Incorporating Technology into Custom Golf Club Fitting
by
Andrew Mauger
Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of
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Abstract

There are currently many different products available for measuring the various
dynamic properties associated with a golfer’s swing. Custom golf club fitters utilize such
products for gaining information by which to properly build a golf club that is custom fit
to a golfer’s unique swing. Each of these products provides the custom fitter with
different pieces of information pertaining to the golfer’s swing, and they range in price
from $100 to in excess of $20,000. Ultimately, the custom fitters need to determine
which of these products will provide them with the best information for the best price so
that they may effectively provide golfers with a custom fit set of golf clubs.

The products currently available for custom fitters were investigated and fitters
were interviewed, then surveyed, to understand their methodology followed during a
custom fitting session and what their consumer needs were with respect to these dynamic
measurement products. The surveys led to the defining and ranking of key dynamic
measurements and product attributes that the fitters required from these products.
Additionally, the fitters were asked to provide information about the systems that they
currently used. Specifically, what measurements the product provided and a ranking of
its product attributes.

The results of the survey were compiled so that rankings of dynamic
measurements and product attributes were utilized as direct inputs into a customized QFD
Matrix. The ranking of specific products were then inputted into this QFD Matrix so that
these products could be directly compared by their resulting rankings. These rankings
were plotted versus their costs to reveal a competitive map of these products.

Finally, some technologies that have yet to be incorporated into the custom fitting
industry were examined to determine their feasibility within this market. The author
hypothesized the measurements and product attributes of these potential products in order
to compare them to the existing products. It was determined that motion analysis
systems, currently utilized for biomechanical analysis, and Artificial Intelligence
Programming, specifically Expert Systems, have the potential to become competitive
products within this industry.

Thesis Advisor: Kim B. Blair
Title: Director, Center for Sports Innovation
Thank You, Laura, for helping me through the last 2 years.
I Love You.
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1 Introduction

Since the recent appearance of Tiger Woods on the Professional Golf Association (PGA) Tour towards the end of 1996, the game of golf has become one of the fastest growing sports in the world. This is seen by the drastic increase in the number of golfers. Prior to 1997, the average number was 2 million new golfers per year. The National Golf Foundation (NGF) estimates that since 1997 an average of 3 million people have taken up the game annually, with 3.2 million starting to play in 1999\(^1\). Golf course construction has risen from 150 new courses per year 15 years ago to over 400 built in the year 2000. More impressively, since 1986 golfers have tripled their annual spending on equipment and fees from $7.8 to $22.2 billion\(^2\).

One important aspect of golf has remained unchanged, the desire for golfers to lower their score. For many years, golfers have sought the insight and wisdom of professional golf instructors, who point out flaws in a golfer's swing and attempt to 'coach' them to a better swing and thus lower their score. This approach to a better golf game, however, is now proving to not be entirely effective unless the golfer is using the right set of golf clubs for his or her swing. This relatively new idea is stemming from a new method of lowering the golf score, which is custom golf club fitting.

Custom club fitting is not a perfected science, but rather more of an art form. Currently, if a golfer was to pursue the purchase of custom fit clubs, they could experience anything from a very simple process of merely filling out a brief questionnaire to spending hours on a practice range with a custom club fitter who interviews them and takes several measurements with various high-tech pieces of equipment while the golfer is hitting golf balls with multiple clubs. The equipment used by custom fitters are tools to assist them in determining dynamic measurements of the club and golf ball during the swing. These tools can be as simple as a radar device that measures the speed of the clubhead as it strikes a golf ball to an extremely complex system that utilizes multiple high-speed cameras to measure the golf ball's initial trajectory, speed and spin rate. Each of these fitting methods and equipment provide different pieces of information pertaining
to the golfer’s swing, but they all are intended to produce the same ultimate output. A golfer visits a custom fitter to receive a set of golf clubs that interface with their particular golf swing and result in the best ballistic characteristics of the golf ball.

The goal of this study was to determine which of these systems best meets the needs of the custom fitters, and to then determine better products for this industry. Before this could be accomplished, the design of the golf club and the dynamics associated with a golfer’s swing were reviewed in Chapter 2. Chapter 3 then provides an overview of the custom fitting process.

The technologies associated with these measurement systems used by custom club fitters had to be understood. This was accomplished by investigating the current products and the underlying technologies they utilize to obtain dynamic measurements. Information was obtained via thorough searches of product websites, patent databases, and discussions with custom fitters. No products were actually purchased for this study, thus no side-by-side comparisons occurred. This phase is reported in Chapter 4.

In Chapters 5 through 7, fitters and golfers were surveyed to learn more information about the stakeholders in the custom club fitting industry. Fitters were further surveyed to determine what dynamic measurements and product attributes they required when custom fitting. Fitters also rated several products that they used, which allowed for a competitive mapping of the products via the use of a customized QFD matrix. The product ranking not only identified the products which best met the identified needs of the fitters, but it revealed opportunities for improvement of the existing products.

Finally, in Chapter 8, new products were proposed with the intention of exploiting identified opportunities revealed through the competitive mapping of existing products. These new products consist of an existing product utilized in other sports applications, and a software technology inspired by the success of an existing software product utilized by custom fitters.
2 The Golf Swing and Club

Before the challenges faced by custom fitters can be discussed, a thorough understanding of the physics of a golfer’s swing and the design of the golf club are required.

2.1 The Golf Swing

The ultimate goal of the golfer during the swing is to have the golf ball leave the clubhead and fly a desired distance, which is typically as far as possible. The distance that the ball travels is dependent upon the initial trajectory angle, speed, and spin of the golf ball. The initial trajectory, or launch angle, is mostly dependent upon the loft of the clubhead at impact, which is the angle of the clubface from vertical. The clubhead speed is mostly generated by the acceleration of the golfer’s hands during the swing. Finally, the backspin of the golfball, which results in a lift force being exerted on the ball, is created by the golf ball being gripped by grooves present on the face of the clubhead during impact.

Figure 1: Address Position
The golf swing starts from the address position (Figure 1), where the golfer is crouching over the golfball, placing the clubhead directly behind the ball. The first part of the swing is called the backswing, which is initiated by the golfer accelerating their hands backwards and slowly rotating their body. This brings the club to the top of the swing (Figure 2) where the golfer transitions from moving their hands backwards to accelerating them towards the ball. Additionally, at the top of the swing, the golfer will begin un-rotating their shoulders and hips, which creates additional clubhead speed.

![Figure 2: Top of the Swing](image)

The downswing brings the clubhead back to the golf ball at the point of impact, where the clubhead is achieving maximum velocity. The faster the clubhead is traveling, the faster the ball will leave the clubface. The point of impact lasts 0.5 milliseconds and results in the golf ball being accelerated from rest to in excess of 125 mph\(^4\).

The backspin of the ball is created at impact. When the clubhead contacts the golf ball, the cover of the ball is compressed and starts to slide up the face of the club. The friction between the ball and the clubface transforms this sliding into a rolling motion, thus when the ball leaves the club, it is spinning\(^4\).
Following impact, the golfer continues this motion during the follow-through. The follow-through consists of the golfer slowly decelerating the club until it comes to rest at the finish, with is similar to the top of the swing.

Figure 3: Shaft Bending

Throughout a golfer’s swing, the motion of the clubhead leads to a bending of the golf shaft in multiple directions\(^5\). This bending can occur in the lead/lag or toe up/down directions (Figure 3), in addition to a twisting of the shaft occurring. Bending in the lead/lag direction, known as shaft deflection, can exceed 3 inches in a stiff shaft during the downswing. This bending causes the clubhead to lag behind the centerline of the shaft, and it transforms kinetic energy into potential energy. Later in the downswing, as the clubhead approaches the golf ball, this potential energy is released as the shaft straightens and actually leads the shaft centerline moments before impact. At impact, both the kinetic energy created from the golfer accelerating their hands towards the ball and the release of potential energy from the shaft are imparted to the golf ball. This flexing of the shaft will also affect the dynamic loft of the club, which is the angle the clubface makes with the vertical when the clubhead impacts the golf ball. The more the clubhead leads the shaft at impact, the more dynamic loft will be created, resulting in a higher launch angle for the golf ball.
The shaft not only plays an important role in the ball’s initial velocity and launch angle, but it also is important in determining the initial direction of the ball due to the flexing that occurs in the up and down direction of the shaft centerline, known as the toe up/down bending (Figure 3). This alters the angle the club makes with the ground during the swing, known as dynamic lie angle. When the clubhead strikes the ball while it is in a toe down position, the loft of the club will not be perpendicular with the ground, resulting in a shot starting right of the target line for a right-handed golfer.

For the ball to start out in the direction of the target, not only does the golfer’s swing path have to be square to the target line and the dynamic lie angle correct, but the clubhead must also be square to the target. Due to the center of gravity of the clubhead being outside the centerline of the shaft, the momentum of the clubhead during a golf swing will cause a twisting of the shaft, known as shaft torsion, to occur. During a golfer’s downswing, as the wrists are rotated, thus accelerating the clubhead, the torsion created in the shaft tends to cause the clubface to close, thus pointing to the left of the target line for a right-handed golfer. As impact is approached, however, the motion is reversed and the clubface opens as the ball is struck, hopefully to a square position. This motion is further complicated by the lead/lag flexing of the shaft also affecting the clubface angle. If the shaft does not respond properly, it could result in a golfer having a closed or open clubface at impact, which would result in an off-target shot.

Thus, it is seen that the golf club exhibits a very complex dynamic behavior during a swing. As there are a vast number of golfers, clubs can be designed to optimize their performance and match the player’s particular swing characteristics.

2.2 Golf Club Design

Golfers typically utilize 14 different golf clubs while playing a round of golf. All of these clubs are collectively referred to as a set of golf clubs. This set can be divided into the major categories of woods, irons, and the putter. Although quite different, each of these clubs consists of the same major components.
The golf club can be divided into three major components: the grip, the shaft, and the clubhead (Figure 1). The grip is the portion of the club that the golfer holds on to during the golf swing, serving as an interface between the golfer and the club. The grip is attached over the end of the shaft. The shaft is a hollow tube that slowly tapers from the grip to where it meets the clubhead. It connects the clubhead to the grip in such a way that the golfer is allowed to stand fairly upright while swinging the club. The clubhead is directly attached to the shaft, and it is what impacts the golf ball, thus imparting its kinetic energy. Table 1 summarizes just a few of the other design attributes that differentiate the three main components of the golf club, as well as attributes pertaining to the entire club.

Figure 4: The Golf Club
### Table 1: Golf Club Component Options

<table>
<thead>
<tr>
<th>Part of Club</th>
<th>Options</th>
</tr>
</thead>
</table>
| **Clubhead:** | Type - Traditional, Low Profile, Perimeter Weighted  
Hosel Offset - No Offset, Slight Offset, Extreme Offset  
Sole Angle - Square Sole, Bounce Sole, Dig Sole  
Sole Radius - Flat Sole, Cambered Sole  
Head Material - Stainless Steel, Aluminum, Graphite, Wood, Titanium  
Loft Angle - Varies by Club  
Face Angle - Open, Square, Closed |
| **Shaft:** | Length - Standard, +/- 1/2 to 2 inches  
Material - Steel, Graphite, Titanium  
Flex - Flexible, Regular, Stiff, Extra Stiff  
Flex Point - High, Mid, Low  
Weight - 2 1/2 oz. to 4 3/8 oz. |
| **Grip:** | Type - Rubber, Synthetic Slip-On, Synthetic Wrap-On, Leather  
Size - Standard, Oversize, Undersize  
Shape - Round, Ribbed  
Weight - 1.5 oz. to 2.5 oz. |
| **Overall Club:** | Lie Angle - Standard, +/- 1 to 6 degrees (Flat or Upright)  
Total Weight - 11 1/8 oz. to 13 3/4 oz.  
Swing Weight - Varies from C-3 to D-6 |

#### 2.2.1 Clubhead

The clubhead is the portion of the club that strikes the golf ball, which affects the flight path of the golf ball. It has numerous options available to a golfer, a few of which will be discussed.

A traditional clubhead has its center of gravity concentrated in the center of the clubface with respect to the clubhead toe and heel. An off-center hit will have less mass behind the golf ball, which results in lost distance. Better golfers typically use this type of club, however, due to the better feedback they receive from the club. Perimeter weighted clubs, on the other hand, have their weight distributed more towards the toe and heel of the clubhead. This causes off-center hits to travel roughly the same distance as a hit off of the center of the clubface.

The hosel is the part of the clubhead that connects to the shaft. Hosel offset refers to the distance from the forward most part of the hosel to the leading edge of the
clubface. If there is no offset, then the two are in line with each other. Slight offset refers to the leading edge of the clubface being set back by up to $\frac{1}{8}$ inches. By moving the clubface back on the club, it will make contact with the ball later in the golfer's swing. This leads to the clubface being more closed (pointed to the left of the target line for a right-handed golfer) at impact, which results in a lower launch angle. This can assist golfers who typically have their clubface open at impact.

Finally, within a set of golf clubs, the loft angle will vary from as low as 7 degrees for a driver to over 60 degrees for some lob wedges. This large variation in loft angle will result in different golf ball launch angles for each club. Since a golfer can only utilize 14 clubs during a round, they want to have the 14 loft angles that will most effectively allow them to navigate a particular golf course.

2.2.2 Shaft

The shaft is known as the 'engine' of the club. Its purpose is to transform the kinetic energy of the golfer's hands and body into clubhead speed. Additionally, it will store energy during the swing by flexing, which results in the generation of additional clubhead speed at the point of impact when the shaft straightens. At the end of the point of impact, however, the shaft needs to bring the clubhead back to a square target position to produce a desired shot. Some of the shaft options that will affect how it performs its function include the shaft flex, flex point, and weight.

Golf shafts vary in stiffness from flexible to extra stiff. The stiffness of the shaft will dictate how much the clubhead will bend throughout the entire swing. The stiffer a shaft, the greater the clubhead will lead the shaft, resulting in the clubface being more closed. Also, the clubhead being forward of the shaft creates dynamic loft, resulting in a higher launch angle. The opposite is true for flexible shafts. Golfers will choose the shafts that will give them the highest probability of having a square clubface at the point of impact.
The shaft flex point refers to where the primary bending of the shaft will occur. This varies from a low flex point, more towards the clubhead, to a high flex point. Shafts with the same stiffness, but different flex points, will result in different launch angles. A shaft with a lower flex point will bend will result in more dynamic loft and a higher ball trajectory. Higher flex points will lead to lower trajectories. Thus the shaft flex point provides golfers with the option to control how high they hit the ball.

Finally, there are many materials utilized for golf shafts, all of which have different weights. Steel is the most common shaft material and it is also typically the heaviest. A heavier shaft will require a lighter clubhead in order to maintain a given swing weight. Graphite and Titanium are lighter materials used in golf shafts that allow for the use of heavier clubheads. The heavier the clubhead, the more mass that a golfer can apply to the golf ball during the swing, resulting in further distance. Lighter shafts with heavier clubheads can result in more shaft twisting occurring at impact, so golfers much balance these tradeoffs.

2.2.3 Grip

The club grip has the sole function of allowing the golfer to maintain positive control of the golf club during the swing. There are numerous types of grips, but a set of clubs will typically all have the same style throughout. Golfers have a choice of many different attributes to choose from with respect to grips, including grip type, size, and shape.

Golfers have different preferences as to what type of grip they use on their golf clubs. They have a choice in the grip material and the method by which it attaches to the golf shaft. Since golf is played outdoors, the grip needs to be effective in a variety of temperatures, as well as in both wet and dry conditions. Additionally, a golfer desires a grip that is durable so it does not need to be replaced frequently. The materials include rubber, a synthetic material, and leather. The methods of attaching to the club are slip-on or wrap-on. These various grips will feel different to golfers, so they want to choose one that provides them the best club interface.
Since all golfers do not have the same sized hands, grips need to vary in size. Additionally, older golfers may suffer from arthritis, in which case softer and larger diameter grips may be more suitable.

Finally, golfers have the option of choosing the grip shape that provides them the best feel of the club. They can choose round or ribbed grips. Ribbed grips provide the golfer with a rib running the length of the grip opposite the clubhead side of the shaft in order to provide the golfer with a reference point. This provides feedback as to how the shaft is aligned with respect to their hands. Ribbed grips tend to be used more by novice golfers, while more experienced golfers prefer the round grips.

2.3 Golf Club Complexity

It is clear that the golf swing is a complex process. Additionally, the golf club consists of many components that may be altered to change how a club reacts throughout a swing. By matching the dynamics of an individual golfer’s swing with the appropriate club performance characteristics, the opportunity exists to configure a set of golf clubs that optimize the transfer of the clubhead kinetic energy to the golf ball, resulting in maximum distance and consistency. This is the reason many players opt for custom fit clubs.
3 Custom Club Fitting

The complexity of the golf swing led to the necessity of numerous variations in golf club components. With the increase in the variety of components has arisen the need for determining which components best match a particular golfer, thus leading to emergence of custom golf club fitting within the golf industry.

Improperly fitted clubs can result in a golfer playing below their optimum potential\(^7\). For example, a golfer settling for clubs that are too short will be forced to crouch more in their posture and result in them generating less clubhead speed during their swing, which equates to less distance. On the other hand, a golfer playing with clubs that are too long will compensate for this by gripping the club further down on the club grip. This results in the player gripping the club at a smaller diameter portion of the grip since the shafts are tapered.

**Table 2: Golfer Characteristic Effects on Club Parameters**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Typical Club Parameters Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Golfer:</strong></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>- Shaft Length, Lie Angle</td>
</tr>
<tr>
<td>Strength</td>
<td>- Total Weight, Swing Weight, Shaft Flex, Shaft Material</td>
</tr>
<tr>
<td><strong>Golfer's Swing:</strong></td>
<td></td>
</tr>
<tr>
<td>Trajectory</td>
<td>- Loft Angle, Lie Angle, Shaft Flex Point, Shaft Flex, Hosel Offset</td>
</tr>
<tr>
<td>Squareness of Hit</td>
<td>- Clubhead Face Angle, Lie Angle, Loft Angle, Shaft Flex, Shaft Length, Grip Size, Total Weight, Swing Weight</td>
</tr>
<tr>
<td>Swing Tempo</td>
<td>- Total Weight, Swing Weight, Shaft Stiffness, Shaft Material</td>
</tr>
<tr>
<td>Clubhead Speed</td>
<td>- Total Weight, Swing Weight, Shaft Stiffness, Shaft Material</td>
</tr>
</tbody>
</table>

Because all golfers are of a different body size and strength, there is no one club combination that is best for everyone. Further, golfers have varying degrees of athletic ability and flexibility. This results in a plethora of different swings. Some key differentiating items in both the golfer’s build and swing that affect these various club options are explained in Table 2 (note that this is far from an all-encompassing list). From this short list, it can be seen that several of these parameters are affected by more than one golfer attribute, and it can be logically concluded that changing one club parameter will affect other parameters.
Additional things to consider when fitting clubs are the different playing abilities and the resulting different expectations for the golf club that come with experience. For example, novice golfers tend to purchase clubs that are perimeter weighted to compensate for the erratic golf swings. The perimeter weighting results in more mass being behind the ball on off-center hits, resulting in little loss in distance. More experienced golfers have more repeatable swings, however, and tend to utilize clubs that have most of their weight in the center of the clubhead. This will provide the golfer with greater feedback when the golf ball is hit off-center. Taking all of this inter-dependence of club parameters combined with golfers having different abilities, expectations and goals, begins to depict the challenge that a club fitter faces when fitting a golfer.

3.1 Information Flow

The job of a custom club fitter, then, is to provide a golfer with the combination of club parameters that will allow the golfer the most effective use of his or her swing. Information about the golfer, in addition to many measurements, need to be obtained prior to a club fitter having the required data to make a decision as to what combination of club parameters to select. The golfer information relates to the golfer’s ability and playing habits, while the measurements can be broken down into static and dynamic measurements (Figure 5).
In order to obtain information about the golfer, a club fitter typically interviews their customer prior to beginning any fitting session. Table 3 gives a list of typically asked questions during a fitter interview. These questions give the fitter an overall insight as to the player's ability, expectations and goals, and it gives the fitter a general idea as to the type of swing the player possesses prior to seeing the golfer hit practice balls. This allows the fitter to focus on specific measurements that need to be obtained from the golfer.
Table 3: Typical Custom Fitter Interview Questions

<table>
<thead>
<tr>
<th>Typical Interview Questions</th>
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</thead>
<tbody>
<tr>
<td>Age?</td>
</tr>
<tr>
<td>Gender?</td>
</tr>
<tr>
<td>Right/Left Handed?</td>
</tr>
<tr>
<td>Golf Handicap (indicates playing ability)?</td>
</tr>
<tr>
<td>Golf Handicap Trend?</td>
</tr>
<tr>
<td>Years of Experience?</td>
</tr>
<tr>
<td>Rounds Played/Year?</td>
</tr>
<tr>
<td>Lessons?</td>
</tr>
<tr>
<td>Practice?</td>
</tr>
<tr>
<td>Hit Balls Before Playing?</td>
</tr>
<tr>
<td>How far do You Hit the Ball?</td>
</tr>
<tr>
<td>Kind of Clubs/Shafts Used Now?</td>
</tr>
<tr>
<td>Shaft Material Preference?</td>
</tr>
<tr>
<td>Favorite Club?</td>
</tr>
<tr>
<td>Confidence with Driver?</td>
</tr>
<tr>
<td>Poor Drive Tendency (hook/slice...)</td>
</tr>
<tr>
<td>Longest Iron Hit with Confidence?</td>
</tr>
<tr>
<td>Poor Iron Shot Tendency (hook/slice...)</td>
</tr>
<tr>
<td>Long-Mid Iron Green Approach Tendency?</td>
</tr>
<tr>
<td>Short Iron Green Approach Tendency?</td>
</tr>
<tr>
<td>Pain When You Swing?</td>
</tr>
<tr>
<td>Arthritis?</td>
</tr>
</tbody>
</table>

To further narrow down the focus of the fitter, static measurements (Table 4) are next obtained from the golfer. These static measurements relate to physical characteristics of the golfer’s body. These are self explanatory and easy to obtain, and the golfer provides several of them, so not much skill is required on behalf of the fitter.

Table 4: Example Static Measurements

<table>
<thead>
<tr>
<th>Example Static Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Glove Size</td>
</tr>
<tr>
<td>Standing: Distance from Longest Finger to Floor</td>
</tr>
<tr>
<td>5-Iron Address Position: Distance from Top of Club to Floor</td>
</tr>
<tr>
<td>Length of Middle Finger</td>
</tr>
<tr>
<td>Distance from Forefinger to Wrist</td>
</tr>
</tbody>
</table>

Up until recently, static measurements were the only measurements taken by a fitter prior to providing a golfer with a set of custom fit golf clubs. But this method was far from accurate, since the most important measurements were being overlooked. These ignored measurements are classified as the dynamic measurements, since these relate to the golfer’s swing. Some of these measurements are summarized in Table 5. These are the most difficult for the fitter to accurately obtain, but they provide the fitter with the best information regarding the golfer’s swing. Some of these measurements are not actually quantified, rather observed by the trained eye of a club fitter. These same measurements, however, are subject to interpretation by fitters, thus club fitting becomes
more of an art form and less of an exact science. With the custom fitters demand for these dynamic measurements has risen the need for measurement technology within the golf club fitting industry.

Table 5: Example Dynamic Measurements

<table>
<thead>
<tr>
<th>Example Dynamic Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball Launch Angle</td>
</tr>
<tr>
<td>Ball Speed</td>
</tr>
<tr>
<td>Ball Spin-Rate</td>
</tr>
<tr>
<td>Ball Trajectory</td>
</tr>
<tr>
<td>Clubface Angle at Impact</td>
</tr>
<tr>
<td>Clubhead Speed</td>
</tr>
<tr>
<td>Max Shaft Stress</td>
</tr>
<tr>
<td>Part of Club that Strikes the Ground</td>
</tr>
<tr>
<td>Power Transfer from Club to Ball</td>
</tr>
<tr>
<td>Shaft Deflection</td>
</tr>
<tr>
<td>Shaft Frequency</td>
</tr>
<tr>
<td>Shot Dispersion</td>
</tr>
<tr>
<td>Swing Path</td>
</tr>
<tr>
<td>Swing Plane</td>
</tr>
<tr>
<td>Swing Tempo</td>
</tr>
<tr>
<td>Where the Ball Strikes the Clubface</td>
</tr>
</tbody>
</table>

It can be seen that the custom club fitter can potentially be dealing with a large number of inputs to process in order to determine an equally large number of outputs, the parameters associated with the custom fit golf club. The shear magnitude of inputs makes the club fitters job difficult, but compounding this is the fact that when the fitter makes a decision to alter one club component, this will result in a completely new set of dynamic measurements that the fitter will have to re-process. Thus, this process (Figure 6) is iterative in nature and can end up being performed several times during a club fitting session.

3.2 Fitting Complexity Example

To illustrate the complexity that can arise when performing a custom fitting, the measurement of dynamic lie angle will be further explained. The lie angle of a club is the angle that the club makes with the ground when it is placed in the address position.
The static lie angle is very easy to determine. The fitter merely has the golfer assume their golfing stance, then he or she proceeds to give the golfer clubs with various lie angles until the proper address position is obtained.

![Figure 7: Static and Dynamic Lie Angle](image)

Fitting for dynamic lie angle is much more complex, however. Due to the fact that the center of mass of the clubhead is not located in line with the centerline of the shaft, when the golfer swings the club, a centrifugal force is created that causes toe down bending. This effect is not something that can be seen by the naked eye. A fitter will take a piece of tape, place it on the bottom of a club, and have the golfer hit a golf ball off a flat surface called a fitting board. As the bottom of the club strikes the fitting board during the golfer's swing, a mark is left on the tape, thus indicating the part of the club that is striking the ground. Ideally, the center of the bottom of the club is striking the ground, thus providing the golfer with the highest probability of hitting a straight shot. If the toe of the club is striking the ground the golfer will have a much higher probability of hitting the shot to the right of the target, for a right-handed golfer, due to the loft of the club not being aligned perpendicularly to the ground. As the club bends downward, the loft is now pointing more to the right of the target line (Figure 8), causing a shot to go right unless the golfer compensates for this effect. The greater the loft of a club, the greater an affect dynamic lie will have on a golfer’s shot.
Dynamic lie occurs as a function of the shaft stiffness, clubhead weight, and shaft length and how they react with the golfer’s swing. As shaft stiffness increases, dynamic lie is reduced. As clubhead weight is increased, dynamic lie is exaggerated, and as shaft length increases, so does the effect of dynamic lie. A fitter must balance all three of these parameters when fitting a golfer. Making the fitter’s job more complex, of course, is the fact that as each of these parameters is adjusted for dynamic lie, they end up affecting other dynamic portions of the golfers swing (Figure 9). Currently, the art of club fitting is a laborious process that involves slowly determining the optimal club parameters for a golfer.
3.3 **Summary of Current Fitting Process**

Custom club fitting is both an art and a science. The art is derived from the club fitter having to process a lot of information in order to make a subjective decision that is based on their level of training and experience. The science arises from the increasing use of technology by fitters to provide them quantifiable dynamic data associated with the golfer's swing. Since the swing is such a complex process, understanding its dynamics is quite difficult. There are many dynamic measurements that a fitter may acquire, and to fully understand the swing, they would need dynamic measurements associated with the clubhead, the shaft, and the golf ball.
4 Current Technology

Currently, fitters rely on limited technology to assist them in their decision making process. Quantifiable dynamic data gives them more information by which to make a better fitting decision. Additionally, it can allow them to add to their knowledge and experience by providing them with previously unknown data, and it can provide more credibility with their customers. The type of technology utilized by these various systems varies from a simple radar device to systems utilizing high-speed cameras and complex computer algorithms. These products will all gather information at different times during the swing as well as different dynamic measurements. Some gather measurements only at impact, while others gather throughout the entire swing. Some gather data on the golf ball, while others just collect information on the golf club shaft.

The technologies that are incorporated into these products must fulfill many fitter requirements. First, the product needs to provide the fitter with accurate information in a timely manner so that fitters can make precise fitting recommendations to their customers without having to spend a long time acquiring data. They will be measuring a dynamic process that can occur at over 100 mph, so it has to be capable of high-speed measurement. Since golf is an outdoor sport, it is much preferred by both the golfer and the fitter that custom club fitting can occur outside on natural grass. Finally, to provide quality information, the technology should not necessitate the golfer to alter their swing. This section describes many of the products that club fitters utilize for obtaining dynamic measurements and provide some insight on their operation.

4.1 Clubhead Speed Measuring Devices

All clubhead speed measuring devices provide the fitter with clubhead speed at the point of impact. Some also provide additional measurements such as ball speed, power transfer index, swing path, and club face angle at impact.
Clubhead speed is one of the more important dynamic measurements utilized by fitters since the correct shaft stiffness is vital to optimize the use of a golfer’s swing\(^6\). One of the drawbacks, however, is that clubhead speed measuring devices are taking data only at impact, so they are unable to provide further information related to shaft dynamics throughout the swing. Although it can assist the fitter with shaft decisions, it should not be the only input that the fitter utilizes, since other dynamic measurements such as swing tempo and shaft frequency are typically used to determine a golfer’s shaft type.

The clubhead speed measuring devices are the most common products that the club fitters use to obtain quantitative data. These products are divided into two different categories based on the technology utilized by each, either Doppler radar or infrared (IR) sensors.

4.1.1 Radar Clubhead Speed Measuring Device

This product is essentially a small radar gun that determines the speed of an object passing in front of the radar beam. It utilizes a Doppler radar that sends out a continuous beam at a specific frequency. A Doppler radar determines the speed of an object based on the return signal from the radar beam\(^9\). If the beam strikes an object moving away from the source, the return signal undergoes a Doppler shift, which results in the return frequency being lower than the original frequency. An increased frequency will result from the radar beam reflecting off of an object moving toward the radar source. By measuring the resulting change in frequency, the device is able to determine the velocity of the particular object in the same direction that the radar is facing. If an object travels perpendicular to the Doppler radar, it will have a velocity of zero in the direction of the radar beam. Thus, one radar will only measure the velocity in one direction. Figure 10 shows an example of one of these products.
These systems provide the fitter with clubhead speed and/or ball speed in the
direction of the radar beam, which will typically be faced towards the target. Some
products may make additional calculations based on the velocity measurements, such as
ball distance or power transfer index. Fitters will use this data as a basis making shaft
stiffness decisions for a golfer.

These products are typically quite small, battery powered, and not light sensitive
so they are easily taken to a driving range, allowing fitters to have the golfers hit
outdoors. The system will provide the fitter with user-friendly data that does not have to
be interpreted, unlike some of the more complex systems yet to be discussed.

4.1.2 Infrared Sensor Clubhead Speed Measuring Device

The IR sensor clubhead speed measuring device is a system that measures the
movement of the golf club just before it strikes the golf ball. These systems utilize IR
sensors, which detect the golf club as it passes over the sensor and interrupts the light
being ‘seen’ by the sensor. Some systems will utilize additional sensors to sense the
initial flight of the golf ball. An algorithm can then be utilized to determine the time it
takes the club or ball to pass over successive sensors. The algorithm can then calculate
clubhead velocity. The sensor data can also be used to provide the swing path, clubface
angle, or ball speed. Figure 11 shows an example of such a system.
These systems provide the golfer with clubhead speed and/or ball speed, in addition to data such as swing path and clubface angle at impact. Software associated with the system can also be used to calculate dynamic measurements not directly measured by the sensors, such as power transfer index, or golf ball distance. Fitters will use these products for making decisions on shaft stiffness, and with more IR sensors in the product, can also make clubhead decisions such as face angle.

As the number of sensors increase, the fitter is provided with more clubhead or ball information in addition to a higher accuracy of the received data. Accuracy is also increased with sensors that are more sensitive. In addition to creating a higher priced product, these improvements can cause issues with the portability of such a system due to requirements for lighting and sensor placement. The IR sensors are able to sense the ball as it passes, but are unable to determine the spin associated with the golf ball. Without the ability to determine the backspin or sidespin of the ball, the overall ball flight calculations are not going to be that accurate since the spin of the golf ball greatly affects the overall distance and flight path. Also, these systems require the golfer to hit off a tee or an unnatural surface, potentially not providing the fitter with the golfer’s true swing.

4.2 Video Analysis Systems

Video Analysis Systems are another common tool utilized by club fitters. Where most other dynamic measurement products provide quantitative data, these systems are
used for qualitative data. They are divided into two categories based on their level of complexity, the basic video camera and the digitized video analysis system.

These products involve video taping a golfer’s swing, and once captured, the fitter is allowed the opportunity to replay the swing. This affords the fitter the ability to review either one swing repeatedly or in slow motion, both of which are useful for seeing characteristics of the entire swing that cannot be noticed by the unaided eye. Although it gathers no specific measurements, it can be used to assess dynamic portions of the golfer’s swing, such as the swing plane, swing path, and swing tempo. The video camera can be used by itself, or a digitized video analysis system will allow the videotape to be digitized to perform more in-depth analysis on a computer.

Slow motion video can allow the fitter to get a better feel for several dynamic measurements that normally occur too rapidly during a real-time golf swing. For example, by watching the video of the clubhead contacting the golf ball in slow motion, the fitter would be able to have a sense of the clubface angle at impact. Although this adds time to the fitting process and does not provide a precise angle measurement, it still gives the fitter more data by which to make a more informed decision. Due to different fitters having a variety of experience and knowledge, however, the information obtained using video analysis will be interpreted differently.

4.2.1 Video Camera

A video camera allows a fitter to videotape a golfer’s swing. The technology of interest in this product is the shutter speed of the camera. The typical video camera will take 60 pictures every second. A high-speed video camera that is used for sports applications, however, will provide pictures between 250 and 1,000 frames per second. High-speed video cameras will provide better still-frame pictures for the fitter, thus allowing for higher quality slow motion information.
High-speed cameras are expensive and require special lighting in order to ensure enough light is passing through the shutter. Additionally, video cameras provide no measurements to the fitter, so the data they can provide is subjective in nature.

4.2.2 Digitized Video Analysis System

A videotaped swing can be made more useful to fitters by digitizing the image so that it can then be further analyzed on a computer. Several companies supply products that come with video cameras, an analog/digital converter (if a digital video camera is not used) and software by which to perform golf swing analysis. These products are typically used by golf instructors to assist them in analyzing a golfer’s swing, but can also be used by club fitters. This allows the fitter to detect the golfer’s swing flaws, so that they can be corrected prior to making a fitting recommendation. The software will allow the fitter to replay the golfer’s swing on a computer. The fitter may then draw reference lines that will remain stationary throughout the swing so that he or she can more easily discern movements made by the golfer (Figure 12). For example, the fitter can draw a circle around the golfer’s head before the swing is initiated so that any movement of the golfer’s head during the swing will result in it moving outside of this circle. This can be utilized to detect a major swing flaw that a fitter would want corrected prior to making fitting recommendations for this golfer.

Many of these products also provide a side-by-side swing comparison feature, which can also be used to detect correctable swing flaws. There will be databases associated with these systems that contain the videotaped swings of various professional golfers. The fitter may videotape a golfer swinging, then replay the golfer’s swing adjacent to the swing of the professional golfer. The swing initiations may be synchronized and viewed at normal speed, in slow motion, or frame-by-frame.
The software of these systems allows the fitter to build on the advantages previously mentioned with the video camera and provides them with a better understanding of the golfer’s swing. Drawing reference lines on the screen does not give the fitter any more quantitative information, but it does allow him or her to better pick out any problem areas of the golfer’s swing.

These systems are better designed for swing analysis rather than custom club fitting due to the lack of quantitative data. Utilizing this product will require the fitter to spend more time with the golfer. It takes time to setup the equipment, videotape the golfer, and then to perform the various analysis that are available on the software. Also, the software by itself is not expensive, but the supporting equipment, such as high-speed cameras (typically 2), VCR, computer, and digitizing equipment result in an expensive product. With the addition of all of the hardware for this system, portability begins to become an issue. Some products are only designed for indoor use, which will limit the functionality of the product since it is taking the golfer to a more artificial environment.
4.3 Shaft Measurement Devices

Since the shaft plays such a large role in the swing, a great deal of emphasis is placed on the selection of the right shaft during a custom fitting session. Because of this, custom fitters demand products that provide them with various dynamic measurements associated with the golf shaft. This leads to fitters typically utilizing a frequency analyzer, shaft accelerometers, or a strain gauge device.

4.3.1 Frequency Analyzer

A frequency analyzer determines a shaft bending frequency in terms of cycles per minute (CPM). A golf club is placed within the device, clamped at the grip-end of the club, and ‘plucked’ by releasing the clubhead from a deflected position. This results in the clubhead end of the club vibrating rapidly at a specific frequency. Typically, these devices will incorporate an IR sensor towards the clubhead end of the shaft to sense the rapid movement of the shaft in front of the sensor. By counting the number of oscillations over a specific time, an algorithm can extrapolate this information in order to determine the cycles per minute. Figure 13 shows the typical construction of a shaft frequency analyzer.

![Frequency Analyzer](image)

**Figure 13: Frequency Analyzer**

Fitters use the results from the bending frequency tests to infer the stiffness of a shaft. Frequency matching is the process a fitter performs to match this bending frequency of each club within a set. It is believed to play a significant role in the golfer’s
perceived feel when impacting a golf ball during a swing. The shaft stiffness, material, weight, clubhead weight, and even how the shaft is attached to the clubhead can affect a shaft’s frequency characteristics\textsuperscript{14}. Additionally, the shorter a club shaft, the higher the shaft bending frequency, and since all clubs within a set have different shaft lengths, a fitter needs to make sure the clubs within a set ‘match’. Some fitters just use clubhead speed as the determining factor for shaft stiffness. However, if a golfer swings a longer, lighter club, the clubhead speed generated will be increased. Conversely shorter, heavier clubs mean lower speeds\textsuperscript{13}. Therefore, fitters who opt to be more precise require measuring the actual frequency of the golf club shaft.

Shaft frequency analyzers are light, easy to setup and easy to operate. Their major disadvantage would be that they only provide one dynamic measurement, thus the fitter is required to use additional products for obtaining more dynamic measurements. Additionally, the frequencies of the clubs are matched based on the frequencies attained when the club is in a vice grip. Since a golfer’s grip is not quite that of a vice, this matching is not based on the true frequency the golfer will experience when hitting the club\textsuperscript{15}.

4.3.2 Shaft Accelerometers

An accelerometer utilizes a known mass and spring with a known spring constant\textsuperscript{16}. When this mass is accelerated, it will exhibit a force on this spring, thus compressing it. The displacement of the spring by the mass can be directly measured. The displacement is proportional to the force felt by the mass when it is accelerated. The force is then used to determine the acceleration of the mass, which is proportional to the force.

The accelerometer is housed in a small plastic piece (Figure 14) and is attached to the club shaft. The accelerometer will measure the angular acceleration throughout the swing in order to determine the downswing time. The downswing time is defined as starting at the point of maximum clubhead acceleration, or maximum angular acceleration, to the point of impact, when the clubhead rapidly decelerates\textsuperscript{17}. This
downswing time can then be used to determine the optimum shaft stiffness for a golfer. These products typically store all of the acceleration information, which can then be downloaded to a computer for further analysis. This allows the fitter to see shaft loading data throughout the entire swing.

![ Shaft Accelerometer by Timeatch ]

Fitters will use these products for making shaft oriented decisions. Knowing the downswing time and shaft loading allow the fitter to estimate shaft stiffness, and flex point for a golfer.

Due to their small size and information storage capacity, they are very portable and can be used with any golfer on any club. The fitter must download all of the swing data to a computer in order to analyze and make a shaft fitting decision, thus increasing the time it takes a fitter to perform a custom fitting. Additionally, these products just provide shaft information, so a fitter would need to purchase more products to obtain other dynamic measurements pertaining to the clubhead or the golf ball.

4.3.3 Shaft Strain Gauges

The True Temper Shaft Lab (Figure 15) utilizes strain gauges that are permanently attached to the inside of a golf club shaft. The strain gauges will measure the displacement of up to 8,000 points on the shaft during a golfer’s swing. Each strain gauge consists of a small piece of metal that is a part of an electrical circuit. The metal will have a given resistance while it is in its normal state. During a golf swing, as the
shaft flexes, it will cause the strain gauge to bend as well. This deformation of the metal will alter the resistance of the gauge, which will alter the properties within the electrical circuit. Since this change in resistance will be dependent upon how much displacement the strain gauge exhibits, the amount of bending can be determined based upon the change in resistance that is seen by the electrical circuit.

![Strain Gauge Device by True Temper](image)

Figure 15: Strain Gauge Device by True Temper

With the Shaft Lab, the fitter is provided with information gathered throughout the entire swing instead of just at the point of impact, so more valuable data is obtained. The information provided by the strain gauges can be utilized to determine such dynamic measurements as shaft deflection, downswing time, amount of droop that the clubhead toe experiences at impact (can be used for fitting dynamic lie), and the relative lead/lag of the clubhead with respect to the shaft at impact. Figure 16 shows the typical graphical output provided to the fitter. A trained fitter is able to look at this information and infer additional information such as the torque being generated by the turning of the golfer’s shoulders and that from the releasing of the golfer’s wrist during the downswing. From all of this data, the fitter is able to determine the best shaft properties for the golfer, such as shaft stiffness, shaft length, and shaft flex point.
The strain gauges utilized by this product provide the fitter with a very accurate swing profile of the golfer. The fitter is provided with a large quantity of quality data. The Shaft Lab also interprets the data from the golfer’s swing and will provide the fitter with a shaft recommendation. There are some drawbacks to this product, however. It can be setup outdoors, but due to a computer being part of the system, portability begins to become an issue so most of these are found at indoor facilities. The product does provide shaft recommendations, which makes the fitter’s job easier, but they are only for True Temper shafts. Since there are no standards governing measurement of shaft stiffness, one company’s stiff shaft may be another company’s standard flex, thus the shaft recommendations are not applicable to other brands of shaft. Also, the golf clubs have wires attached to them, which can potentially alter a golfer’s swing.

### Spine Alignment

A new shaft analysis tool has recently been incorporated by custom fitters. The product is made by Strategic Shaft Technologies (SST) and is used for performing a new process called ‘spine alignment’. Due to imperfections that naturally exist in a golf shaft, it will not have symmetrical bending properties along its length. Because of this, different clubs will bend differently during a swing. By determining the bending properties of each shaft and aligning them so that the bending will primarily occur in the swing plane for each club, golfers can benefit from a better harnessing of the shafts.
potential energy in addition to more consistent behavior from one club to the next. A search of manufacturer information and patent databases revealed little about this product; therefore, it was not further investigated for this research.

4.3.5 Summary of Shaft Measurement Devices

All of these shaft measuring devices provide very useful shaft information that fitters need. But, since these products just provide shaft information, a fitter would require other products for obtaining clubhead and ball related information. Additionally, both provide different measurements associated with the shaft, so one product does not replace the other.

4.4 Ball Flight Analyzers

All ball flight analyzer systems provide the club fitter with quantitative data associated with the golf ball. Information is gathered on the golf ball during its initial flight, immediately after impact. The fitter is typically provided with ball speed, launch angle, azimuth angle (angle of left-right deviation), and spin rate (both sidespin and backspin). All of these measurements are necessary in order to accurately calculate the resulting ball flight\textsuperscript{23}. From this data, dynamic properties of the golfer’s swing can be inferred. Since the ultimate goal of a golfer is to have the golf ball leave at the optimum speed, trajectory and spin, ball flight data is useful information for the fitter to receive in order to provide a golfer with a best-fit club. There are at least three types of ball flight analyzers, and they are differentiated based on the technology utilized to determine the ballistics of the golf ball. One uses lasers, one uses Doppler radar, and the third uses high-speed cameras. All of these products provide the fitter with dynamic information associated with the golf ball, thus allowing the fitter to alter club parameters for a golfer until optimal initial golf ball ballistics are achieved.
4.4.1 Laser Ball Flight Analyzer

The laser ball flight analyzer operates via the use of laser Doppler velocimeters, which consist of a laser and a photo detector\textsuperscript{16}. The laser sends out a beam toward the target, which in this case is the golf ball. The laser beam bounces off of the ball, and the reflected light is received by the photo detector. Based on the previously discussed Doppler effect, the reflected beam will return with a different wavelength, which is inversely proportional to frequency, since it is bouncing off of a moving object. Thus the velocity of the golf ball can be determined by measuring the change in wavelength of the beam. Since the price of lasers has dropped substantially over the last couple decades, their use is finally becoming practical in such products. An example of this type of ball flight analyzer is seen in Figure 17.

![Figure 17: Laser Ball Flight Analyzer by Focaltron\textsuperscript{17}](image)

As laser technologies continue to mature, these products will become more accurate and less expensive. Currently, these products provide accurate measurements of velocity, thus providing a fitter with reliable ball speed, launch angle, and azimuth angle. These products do not directly measure spin rate, however, which is a key component to calculating the overall ball flight. A fitter is provided with spin rate measurements that are calculated via a proprietary algorithm, and the accuracy of this calculation was not available information. Additionally, these products are dependent upon the lasers and photo detectors being perfectly aligned, thus they are not easily modified by the fitter. Due to this difficulty in adjusting, laser ball flight analyzers cannot be used by both right-handed and left-handed golfers.
4.4.2 Radar Ball Flight Analyzer

The radar ball flight analyzer operates similarly to the previously described radar clubhead speed measuring device. Again, this product utilizes Doppler radar to determine the initial ballistics of the golf ball. Doppler radar provides velocity information, so utilizing multiple radar allows for velocities in three dimensions to be provided. A computer algorithm can then be utilized to calculate more information such as spin rate, distance, and trajectory. Figure 18 shows an example product.

![Radar Ball Flight Analyzer](image)

**Figure 18: Radar Ball Flight Analyzer by Distance Caddy**

A fitter would use this product in the same way as the laser ball flight analyzer, adjusting club components until the optimal ball ballistics are achieved.

Doppler radar provides excellent velocity information. Ball spin rate information is calculated by a proprietary algorithm. No information is available on the accuracy of the spin rate calculations. Also, these products are quite cumbersome, having multiple radar devices that need to be arranged in the correct orientation, making it difficult to setup and move them.
4.4.3 High-Speed Camera Ball Flight Analyzer

The third type of ball flight analyzer uses high-speed cameras, typically 250 to 1,000 frames per second, to capture the initial flight of the golf ball. These systems have cameras focused on the point where the clubhead will strike the golf ball and a certain distance beyond this point where the initial ball flight can be captured on video. The challenge is to not only capture this event on video, but to then be able to determine the ballistic properties of the ball. Since the golf ball accelerates from rest to a speed that can exceed 125 mph in under 0.5 milliseconds, the video cameras need to operate at a high speed in order to accumulate enough information to calculate the golf ball’s ballistics. The ball will have to be marked such that there are reference points on the ball by which to measure its movement from one still-frame to the next. Since multiple cameras are used, the camera positioning allows for triangulation of the golf ball’s position, therefore allowing the system to better determine the launch angle, speed, and spin rate. All of the information is captured by the video cameras, digitized and sent to a computer where calculations can be made from one frame to the next in order to determine velocity, launch angle, and spin rate. Figure 19 shows an example of such a product.

![High-Speed Camera Ball Flight Analyzer](image)

Figure 19: High-Speed Camera Ball Flight Analyzer by Swing Dynamics

By taking video at the point of impact, a fitter can be provided with qualitative information with respect to swing path, swing plane, clubface angle at impact, and where the ball strikes the clubface, in addition to ball dynamic measurements such as launch
angle, speed, and spin-rates. Since ball spin rates are directly measured, their accuracy will depend upon the sample rate of the camera. The faster the speed of the camera, the more accurate the calculated spin-rates.

Faster cameras and multiple cameras provide more information that the computer algorithm can utilize to make more accurate calculations. This all comes at a price, however. The more cameras used, and the higher the camera speed, the more expensive this product becomes. Additionally, as the camera speed increases, so does the requirement for better lighting. Because of this, the higher-end systems’ cameras have lights placed near them (the lights can be infra-red to minimize distracting the golfer) and near the golf ball, making it more difficult to use them outdoors. This places the golfer in an unnatural environment, which can affect his or her swing. Finally, as the complexity of the system setup and operation increase, so too does the time required for the club fitter to spend with the golfer.

4.5 Summary of Current Technology

This chapter reviewed the various products and associated technologies that custom fitters utilize to obtain dynamic measurements of a golfer’s swing. The information provided by these products allow the fitter to make a more informed decision when providing a golfer with custom fit clubs.

Table 6: Summary of Dynamic Measurement Products

<table>
<thead>
<tr>
<th>Dynamic Measurement Product</th>
<th>Typical Measurements</th>
<th>Estimated Price Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar Clubhead Speed Measuring Device</td>
<td>Clubhead Speed, Ball Speed</td>
<td>$100 - $500</td>
</tr>
<tr>
<td>IR Sensor Clubhead Speed Measuring Device</td>
<td>Clubhead Speed, Ball Speed, Swing Path, Clubface Angle</td>
<td>$500 - $1,500</td>
</tr>
<tr>
<td>Video Camera</td>
<td>Qualitative Measurements</td>
<td>$200 - $2,000</td>
</tr>
<tr>
<td>Digitized Video Analysis System</td>
<td>Qualitative Measurements</td>
<td>$10,000 - $25,000</td>
</tr>
<tr>
<td>Frequency Analyzer</td>
<td>Shaft Frequency</td>
<td>$100 - $500</td>
</tr>
<tr>
<td>Shaft Accelerometer</td>
<td>Downswing Time, Shaft Loading</td>
<td>$1,000 - $2,000</td>
</tr>
<tr>
<td>Shaft Strain Gauge Device</td>
<td>Shaft Deflection, Toe Drop, Lead/Lag of Clubhead with respect to the Shaft, Downswing Time, Shaft Loading</td>
<td>$7,500 - $10,000</td>
</tr>
<tr>
<td>Laser Ball Flight Analyzer</td>
<td>Ball Speed, Launch Angle, Azimuth Angle, Estimates Spin Rates</td>
<td>$4,000 - $6,000</td>
</tr>
<tr>
<td>Radar Ball Flight Analyzer</td>
<td>Ball Speed, Launch Angle, Azimuth Angle, Estimates Spin Rates</td>
<td>$8,000 - $15,000</td>
</tr>
<tr>
<td>High-Speed Camera Ball Flight Analyzer</td>
<td>Ball Speed, Launch Angle, Azimuth Angle, Spin Rates, Swing Path, Clubface Angle, Where Ball Strikes Clubface</td>
<td>$15,000 - $25,000</td>
</tr>
</tbody>
</table>
Table 6 summarizes the dynamic measurement products, what they measure, and typical prices. The more measurements that they provide fitters, the more useful they can become. Also, the more accurate the data, the more it will assist the fitter. More measurements usually require more complex technologies, however, which can result in a higher price, sensitivity to light (can only be used indoors), loss of portability, long setup times, or lots of initial training required in order to use the product.
Initial Market Research

Custom golf club fitters have many tools available to them by which to perform their trade. The goal of this research phase was to determine which of these tools provides the fitter with the best information at a reasonable price. To best reach this conclusion first required determining the needs of the custom fitters, who are the ones purchasing these dynamic measurement tools. Additionally, the needs of the golfers needed to be determined since they are also stakeholders in the custom fitting process.

Initial phone interviews with fitters and viewing several of their websites revealed a large variety in custom fitter’s processes. Some fit a golfer with a set of golf clubs through the use of an online questionnaire filled out by the golfer. This questionnaire provides the fitter with a lot of the same information previously depicted in Figure 1, but it is from the golfer’s own self-assessment rather than from the trained eye of a fitter. They would require the golfer to first answer questions that would provide them with information typically received during an interview session with the golfer. The golfer then provides specific static measurements. Finally, the golfer provides qualitative descriptions of various dynamic parts of their swing. For example, ‘when you mis-hit the ball, do you typically slice or hook?’ The fitter processes all of this data and provides the golfer with a set of custom fit golf clubs without any direct golfer-fitter interaction.

Other fitters rely on extended direct contact with the golfer. A typical custom club fitting session for these fitter’s will start with the golfer showing up with their current set of clubs to hit golf balls. First, they’ll hit golf balls to warm up their golf swing. Next, a fitter will videotape them and analyze their swing with a digitized video analysis system to determine any major swing flaws that need to be corrected. Once the golfer is showing a decent, repeatable swing, the fitter will have them swing a club with a shaft measuring device, such as the True Temper’s Shaft Lab, to determine which type of shaft the golfer needs. Once that is determined, the fitter provides the golfer with that shaft and an initial best guess as to the rest of the club components. The golfer than hits practice balls while the fitter obtains dynamic measurements such as club head speed,
face angle at impact, and swing plane. The fitter then adjusts the club accordingly and has the fitter repeat the process of hitting practice balls. This process will repeat until the fitter is satisfied the golfer has achieved optimum dynamic measurements for his or her swing. This entire process takes up to 2 hours, and has a lot of interaction between the custom fitter and the golfer.

After seeing this wide spectrum in custom golf club fitters, it was obvious that golfers have a variety of options when it comes to getting their clubs fit. To get a better understanding of both custom fitters and golfers, two surveys were created. The first survey was just for custom fitters. The goal of this survey was to obtain raw data that could be interpreted to determine the needs of the fitter. The second survey was created to determine the customer needs of the end-user, the golfer. Questions in the survey were designed to determine the fitter’s quantity of business, how much they charged, how long they spent with golfers, the golf club components that were custom fit, what sort of dynamic measurements they utilized, and what sort of products they used to obtain these measurements.

The surveys were posted on a website for both fitters and golfers to visit online. The link to the website was then sent via email to participants. Once a survey was filled out, it was submitted by the fitter or golfer, which resulted in all of their information be returned via email. All of the emails were collected in order to input the data into spreadsheets for further analysis. All comments were read and utilized in further understanding the received information.

In order to facilitate both taking the surveys and data entry into a spreadsheet, many survey questions were designed with designated ranges for answers. For example, if a fitter provided golfers with 52 sets of custom fit clubs last year, they would indicate this by checking that they fit 50-100 sets of custom clubs. All data presented will be based on the defined divisions that were established in the survey design.
5.1 First Fitter Survey

The first fitter survey is shown in Appendix A. The link to the website containing the survey was distributed to the various custom club fitters that could be found via the Internet. This proved to be a laborious and inefficient method of getting fitter feedback. Approximately one out of every five fitters that were emailed would visit the survey website and submit a survey. After a week of pursuing this, the Professional Clubmakers' Society\(^2\) (PCS) offered their assistance. By distributing the website link for the fitter survey to their approximately 1200 members, the PCS allowed the website to be seen by significantly more custom fitters. The survey was taken by 192 custom fitters, which represents between 0.77% and 0.96% of the estimated 20,000 to 25,000 custom fitters in the US.

5.1.1 Background Information

The first important result from the fitter's survey revealed the typical number of clubs fit by a custom fitter per year (Figure 20). It can be seen that 72% fit less than 100 sets per year. This implies that the majority of these club fitters perform this service on a part-time basis.

![Sets of Custom Clubs Built Last Year](image)

**Figure 20: Number of Sets of Clubs fit by Custom Fitters**
At the other extreme are fitters providing golfers with over 1,000 sets of fit clubs per year. This implies that the fitters are providing these sets of clubs rapidly, so the quality of the fit of clubs is questionable. When a golfer is provided “custom fit clubs” after only a few static measurements, the fitter is merely specifying which club components the golfer requires. This is a lot different then a fitter spending over an hour with a golfer having them hit several golf balls with various clubs in order to determine the best club component combination.

![Custom Club Premium]

**Figure 21: Premium Charged by Custom Fitters**

The premium charged by custom fitters is the amount the golfer pays the fitter for a fitting. Figure 21 shows the range of premiums charged by participating fitters. Over 45% of fitters indicated that they do not charge a fee for performing a custom fitting session. This would require the fitting to be done quickly in order for it to be cost effective to the fitter. It is believed that the majority of custom fitters are also club makers or work in a golf store that sells golf clubs. When a golfer comes in to buy a set of golf clubs, the fitter will take some measurements in order to specify which components a set of clubs should have for a given golfer. The cost of this fitting ends up being buried in the price of the set of clubs, so it is not seen by the golfer and it provides him or her an incentive to buy the clubs.

The next most popular fitting premium is $51-$100, with 20% of the fitters. Excluding the free fitting sessions, the average fit will cost a golfer approximately $100,
with some costing in excess of $200. This premium represents the skill level of custom fitters combined with the use of the high-tech systems.

![Bar Chart: Time Spent with Customers]

**Figure 22: Amount of Time it takes for a Fitting Session**

The next data reveals the amount of time that a custom fitter will typically spend with a golfer during a fitting session (Figure 22). Approximately 35% of the fitters spend between 1 hour and 1.5 hours with their customer, with a fairly symmetrical distribution around this time. It can be hypothesized that the fitters who spend less than 15 minutes with a customer are the same ones who are specifying club components rather than performing a custom fitting.

### 5.1.2 Custom Fitting Sessions

The golf club components fit or specified by the custom fitters can be seen in Figure 23 and Table 7. Figure 23 shows the commonly fit components that were provided on the survey for the fitters to acknowledge fitting. It can be seen that over 94% of them fit golfers with grip size, shaft length, shaft stiffness, shaft material, club type, swing weight, and lie angle, all of which require minimal dynamic inputs, if any, in order to fit.
The list of components provided in the survey was far from all-inclusive, however, so they were provided the opportunity to list any additional components that they fit to a golfer while custom fitting. Table 7 summarizes their responses. The reason this table was listed separately is that components listed in the survey have a much higher chance of being submitted data due to the convenience of not having to type a response. Of the fitter listed components, club loft is the most popular at 19%, being nearly double the next most mentioned components of shaft frequency matching, total weight, and shaft spining. It can be seen that 13 additional components were mentioned, some of which are groupings of similar components. Of note, however, is that some of these are the more difficult elements to fit, such as the previously described frequency matching and spine
alignment of a set of shafts. The total number of fit components on a golf club is between 22 and 30 components depending upon how they are divided.

Next, the dynamic measurements utilized by custom fitters were examined. Once again these are separated into a graph showing the breakdown of the dynamic measurements that were given to the fitters in the survey (Figure 24), and a table showing the measurements that fitters provided in addition to those mentioned (Table 8). The graph reveals that over 97% of the fitters utilize clubhead speed while fitting. This is believed to be due to clubhead speed measuring devices being the cheapest and easiest to use dynamic measurement devices. Over 80% of fitters use the dynamic measurements of ball trajectory, ball flight, swing tempo, the average distance of a certain club, the point where the clubhead strikes the ground, and the point where the ball strikes the clubface. Previously discussed products can determine all of these. An experienced fitter without the use of any expensive tools can also qualitatively determine or estimate them, which is probably why they are so popular. Finally, the power transfer index is only used 20% of the time. The power transfer index requires two dynamic measurements, initial ball speed and clubhead speed. Few systems are capable of supplying this information.

Figure 24: Dynamic Measurements Utilized by Custom Fitters
Table 8: Dynamic Measurements (Not in Survey) Used by Custom Fitters

<table>
<thead>
<tr>
<th>Dynamic Measurement</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft Acceleration / Loading / Toe Droop</td>
<td>12.6%</td>
</tr>
<tr>
<td>Ball Speed</td>
<td>2.1%</td>
</tr>
<tr>
<td>Launch Angle</td>
<td>2.1%</td>
</tr>
<tr>
<td>Ball Spin Rate</td>
<td>1.6%</td>
</tr>
<tr>
<td>Shaft Frequency</td>
<td>1.0%</td>
</tr>
<tr>
<td>Wrist Release to Impact Time / Wrist Release Point</td>
<td>1.0%</td>
</tr>
<tr>
<td>Balance</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

The custom fitters were able to list dynamic measurements that they utilized, but were not listed in the survey. Of these measurements, those dealing with shaft acceleration, shaft loading and toe droop were the most popular at 12.6%. All three of these measurements are provided by the True Temper Shaft Lab, and since the price of this device is fairly expensive, it is probably not used by a lot of fitters. The rest of the dynamic measurements in this table were measured by less than 2% of the fitters. These measurements are all associated with the more expensive digitized video analysis systems and the ball flight analyzers. None of these measurements can be accurately estimated by the custom fitter observing the golfer.
Lastly, the fitter survey requested the fitter provide the dynamic measurements they desired in order to better perform their custom fitting (Table 9). Some of the more popular responses, launch angle, ball spin rate, ball speed, ball trajectory and ball distance are all typical measurements that are provided by the ball flight analyzers, which are expensive. The other more frequently requested measurements, which included shaft loading, shaft deflection, shaft stress, downswing time, and club acceleration / deceleration, are all provided by the shaft strain gauge devices. Additionally, the higher end clubhead speed measuring devices and digital video analysis systems can provide information pertaining to clubface angle at impact, swing tempo, shot dispersion, and swing path. Measurements that current systems do not address quantitatively include the angle of attack (angle at which the clubhead approaches the golf ball), and the wrist turn-rate/ wrist release point.

### Table 9: Dynamic Measurements (Not in Survey) Desired by Custom Fitters

<table>
<thead>
<tr>
<th>Desired Dynamic Measurements</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Angle</td>
<td>5.3%</td>
</tr>
<tr>
<td>Ball Spin Rate</td>
<td>5.3%</td>
</tr>
<tr>
<td>Shaft Loading, Deflection, Stress</td>
<td>3.7%</td>
</tr>
<tr>
<td>Downswing Time</td>
<td>3.2%</td>
</tr>
<tr>
<td>Ball Speed</td>
<td>3.2%</td>
</tr>
<tr>
<td>Ball Trajectory</td>
<td>3.2%</td>
</tr>
<tr>
<td>Ball Distance</td>
<td>2.1%</td>
</tr>
<tr>
<td>Clubface Angle at Impact</td>
<td>2.1%</td>
</tr>
<tr>
<td>Club Acceleration / Deceleration</td>
<td>1.1%</td>
</tr>
<tr>
<td>Angle of Attack</td>
<td>1.1%</td>
</tr>
<tr>
<td>Wrist Turn-Rate / Wrist Release Point</td>
<td>1.1%</td>
</tr>
<tr>
<td>Swing Tempo</td>
<td>1.1%</td>
</tr>
<tr>
<td>Shaft Frequency</td>
<td>1.1%</td>
</tr>
<tr>
<td>Golfer Weight Distribution</td>
<td>1.1%</td>
</tr>
<tr>
<td>Stop Video</td>
<td>1.1%</td>
</tr>
<tr>
<td>Shot Dispersion</td>
<td>0.5%</td>
</tr>
<tr>
<td>Swing Path</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

5.1.3 First Fitter Survey Summary

Based on the results of this survey, it can be seen that there are at least two types of fitters. The first major type of fitter is one who specifies the components of a golf club for a golfer buying a new set of clubs. They sell many sets of clubs per year, charge very little for their service because it is typically included with the price of the set of clubs,
and spend very little time with golfers gathering dynamic measurements. The measurements these fitters do gather are either qualitative in nature, so they can be determined estimated by observing a golfer hitting golf balls, or they are the more common dynamic measurements such as clubhead speed, which can be acquired by an inexpensive clubhead speed measuring device. It is estimated that these fitters make up about 20% of the fitting industry.

The second major type of fitter is the one that performs a thorough fitting for a golfer. These fitters perform few fittings per year, charge approximately $100 to $200 per fitting, and spend at least an hour with the golfer. It is estimated that this type of fitter makes up 50% of the fitting industry. These fitters often use the more expensive dynamic measurement products in order to allow them to obtain more information by which to make better fitting decisions. This type of fitter performs a service that is much more in depth than specifying the a few club components for a golfer. They actually provide the golfer with a custom fit club by performing in-depth analysis and fitting more obscure components such as shaft frequency, spine alignment, shaft torque, and clubface angle.

5.2 Golfer Survey

The golfer survey is shown in Appendix B. It was distributed in the same manner as the fitter survey, by emailing the website link to the survey to several golf fitters to pass on to their customers. The purpose of this survey was to obtain an understanding of the typical golfer that purchases a set of custom fit clubs, focusing on the age, income, and playing ability. The survey also inquired about the cost and quality of the last set of custom clubs purchased, and tried to determine how much the golfer was willing to spend for a set of golf clubs that fit their golf swing perfectly. The survey was taken by 44 golfers from across the country.
5.2.1 Golfer Characteristics

According to the NGF, today's typical golfer is male, just over 40 years old, has a household income of $71,558 and plays 22 rounds per year. Although this survey did not request gender information, it does follow the general trend shown by the NGF. Figure 25 shows the average age of the participating golfer to be approximately 46 years old, slightly higher than that of the average golfer.

![Golfer Age Breakdown](image1)

**Figure 25: Age of Golfers with Custom Fit Clubs**

![Golfer Income](image2)

**Figure 26: Household Income of Golfers with Custom Clubs**
The average household income for these golfers is also higher than that of the average golfer. Figure 26 shows that 61% of the golfers had a household income greater than $100,000, with the average being approximately $135,000.

![Figure 26](image)

**Figure 26:** Percentage of Golfers with Household Income Greater than $100,000

According to the NGF, avid golfers are those who play more than 25 rounds per year, and that there are 6.3 million avid golfers today (23.6% of golfers). Figure 27 shows that 64% of the golfers using custom fit golf clubs (assuming an equal distribution in the golfers who played 20-30 rounds) played more than 25 rounds last year, which indicates that golfers purchasing custom clubs are typically avid golfers. The average number of rounds played by participating golfers was 32 rounds.

![Figure 27](image)

**Figure 27:** Rounds Played Last Year by Golfers with Custom Fit Clubs

Finally, it was found that custom fit clubs were not just purchased by the golfers with the best ability, or just the worst golfers. Figure 28 shows that there is an equal distribution of playing ability, as depicted by the golfer’s handicap. According to the NGF, the average score for male golfers is a 97 and that of female golfers is 114. Only 20% of golfers maintain a handicap, and the average handicap is 19 to 20. With the average handicap of this survey being approximately 13.7, which corresponds to a score of about 86, it can be concluded that the average golfer playing with custom fit clubs is an above average player.

![Figure 28](image)
Overall, the average golfer purchasing custom clubs is slightly older, has a higher income, plays approximately 45% more golf, and plays better than the average golfer. These golfers are more serious about the game of golf, making them more likely to make a purchase towards improving their game. Additionally, having extra disposable income allows them to conveniently purchase this service.

5.2.2 Custom Fit Clubs

Golfers playing with custom clubs seem to be content with their purchase. Of those surveyed, 72% felt that their custom clubs fit significantly better or perfectly when compared to playing with clubs purchased off-the-shelf (Figure 29).
Figure 29: Golfer’s Satisfaction with Custom Golf Clubs

Figure 30 depicts the price range over which golfers paid to receive their last set of custom fit clubs. Over 73% spent under $700 for their custom fit clubs, with the average price paid being approximately $620. The NGF statistics show that avid golfers spend $222 per year on golf clubs. If the surveyed golfers playing with custom fit clubs were to buy a new set of clubs every 3 years, they would be spending roughly $207 per year on custom clubs.

Figure 30: Price Golfer’s Paid for their last set of Custom Golf Clubs
Next, the golfers were asked to say how much they would pay for a set of golf clubs that fit perfectly. The results are shown in Figure 31, and it can be seen that the median price that most golfers are willing to pay is between $500 and $699. The average price, approximately $665, is slightly higher than what they did pay for their current set of custom clubs.

![Value of Perfect Fitting Clubs](image)

**Figure 31: Golfers Perceived Value for Perfect Fitting Custom Golf Clubs**

More interesting, however, is the amount of time golfers are willing to spend with custom fitters for perfectly fitting clubs. Figure 32 reveals that the median time golfers are willing to spend with a fitter is 2 to 3 hours. The average time is approximately 3 hours, which is more than double the average of 1.3 hours that fitters currently spend with golfers. This shows that golfers feel that this process should take longer than it currently does, and that more time with the fitter results in the perception of more value added to the fitting process.
5.2.3 Golfer Survey Summary

Golfers who currently play with custom fit clubs are generally satisfied with their club purchase. There is room for improvement, however, since approximately 70% of golfers feel that their custom fit clubs are not perfect. The average custom club fitter customer is willing to pay almost $50 more and spend an additional 1.5 hours with a fitter in order to receive a set of clubs that fits their swing perfectly.

5.3 Summary of Surveys

It was seen that golfers are looking for more value from their custom fitting sessions. To satisfy the needs of these golfers, they need to visit the fitters that perform the more detailed fitting service instead of the fitters that merely specify club components to a golfer.

Since golfers are willing to spend more time and money for a better fit, fitters need to consider utilizing more or additional products that will provide them with more detailed dynamic data by which to make better fitting decisions. These products may lead to longer fitting sessions, but golfers are willing to spend this additional time for a
better end product. Also, the cost of additional products can be justified by increased fitting charges that golfers are willing to pay.
Determination of Customer Needs

The initial market research created a solid understanding of the fitting industry. Fitters provided information on numerous dynamic measurements that they utilize during a fitting session that were not mentioned in the survey. Also, an understanding of the importance of the dynamic measurements that were listed on the survey was obtained, but that list was found to be far from all-inclusive. Fitters provided some information on the systems that they currently used for retrieving dynamic measurement data. A lot of fitters provided comments, both favorable and unfavorable, about these systems. From these comments, some product attributes (i.e. portability, price, accuracy, etc.) of these systems that were important to fitters were established.

It was determined that more data needed to be obtained, so a second survey was created for the custom fitters, shown in Appendix C. The purpose of this survey was to have fitters rank the importance of a more complete list of dynamic measurements and the identified product attributes. A greater understanding of how these systems are used by the fitters was also necessary in order to rank the product attributes. All of this information was utilized to compare the different systems by their dynamic measurements and product attributes. This product ranking was determined via a Quality Function Deployment (QFD) Product Planning Matrix.

The second survey was again created on a website, with the link to that website passed on to the PCS to distribute to its members. This longer and more in-depth survey was taken by 43 custom fitters compared to the 192 fitters that took the first survey.

Second Fitter Survey – General Ranking

The preliminary questions pertained to the number of clubs fit last year, price charged for a custom fitting session, and time spent with customers, which yielded a similar distribution of responses as the initial fitter survey.
This survey also inquired about whether custom fitting was a full-time or part-time job, and whether or not they also made clubs, or just fit them. The results (Figure 33) show that 55% of these fitters were part-time club fitters and club makers.

The fitters were given a list of 28 of the most mentioned dynamic measurements that were in the previous survey, and they were asked to rank these measurements on a scale from 1 to 5, with 5 being the most important. Table 10 shows the results of this ranking. Dynamic lie, which is a downward flexing of the shaft during a swing, was given the highest rank by the fitters. The reason for this is due to dynamic lie playing
such a key role in allowing the golfer to hit a straight and solid shot. If this is measured incorrectly, and subsequently the golfer is provided with poorly fit clubs, the chances of them having a consistent shot are greatly reduced.

The next highest ranking was the golfer feel/comfort. This is something that cannot be directly measured, rather it requires the golfer’s feedback to the fitter. It bears relevance, however, since this is a key input that fitters must take into consideration during the fitting process. The overall average score of these rankings was a 3.69.

Table 11: Percentage of Fitters that Utilize Each Dynamic Measurement

<table>
<thead>
<tr>
<th>Desired Dynamic Measurements</th>
<th>Percentage</th>
<th>Desired Dynamic Measurements</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golfer Feel/ Comfort</td>
<td>100.0</td>
<td>Club Angle at Impact</td>
<td>65.0</td>
</tr>
<tr>
<td>Clubhead Speed</td>
<td>97.5</td>
<td>Launch Angle</td>
<td>57.5</td>
</tr>
<tr>
<td>Ball Strikes Club</td>
<td>95.0</td>
<td>Ball Speed</td>
<td>55.0</td>
</tr>
<tr>
<td>Swing Tempo</td>
<td>92.5</td>
<td>Angle of Attack</td>
<td>47.5</td>
</tr>
<tr>
<td>Shaft Frequency</td>
<td>92.5</td>
<td>Shaft Acceler</td>
<td>42.5</td>
</tr>
<tr>
<td>Dynamic Lie</td>
<td>87.5</td>
<td>Downswing Time</td>
<td>40.0</td>
</tr>
<tr>
<td>Shaft Loading</td>
<td>85.0</td>
<td>Shaft Deflection</td>
<td>40.0</td>
</tr>
<tr>
<td>Shaft Spine</td>
<td>85.0</td>
<td>Release to Impact Time</td>
<td>30.0</td>
</tr>
<tr>
<td>Typical Club Distance</td>
<td>85.0</td>
<td>Ball Spinrate</td>
<td>27.5</td>
</tr>
<tr>
<td>Swing Path</td>
<td>80.0</td>
<td>Wrist Release Point</td>
<td>22.5</td>
</tr>
<tr>
<td>Ball Trajectory</td>
<td>75.0</td>
<td>Power Transfer Index</td>
<td>17.5</td>
</tr>
<tr>
<td>Ball Flightpath</td>
<td>75.0</td>
<td>Smash Factor</td>
<td>17.5</td>
</tr>
<tr>
<td>Ball Distance</td>
<td>72.5</td>
<td>Max Shaft Stress</td>
<td>17.5</td>
</tr>
<tr>
<td>Shot Dispersion</td>
<td>67.5</td>
<td>Wrist Turn Rate</td>
<td>10.0</td>
</tr>
</tbody>
</table>

This same data was also viewed from the perspective of how many fitters utilized each measurement during their fitting sessions (Table 11). It can be seen that the order of the measurements in this table closely resembles that of Table 10, thus showing that the fitters feel that the measurements they are using are important. In general, the measurements that are most used can either by obtained qualitatively by a fitter ‘eye-balling’ a golfer’s swing, or through the use of some of the cheaper dynamic measurement products. Conversely, the less frequently used measurements can only be acquired through the use of the high-end products, thus they are not used by many fitters.
Table 12: Ranking of Product Attributes

<table>
<thead>
<tr>
<th>System Product Attributes</th>
<th>Ranking</th>
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<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliable</td>
<td>4.85</td>
<td>Ease of Learning</td>
<td>3.70</td>
</tr>
<tr>
<td>Consistant</td>
<td>4.58</td>
<td>Quality of Data</td>
<td>3.65</td>
</tr>
<tr>
<td>All Golfers Use</td>
<td>4.55</td>
<td>Portable</td>
<td>3.48</td>
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<tr>
<td>Accurate</td>
<td>4.45</td>
<td>Intuitive Display</td>
<td>3.38</td>
</tr>
<tr>
<td>Ease of Operation</td>
<td>4.13</td>
<td>Provides Printout</td>
<td>3.28</td>
</tr>
<tr>
<td>Quick Feedback</td>
<td>4.13</td>
<td>Archives Data</td>
<td>3.28</td>
</tr>
<tr>
<td>Short Set-up Time</td>
<td>4.10</td>
<td>Low Cost</td>
<td>2.74</td>
</tr>
<tr>
<td>No Special Markers</td>
<td>4.00</td>
<td>Not Hit off Mat</td>
<td>2.43</td>
</tr>
<tr>
<td>Used Outdoors</td>
<td>3.84</td>
<td>Quantity of Data</td>
<td>2.15</td>
</tr>
<tr>
<td>Not affected by Sunlight</td>
<td>3.77</td>
<td>Elegant Looks</td>
<td>1.72</td>
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</table>

Next, the fitters were asked to rank 20 different product attributes associated with the tools they use for obtaining dynamic measurements. Table 12 summarizes the results of this ranking, and a complete description of each attribute can be found in the survey in Appendix C. It can be seen that attributes such as reliable, pertaining to the product infrequently malfunctioning, and consistent, meaning that the product provides the same result for different operators, were the top two attributes.

Of note is that some of the lower ranking attributes include cost, not hitting off of mats, and quantity of data. These are typically the attributes that the product manufacturers utilize to promote their products, thinking that fitters do not want to spend much, that they want products that allow for golfers to hit off of grass, and that more data is better.

6.2 Quality Function Deployment Product Planning Matrix

The rankings of the dynamic measurements and the product attributes provided a ranking of the needs of the custom fitters with respect to dynamic measurement products. These needs could now be used as a means of comparing the various systems currently used by the fitters. The tool that was chosen to perform this ranking was the QFD Product Planning Matrix²⁸.
6.2.1 Quality Function Deployment Process

QFD is a tool used in product development, and has the purpose of incorporating customer needs into the end product. It consists of a series of matrices and charts, and the one that is applicable to this study is the Product Planning Matrix, which is the first matrix used in the QFD process.

![Generic QFD Product Planning Matrix](image)

**Figure 34: Generic QFD Product Planning Matrix**
The QFD Product Planning Matrix is specifically utilized for translating customer needs, or the "What's", into the technical requirements for the product, or the "How's". The applicable portions of this matrix to this study are depicted in Figure 34. It should be noted that the matrix has been simplified for the purpose of discussing only the portions pertaining to this study. The matrix starts with a listing of the customer needs in the left-most column. These are typically generated through interviews, surveys, and focus groups with customers. These needs are given a ranking of 1-10, 10 being the most important, based on the inputs of the customer. Next, the design requirements are generated and placed along the top of the matrix. These are various neutral concepts that have been identified as possible technologies or processes that may be incorporated into the final product architecture.

The relationship matrix addresses how each technical requirement satisfies each customer need. A common practice is to complete this matrix by determining the relative strength for how each technical requirement satisfies each customer need. This relative strength can either be depicted by graphical symbols that indicate strong, medium, or weak relationships, or with corresponding numerical strength values of 9, 3, or 1. Thus, the matrix will reveal that a specific technical requirement has a strong, medium, or weak effect on a corresponding customer need.

Once the relationship matrix is completed, the technical requirements importance values may be calculated to provide a means of comparing the various technical requirements. The importance value is a weighted sum of the customer needs importance weighting and the associated technical requirements relationship. If customer need X had a weighting of 5 and technical requirement Y was given a medium relationship for X, then the corresponding importance weight for Y would be 15 (= 5 x 3). All of the importance weights for Y would then be summed over all customer needs to determine the overall technical requirement importance value. All technical requirements will have importance values calculated, thus allowing for them to be directly compared to one another and a relative ranking can be compiled. This ranking provides a screening basis.
by which to make decisions on which technical requirements are worthy of further investigation and which are not going to be used in the product.

6.2.2 Quality Function Deployment Applied to Product Ranking

A customized version of this matrix was utilized for comparing the various custom fitting systems that fitters assessed in the second survey.

Figure 35: Modified QFD Product Planning Matrix Used for Product Rankings

The customer needs were replaced by the ranked dynamic measurements in one matrix and by product attributes in the other (Figure 35). The technical requirements were replaced by the specific dynamic measurement products for both matrices. If this
QFD was to be utilized to design a fitting tool from scratch, then concepts would be placed in the technical requirements. Since the matrix is being used to compare products that already have a defined form, however, the technical requirements became the specific products. The relationship matrix measured how effectively each product addressed the customer needs, as assessed by the custom fitters. Finally, the importance weightings were summed by multiplying the customer need’s weightings by the product relationship, thus providing a weighted sum which was the overall product ranking for that specific QFD matrix. This allowed for a comparison of the various products based on their ability to satisfy the custom fitters. Before the ranking of the dynamic measurement systems could occur, however, the fitters had to provide ranking data on specific products.
7 Ranking Custom Fitter’s Systems

In order to provide information for this applied QFD matrix, the second fitter survey also had the custom fitters answer questions regarding the specific systems that they used to obtain dynamic measurements. Specifically, they provided the cost of the product, what dynamic measurements it provided, and they ranked the 20 product attributes for the system on a scale of 1 to 5, with 5 being the highest ranking. Fitters provided 40 responses on 17 different systems. Five of these fitters provided information on 2 products, which indicates that fitters will purchase multiple products in order to achieve more dynamic measurements. A list of the systems rated, a brief system description, and the price range (as provided by the fitters) is summarized in Table 13.

Table 13: Systems Rated by Custom Fitters

<table>
<thead>
<tr>
<th>System</th>
<th>Type of System</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Beltronics Swing Mate</td>
<td>Doppler Radar Clubhead Speed Measuring Device</td>
<td>&lt;$500</td>
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<tr>
<td>Bengston Company Swing Analyzer</td>
<td>IR Sensor Clubhead Speed Measuring Device</td>
<td>$500-$1k</td>
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<tr>
<td>DeadSolid VideoMentor</td>
<td>IR Sensor Clubhead Speed Measuring Device / Digitized Video Analysis</td>
<td>$10k-$15k</td>
</tr>
<tr>
<td>Distance Caddy Par 4</td>
<td>Doppler Radar Clubhead Speed Measuring Device</td>
<td>$1k-$2k</td>
</tr>
<tr>
<td>Dynacraft Frequency Analyzer</td>
<td>Frequency Analyzer</td>
<td>&lt;$500</td>
</tr>
<tr>
<td>ESP Fitting System</td>
<td>Shaft Software *</td>
<td>$7.5k-10k</td>
</tr>
<tr>
<td>Fit Chip</td>
<td>Shaft Accelerometer</td>
<td>$1k-$2k</td>
</tr>
<tr>
<td>Focaltron Golf Achiever</td>
<td>Laser Ball Flight Analyzer</td>
<td>$3k-$8k</td>
</tr>
<tr>
<td>Golfsmith Shaft Frequency Machine</td>
<td>Frequency Analyzer</td>
<td>&lt;$500</td>
</tr>
<tr>
<td>GolfTek Mini Pro 100</td>
<td>IR Sensor Clubhead Speed Measuring Device</td>
<td>$500-$1k</td>
</tr>
<tr>
<td>GolfTek Pro V</td>
<td>IR Sensor Clubhead Speed Measuring Device</td>
<td>$3k-$5k</td>
</tr>
<tr>
<td>Holiday Golf - Coach 2000</td>
<td>Digital Video Analysis</td>
<td>$5k-$7.5k</td>
</tr>
<tr>
<td>Mitsubishi Swing Trainer</td>
<td>IR Sensor Clubhead Speed Measuring Device</td>
<td>$500-$1k</td>
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<tr>
<td>Sportech Swing Analyzer</td>
<td>IR Sensor Clubhead Speed Measuring Device **</td>
<td>$5k-$7.5k</td>
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<tr>
<td>Swing Dynamics Ball Flight Monitor</td>
<td>High Speed Camera Ball Flight Analyzer</td>
<td>$15k-$20k</td>
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<tr>
<td>True Temper Determinator</td>
<td>Shaft Accelerometer***</td>
<td>$500-$1k</td>
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<tr>
<td>True Temper Shaft Lab</td>
<td>Shaft Strain Gauges</td>
<td>$7.5k-$10k</td>
</tr>
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</table>

* ESP Fitting System inputs clubhead speed, swing tempo, and fitter inputs and calculates the best shaft for a golfer
** The Sporttech Swing Analyzer also measures weight distribution throughout the swing
*** The True Temper Determinator has been discontinued, so very little additional information was gathered on it

7.1 Ranking Systems Based on Dynamic Measurements

The first system ranking performed was based on the dynamic measurements that the system provided to the custom fitter. The 17 systems were placed along the technical requirements row along the top of the previously discussed QFD Product Planning Matrix, with dynamic measurements placed along the customer needs column. The
weights associated with the dynamic measurements were taken from the ranking provided by the fitters in Table 10. These rankings were converted from a 1-5 scale to a 1-10 scale by taking the highest-ranking measurement, dynamic lie, and assigning it a weight of 10. Next, the lowest-ranking measurement, power transfer index, was given the ranking of 1. The remaining measurement’s weights were converted to the 1-10 scale via interpolation.

Table 14: QFD Matrix for Ranking Fitting Systems by Dynamic Measurement

<table>
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<tr>
<th>Dynamic Lie</th>
<th>Golfer Feel/ Comfort</th>
<th>Clubhead Speed</th>
<th>Shaft Frequency</th>
<th>Ball Strikes Club</th>
<th>Swing Tempo</th>
<th>Shot Dispersion</th>
<th>Shaft Deflection</th>
<th>Club Angle at Impact</th>
<th>Ball Flightpath</th>
<th>Shaft Loading</th>
<th>Downswing Time</th>
<th>Shaft Spine</th>
<th>Launch Angle</th>
<th>Shaft Acceler</th>
<th>Typical Club Distance</th>
<th>Ball Speed</th>
<th>Ball Trajectory</th>
<th>Swing Path</th>
<th>Smash Factor</th>
<th>Ball Distance</th>
<th>Max Shaft Stress</th>
<th>Angle of Attack</th>
<th>Ball Spinrate</th>
<th>Release to Impact Time</th>
<th>Wrist Release Point</th>
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<td>1.9</td>
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</tbody>
</table>

Total: 49 158 186 64 28 179 92 160 26 75 202 166 126 199 235 83 23 122
The relationship matrix was filled out next (Table 14), based on the inputs provided by the fitters. The survey only asked the fitter to indicate what dynamic measurements the system measured, not how well it measured each dynamic measurement. Therefore, the relationship matrix could not be utilized to indicate a strong, medium, or weak relationship between the product and the dynamic measurement based on the fitter’s input. If the fitter indicated that the system provided a certain measurement, then it was given a medium relationship, which was indicated by the number 3. If more than one fitter ranked the same product, then their responses were compared. If the fitters provided different dynamic measurements for this same system, then the dynamic measurements where they differed were given a weak relationship, which is represented with the number 1.

The average received score by all of the products was 128. It can be seen that the Swing Dynamics Ball Flight Monitor has the highest total with a score of 235. This product is a high-speed camera ball flight analyzer, which provides the fitter with numerous quantitative measurements associated with the golf ball and clubhead. This system, however, will cost a custom fitter between $15,000 and $20,000. Two frequency analyzers received the lowest score of 26. A frequency analyzer only measures one dynamic measurement, the shaft frequency, so this results in its low score. However, they typically cost less than $500.

Of the 17 products ranked, 12 of them provide the fitter with clubhead speed, which is one of the measurements ranked highly by fitters, which can be seen by its dynamic measurement weighting of 9.7 (Table 14). Several other important measurements, however, are not provided by many of these products. One of the four fitters that use the Belltronics SwingMate, a radar clubhead speed measuring device, claimed it measured dynamic lie. No other products provided this measurement, however, revealing that this is a fitter need, which has a weighting of 10, that is not being met by these products. Shaft deflection is another highly ranked dynamic measurement that is only provided by one product. If a new product were to be designed after seeing
the ranking of these dynamic measurements, it would need to focus on providing fitters with the higher ranking measurements in order to achieve a high QFD measurement score.

To investigate the QFD measurement score relationship with the product cost, a graph was constructed for the 17 systems (Figure 36).

![Figure 36: QFD Measurement Score versus Product Cost](image)

This graph, also called a competitive map in product development, illustrates where the products lie with respect to the average QFD measurement score of 128 and the average product cost of $4,100.

On the lower left quadrant of the graph are the simple products that measure 1 or 2 dynamic measurements, such as a frequency analyzer or a simple clubhead speed
measuring device. These products, although less functional for the custom fitter, are inexpensive and well within the budget of any fitter. As the number of measurements provided by the product increases, so does the complexity of the product, thus the product cost is higher.

The products residing in the upper right quadrant all have above average dynamic measurement scores, but with an associated above average cost to the fitter. An example product, the Holiday Golf Coach 2000, is a digitized video analysis product that provides the fitter with a much more functional analysis tool than the simpler products. As a result, it has a QFD measurement score of 202, but this increased functionality adds product cost. Also, the Focaltron Golf Achiever is a laser ball flight analyzer, which also has a higher QFD measurement score and a corresponding higher price. Finally, the Swing Dynamics Ball Flight Monitor shows that highest score is achieved at the highest cost to the consumer.

The products of note, however, are the True Temper Shaft Lab and the Bengston Company Swing Analyzer. The True Temper product has an above average cost, but with an associated low QFD measurement score. Based on this result, the product would not be desirable for custom fitter. This product does offer some unique measurements, however, such as the clubhead lead/lag with respect to the shaft and the shaft deflection which make it a valuable tool to fitters, but is not necessarily captured by this ranking criteria. It could also be a result of the Shaft Lab providing shaft recommendations for just True Temper shafts. The Bengston Company product, on the other hand, is the only product to provide above average dynamic measurements at a below average cost. This product is an IR sensor clubhead speed measuring device that provides fitters with a lot of the measurements they value, such as clubhead speed, swing tempo, and where the ball strikes the club, which give it such a high score.
Figure 37: Relationship of QFD Measurement Score and Product Cost

Figure 37 reveals that the relationship between the QFD measurement score and the product cost is not a linear one. Initially, the data reveals a relatively steep relationship, where an increase in the number of dynamic measurements does not result in a large price increase. The products in this region consist of frequency analyzers, and products typically using Doppler radar, IR sensors, and accelerometers. This relationship changes, however, once the QFD score gets above approximately 150, which indicates that the product provides more than a few measurements that fitters find important. These products are using more expensive technologies such as lasers, strain gauges, computer software, or high-speed cameras. The resulting increase in measurements leads to an increase in product complexity, which results in a more expensive product for the fitter. Above the score of 150, the slope of the relationship between the QFD score and the product cost transitions to a very gradual upward slope. Now, incremental improvements in the QFD measurement score result in a large increase in product cost.
7.2 Ranking Systems Based on Product Attributes

The next comparison focused on the product attributes (Table 15). The same 17 systems for which fitters provided dynamic measurement information were also rated for how well they met the product attribute needs of the fitter. A product might provide the fitter with all of the vital golfer measurements, but if it takes an hour to setup and it can only be used indoors by right-handed golfers, its value is greatly reduced in the eyes of the fitter. The rated systems were again placed along the top row of a QFD matrix and the 20 product attributes, already ranked by fitters, were placed in the customer needs column. The attribute weights were again calculated via interpolation after assigning the highest ranking attribute, reliable, a value of 10 and the lowest attribute, elegant looks, a value of 1. The relationship matrix was then filled in with the survey data provided by the fitters. When a system was ranked by more than 1 fitter, the ranks were averaged.

Table 15: QFD Matrix for Ranking Fitting Systems by Product Attributes

<table>
<thead>
<tr>
<th></th>
<th>Ballistics Swing Make</th>
<th>Ballistics Swing Analyzer System</th>
<th>Head Solid Video Monitor</th>
<th>Distance Caddy Fairway</th>
<th>Dynacraft Frequency Analyzer</th>
<th>ESS Fitting System</th>
<th>Fit Chip</th>
<th>Focusfit Golfer Achiever</th>
<th>Goldsmith Shaft Frequency Machine</th>
<th>Goldie Mini Pro 100</th>
<th>Goldie Pro V</th>
<th>Golfsmith Pro 200</th>
<th>Holiday Golf - Coach 200</th>
<th>Mitsubishi Swing Analyzer</th>
<th>Sportech Swing Analyzer</th>
<th>Swing Dynamics Ball Flight Monitor</th>
<th>True Temper Shaft Lab</th>
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<tr>
<td>Reliable</td>
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<td>46</td>
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</tbody>
</table>
All attributes were not ranked by fitters for all products, so those products that were only partially rated have significantly lower total QFD attribute scores. In order to allow all of the products to be compared to one another, an average attribute score was calculated for each product. The resulting data show that the highest average attribute score was received by the Dynacraft Frequency Analyzer, with a score of 35.6. The lowest average attribute score was 16.3, received by the Sporttech Swing Analyzer, which is an IR sensor ball flight analyzer that also provides measurements associated with the golfer’s weight distribution throughout their swing. The average of the average attribute score was a 25.6. A second competitive map was created to depict the relationship between product cost and the QFD attribute score (Figure 38).

![Figure 38: QFD Average Attribute Score versus Product Cost](image)

Again, this graph was divided into quadrants to reveal how the products compare with respect to the average product cost and the average attribute score. This graph
reveals a general trend of a decreasing QFD attribute score with increasing product cost. The cheaper products, such as the frequency analyzers, tend to have an overall higher attribute score. The decreasing attribute score with increasing cost is most likely associated with the increasing complexity of the technology present in the higher-end products. Although these products will provide more measurements, some of the following problems may arise with the product complexity:

- Becomes less portable due to equipment such as computers or video cameras.
- Requires spending more time with the golfer, thus slowing down the process.
- Product is required to be used in an indoor environment.
- Takes longer to learn how to operate and setup.
- Requires special lighting.

All of these result in lower attribute ranking for the more complex products.

The exception to this observation is the ESP Fitting System, which is purely a software product and does not generate any dynamic measurements by itself. It is typically utilized in conjunction with a clubhead speed measuring device and a fitter’s expert inputs to calculate the type of shaft a golfer should use. This product received a high attribute score, which was due to its accuracy, reliability, and ease of use.

7.3 Dynamic Measurement versus Product Attributes

After analyzing the QFD dynamic measurement scores versus the QFD product attribute scores, it was seen that many of the products that performed well in one category, performed poorly in the other. For example, the highest attribute score was received by the Dynacraft Frequency Analyzer, with a score of 35.6. This is the same frequency analyzer that received the lowest dynamic measurement score of 26. The lowest attribute score was 16.3, received by the Sporttech Swing Analyzer, which received one of the highest dynamic measurement scores of 199. To further depict this, a final competitive map was created, disregarding the product cost and only comparing the products based on their dynamic measurement and product attribute scores (Figure 39).
Figure 39: QFD Measurement Score versus Average Attribute Score

This competitive map shows only one product that is above average in both categories, the ESP Fitting System. As was previously mentioned, this system does not provide the fitter with any independent dynamic measurements, rather it takes fitter inputs, performs thousands of calculations, and makes a shaft recommendation to the fitter. Excluding this product, then, reveals that no dynamic measurement products achieve superior scores in both categories. It can be seen that several more complex products provide the fitters with above average dynamic measurement data, but at the cost of low product attribute scores due to their complexity. Conversely, the products with the high product attribute scores are the simple products that do not achieve a high dynamic measurement score due to their minimal dynamic measurements. This allows the opportunity for new products utilizing different technologies to take advantage of the fact that the existing products in this market do not satisfy all of the needs of the consumer.
From a product development perspective, the dynamic measurement QFD matrix and competitive map provide vital information. Specifically, it reveals the dynamic measurements that are most important to fitters, and where the competition’s products currently stand with respect to these fitter needs. A competitive product would need to provide above average dynamic measurements, while not sacrificing the product attributes that fitters value. To develop a new product for fitters, a company would want to focus on exploiting the fact that only one product was found to meet these fitter dynamic measurement and product attribute needs. Since it is now known what dynamic measurements are most important to custom fitters, these should be incorporated in the product development process as customer needs, and some associated product specification goals would be set accordingly. These would become product goals early on in the process before a technology has been chosen. Then, the development team would begin their concept development, incorporating various technologies, in order to identify the ones that could achieve these specifications at a low cost and thus create a product that fitters will want to buy. This process allows for incorporating the voice of the customer, the club fitter, into the design process so that a product is created that truly satisfies their needs.

The product attribute information can also be utilized to create a product that is designed to satisfy the custom fitters. By understanding the importance of the various attributes and where competing products rank, initial product specification goals can be established to achieve a high attribute score that would separate a new product from the competition. The product goals created by this data might conflict with those previously established from the dynamic measurement data, resulting in tradeoffs that will eventually have to be addressed by a product development team. The goals, however, need to be established in order to create measures of success by which to determine the success of their product design.
By creating the competitive map showing the tradeoffs between quality dynamic measurements and fitter-oriented product attributes, it was revealed how a new product can truly become competitive in this industry. First, the graph showed that, except for a software product, the competition either focuses on complex, restrictive products or simple products that provide limited value to the fitter. This reveals that if a product were to be designed in this industry that provided above average dynamic measurements while maintaining above average product attribute characteristics, it would be a unique product that truly would satisfy the needs of the custom fitter.

A more competitive product could be created by making incremental changes to current products and technologies in this industry. These changes could focus on enhancing the product attribute characteristics of some of the more complex products with high dynamic measurement scores. This could also occur by having the simpler products provided more useful dynamic measurements to custom fitters, either by direct measurement or through the use of computer software that makes calculations based on already provide dynamic measurements. The incremental improvements would most likely not create a significantly more competitive product, however, since their improvements would be slight.

Two new systems are proposed for custom fitters. Both products utilize technologies that are proven, but have not yet been incorporated by custom club fitters. Since they utilize proven technology, this would lower the barriers to entry for these new products, increasing their chances of being successful.

8.1 Motion Analysis Systems

Motion Analysis Systems are existing products that allow for measurements such as acceleration, velocity, or distance to be accurately measured from a dynamic event that has been captured on videotape. They are utilized for performing biomechanical analysis, primarily in the medical field, and they can also be found in the sports industry, utilized as a coaching/teaching aid. Specific applications of this product include a
physical therapist monitoring a patient’s progression of recovery from an injury, or in the case of a golf instructor, analyzing a golfer’s swing.

8.1.1 Application to Custom Fitting

Golf instructors utilize many of the same products as custom golf club fitters, since understanding the dynamic portions of the golfer’s swing is beneficial to both. The use of such a system has been found in the golfing industry by golf teaching professionals, but not by custom fitters. An example of such a product is the Peak Modus® by Peak Performance (Figure 40).

![Peak Modus® Motion Measurement System](image)

Figure 40: Peak Modus® Motion Measurement System

Similar to the digitized video analysis products, the motion analysis system utilizes an analog-to-digital converter to allow information captured by up to 6 video cameras to be analyzed on a computer. When used by golf instructors, they are able to analyze the movement, velocity, and acceleration of any portion of the golfer’s body, the golf club, or even the golf ball. This is performed by attaching a reflective piece of tape to any point that the instructor desires to track. Then, the golfer will hit golf balls, and that motion will be captured on the various video cameras. By having more than one video camera and placing them at multiple angles, motion of these various points can be captured, the videos synchronized, and the motion analyzed in 3 dimensions. The more
cameras present, the higher the likelihood that at least two cameras will view the motion of a particular point throughout the entire event. Special lighting is arranged so that the various points on the golfer can be easily determined at all stages of their swing. All of the camera data is digitized and sent to the computer so that it can all be compiled in order to begin the 3-D analysis. The instructor synchronizes the videos at a common starting point, and then correlates the various markers between all of the views. Then a coordinate system is established on the digitized video of the golfer via a calibration unit. The computer software is then able to track the various markers during the swing and their movement is determined relative to the established coordinate system in order to calculate the distance traveled by each point. The software can then be used to differentiate the obtained position data to calculate the velocities and acceleration of any point throughout the entire swing.

Motion analysis systems are modular in nature, so various components can be combined to meet the needs of the fitter. There are configurations of this product that would allow for the golfer to not wear reflective markers. In this setup, the golfer is filmed hitting golf balls in normal attire, outside or inside, with multiple cameras. All of the video is again digitized and sent to a computer for analysis. Once there, the fitter would synchronize the multiple videos, and then manually selects distinct points on the golfer’s body, golf club, or golf ball that should be tracked throughout the swing. This is done frame-by-frame for the first few frames, after which the software is able to predict the future position of this point in order to track it to the next frame. The software will then correlate the points throughout the golfer’s swing to obtain the desired dynamic measurements.

With this manual tracking option, the video footage can be taken outside, without markers, allowing the video footage of the golfer’s swing to be taken in an environment more conducive to the golfer’s normal surroundings. Using this option, however, is very time consuming, since the fitter would have to go through frame-by-frame for several frames to enable the software to perform its tracking of designated points. Also, downloading all of the video footage to a computer can also take a lot of time. Using
reflective markers is a much quicker method for obtaining data, however it would have to be performed in a controlled lighting environment. Also, for optimal results, all points have to be viewed by at least two cameras at all times. This may require more than two cameras, and since high-speed cameras are utilized for this product, the purchasing of addition cameras can greatly add to the price. The more cameras that are utilized also result in an increased time to receive data, due to both a greater setup time and more data to download to the computer for analysis.

Regardless of how the points are tracked, the fitters will be able obtain quantitative data that used to only be qualitative in nature. Using a motion analysis system gives the them the ability to measure the position, velocity and acceleration of any chosen point, thus providing them with the potential to analyze more than just the clubhead, shaft, or ball. For example, the fitter can obtain specific measurements associated with the golfer's swing path. Previously, this information could be provided by an IR sensor clubhead speed measuring device, but it would only show the fitter the general motion of the clubhead at the point of impact. This would indicate if the clubhead was traveling a square, inside-to-outside or outside-to-inside path as the golfer was striking the ball. Utilizing the motion analysis system, however, also enables the fitter to be able to determine the number of inches the swing path digresses from the proper swing plane and the velocity across the ball in addition to down the target line. Like the digitized video analysis systems, the motion analysis systems allows for side-by-side swing analysis with professional golfer's swings. Therefore, professional golfers with good swings can be used to provide reference data.

For the custom fitter, a motion analysis system provides information related to the shaft that was previously only received through products utilizing strain gauges. Such measurements would include shaft deflection, toe droop, and the lead/lag of the clubhead relative to the shaft at impact. Unlike the strain gauge products, however, the golfer is not swinging a club with wires attached. Additionally, the motion analysis system is able to provide the fitter with information related to the golf ball, which previously required the use of a ball flight analyzer. Information such as ball speed, launch angle, and
azimuth angle can accurately be determined from the 3-D motion analysis. The software can also be utilized to accurately calculate the ball spin rate, both in terms of sidespin and backspin, the same way the high-speed camera ball flight analyzer does, which greatly increases its value to fitters.

Motion analysis systems will get faster, more reliable and cheaper as a function of the improving technology associated with the camera equipment, computers, and tracking software. As computer speeds increase, the download times will decrease, making this a more attractive option. Also, as the camera equipment becomes faster, better quality images will be provided. Higher resolution digital photos increase the ability of the software to manually track selected data points. Improvements in tracking software will decrease the user input requirements. All of this will lead to a product that is easier to use outdoors and in a wide variety of lighting conditions.

8.1.2 QFD Analysis

Motion analysis systems enable the fitter to obtain most, if not all, of the same measurements as a combination of a clubhead speed measuring device, strain gauge system, and ball flight analyzer. It also allows for all of the same slow motion analysis tools that digitized video analysis products utilize. Because of this, this system would achieve an extremely high QFD dynamic measurement score since it can obtain nearly all of the desired measurements of custom fitters, plus many that fitters currently do not use. These products start at a price of around $25,000 for a computer, the software, and two high-speed cameras.

A motion analysis system’s cost is more expensive than the previously discussed products, but it can take the place of multiple products. Based on the second fitter survey, there are custom fitters who purchase more than one dynamic measurement product since these products all provide different pieces of information pertaining to the golfers swing. For example, one fitter utilized the DeadSolid VideoMentor, which is both an IR sensor clubhead speed measuring device and a digitized video analysis product, and the True Temper Shaft Lab, which is a shaft strain gauge device. Together,
these products cost between $17,500 and $25,000, and neither one provides accurate ball flight information. Combined these products achieve a QFD measurement score of 263 as seen in Table 16 (note that there are overlapping measurements, so the raw QFD measurement scores cannot be added together). Another fitter owned the Swing Dynamics Fall Flight Monitor, which is a high-speed camera ball flight analyzer, and the GolfTek Pro V, which is an IR sensor clubhead speed measuring device. These two products cost between $18,000 and $25,000 and neither provide accurate shaft information. They receive a combined QFD measurement score of 260.

Table 16: QFD Analysis for Motion Analysis System

<table>
<thead>
<tr>
<th>Dynamic Lie</th>
<th>DeadSolid + Shaft Lab</th>
<th>Swing Dynamics + Pro V</th>
<th>Motion Analysis System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Lie</td>
<td>10.0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Golfer Feel/ Comfort</td>
<td>9.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clubhead Speed</td>
<td>8.8</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Shaft Frequency</td>
<td>8.8</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ball Strikes Club</td>
<td>8.4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Swing Tempo</td>
<td>7.7</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Shot Dispersion</td>
<td>7.5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Shaft Deflection</td>
<td>7.4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Club Angle at Impact</td>
<td>7.3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Ball Flightpath</td>
<td>7.2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Shaft Loading</td>
<td>6.9</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Downswing Time</td>
<td>6.9</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Shaft Spine</td>
<td>6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch Angle</td>
<td>6.3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Shaft Acceler</td>
<td>6.2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Typical Club Distance</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball Speed</td>
<td>5.9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Ball Trajectory</td>
<td>5.3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Swing Path</td>
<td>5.3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Smash Factor</td>
<td>4.9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Ball Distance</td>
<td>4.7</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Max Shaft Stress</td>
<td>4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle of Attack</td>
<td>4.0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Ball Spinrate</td>
<td>2.9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Release to Impact Time</td>
<td>2.3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Wrist Release Point</td>
<td>1.9</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Wrist Turn Rate</td>
<td>1.3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Power Transfer Index</td>
<td>1.0</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Total: 263 260 338
Assuming the cost of a motion analysis system to be set at $25,000, a fitter could purchase one of these and immediately have a product that achieved a QFD dynamic measurement score of over 338 (Figure 41).

![Figure 41: Motion Analysis System QFD Measurement Score Goals](image)

Assessing a motion analysis system for its QFD product attribute score is more difficult, however, since it has not been utilized by custom fitters. It would require getting the feedback from fitters after they performed several custom fitting sessions with this product. It is also difficult to determine a combined QFD product attribute score for the fitters that utilize more than one dynamic measurement product. Due to the fact that more than one product has to be used, however, has to result in a collective attribute score being at most equal to the lowest individual product attribute score. It would be much more convenient for a fitter if they could utilize one product to obtain all measurements.
By looking at the product attribute competitive map, a marginal and ideal goal can be set for a motion analysis system based on the ultimate goal of achieving an above average product attribute score (Figure 42). This could probably be attained since the product is modular and it could be customized for use by custom fitters. It would have to be designed such that heavily weighted product attributes such as reliable, consistent, used by all golfers, and accurate were the focus of a product design team. Since attributes such as product cost, used outdoors and no special markers do not have the heaviest weights associated with them in the QFD Matrix, these should not prevent a motion analysis system from achieving a high attribute score.

Figure 42: Motion Analysis System QFD Product Attribute Score Goals
With both the dynamic measurement and product attribute goals established, a competitive map comparing dynamic measurements and product attributes (Figure 42) illustrates how this potential product would truly be superior in terms of these measurements of fitter satisfaction.

8.1.3 Market Entry

From a product development perspective, a team could easily enhance a motion analysis system by creating customized software for fitters to facilitate obtaining the pertinent dynamic measurements. This team could set goals, both ideal and marginal, for
the product to achieve in terms of the dynamic measurement score. Doing this would create product that was truly differentiated from existing products on the market.

To begin an entry into the custom fitting market, this product would have to be focused on being sold to custom fitters that are currently using two or more custom fitting products in order to obtain ample dynamic measurements. These are the fitters that realize the value of these measurements and would also understand that there is not one product that will provide a majority of the desired measurements. Another segment of the fitting industry that would embrace this product’s introduction would be the custom fitters that are also golf instructors. This product would provide them with applicable measurements and features to perform both jobs to a superior level.

8.1.4 Product Evolution

To be a truly competitive product, motion analysis systems would have to become available to a larger percentage of the custom fitters. Once the early adopting fitters achieved successful results with this product, the desire for other fitters to have such a product would be initiated via word-of-mouth. Following this with an aggressive marketing campaign depicting the benefits of this product over the competition would ensure the product continued to gain popularity.

As the technology for such a product becomes more affordable, the product can be split into a high-end and an entry-level product. Making a more affordable version would allow hesitant fitters the justification to make the large purchase.

Over time, similar products would enter this market trying to benefit from the success received from attaining the first-mover advantage in a market. To remain competitive when this begins, a company would need to remain focused on satisfying the custom fitters. By continually incorporating the voice of the fitter into follow-on products, a company will ensure that they remain the product of choice.
8.2 Artificial Intelligence Programming (Expert Systems)

Based on the high QFD scores of the ESP Fitting System, which is a software product used for interpreting fitter inputs to determine a best shaft recommendation, another new technology that deserves mentioning is Artificial Intelligence Programming, specifically Expert Systems. While motion analysis would provide an improvement to the current custom fitting industry by utilizing a new technology to obtain more dynamic measurements, an Expert System could be utilized to better harness the current data that club fitters receive. Since this product does not provide dynamic measurements, it will not be analyzed by estimating potential QFD scores, rather discussed on how it would benefit custom fitters.

Custom fitting is both an art form and a science. As more products are created to provide a fitter with new and more accurate quantitative measurements, this process slowly shifts to becoming more and more of a science. No matter how many measurements a fitter is provided, it is still the fitter that makes the decision as to what elements of the club to fit to the golfer. Due to their being no standardized fitting procedures and fitters with a different fitting experience utilizing numerous products, it can be assumed that a wide variation of custom fitting is present within the industry. An Expert System can be employed to alleviate this lack of consistency by providing all fitters with an expert knowledge base (Figure 44).
Expert Systems have been developed in Artificial Intelligence Programming in order to construct computer programs that replicate human logic\textsuperscript{31}. These programs are created to emulate human expertise in a well-defined area, for example in product design\textsuperscript{32}, such that the program can be provided with a series of inputs and it will logically come to a best solution. The Expert System will methodically match these inputs against patterns and automatically determine the appropriate rules that apply and make a decision based on these rules. Of course, the system needs to be provided with rules by which to make its decisions, so an expert custom golf fitter (or many fitters) would have to be employed in the construction of such a product. Additionally, the Expert System could incorporate the kinematic knowledge possessed by a physical therapist, the golf swing understanding of a golf instructor, and the material knowledge of a golf club maker to create the ultimate fitting knowledge base.
Ultimately, this product would change how custom fitting is performed. It could build on the current infrastructure of custom fitters, since it needs to be provided with measurements. In fact, the more measurements it is given the more accurate its decision making process, so a custom fitter would be encouraged to have multiple products that capture dynamic measurements. Instead of providing more information for the fitter to process, this product would more efficiently process the same data the fitter currently uses. Based on all of the information, it could then be programmed to provide the best club component recommendations for the fitter to best fit the golfer. The fitter could then provide the golfer with that recommended combination of club elements and take more data on the golfer’s swing. This new data would also be input into the program in order to make a refined recommendation. The overall process of a fitter ‘dialing in’ on the best fit clubs for the golfer would still be the same, only now it would most likely achieve the desired end state in a much shorter time. Currently a fitter will spend in excess of an hour with a golfer making incremental changes in the club components in order to determine a best fit club. This system could allow the incremental steps to become much larger, thus significantly decreasing the time.

Additionally, this product would provide more experience to fitters that are relatively new to the process. Since currently all data is processed by the custom fitter, he or she is the limiting factor to the quality of the fit a golfer will receive. If this fitter is given recommendations from an Expert System, technically it would be as if the golfer was being fit by the all of the experts that were utilized in the creation of the program. Fitters that already have lots of experience could utilize the additional knowledge captured from the physical therapist, golf instructor, or golf club maker. Ultimately, it would provide any fitter with more customer credibility and a faster fitting process.

This system would provide custom fitters with a more methodical method of custom fitting that would be capable of processing the wide variety of inputs currently utilized by custom fitters. The new process would substitute the Expert System as the processor of all of the data, thus allowing the fitter to become more focused on obtaining
quality data and maintaining the big picture on the process. Such a system would allow for the processing of many more dynamic measurements without adding significant time to the fitting process by bogging down the custom fitter, thus making it a potentially very competitive product in the custom fitting industry.
Conclusions

This thesis explained the complexities associated with the golf swing and golf club design, and then investigated the various product technologies custom fitters utilize to overcome these challenges. After discussing these products, custom golf club market research was performed, surveying both custom fitters and golfers that use custom clubs. This initial research revealed that golfers are willing to pursue the custom fitters that perform a detailed fitting service, where they will receive a set of clubs that is custom fit to their swing. These golfers are willing to spend more than an additional 1.5 hours and $50 in order to receive a perfectly fit set of clubs.

Next, the product needs of custom club fitters were established by ranking the dynamic measurements and product attributes that they find most important. Information about specific products, provided by custom fitters, was then used to compare these products by their dynamic measurements and product attributes in order to determine how well they satisfied the needs of the fitters. This comparison was conducted through the customized use of a product development tool, the QFD Product Planning Matrix.

Based on this product comparison, only one product ranked above average in both the categories of dynamic measurement and product attributes, the ESP Fitting System. This product, however, is not a dynamic measurement system. Instead, it is a software product that processes measurements input from custom fitters in order to make a shaft recommendation to the fitter. Therefore, no dynamic measurement products achieved an above average ranking in both categories.

This comparison revealed the opportunity for new products to be created that would take advantage of the determined the needs of the custom fitters, and the discovered inadequacies of the existing products. This opportunity was viewed from a product development perspective in order to determine potential products that could provide a fitter with quality dynamic measurements without sacrificing the product attributes that custom fitters desire.
New technologies were investigated to propose new superior products what would satisfy the fitter’s needs. The first proposed product is a motion analysis system, an existing product that has not yet been used by custom fitters. This product was shown to have great potential for supplying fitters with numerous dynamic measurements that they find important. The second product was proposed based on the high rankings achieved by the ESP Fitting System. This new product would also be software, but instead of making shaft fitting recommendations, it would fit the entire golf club. This product would incorporate a relatively new software technology, Artificial Intelligence Programming, specifically an Expert System. It would benefit the fitter by utilizing an expert knowledge base that would make expert fitting recommendations. This product would not only make custom fitting more reliable, but would greatly decrease the amount of time that fitters would need to spend with golfers.

This thesis is by no means a complete study of the custom fitting industry. To truly compare all of these products, each would need to be purchased and tested. Doing this would allow for comparing the accuracy of dynamic measurements between products and technologies, in addition to capabilities. For example, all three types of ball flight analyzers claim to measure ball spin rate. Based on the technologies utilized, however, both the laser and Doppler radar ball flight analyzers are believed to calculate the spin rate via an algorithm, while the high-speed camera ball flight analyzer is truly capable of measuring the spin rate. Therefore, a direct comparison of these three technologies would provide a better understanding of their accuracy and capabilities. Directly comparing all products would allow for a more accurate competitive mapping of these products and it would provide more precise product specifications for future superior products to use as product design goals.

By revealing the opportunity for the entry of a new product in this market is just the beginning of the product development process. To truly take advantage of the inability of existing products to satisfy the needs of the fitter, a product development team would need to investigate a more extensive list of concepts that have the potential of
addressing the identified needs. By knowing the dynamic measurements and product attributes of the customer in the beginning of the process, however, will allow the design of a new product to focus on addressing the important needs through establishing product specification goals. Once a few concepts are identified as viable solutions, a more detailed ranking would need to occur, investigating the accuracy of such concepts and the feasibility of their production. Once a concept is identified, prototypes can be created, which then would provide the fitters something to test instead of talk about. This provides valuable feedback to the product development team and true insight as to how the product will be utilized. Finally, after incorporating fitter feedback, the product development team would have a product that could be tested in order to assess the achievement of the product specification goals, thus allowing them to determine if they created a competitive product for this market.
Bibliography


25. Distance Caddy; http://www.distancecaddy.com/.


Appendix A: First Custom Club Fitter Survey
# Survey for Custom Golf Club Fitters

This website was established June 1st, 2001. All information will be emailed to Andrew Mauger.

<table>
<thead>
<tr>
<th>Company</th>
<th>State of Residence</th>
</tr>
</thead>
</table>

**Approximately how many sets of CUSTOM clubs did your company fit last year?**

- Less than 50 sets
- 50 - 100 sets
- 100 - 200 sets
- 200 - 300 sets
- 300 - 500 sets
- 500 - 1,000 sets
- More than 1,000 sets

**How many years have you been making custom golf clubs?**

- Less than 2 years
- 2 - 5 years
- 5 - 10 years
- 10 - 15 years
- 15 - 20 years
- 20 - 30 years
- More than 30 years

**How much time (on average) is required with the customer in order to obtain all of the measurements required for custom fitting?**

- Less than 15 minutes
- 15 minutes - 30 minutes
- 30 minutes - 1 hour
- 1 hour - 1.5 hours
- 1.5 hours - 2 hours
- 2 hours - 3 hours
- More than 3 hours

**How much additional time is required to complete the custom clubs (watching video tape, converting video tape to a digital image for the computer, etc.)?**

- Less than 15 minutes
- 15 minutes - 30 minutes
- 30 minutes - 1 hour
- 1 hour - 1.5 hours
- 1.5 hours - 2 hours
- 2 hours - 3 hours
- More than 3 hours

**How much is the price of golf clubs increased after custom fitting?**

- It's Free
- Less than $25
- $25 - $50
- $51 - $100
- $101 - $150
- $151 - $200
- More than $200

**What components of the golf club do you custom fit?** (check all that apply)

- Grip size
- Shaft length
- Shaft stiffness
- Shaft flex point
- Shaft material

**What dynamic measurements do you utilize when creating custom fit clubs?** (check all that apply)

- Clubhead speed
- Swing path
- Typical distance of certain club (5-iron)
What additional dynamic measurements, if any, would you like to have when custom fitting?

Rank these measurements as Significantly Important, Somewhat Important, or Not Important with respect to custom fitting:

<table>
<thead>
<tr>
<th>Clubhead speed</th>
<th>Swing path</th>
<th>Typical distance of certain club (5-iron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select</td>
<td>Select</td>
<td>Select</td>
</tr>
<tr>
<td>Shaft deflection</td>
<td>Swing tempo</td>
<td>Part of club that strikes ground</td>
</tr>
<tr>
<td>Select</td>
<td>Select</td>
<td>Select</td>
</tr>
<tr>
<td>Ball trajectory</td>
<td>Clubface angle at impact</td>
<td>Where ball strikes clubface</td>
</tr>
<tr>
<td>Select</td>
<td>Select</td>
<td>Select</td>
</tr>
<tr>
<td>Ball flightpath</td>
<td>Power transfer index</td>
<td>Other:</td>
</tr>
<tr>
<td>Select</td>
<td>Select</td>
<td>Select</td>
</tr>
</tbody>
</table>
**What type of system did the fitter utilize to obtain information regarding your swing?**

(choose all that apply)

- Inputs from golfer (verbal or via survey)
- Swing analysis system (video tape swing then analyze on computer by drawing reference lines to show the swing path)
- Watching golfer hit golfballs
- Shaft strain gauge (attaches to shaft and provides speed and deflection data to computer)
- Marker tape on clubface
- Motion analysis system (swing analysis system that also measures displacement, velocity and acceleration of golfer's swing - usually wear reflectors while swinging)
- Video taping golfer
- Ball trajectory analysis system
- Clubhead speed measuring device
- Other:__________________

---

**How much did your company pay for the system?**

<table>
<thead>
<tr>
<th>Price Range</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than $500</td>
<td>ᵐ</td>
</tr>
<tr>
<td>$500 - $999</td>
<td>X</td>
</tr>
<tr>
<td>$1,000 - $4,999</td>
<td>X</td>
</tr>
<tr>
<td>$5,000 - $9,999</td>
<td>X</td>
</tr>
<tr>
<td>$10,000 - $49,999</td>
<td>X</td>
</tr>
<tr>
<td>$50,000 - $99,999</td>
<td></td>
</tr>
<tr>
<td>More than $100k</td>
<td></td>
</tr>
</tbody>
</table>

What is included with this cost? ____________________________

**How much training time was necessary to become proficient using this system?**

<table>
<thead>
<tr>
<th>Training Time</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 hr</td>
<td>X</td>
</tr>
<tr>
<td>1 hr - 2 hr</td>
<td>X</td>
</tr>
<tr>
<td>2 hr - 3 hr</td>
<td>X</td>
</tr>
<tr>
<td>3 hr - 6 hr</td>
<td>X</td>
</tr>
<tr>
<td>6 hr - 12 hr</td>
<td>X</td>
</tr>
<tr>
<td>1 day - 5 days</td>
<td>X</td>
</tr>
<tr>
<td>More than 5 days</td>
<td></td>
</tr>
</tbody>
</table>

What needed to be learned? ____________________________

---

Please comment on what you LIKE most about this system(s):_______________
Please comment on what you DISLIKE most about this system(s):

Additional Comments/Suggestions:
Use the space below to tell me any additional comments or recommendations regarding custom golf club fitting.

Thanks again for your time, and may the Golfing Gods shine favorably upon you!
Appendix B: Golfer Survey
Survey for Golfers Who Play (or Have Played) with Custom Golf Clubs

This website was established June 1st, 2001. All information will be emailed to Andrew Mauger.

<table>
<thead>
<tr>
<th>State of Residence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

**What age group are you in?**

- Under 20
- 20-29
- 30-39
- 40-49
- 50-59
- 60-69
- Over 70

**What is your yearly household income?**

- $30,000 or less
- $30,000-$49,999
- $50,000-$74,999
- $75,000-$99,999
- $100,000-$149,999
- $150,000-$199,999
- $200,000 or more

**How many years have you been playing golf?**

- < 2 years
- 2 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 30
- > 30 years

**How many rounds have you played in the last year?**

- < 5 rounds
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 30
- 30 - 40
- > 40 rounds

**What is your current handicap?**

- 0 or better
- 0 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- > 20
- Unsure

**How many tournaments have you played in over the last year?**

- None
- 1 - 2
- 3 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- > 20

**Do you currently play with custom fit golf clubs?**

- Yes
- No

**How many sets of custom clubs have you owned?**

- 1
- 2
- 3
- 4 or More

For the most recent set of custom golf clubs that you have purchased:

**How much did you pay for the clubs?**
### Premium for Club Custom Fit

<table>
<thead>
<tr>
<th>Amount</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than $300</td>
<td></td>
<td>![Yes]</td>
</tr>
<tr>
<td>$300 - $499</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>$500 - $699</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>$700 - $899</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>$900 - $1199</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>$1200 - $1499</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>More than $1500</td>
<td>![Yes]</td>
<td></td>
</tr>
</tbody>
</table>

### Time with Fitter

<table>
<thead>
<tr>
<th>Time</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 15 min</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>15min - 30min</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>30min - 1 hr</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>1hr - 1.5hr</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>1.5hr - 2hr</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>2hr - 3hr</td>
<td>![Yes]</td>
<td></td>
</tr>
<tr>
<td>More than 3 hrs</td>
<td>![Yes]</td>
<td></td>
</tr>
</tbody>
</table>

### Clubs Custom Built

- [ ] 2-pw
- [ ] Driver

### Clubs Fit for Swing

- [ ] The same
- [ ] Somewhat better
- [ ] Significantly better
- [ ] They fit perfectly

### Swing Information

- Inputs from golfer (verbal or via survey)
- Swing analysis system (video tape swing then analyze on computer by drawing reference lines to show the swing path)
- Watching golfer hit golfballs
- Shaft strain gauge (attaches to shaft and provides speed and deflection data to computer)
- Marker tape on clubface
- Motion analysis system (swing analysis system that also measures displacement, velocity and acceleration of golfer's swing - usually wear reflectors while swinging)
- Video taping golfer
- Ball trajectory analysis system
- Clubhead speed measuring device
- Other: 

### Golf Club Measurements

- Grip size
- Club type (brand or style)
- Shaft length
- Swing weight
<table>
<thead>
<tr>
<th>Shaft stiffness</th>
<th>Clubhead lie angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft flex point</td>
<td>Offset or Onset</td>
</tr>
<tr>
<td>Shaft material</td>
<td>Other:</td>
</tr>
</tbody>
</table>

**Do you see yourself purchasing custom golf clubs in the next 5 years?**
- [ ] Yes
- [ ] No

**Do you see yourself purchasing custom golf clubs in the next 10 years?**
- [ ] Yes
- [ ] No

**How much would you be willing to pay for a set of perfect fitting irons (3-pw)?**
- [ ] Less than $300
- [ ] $300 - $499
- [ ] $500 - $699
- [ ] $700 - $899
- [ ] $900 - $1199
- [ ] $1200 - $1499
- [ ] More than $1500

**How much time would you be willing to spend with the fitter for these irons?**
- [ ] Less than 15 minutes
- [ ] 15 min - 30 min
- [ ] 30 min - 1 hr
- [ ] 1hr - 1.5hr
- [ ] 1.5hr - 2hr
- [ ] 2hr - 3hr
- [ ] More than 3 hours

**Comments:**
Use the space below to tell me any additional comments or recommendations regarding custom golf club fitting.

```

```

Thanks again for your time, and may the Golfing Gods shine favorably upon you!
Appendix C: Second Custom Club Fitter Survey
## The New & Improved

### Survey for Custom Golf Club Fitters

This website was established August 1st, 2001. All information will be emailed to Andrew Mauger.

<table>
<thead>
<tr>
<th>Company</th>
<th>State of Residence</th>
</tr>
</thead>
</table>

**Approximately how many sets of CUSTOM clubs did your company fit last year?**

<table>
<thead>
<tr>
<th>&lt; 50 sets</th>
<th>50 - 100</th>
<th>100 - 200</th>
<th>200 - 300</th>
<th>300 - 500</th>
<th>500 - 1,000</th>
<th>&gt; 1,000 sets</th>
</tr>
</thead>
</table>

**Which of the following best describes your role as a Custom Club Fitter?**

<table>
<thead>
<tr>
<th>Full-time Clubfitter</th>
<th>Part-time Clubfitter</th>
<th>Full-time Clubmaker/Fitter</th>
<th>Part-time Clubmaker/Fitter</th>
<th>Other:</th>
</tr>
</thead>
</table>

**What do you charge for fitting Custom Clubs (above and beyond the price of the clubs)?**

<table>
<thead>
<tr>
<th>It is Free</th>
<th>Less than $25</th>
<th>$25 - $50</th>
<th>$51 - $100</th>
<th>$101 - $150</th>
<th>$151 - $200</th>
<th>More than $200</th>
</tr>
</thead>
</table>

**How much time (on average) is required with the customer in order to obtain all of the measurements required for custom fitting?**

<table>
<thead>
<tr>
<th>Less than 15 minutes</th>
<th>15min - 30min</th>
<th>30min - 1 hr</th>
<th>1hr - 1.5hr</th>
<th>1.5hr - 2hr</th>
<th>2hr - 3hr</th>
<th>More than 3 hours</th>
</tr>
</thead>
</table>
Please rank the Dynamic Measurements below by their importance with respect to YOUR Custom Fitting. (5 = very important, 1 = slightly important)

<table>
<thead>
<tr>
<th>Do Not Use</th>
<th>Ball Speed</th>
<th>Do Not Use</th>
<th>Swing Path</th>
<th>Do Not Use</th>
<th>Shaft Frequency (CPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch</td>
<td>Swing</td>
<td>Tempo</td>
<td>Clubface</td>
<td>Angle at Impact</td>
<td>Shaft Loading</td>
</tr>
<tr>
<td>Do Not Use</td>
<td>Ball</td>
<td>Angle of Attack</td>
<td>Clubhead Speed</td>
<td>Shaft Deflection</td>
<td>Shaft Acceleration</td>
</tr>
<tr>
<td>Flightpath</td>
<td>Ball Spin</td>
<td>Rate</td>
<td>Dynamic Lie Angle</td>
<td>Where Ball Strikes Clubface</td>
<td>Max Shaft Stress</td>
</tr>
<tr>
<td>Distance</td>
<td>Power</td>
<td>Transfer Index</td>
<td>Dynamic Lie Angle</td>
<td>Release to Impact Time</td>
<td>Shaft Spine</td>
</tr>
<tr>
<td>Smash Factor</td>
<td>Shot Dispersion</td>
<td>Wrist Release Point</td>
<td>Wrist Turn Rate</td>
<td>Other 1:</td>
<td>Typical Distance of a Club (i.e. 5-Iron)</td>
</tr>
<tr>
<td>Dispersion</td>
<td>Other 2:</td>
<td>Other 1:</td>
<td>Other 2:</td>
<td>Other 2:</td>
<td>Comfort</td>
</tr>
</tbody>
</table>
Please rank the Attributes of a system you would purchase to assist you in obtaining Dynamic Measurements, (i.e. a clubhead speed measuring device). (5 = very important, 1 = slightly important)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Importance</th>
<th>Description</th>
<th>Importance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable (easily moved by 1 person)</td>
<td>Not Important</td>
<td>Consistent (different fitters will get same results)</td>
<td>Low Cost</td>
<td></td>
</tr>
<tr>
<td>Does not Require Hitting off of a Special Mat/Tee</td>
<td>Not Important</td>
<td>Reliable (infrequent malfunctions)</td>
<td>Elegant Looks</td>
<td>Instantaneous Feedback</td>
</tr>
<tr>
<td>Can be Used Outdoors</td>
<td>Not Important</td>
<td>Accurate</td>
<td>Intuitive Display</td>
<td>(golfers can understand)</td>
</tr>
<tr>
<td>Not Affected by Sunlight</td>
<td>Not Important</td>
<td>Ease of Learning how to Operate (initially intuitive)</td>
<td>Intuitive Display</td>
<td>(golfers can understand)</td>
</tr>
<tr>
<td>Requires Golfer to Wear Special Devices (i.e. reflective tape)</td>
<td>Not Important</td>
<td>Short Set-Up Time</td>
<td>Provides Printout for Golfer</td>
<td></td>
</tr>
<tr>
<td>All Golfers Can Use (i.e. left handed, Jr's)</td>
<td>Not Important</td>
<td>Ease of Operation (fitter is free to monitor golfer during operation)</td>
<td>Archives Data</td>
<td>(to allow for future comparisons)</td>
</tr>
<tr>
<td>Large Quantity of Measurements</td>
<td>Not Important</td>
<td>Quality of Data (fitter interpretation required vs. 'golfer should use shaft x')</td>
<td>Other:</td>
<td></td>
</tr>
</tbody>
</table>
Regarding Systems You Currently Use (or have used in the past):

There is room to enter inputs on 2 different systems.
If you have more than 2 systems, you are welcome to submit a 2nd survey.
Scroll to the bottom when complete in order to submit your survey. Thanks.

<table>
<thead>
<tr>
<th>System 1:</th>
<th>Name of System:</th>
<th>Cost:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
</tbody>
</table>

Dynamic Measurements Obtained by System 1 (check all that apply):

- Ball Speed
- Launch Angle
- Ball Trajectory
- Ball Flightpath
- Ball Spin Rate
- Where Ball Strikes Clubface
- Ball Distance
- Power Transfer Index
- Smash Factor
- Shot Dispersion
- Swing Path
- Swing Tempo
- Clubface Angle at Impact
- Angle of Attack
- Clubhead Speed
- Dynamic Lie Angle
- Release to Impact Time
- Wrist Release Point
- Wrist Turn Rate
- Downswing Time
- Shaft Frequency (CPM)
- Shaft Loading
- Shaft Deflection
- Shaft Acceleration
- Max Shaft Stress Point
- Shaft Spine
- Other 1:
- Other 2:
- Other 3:
- Other 4:
Please Rank the Attributes of System 1: (5 = Strongly Agree, 1 = Strongly Disagree)

<table>
<thead>
<tr>
<th>Not Ranked</th>
<th>Portable (easily moved by 1 person)</th>
<th>Not Ranked</th>
<th>Consistent (different fitters will get same results)</th>
<th>Not Ranked</th>
<th>Low Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Ranked</td>
<td>Does not Require Hitting off of a Special Mat/Tee</td>
<td>Not Ranked</td>
<td>Reliable (infrequent malfunctions)</td>
<td>Not Ranked</td>
<td>Elegant Looks</td>
</tr>
<tr>
<td>Not Ranked</td>
<td>Can be Used Outdoors</td>
<td>Not Ranked</td>
<td>Accurate</td>
<td>Not Ranked</td>
<td>Instantaneous Feedback</td>
</tr>
<tr>
<td>Not Ranked</td>
<td>Not Affected by Sunlight</td>
<td>Not Ranked</td>
<td>Ease of Learning how to Operate (initially intuitive)</td>
<td>Not Ranked</td>
<td>Intuitive Display (golfers can understand)</td>
</tr>
<tr>
<td>Not Ranked</td>
<td>Does not Require Golfer to Wear Special Devices (i.e. reflective tape)</td>
<td>Not Ranked</td>
<td>Short Setup Time</td>
<td>Not Ranked</td>
<td>Provides Printout for Golfer</td>
</tr>
<tr>
<td>Not Ranked</td>
<td>All Golfers Can Use (i.e. left handed, Jr's)</td>
<td>Not Ranked</td>
<td>Ease of Operation (fitter is free to monitor golfer during operation)</td>
<td>Not Ranked</td>
<td>Archives Data (to allow for future comparisons)</td>
</tr>
<tr>
<td>Not Ranked</td>
<td>Large Quantity of Measurements</td>
<td>Not Ranked</td>
<td>Quality of Data (fitter interpretation required vs. 'golfer should use shaft x')</td>
<td>Not Ranked</td>
<td>Other:</td>
</tr>
</tbody>
</table>

**Additional Comments Regarding System 1:**
**System 2:**

<table>
<thead>
<tr>
<th>System 2:</th>
<th>Name of System:</th>
<th>Cost:</th>
</tr>
</thead>
</table>

**Dynamic Measurements Obtained by System 2 (check all that apply):**

- **Ball Speed**
- **Launch Angle**
- **Ball Trajectory**
- **Ball Flightpath**
- **Ball Spin Rate**
- **Where Ball Strikes Clubface**
- **Ball Distance**
- **Power Transfer Index**
- **Smash Factor**
- **Shot Dispersion**
- **Swing Path**
- **Swing Tempo**
- **Clubface Angle at Impact**
- **Angle of Attack**
- **Clubhead Speed**
- **Dynamic Lie Angle**
- **Release to Impact Time**
- **Wrist Release Point**
- **Wrist Turn Rate**
- **Downswing Time**
- **Shaft Frequency (CPM)**
- **Shaft Loading**
- **Shaft Deflection**
- **Shaft Acceleration**
- **Max Shaft Stress Point**
- **Shaft Spine**

Other 1: [Blank]
Other 2: [Blank]
Other 3: [Blank]
Other 4: [Blank]
Please Rank the Attributes of System 2: (5 Strongly Agree, 1 = Strongly Disagree)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable (easily moved by 1 person)</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Consistent (different fitters will get same results)</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Low Cost</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Does not Require Hitting off of a Special Mat/Tee</td>
<td>Not Ranked</td>
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<tr>
<td>Reliable (infrequent malfunctions)</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Elegant Looks</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Can be Used</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Accurate</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Instantaneous Feedback</td>
<td>Not Ranked</td>
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<tr>
<td>Not Affected by Sunlight</td>
<td>Not Ranked</td>
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<tr>
<td>Ease of Learning how to Operate (initially intuitive)</td>
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<td>Intuitive Display (golfers can understand)</td>
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<td>Does not Require Golfer to Wear Special Devices (i.e. reflective tape)</td>
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<tr>
<td>Ease of Operation (fitter is free to monitor golfer during operation)</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Archives Data (to allow for future comparisons)</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>All Golfers Can Use (i.e. left handed, Jr's)</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Large Quantity of Measurements</td>
<td>Not Ranked</td>
</tr>
<tr>
<td>Quality of Data (fitter interpretation required vs. 'golfer should use shaft x')</td>
<td>Not Ranked</td>
</tr>
</tbody>
</table>

Additional Comments Regarding System 2:

---

Thanks again for your time, and may the Golfing Gods shine favorably upon you!