
<td></td>
</tr>
<tr>
<td>1/4-20 Black Plastic Wing Nuts (50) - 94924A600</td>
<td>$8.14</td>
<td><a href="http://www.mcmaster.com">www.mcmaster.com</a></td>
<td></td>
</tr>
<tr>
<td>Milling and metal work</td>
<td>-</td>
<td>-</td>
<td>Cal Poly Machine Shops</td>
</tr>
<tr>
<td>Water Jet</td>
<td>-</td>
<td>-</td>
<td>Cal Poly IT Labs</td>
</tr>
<tr>
<td>Total</td>
<td>$39.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The final cost of producing the Test putter was $39.85 (Table 3). While this is above our target production cost of $30, it was acceptable for a prototype. The prices in Table 3 are the total cost of all of the packages, including extra materials. Buying stock and materials in bulk and using them completely for a production run of numerous putters will significantly reduce this cost to well under $30. All though we did not pay for shafts, grips and machining processes, they are available at low cost for a production run. Table 4, below, show the material cost per putter, if all materials are used in a production run.
Table 6: Test putter production cost breakdown.

<table>
<thead>
<tr>
<th>Part/Process</th>
<th># of Putters/Item</th>
<th>Cost/Putter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMCo 1 1/2 Inch 3&quot;x10&quot; 6061 Aluminum Bar Stock</td>
<td>4</td>
<td>$4.99</td>
</tr>
<tr>
<td>0.370&quot; Steel Putter Shaft</td>
<td>1</td>
<td>$0.00</td>
</tr>
<tr>
<td>USP Nylon Threaded Rod 1/4-20 4'</td>
<td>6</td>
<td>$0.75</td>
</tr>
<tr>
<td>COFFEE BEAN GRIP GOLD PHOENIX</td>
<td>1</td>
<td>$0.00</td>
</tr>
<tr>
<td>1/4&quot; Copper Washers (25) - 93744A130</td>
<td>2</td>
<td>$3.63</td>
</tr>
<tr>
<td>1/4-20 Black Plastic Wing Nuts (50) - 94924A600</td>
<td>12</td>
<td>$0.68</td>
</tr>
<tr>
<td>Milling and metal work</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Water Jet</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total/Putter</strong></td>
<td></td>
<td><strong>$10.05</strong></td>
</tr>
</tbody>
</table>

From Table 4, if all materials are used, the cost per is lowered to $10, leaving $20 available for machining. Given a large enough production run, $20/putter machining cost is very feasible.

**Technical Testing Procedure**

This area was to be comprised of quantifiable data where we will compared our designs against the benchmark in terms of accuracy and precision. The technical testing was broken down into two parts, indoor and on-course testing. Both of these test were to be run very similarly with a couple key differences, the participants and the environment. The indoor test was to be run in a lab at Cal Poly with a selected group of individuals and the putting machine, and the on-course test was to be performed at Morro Bay Golf Course with random participants who happen to be there and volunteer. Participants were to putt at a target or hole from two distances, 6 and 13 feet, starting with the shorter distance. These distances were determined based off of the average putt distances of the PGA tour modified to fit an amateur golfer.

For both the indoor and on-course testing, the player was to:

- Perform 5 putts with one putter from each distance,
- A camera setup will record the location of the ball on the clubface and the putt distribution.
- The balls were to be cleared after each putt.
- The player will then change putters and repeat the procedure for each of the remaining putters.
- For the indoor test, the putting machine will also be used.
- The putting machine will do 20 putts at five positions on the club face for each of the previous distances along with putts from 20 feet.
Data was to be collected centered around the accuracy and precision of our putter designs and compared to a benchmark, in this case a Odyssey White Hot XG. This data was to allow us to see which features from each putter had the most effect and was to be carried through to the final design. The full procedure and the relevant data sheets can be found in Appendix C. The data sheets could then have been used for the on course and indoor testing along with the human and machine testing.

Subjective Testing Procedure

This test required the following items:
- 4 Testing Putters
- Plenty of response forms for all golfers (Appendix C)

Subjective putter testing was to occur whenever humans are using the putters for the test. However, there were two different versions of the subjective testing run during different tests:

During testing the following survey and interview procedure were to be followed:

- The subject was to approach a rack of four putters and pick one, their choice was to be noted
- The subject was then to run the putting test. The team member leading the test was to take note of subject-club interactions. These interactions could have included:
  - Any comment about putter
  - Facial expression and gestation
  - Inspection or investigation on certain putter parts
  - Once the test has been run, they were to complete Survey A, seen in Appendix C
  - This process was to be repeated until all putters have been test.
  - Once all putter’s have been tested, the player will undergo a short interview. This interview will take about 2-3 minutes.
  - The interview will follow the format and be recorded on Survey B by a member of the testing team.
  - After the interview, the test is complete and the participant was to be released.

During the On-Course Putter Testing, a short, simple aesthetic test was to be conducted. The procedure was as follows:

- While the putting test was being run, a team member with a notebook was to be recording putter-golfer interactions. (Examples in previous test)
- Once golfer had finished the test, they were to be summoned by a group member.
- The group member were to conduct a short interview (2-3 minutes) to complete Survey B
- After the interview, the test was complete and the participant was to be released.
This was to give insight into the desires and thoughts of numerous golfers without taking up too much of their time.

The data analyzed in this test was to be paired with our objective data to correlate feel and product enjoyment to specific elements of our designs.

**Mass Properties Tuning**

In order to decide on a weighting scheme for the final putter, a combination of input from the HiCOG and Data putter tests was to be combined with a test run with the Test Putter. The following test was to be used to tune the mass properties of the putter and was to be conducted with few (2-4) amateur golfers. All of the mass property tuning will use the Test Putter, and recorded in the Mass Tuning Form in Appendix C. The procedure was to be as follows:

**Total Mass Tuning**
- The test putter will have the weighted shafts located on the center of mass holes.
- The test masses were to be located centrally on the weighted shafts.
- The putter was to be configured to low mass (~300g)
- Each golfer will putt around 3 times or until they feel they have reached an opinion on the weighting scheme.
- This was to be repeated for medium mass (~450g) and high-mass (~600g) configurations.
- On the Mass Tuning Form, Part A, the mass configurations were to be ranked by the golfer.
- The most favorable mass was to be used in further testing.

**Vertical COG Tuning**
- The tuned mass amount was to be located centrally on the weighting shafts.
- The weighting shafts were to be located in the lowest holes.
- Each golfer were to putt around 3 times or until they feel they have reached an opinion on the weighting scheme.
- Shafts were to be moved upward and the process with be repeated until all five holes have been tested.
- On the Mass Tuning Form, Part B, the mass configurations were to be ranked by the golfer.
- The most favorable mass location was to be used for further testing.

**Horizontal COG Tuning**
- The tuned mass amount was to be located at the height selected in the results of the previous test.
- The tuned weights were to be located at 1, near the putter face.
• Each golfer will putt around 3 times or until they feel they have reached an opinion on the weighting scheme.
• Shafts were to be moved outward and the process with be repeated until all three locations have been tested.
• On the Mass Tuning Form, Part C, the mass configurations were to be ranked by the golfer.

Once all tests had finished, the golfers were to rank in the effectiveness of each degree-of-freedom in Part D of the form.

A checklist for the testing procedure can be found in the Design Verification Planning Report (Appendix E).

Chapter 4: Designs for Testing and Analysis

Upon the completion of CDR, a new aspect of putter design was added, which was putter face inserts. The testing of the Data and HiCOG putters were set aside in order to focus on the properties of the putter face material and how they affected putter performance. The idea behind the shift in our plan was to maximize innovation in the club whilst still using the test putter to determine the ideal mass properties.

Four new putters were created for the face insert testing, each with a unique face material; Aluminum, Copper, Bamboo, and D3O foam. The putters were rectangles machined out of aluminum, this was done for a couple of reasons, first off it kept the cost of manufacturing low and made it easy to control the putter properties. A cavity was then milled out of the face for the face insert, and four holes were milled out of the back which were then filled with lead to achieve the desired weight of the club head. A straight shaft was then inserted at a 20 degree angle from vertical to create the correct lie, and secured using epoxy. The result was four identical putters with different face materials, which were then subjected to testing.

Table 7: Face insert putter specifications.

<table>
<thead>
<tr>
<th>Material</th>
<th>Aluminum + Insert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>250g</td>
</tr>
<tr>
<td>Lie</td>
<td>20°</td>
</tr>
<tr>
<td>Loft</td>
<td>0°</td>
</tr>
</tbody>
</table>
Each face insert material was chosen with a general hypothesis in mind:

**Aluminum (Control)** - Used to compare the performance of the face inserts.

*D3O Foam* – Rate-dependent foam material, would harden upon impact but still have deflection in the foam which would serve to help correct miss-hits.

**Bamboo** - The natural fibers and inherent softness of the wood would communicate more feel and feedback to the player.
Copper - Maintains the familiarity of a milled face while adding more feel due to its softness.

In addition to the face insert putters, the mass tuning test putter remains an integral part of testing. Only one shaft location was used to reduce the amount of trials needed and because everyone testing it, swung right handed. The plastic rails were also replaced with steel rods for greater support. This putter allowed us to test head weight, center of gravity and moment of inertia through the use of subjective testing.
Table 8: Mass tuning putter specifications.

<table>
<thead>
<tr>
<th>Material</th>
<th>Aluminum head, Brass weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>190g, 300g, 430g, 600g</td>
</tr>
<tr>
<td>Lie</td>
<td>20°</td>
</tr>
<tr>
<td>Loft</td>
<td>0°</td>
</tr>
</tbody>
</table>

The mass tuning putter remained largely the same as before, but a few small changes were made. The multiple shafting locations were not used. Also the polymer rails were swapped for steel bolts because the polymer would yield under load.

Figure 22: Mass Tuning Putter.
Chapter 5: Design Verification

With the change in our design focus, our testing procedure had to modified to better suit testing the different putter faces. The overall testing process remained similar but there were modifications made to accommodate different testing criteria and to accommodate for the limitations of the putting machine.

Machine Testing

![Putting machine testing apparatus.](image)

The machine testing procedure remained relatively the same throughout the testing. The machine was utilized indoors on a carpeted surface. We felt this was a similar enough surface to a putting green to produce useful data. The amount of locations on the clubface was reduced from five to three. One location was directly on the center of the face insert with the other locations being offset by 0.5” towards the heel and toe of the face insert. 10 putts were performed at 6ft and 13ft. The 20ft distance was omitted from the machine testing because the machine proved to be too unreliable when having to swing at the speed required. After every putt, the ball was removed and marked using a piece of tape.

Procedure:

- Set up the putting machine to an average posture and height.
- Find the needed swing speed using the control face insert for the desired distance.
- Replace the ball after each putt, marking the location with a piece of tape.
- After 10 putts have been performed, take a picture of the tape markings and remove the tape.
- Repeat for each face location, distance and face insert keeping the swing speed constant between putters.
Matlab was used to compile and analyze the data.

On Course Testing
The on course technical testing procedure remained very similar to the preliminary testing. After beginning the tests, it became apparent that it would take considerably more time to complete the testing than anticipated and the results were more indicative of the individual golfer’s skill than the forgiveness of the putter design. To compensate for this, we increased the number of putts we performed to ensure we had enough data and to reduce the learning curve of adjusting to a new putter.

Procedure:
- Set up a marker at the desired distance
- Clear the ball after every putt and mark the location with a piece of tape. Indicate if the putt was made or not.
- After 10 putts have been performed, take a picture of the tape markings and remove the tape.
- Each person performs the test for a single putter before proceeding through each putter.
- Repeat for each distance.

Interview
The core essence of the subjective testing remained the same but the scope of the testing changed. Since we no longer were performing the in-depth, controlled human testing, we focused more on the on-course testing. We also transitioned the focus from aesthetics to putter feel.

Procedure:
- The subject is given the option of using any putter. They will rotate through each putter, performing as many putts as they feel comfortable with.
- While the putting test is being run, a team member with a notebook will be recording putter-golfer interactions.
- Once golfer has finished the test, they will be summoned by a group member.
- The group member will conduct a short interview (2-3 minutes) to complete Survey B
- After the interview, the test is complete and the participant will be released.

Mass Tuning
In order to decide on a weighting scheme for the final putter, the Test putter was used. The following test were used to tune the mass properties of the putter and were conducted by the Gingham Golf team. All of the mass property tuning used the Test Putter, and recorded in the Mass Tuning Form in Appendix C. The procedure will be as follows:

Total Mass Tuning
- The test putter will have the weighted shafts located on the center of mass holes.
• The test masses will be located centrally on the weighted shafts.
• The putter will be configured to low mass (~300g)
• Each golfer will putt at least 3 times or until they feel they have reached an opinion on the weighting scheme
• This will be repeated for medium mass (~450g) and high-mass (~600g) configurations.
• On the Mass Tuning Form, Part A, the mass configurations will be ranked by the golfer.
• The most favorable mass will be used in further testing.

Vertical COG Tuning
• The tuned mass amount will be located centrally on the weighting shafts
• The weighting shafts will be located in the lowest holes.
• Each golfer will putt around 3 times or until they feel they have reached an opinion on the weighting scheme.
• Shafts will be moved upward and the process will be repeated until all five holes have been tested
• On the Mass Tuning Form, Part B, the mass configurations will be ranked by the golfer.
• The most favorable mass location will be used for further testing.

Horizontal COG Tuning
• The tuned mass amount will be located at the height selected in the results of the previous test.
• The tuned weights will be located at 1, near the putter face.
• Each golfer will putt around 3 times or until they feel they have reached an opinion on the weighting scheme.
• Shafts will be moved outward and the process will be repeated until all three locations have been tested.
• On the Mass Tuning Form, Part C, the mass configurations will be ranked by the golfer.

Once all tests have finished, the golfers will rank in the effectiveness of each degree-of-freedom in Part D of the form.

Our final putter will likely be designed to carry the mass properties of the most favored mass configurations. Outside input from the other putter tests and golfers will be considered in conjunction with the data collected in the Mass Properties Tuning tests.

A checklist for the testing procedure can be found in the Design Verification Planning Report (Appendix E).

Once the raw data was collected, the subjective information was compiled and shot charts were created using the images of putt distributions. A Matlab program, Appendix I, converted the imaged to numerical data and produced both statistics and shot charts (Appendix H). In order to do this, each image was manually marked in Photoshop with dots of known RGB values. The putts were marked in blue (RGB: [0 0 255]), the hole was marked in green ([0 255 0]) and the
scale was marked in red ([255 0 0]). From there a series of filters were run which picked out the dots of only these RGB values. Additionally, a cleanup was done by removing pixel in small groups. The process images looked like Figure 24, below:

![Figure 24: Processed image used to locate critical data points for shot charts.](image)

Once the image was filtered to a binary (black and white), Matlab is able to locate distinct objects. Each dot was located by finding the pixel coordinates of its centroid (easily found using a built-in function). The scale, marked using red dots, converted the pixel locations to inch locations. Once each location in inches was determined, the Matlab program used the location of the hole, marked in green, to tare the data relative to the target. From there, simple average distances were calculated and shot charts were created using a sale intended to visually expose trends. A flow chart representing the process can be seen in Figure 25. Every shot chart can be seen in Appendix H.
After compiling and analyzing the data, we confirmed some of our suspicions about the on course testing. It was useful to find some subjective information, but did not yield anything useful from the shot charts. The data depended much more on the skill of the user and the conditions, than the putters themselves. This can be seen in the following shot charts from the on course data (Figure 26). None of the charts revealed a significant trend in the accuracy of putts.

![Figure 25: Matlab process used to create shot charts.](image)

![Figure 26 On-Course shot charts from copper face insert. Other materials also showed no significant trends in their data (Appendix H).](image)

However, comments on feel, design and perceived performance were useful in determining the properties and aesthetic of the final design. Although the opinions were rather diverse, there were a few useful trends. The copper and aluminum putters were routinely rated similarly and
highly. For the most part, a putter that is similar to the convention is nice to use since the golfer does not need to radically adapt their technique to compensate for the design. The bamboo and, in particular, the foam putter were polarizing. The unfamiliar feels were either loved for being unique, or hated for the same reason. The D3O foam is the particularly interesting case here. Universally, the feel was unfavorable, but the performance was mixed. Generally, the foam was forgivable, allowing even inexperienced golfers to putt well, but lacked the precision feel the better golfers desire to control their putts. Despite the good performance, only one golfer (among the least experienced we tested) felt it was a favorite. As expected, good “feel” and “weight” was desired across the board. Below are a few selected quotes from the golfers tested (Full list is available in Appendix G):

- “Uninspiring sound, putts well short but not long” (Foam)
- “It’s [Putting] is a mental thing”
- “Poppy” (Bamboo)
- “Weird, but I like it” (Foam)
- “Normal” (Copper and Aluminum)
- “Function over form [is preferred]”

Additionally, regardless of mallet style, most golfers said they preferred a minimalist design, centered around alignment tools. One rather self-aware golfer said he only cared about the price and name. He said he liked an expensive putter from a well respected brand. He said that as long as the putter was in the realm of “normal” in design, the social benefits of the model directly correlated to perceived performance. The main take away from this testing was, in the realm of normal design, marketing, aesthetics and “placebo effects” are main forces at work. Also, most golfers would rather have a club that they feel comfortable approaching, rather than a radical design that could throw-off their finely-tuned feel.

The results of machine testing indicated clearer trends than the on course testing. For all the putters, there was a clear grouping for the heel, center and toe shots. The control putter shows this trend clearly.
These results are what we would expect. When the ball is not struck at the ideal point on the putter face, the ball does not travel as far and deflects to the left for heel hits and to the right for toe hits. The machine testing showed that the foam putter face performed the best in terms of forgiveness. The grouping was the tightest of any of the putters with little difference between a heel, center and toe hit. This can be seen below in Figure 28.

The bamboo and copper putters did not show significant improvement over the control. While the distributions are slightly different, the overall spread of the puts indicates similar performance at both 6ft and 13ft.
The mass tuning putter data led to a clear set of mass properties. Each player preferred the lowest vertical mass location possible, which was 0.38" below the center of the club head. They also preferred the mass closer to the face of the putter rather than extended out behind the face. Finally, an overall mass was determined to be on the higher end of the range between 300g and 430g. As the mass tuning was a highly subjective test, it's possible that the preferred weighting scheme was influenced by players being used to “normal” clubs, thus preferring similar mass properties to what is currently on the market.

Safety Considerations

There were two main areas that required special safety considerations, the machining process and the machine testing. For the machining process, it was important to follow all the safety rules and regulations of the machine shops. It was also important to machine a putter head that was safe to use. A putter head that did not have significantly sharp edge, sharp corners, or any feature that could injure a golfer or damage their equipment when used normally. For the testing portion, there are significant safety risks when operating the putting machine. Users should be wary of pinch points and sharp edges especially when transporting the machine. Only one person should operate the machine to reduce the chance of unknowingly injuring someone due to the swinging arm. All users should be aware when someone is performing a test to reduce the chance of injury.
Chapter 6: Final Design

Using the results from the mass tuning test our final design featured a high moment of inertia and a medium weight. The design was focused on simplicity in order to create a focus on alignment and functionality. The putter featured a cavity back design in order to create the desired high moment of inertia property. A high MOI as mentioned earlier allows the club head to rotate less throughout the swing and impact, lending to more accuracy and increased forgiveness. The club also featured a single bend shaft, which people unanimously preferred to a straight shaft input at an angle, with zero shaft offset. The material used was stainless steel, chosen for its high density in order to achieve the desired weight.

Table 9: Final Putter Specifications.

<table>
<thead>
<tr>
<th>Material</th>
<th>Stainless Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>384g</td>
</tr>
<tr>
<td>Lie</td>
<td>20°</td>
</tr>
<tr>
<td>Loft</td>
<td>0°</td>
</tr>
</tbody>
</table>

This final putter differs immensely from our previous designs in one major area, manufacturing. While previously we had relied on CNC Milling to make the putters, this putter was made with stainless steel additive manufacturing. This technology has the potential to be the future of the golf industry, and as the original project goal centered around innovation it seemed fitting to use this manufacturing method in our final design.

Figure 30: Final Putter Rendering
The final putter was brought to the senior project expo, where it was subjected to testing by a number of people attending the expo. Throughout the day the putter received positive remarks in regards to feel, aesthetics, and performance. These remarks came from people who had never played to avid golfers, and was pleasant to see it was so well received over such a broad audience.

A final cost estimate was done below. Our actual costs are compared with what we would expect based off our research to be the manufacturing cost for the putter.

<table>
<thead>
<tr>
<th>Part</th>
<th>Our Cost</th>
<th>Estimated Manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additive Manufactured Steel Head</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Shaft</td>
<td>$ 12.99</td>
<td>$ 1.86</td>
</tr>
<tr>
<td>Grip</td>
<td>$ 24.99</td>
<td>$ 3.57</td>
</tr>
<tr>
<td>Epoxy &amp; Adhesive</td>
<td>$ 15.99</td>
<td>$ 0.27</td>
</tr>
<tr>
<td>Total</td>
<td>$ 53.97</td>
<td>$ 5.69</td>
</tr>
</tbody>
</table>

The primary differences in our cost compared to the estimated cost is we were not able to purchase our supplies at wholesale prices and in bulk which increased our cost. The epoxy used to attach the shaft to the putter head and the adhesive used to attach the grip to the shaft cost less for a full production run because the epoxy and adhesive can be used for more than just the one putter we used it for.
One significant unknown in our cost estimate is the cost to manufacture using additive steel manufacturing. For our production, Mechanical Engineering graduate students used the SLM printer donated by Lawrence Livermore National Laboratory to print our putter head for free. At this time, this machine costs approximately $500,000. This is currently a prohibitively expensive purchase for a much slower manufacturing time than traditional milling or casting methods. It took approximately 6 hours to produce the putter head and that did not include the time it took to do clean up machining or assemble the putter. At this time, the production time is too long to be an efficient and cost effective way of manufacturing putter heads.
Chapter 7: Conclusion

Initially, we set out to create a putter that was both innovative and forgivable in design. To do this, we intended to test every aspect of putter design to determine what was actually important. Those important factors were then to be melded with an aesthetic ideal to produce our final design. Our project was going to be a project that focused heavily on design. Quickly, we realized the broadness of our approach required much more testing than we were capable of doing. Three independent designs were created and a competition would determine the properties of our final design. As we were creating our designs, it became apparent that the prototypes did not effectively isolate the specific characteristics that we were trying to test. So, keeping our mass properties testing, we pivoted to test the effect of face inserts. This was a focused aspect of design that would hopefully produce tangible results while still allowing for innovation and creativity. We aimed to pick materials from the traditional to the unconventional. This landed us at aluminum, copper, bamboo and foam.

Our testing revealed an interesting contradiction. Based on the technical testing, both machine and on-course, the foam performed the best. But the results of the subjective tests, showed that a majority of golfers had very strong negative feelings for the putter irrespective of their performance with it. This illustrated the very idea that what we are trying to combat. The inertia of what is normal in the golf industry hampered an apparent innovation. What we did learn was that innovation is possible, but it must happen slowly and naturally. Our most innovative ideas were reigned in by regulation or hampered by the tightly held preferences of the user, thus making it difficult to break through.

In future, we could see our face insert testing applied in two ways. First, bamboo had nice feel, but required treatment to be durable. Second, to harness the forgiveness of the foam, but sustain the feel of a metal putter, we believe applying a very thin layer of foam to the face of a metal putter would be much more successful. This could either be innate to the design or applied by adhesive to any putter.

Our lack of conclusion led to the ultimate take-away from this project. As long as it has a flat face and can project a ball, a good golfer can learn to put with just about anything. What really makes an amateur golfer enjoy their putter are the intangibles. One of the most important qualities is how the putter feels to them, which is something inherently impossible to quantify effectively. Golfers have an ingrained sense of what feels good to them, and that generally means something that is normal, not deviating from industry standards significantly. Business aspects of the golf industry, such as the brand, pricing and marketing also held a great impact on perceived putter quality which is something completely outside the scope of our project. Ultimately we built a putter that felt ‘best’ to us, which meant normal. Its design is simple, and aesthetically clean, but there is not much innovative about the actual putter. What is innovative is the manufacturing process and how we chose to present it. By using the cutting edge steel additive manufacturing process, we fabricated an innovative feel. In addition, the bespoke nature of a printed-putter fostered the feeling of exclusivity, a highly sought after reputation in the golf industry and central to the Kronos spirit.

The final design was universally enjoyed. Everyone from first-timers to experienced golfers hailed its design and feel. Everybody was making putts and enjoying their experience, which is all we could ever have asked for. To improve upon our final design, we would like to see the thin foam or bamboo face insert applied to the final design. We feel this would maintain the positive
aspects of our final design and add the innovation that we developed from our testing, while still being palatable to the everyday golfer.
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   http://www.golf.com/equipment/golf-equipment-innovations-golf-technology-timeline

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USGA - United States Golf Association, Accessed February 5th 2017
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   http://www.golf.com/equipment/golf-equipment-innovations-golf-technology-timeline

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Golf Digest, February 7th 2016
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“Putter Test 2015” Today’s Golfer, August 17th 2015
   http://www.todaysgolfer.co.uk/equipment/equipment-features/the-tests-2015/putters-test-2015/

“What you need to know now that the anchoring ban has finally arrived”
Golf Digest, January 1st 2016
   http://www.golfdigest.com/story/what-you-need-to-know-now-that-the-anchoring-ban-has-finally-arrived

Competitor Quotes

Scotty Cameron- Futura Line: http://www.scottycameron.com/putters/futura/
Evnroll- https://evnroll.com/technology/
TaylorMade- SpiderTour: http://taylormadegolf.com/taylormade-putters-spider/
Appendix B – Drawing Packet
NOTES:
1. BREAK ALL SHARP EDGES
2. ALL FILLETS R0.10
3. MATERIAL: ALUMINUM 6061
NOTES:
1. BREAK ALL SHARP EDGES
2. ALL INTERNAL EDGES ARE FILLETS R0.125
3. ALL EXTERNAL EDGES ARE CHAMTERS R0.5X45°
4. MATERIAL: ALUMINUM 6061

45° CHAMFER

PART # | PART NAME | DESCRIPTION | QTY.
--- | --- | --- | ---
7 | DATA PUTTER HEAD | MATERIAL: ALUMINUM | 1
5 | KRONOS SHAFT | .375 DIAMETER | 1
6 | KRONOS GRIP | COFFEE, SLIM | 1

Cal Poly Mechanical Engineering
ME 429 - SPRING 2017

Lab Section 01
Title: DATA PUTTER CDR
Drawn By: JOEY GAVIN
Date: 5/4/17
Scale: 1:1
CIRCS. By: ERIC HANAMAN
NOTES:
1. BREAK ALL SHARP EDGES
2. REAR HOLES FILLED WITH LEAD
3. MATERIAL: ALUMINUM 6061
4. FRONT SLOT FILLED WITH INSERTS
   1. ALUMINUM (NO SLOT)
   2. D30 FOAM
   3. BAMBOO
   4. COPPER
5. SLOT DEPTH DEPENDENT ON MATERIAL
NOTES:
1. BREAK ALL SHARP EDGES
2. ALL FILLETS R0.01
3. MATERIAL: STAINLESS STEEL
4. MASS: 385g
5. MANUFACTURED USING ADDITIVE MANUFACTURING. ONLY CRITICAL DIMENSIONS ARE SHOWN
### Appendix C – Testing Forms and Data Sheets

<table>
<thead>
<tr>
<th>Golfer:</th>
<th></th>
<th></th>
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<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Putt #</td>
<td>Distance to Hole (ft)</td>
<td>X Offset (ft)</td>
<td>Y Offset (ft)</td>
<td>Absolute Distance</td>
<td>Angle from Hole</td>
<td>Angle from Impact</td>
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### Interview Form A

<table>
<thead>
<tr>
<th>HiCOG</th>
<th>Data</th>
<th>Test</th>
<th>Control</th>
<th>Test Order</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>This paper is...</th>
<th>Very</th>
<th>Somewhat</th>
<th>Not really</th>
<th>Not at all</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggressive</td>
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<td></td>
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<td>Pretty</td>
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</tr>
<tr>
<td>High Quality</td>
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</tr>
<tr>
<td>Silly</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Forgivable</td>
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</tr>
<tr>
<td>Accurate</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Precise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Describe Feel

Describe Design

Likely to buy?

| 1 | 2 | 3 | 4 | 5 | 6 |

Likely to use?

| 1 | 2 | 3 | 4 | 5 | 6 |
## Interview Form B

**Favorite Putter (Circle):**

<table>
<thead>
<tr>
<th>Data</th>
<th>HiCOG</th>
<th>Test</th>
<th>Control</th>
</tr>
</thead>
</table>

Explain why this putter was the favorite.

What do you want in a putter in terms of performance?

What do you want in a putter in terms of aesthetics?

Additional Notes:
Mass Tuning Form

Part A - Total Mass Tuning - Rank total mass

<table>
<thead>
<tr>
<th>Low - 300g</th>
<th>Med - 450g</th>
<th>High - 600g</th>
</tr>
</thead>
</table>

Part B - Vertical COG Tuning - Rank weight locations

<table>
<thead>
<tr>
<th>Height 1</th>
<th>Height 2 - COG</th>
<th>Height 3</th>
<th>Height 4</th>
<th>Height 5</th>
</tr>
</thead>
</table>

Part C - Horizontal COG Tuning - Rank weight locations

<table>
<thead>
<tr>
<th>Near (1)</th>
<th>Med (2)</th>
<th>Far (3)</th>
</tr>
</thead>
</table>

Part D - Tuning Effectiveness - Rank perceived impact on putt performance

<table>
<thead>
<tr>
<th>Total Mass</th>
<th>Vertical Location</th>
<th>Horizontal Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Name</td>
<td>Start</td>
<td>End</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Research</td>
<td>1/22/17</td>
<td>3/12/17</td>
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<tr>
<td>Define Problem</td>
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<td>2/7/17</td>
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<td>Brainstorm</td>
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<td>4/2/17</td>
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<tr>
<td>Individual Designs</td>
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<td>5/3/17</td>
</tr>
<tr>
<td>Fabrication</td>
<td>4/2/17</td>
<td>5/18/17</td>
</tr>
<tr>
<td>Testing</td>
<td>5/8/17</td>
<td>6/2/17</td>
</tr>
<tr>
<td>Final Group Design</td>
<td>10/20/17</td>
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<tr>
<td>Fabrication 2</td>
<td>11/6/17</td>
<td></td>
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<td>Testing 2</td>
<td>12/10/17</td>
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<td>Report</td>
<td>12/12/17</td>
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<tr>
<td>Test Plan</td>
<td>Test Report</td>
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</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
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</tr>
<tr>
<td>Item No.</td>
<td>Specification or Event Reference</td>
<td>Test Description</td>
</tr>
<tr>
<td>1</td>
<td>Forgiveness-Machine</td>
<td>Very impact location on the quality of the score. Goal is to test the</td>
</tr>
<tr>
<td>2</td>
<td>Repeatability-Outdoor</td>
<td>Similar to previous test but in a more controlled environment, more pulls, less</td>
</tr>
<tr>
<td>3</td>
<td>Repeatability-Indoor</td>
<td>Similar to previous test but in a more</td>
</tr>
<tr>
<td>4</td>
<td>User Experience</td>
<td>Quality of questions and observations used to analyze test and subjective responses to designs.</td>
</tr>
<tr>
<td>5</td>
<td>Mass Properties Tuning</td>
<td>Test pulling first under various weighting schemes to optimize, CCG location, MOI and mass.</td>
</tr>
<tr>
<td>6</td>
<td></td>
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</tbody>
</table>
## Appendix F - FMEA

### Design Failure Mode and Effects Analysis

<table>
<thead>
<tr>
<th>Item / Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>Potential Cause(s) / Mechanism(s) of Failure</th>
<th>Action Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puller</td>
<td>Club head becoming separated from shaft</td>
<td>Impact (D0)</td>
<td>Defect (D0) Design and manufacture to USGA specification.</td>
<td>joy, 5/8/2017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Course (D0)</td>
<td>Design and manufacture to USGA specification.</td>
<td>joy, 5/8/2017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disqualification (D0)</td>
<td>Design and manufacture to USGA specification.</td>
<td>joy, 5/8/2017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equipment damage (D0)</td>
<td>Design and manufacture to USGA specification.</td>
<td>joy, 5/8/2017</td>
</tr>
</tbody>
</table>

### Notes

- **Date:**
- **Prepared by:**
- **Responsibility & Target Completion Date:**
- **Revision Date:** 5/8/2017
Appendix G – Course Data Input

<table>
<thead>
<tr>
<th>Aluminum</th>
<th>Copper</th>
<th>Bamboo</th>
<th>Foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Comments on Aluminum Putter
- Favorite for long putts
- Lots of power
- Standard
- Nice and normal

Comments on Copper Putter
- Felt solid
- Overall the best
- Normal
- Felt nice
- More power than Aluminum

Comments on Bamboo Putter
- Weird
- “Poppy”
- Good feel
- Nice, but soft
- Need to hit hard
- Liked immediately
- Smooth

Comments on Foam Putter
- Weird
- Favorite for short putts
- Uninspiring sound, putts well short but not long
- “What the f*** is this thing?”
- Weird but I like it
- Interesting
- Always went the right distance
- Always went straight
- Nice
- Alright sound

What do you want in a putter?
- Simple design
Appendix H – Matlab Plots

On Course Test – Bamboo – 6ft

plot-b6
X average: 0.45673
Y average: -0.6741
D average: 8.6504

On Course Test – Bamboo – 13ft

plot-b13
X average: -2.2364
Y average: 2.0407
D average: 14.32
On Course Test – Foam – 6ft

plot-6
X average: -0.048791
Y average: 5.068
D average: 5.2813

On Course Test – Foam – 13ft

plot-13
X average: -3.0827
Y average: -8.1314
D average: 17.1255
On Course Test – Copper – 6ft

plot-cu6
X average: 0.35747
Y average: -2.1011
D average: 3.6543

On Course Test – Copper – 13ft

plot-cu13
X average: -6.7668
Y average: 3.8807
D average: 29.0298
On Course Test – Odyssey – 6ft

plot-o6
X average: -1.42
Y average: 1.2512
D average: 3.4529

On Course Test – Odyssey – 13ft

plot-o13
X average: -1.989
Y average: -0.48181
D average: 15.773
Machine Test – Bamboo – 6ft

plot-rb6
X average: 10.543
Y average: 4.8094
D average: 11.9064

Machine Test – Bamboo – 13ft

plot-rb13
X average: 11.4212
Y average: 6.8049
D average: 14.9733
Machine Test – Control – 6ft

plot-rc6
X average: 6.7853
Y average: -9.8469
D average: 23.3118

Machine Test – Control – 13ft

plot-rc13
X average: 4.4958
Y average: -22.5542
D average: 23.3681
Machine Test – Foam – 6ft

plot: rf6
X average: 5.7643
Y average: -12.5322
D average: 14.0464

Machine Test – Foam – 13ft

plot: rf13
X average: -0.19173
Y average: -54.9804
D average: 5.4949
Machine Test – Copper – 6ft

plot-rcu6
X average: 10.0082
Y average: 3.7144
D average: 16.942

Machine Test – Copper – 13ft

plot-rcu13
X average: -1.8408
Y average: -2.9954
D average: 7.0756
Main Code Block

```matlab
clc
clear all

% Input Images
input = ["robot", "bartlett", "gavin", "hanaman"];
material = ["odyssey", "control", "foam", "bamboo", "copper"];
distance = ["6", "13"];

% a = strcat(input(2),material(2),distance(1),'.jpg')
% b = imread(char(a));
% imshow(b)

m = 1;
d = 1;
for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.o6(:,:,i) = GatherPoints(char(a),6,0);
end
d = d+1;
for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.o13(:,:,i) = GatherPoints(char(a),6,0);
end
d = d-1;
m = m+1;
for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.c6(:,:,i) = GatherPoints(char(a),6,0);
end
d = d+1;
for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.c13(:,:,i) = GatherPoints(char(a),6,0);
end
d = d-1;
m = m+1;
for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.f6(:,:,i) = GatherPoints(char(a),6,0);
end
d = d+1;
```

Appendix I – Matlab Code
for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.f13(:,:,i) = GatherPoints(char(a),6,0);
end

d = d-1;
m=m+1;

for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.b6(:,:,i) = GatherPoints(char(a),6,0);
end

d = d+1;

for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.b13(:,:,i) = GatherPoints(char(a),6,0);
end

d = d-1;
m=m+1;

for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.cu6(:,:,i) = GatherPoints(char(a),6,0);
end

d = d+1;

for i = 1:3
    a = strcat(input(i+1),material(m),distance(d),'.jpg');
    data.cu13(:,:,i) = GatherPoints(char(a),6,0);
end

Function that locates putts from image.

function [locs] = locate(color,image)

    % 1,2,3 = r,g,b
    % Read the image file
    myPhoto = imread(image);
    
    % Convert Grayscale
    myBWPhoto = rgb2gray(myPhoto);
    
    % Compare Colors
    myColor = imsubtract(myPhoto(:,:,color),myBWPhoto);
    
    % Filter the image
myFilt = medfilt2(myColor, [3 3]);

% Calculate a threshold
thres = 0.3; % or 0.25

% Create a binary range
myBinary = im2bw(myFilt, thres);

% Remove Small Objects
myObjects = bwareaopen(myBinary, 100);

% Find the objects
labels = bwlabel(myObjects, 8);
stats = regionprops(labels, 'BoundingBox', 'Centroid');

for i = 1:length(stats)
    locs(:,i) = stats(i).Centroid;
end

% Plotting Function

% Specify Graph
clear all
load('coursedata.mat')
load('RobotData.mat')

p = data.o13;
name = 'plot-o13';

hold on
figure(1)

%plot(0,0, 'go', 'LineWidth', 2, 'MarkerSize', 13);
k = 1;
h = 0;

for i = 1:10
    j = 1;
    if i < 10
        plot(p(1,i,j), p(2,i,j), 'bo', 'LineWidth', 2, 'MarkerSize', 13);
        d(k) = p(3,i,j);
        x(k) = p(1,i,j);
        y(k) = p(2,i,j);
        k = k + 1;
    end
end
end
j = 2;
plot(p(1,i,j), p(2,i,j), 'ro', 'LineWidth', 2, 'MarkerSize', 5);
d(k) = p(3,i,j);
x(k) = p(1,i,j);
y(k) = p(2,i,j);
j = 3;
plot(p(1,i,j), p(2,i,j), 'go', 'LineWidth', 2, 'MarkerSize', 5);
d(k) = p(3,i,j);
x(k) = p(1,i,j);
y(k) = p(2,i,j);
k = k+1;
end

xave = mean(x);
yave = mean(y);
dave = mean(d);

text(-40,34,strcat('X average: ',num2str(xave)))
text(-40,31,strcat('Y average: ',num2str(yave)))
text(-40,28,strcat('D average: ',num2str(dave)))

axis([-40 40 -40 40])
%axis equal
legend('Alex', 'Joey', 'Eric')
text(-40,38,name)

ax = gca;
ax.XAxisLocation = 'origin';
ax.YAxisLocation = 'origin';

hold off

saveas(figure(1),name,'jpeg')

close all

Function to tare data.

function [a] = dist(putt,hole,scale)
a = (putt(1)-hole(1))*scale;
b = (putt(2)-hole(2))*scale;
c = sqrt(a^2 + b^2);
end

Function that switches color targets and collects numerical data.

function [ ans ] = GatherPoints(img,a,mod)
hole = locate(2,img);

%Locate Putts
putt = locate(3, img);

% Locate Scale

scale = locate(1, img);
px2in = a/sqrt((scale(1,1) - scale(1,2))^2 + (scale(2,1) - scale(2,2))^2);

ans = zeros(3, 10);
len = length(putt(1,:));

for i = 1:len
    ans(:,i) = dist(putt(:,i), hole, px2in);
    if mod ~= 0;
        ans(2,i) = ans(2,i) - mod;
    end
end
# Appendix J – Putter Weight Data

## Total Weight Rankings

<table>
<thead>
<tr>
<th></th>
<th>300g</th>
<th>430g</th>
<th>600g</th>
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<tbody>
<tr>
<td>Alex</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Joey</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Eric</td>
<td>2</td>
<td>1</td>
<td>3</td>
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</tbody>
</table>

## Vertical Mass Location (Relative to unweighted COG) Rankings

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<tr>
<th></th>
<th>-0.38”</th>
<th>0.00”</th>
<th>0.38”</th>
<th>0.75”</th>
<th>1.13”</th>
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</thead>
<tbody>
<tr>
<td>Alex</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Eric</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Joey</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>5</td>
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</table>

## Horizontal Mass Location (Relative to face) Rankings

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<th>Near</th>
<th>Mid</th>
<th>Far</th>
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<tbody>
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<td>2</td>
</tr>
<tr>
<td>Joey</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Eric</td>
<td>1</td>
<td>2</td>
<td>3</td>
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</table>