Callaway Measurement Device

Final Design Review

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Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Abstract

The purpose of this document is to illustrate the Callaway Measurement Device senior project from start to finish. The challenge given to the team was to update and improve a gauge used by Callaway employees to measure the loft, lie, and face angle of their full spectrum of golf clubs. Once the team understood how the pre-existing gauge operates, the team conducted background research into other technologies that could improve the gauge. The team decided to digitalize the device amongst other tweaks to reduce error. Because the CAD files were not available for the pre-existing device, the team began reverse engineering the device. The team iterated through design choices for each subsystem of the device and decided to alter the clamping and lie system for ease of manufacturability and effectiveness, while mimicking the loft and face angle subsystems. Based on these design choices in early prototyping, the team created a CAD design. Once the CAD was polished and material was selected, the team and sponsors decided to switch to 3D printed parts to save on material and manufacturing costs. This altered the design into more of a concept prototype. During manufacturing, the team iterated through many design tweaks by reprinting 3D parts, altering the code and encoder types of the digital assembly, machining some metal parts, and assembling various components and subsystems. During testing, the team found that as expected, the device did not reach the accuracy goal. However, this is believed to be a result of the flexibility and non-uniformity of the 3D printed parts. Because the resolution and precision of the device surpassed the goals, the team believes that if their device was made from sturdier material such as metal in a future iteration it would improve upon the pre-existing device and surpass the goals given to the team by Callaway Golf.

Contents

PART I: SCOPE OF WORK (SOW)

Abstract

This Scope of Work document will cover the senior design project of four mechanical engineering students currently attending California Polytechnic State University, San Luis Obispo. The main goal of this report is to give the reader a solid understanding of the project by describing the problem we are facing and the plan to execute it. The Background section shows what we have learned through design research on the topic up to this point and some similar existing products. The Project Scope section covers the deliverables requested by our sponsor and what we plan to achieve by the end of the project. The Objectives section defines the goals and constraints for our design specifications. The Project Management section will show an overview of our current plan to take on this project through description of our milestones and the corresponding completion dates.

1. Introduction

When golf clubs are manufactured it is important that multiple dimensions and attributes of the head component are measured and meet the necessary tolerance. These attributes include the loft, lie, face angle, keel point, bounce angle, F1, and hosel length. One method of measurement uses a Coordinate Measuring Machine “CMM” which is a very high-tech and expensive device. While these machines are extremely accurate, they are slow to operate. Another device is called the “Green Gauge” which is a term used by Callaway for their most common gauge. The “Green Gauge” is a cheaper and quicker method; however, it lacks accuracy and consistency. The goal is to design a device that is inexpensive and fast like the “Green Gauge” but improves the accuracy and consistency of measurement across different operators.

This project will be taken on by Blake Sousa, Grant Gabrielson, Roman Hays, and Andre Fisher. We are all fourth-year mechanical engineers attending California Polytechnic University, San Luis Obispo. This document will outline our three-quarter plan to finish this project and deliver a complete product to our sponsor contacts Richard Ward and Matthew Hannen at Callaway Golf.

2. Background

The measurements our team will be focusing on are defined below:

loft, lie, face angle, and F1.

1. Loft Angle

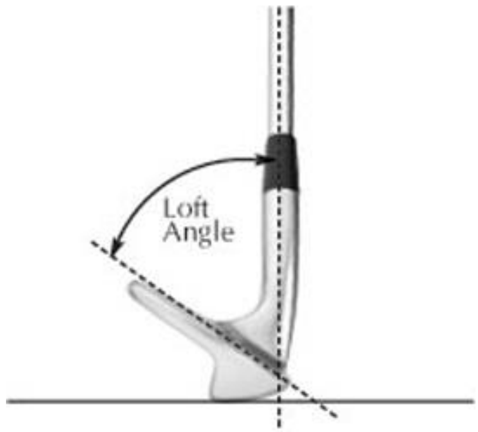

Figure 1: Visual depiction of the loft angle measurement (5).

The loft angle of the golf club is the angle of the clubface as positioned to the shaft which is relative to the vertical plane of the club rather than the ground.

2. Lie angle

Figure 2: Visual depiction of the lie angle measurement (Kelley).

The lie angle of the golf club is defined by the angle created between the center of the shaft and the ground when the clubhead is resting flush against the ground.

3. Face angle

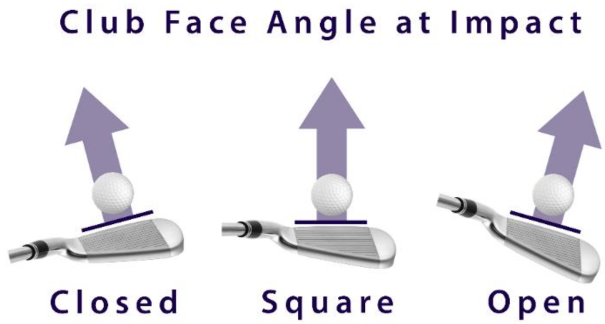

Figure 3: Visual depiction of the face angle measurement (4).

The face angle is the direction that the club face is pointed, which can typically be referred to as an open or closed club face.

4. F1 measurement

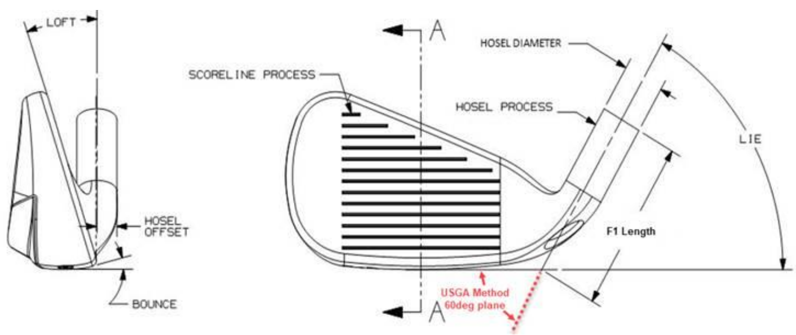

Figure 3: Visual depiction of the F1 measurement.

The F1 measurement takes place when the lie angle is set to 60 degrees and measures the length from the tip of the hosel to the first point of contact between the clubhead and the set, 60 degree plane.

Before beginning the ideation process, we conducted comprehensive background research to fully understand the possibilities for our design. We primarily focused on learning about existing solutions, the technologies that drive them, the users that will be impacted by our design, and any relevant technology that can be applied to our new solution. We have decided to split our background research into the following categories:

- Stakeholders and Needs
- Existing Solutions
- Technical Challenges

This research has been conducted through numerous methods, which will be discussed in each section.

2.1 Stakeholders and Needs

The primary stakeholders for this design include those who will directly interact with the product and those who are directly impacted by the project's outcome. We have categorized the stakeholders into the following three groups:

1. The sponsor
2. Manufacturing and Quality
3. GEQ (Engineering Department)

2.1.1 The Sponsor

The sponsor represents our direct contacts in the company along with any management who are directly impacted by the success of our device. The primary interaction between our device and their needs is that if our device is successful, it will save Callaway money directly and indirectly. We will save them money directly by making the gauge cheaper than their existing products. We will save them money indirectly by increasing the efficiency of the total manufacturing process which will increase the output of their products.

We conducted our sponsor research through a direct meeting with Ricky Ward, who provided us with a device to reference for our design process along with the following information:

1. We need to improve measurement time and resolution
2. The created device should be cheaper than the reference device
3. Loft, lie, face angle and F1 length are the most crucial measurements for this device
4. Transportability is not a major concern
5. It is crucial that there is no risk of damage to the products being tested
6. The device can be manufactured either in house or through outside sources but preferably manufactured in house
7. Reliability and repeatability are a primary concern

This information has been categorized into wants and needs, which are presented in the following table:

Wants	**Needs**
Transportability	Improved resolution
Fully manufacturable in house	Improved measurement consistency
Improved measurement time	Cheaper than the reference device
Measurement of other design parameters	Measurement of loft, lie, F1 length, and face angle
	Will cause no damage to products

For more information regarding the specifications that were provided by the sponsor, please refer to the project scope section of this document (Section 3.2).

.1.2 Manufacturing and Quality

Manufacturing represents those who will interact with the device on the most consistent and frequent basis. They are the ones who will test numerous golf clubs daily and will benefit the most from a streamlined measurement device. Those in manufacturing are the stakeholders that can provide us with the most information as to design specifics that will assist us going forward in ideation, so their feedback is crucial.

We are conducting our manufacturing research through a survey that we sent to be spread among the members of the company. We have yet to integrate the results and will update this document accordingly when sufficient answers have been received. This survey asks a series of questions that inquire of users' experience with the device, including asking about the average measurement time per club and the users' personal grievances with said device.

2.1.3 GEQ

This represents Callaway's engineering department, which will play a vital role in the development of our product. The device will help with ensuring that a club head meets the needed specs after being designed and developed by the engineering team. Without the device their best option would be to use a CMM machine which will be explained later to obtain good and accurate results on the club head design.

2.2 Existing Solutions

The existing solutions that we are the most concerned about have already been presented to us by our sponsor. The three existing solutions we are focusing on are as follows:

A. "Green Gauge" [24]
B. Digital Gauge [25]
C. CMM [27]

2.2.1 "Green Gauge"

The "Green Gauge", seen in Figure 1, is the most basic solution for our problem and is currently in use by Callaway; it is the baseline from which we are trying to improve. The resolution is not ideal, with a typical tolerance of approximately 0.8 degrees for each angle measurement. The measurements can also be inconsistent due to a high potential for user error due to the inherently tick-based mechanical readings and high variability in setup between different users. This gauge, however, is cheap and easy to manufacture which makes it easy to use on a large scale. Because it is so easily manufactured and is an industry standard, it is produced by a large range of manufacturers and is not considered a single design rather a baseline that individual manufacturers improve upon.

Figure 1: Green Gauge.

2.2.2 Digital Gauge

The digital gauge, seen in Figure 2, is like the design of the "Green Gauge" on a mechanical level. This device is sold by a company called Golf Mechanix [25]. The major differences in the digital gauge are that it has a higher precision, an easily read digital interface, and is far more expensive than the green gauge. This gauge can measure with a resolution of 0.1 degrees but costs $2600 dollars. This gauge's greatest shortcoming is that its high price does not justify the small improvement in precision over the "Green Gauge". If we wanted to make something like this gauge, we would need to find a way to make it far cheaper and speed up the measurement process.

Figure 2: Digital gage.

2.2.3 CMM

The CMM, seen in Figure 3, is more than adequate for measurement tolerance purposes. The photographed device was found in a Cal Poly classroom, but the CMM that we conducted research on is manufactured by a company called Mitutoyo [27]. It uses probing technology to measure the geometries of a club head to a high resolution. The drawback is that it is an expensive machine and takes a long time for each measurement. We are unlikely to adopt any of the design principles from this existing solution.

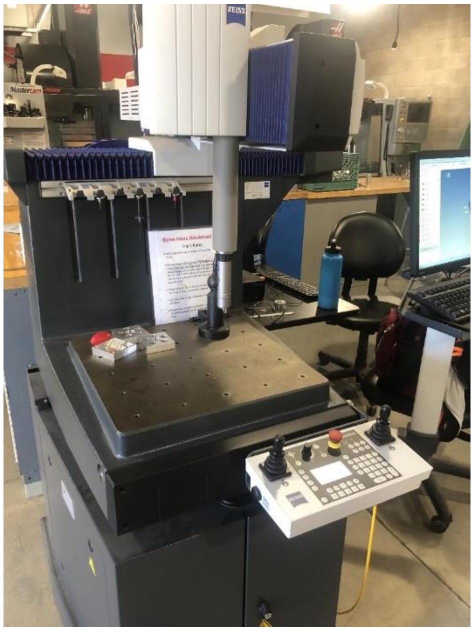

Figure 3: Coordinate Measuring machine.

2.3 Relevant Technologies

The final portion of our research was based upon investigation into technology that can be used for our solution. The first technology we researched was the potential use of a microcontroller to digitize measurements. This can be accomplished by attaching an encoder to each rotating axis that will take measurements for angular rotations and translate them to a user interface [7]. While this will require a very intensive calibration process, we believe that this may be able to obtain an excellent resolution for our device.

Another technological sector we investigated was light-based measurement. Certain articles we investigated covered the implications of using light and sensors to create a fully accurate 3-D rendering of the desired subject. This is overkill however, so it is not a strong consideration currently.

We have conducted research on ten relevant patents and have summarized the primary takeaways below in Table 1. To view the full list of patents, see Attachment A.

Table 1: Significant Patents Researched.

Patent Name	**Patent Number**	**Main Takeaway**
Loft and Lie Gauge for Golf Clubs [11]	US6430829B1	The use of a hollow cylindrical unit to hold the shaft in place axially can be useful, albeit difficult to implement for fast measurement.
Loft Lie Tester for Golf Clubs [13]	US4858332A	This design uses an interesting mechanism that latches the club at multiple different points, which may be highly beneficial for increased security and consistency when taking measurements.
Golf Club Measuring Device [19]	US4875293A	This measuring apparatus keeps the club head entirely still during measurement, which is a strategy that may be effective with the proper execution.
Golf Club Fixture [20]	US4094072A	The clamping mechanism at the bottom of this apparatus is a potential solution that we can use to stabilize the club.

Our research is far from concluded at this point. We want to gain more insight from stakeholders and want to look further into potential light-based measurement devices. Additionally, we want to make sure that we can execute these ideas. Therefore, it is necessary to have a thorough understanding of the relevant technology rather than the more rudimentary knowledge base we currently have.

3. Project Scope

3.1 Boundary Sketch

In Figure 4, we represent the scope of our design by drawing a rudimentary sketch of a hypothetical measurement device. This sketch indicates what lies in the focus of our design, and what does not.

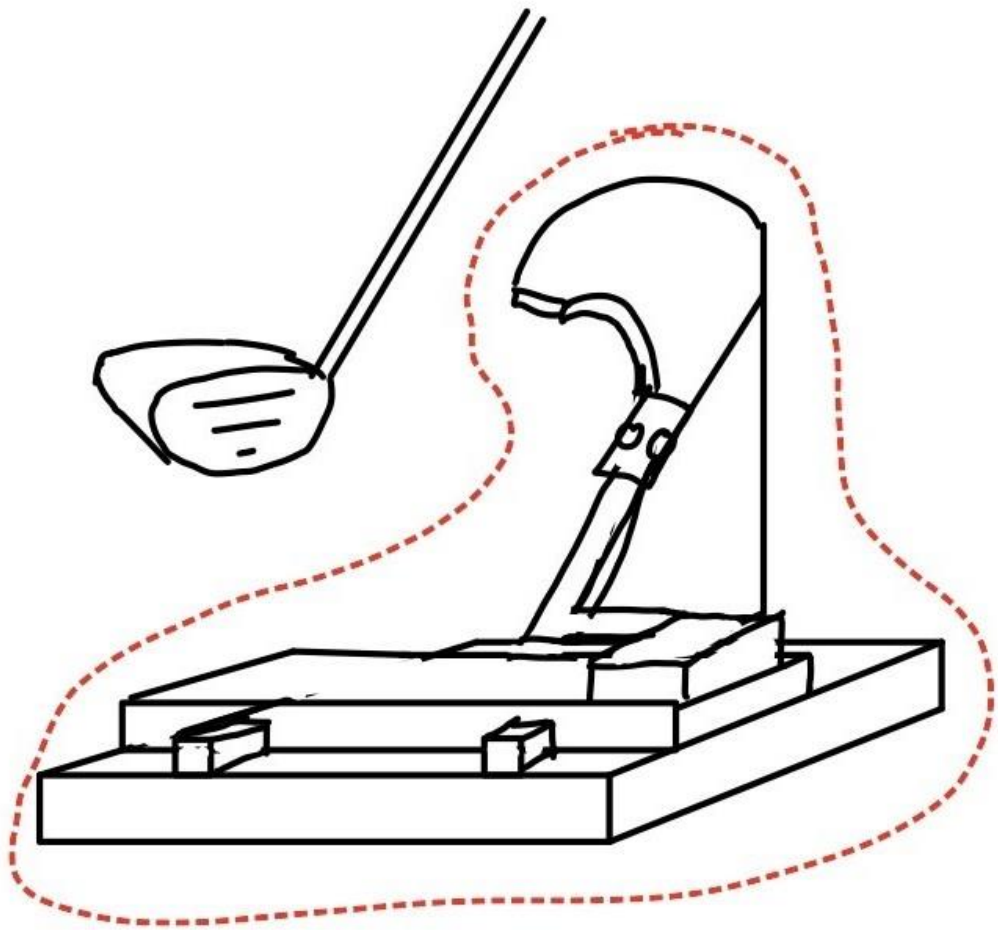

Figure 4: Boundary sketch of an example measurement device we will be designing, excluding the actual golf club as we will not be responsible for designing the clubs being measured by our device.

3.2 Stakeholders' Wants and Needs

Product analysts at Callaway need a way to reduce the tolerances in measuring the loft, lie, and face angle of all their golf clubs. They need the time to take these measurements for each club to stay under the current time of their "Green Gauge". They need the device to be manufactured at a cost of less than $2500 per device. Each measurement must be repeatable.

3.3 What Our Design Should Be Able to Do

Our device should reduce total error of measurements to a maximum of +/-0.5 degrees from their current green gauge error of +/-0.8 degrees for measurements of loft, life, and face angle. At the very least, our device should measure loft, lie, and face angle, but is not limited to these and can also include bounce and keel point measurements.

The time it takes to set up the device for each golf club should take less than one minute. The time to complete all the measurements for each club should take less than two minutes.

The device should be made of durable materials to last for up to 10,000 measurements. It should be designed in a way so that it does not damage the clubs when taking measurements.

The device should be intuitive to operate to reduce user error, requiring little to no training.

The following functional decomposition helps to visualize the basic functions that this design needs to serve. The main functions that we included include taking each individual measurement and making sure the measurements are as accurate and consistent as possible. These are what we consider the most essential considerations for this design.

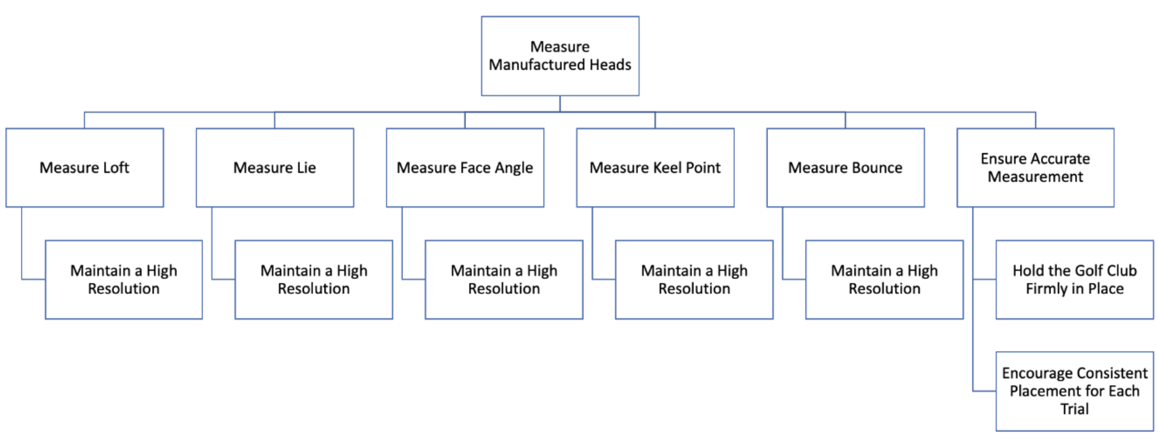

Figure 5: Functional decomposition that breaks down the most basic functionalities of the design.

3.4 End Goal Deliverables

At the end of the project, we plan to have a working prototype of our measurement device. In addition, we will have test data that shows the average precision for each measurement and the average total time to both set up the device for any given club and to take all the measurements for the corresponding club. We will give our sponsor this prototype and test data, as well as all computer-aided design (CAD), files necessary to manufacture our final product.

4. Objectives

4.1 Needs and Wants

The quality analysis team at Callaway Golf need a way to consistently and with user friendly ease measure loft, lie, and face angle of the full spectrum of their golf clubs while reducing time and measurement uncertainty with a reproducible device, improving on their current "Green Gauge".

4.2 QFD House of Quality

In creating our Quality Function Deployment "QFD", seen in Attachment B, we began by identifying the "Who", "What", and "Now". We defined our stakeholders as our sponsor, R&D, and Quality Assurance Department (Manufacturing). Our sponsor needs certain benchmarks met for our product, like those of Quality Assurance analysists at Callaway, and R&D using the device for other reasons. We decided that the "wants" and "needs" of our stakeholders include maintaining low cost, maximizing resolution, limiting size, manufacturability, ease of operation, speed of measurement, weight, durability, transportability, assembly, and repeatability of measurements. We then rated how important each want/need is to each stakeholder on a ten-point scale. We looked at three existing products we are familiar with and rated them on a scale from one to five for each want/need.

Next, we defined the "How". To do this, we listed potential specifications as tests. We compared the "How" to the "What" by introducing a symbol representing a strong, moderate, or weak correlation.

We benchmarked to see how each current product meets the "What", rating each want/need on a five-point scale.

Then, we further defined our specifications, as "How Much". We chose numerical target values for each specification by comparing our benchmarking results from the existing products as well as the relative weight of each specification.

After this, we chose a direction of improvement for each specification indicating which direction would yield a better product.

Finally, in the pyramid or roof, we compared how each specification is related to one another with a correlation symbol based on the direction of improvement.

This process allowed us to determine the target value for each specification, see how well current products meet each target value, and the relative importance of each target.

4.3 Engineering Specifications Table

As can be seen in Table 2, we indicated the target, tolerance, risk, and compliance of each specification we will be evaluating as we design our measurement device.

Table 2: Measurement device specifications table

			Target	Tolerance	Risk *	Compliance **
Specification	1	Time to measure a club	< 2 minutes	+ 8 minutes	H	T
	2	Amount of measurement types	3 minimum	+ 3	L	I
	3	Is it intuitive?	zero training required	10 minute demonstation	H	T,A
	4	Set up time	< 1 minute	+3 minutes	M	T
	5	Amount of components	one component	+2 components	L	A,I
	6	Battery/Plug Required?	not required	1 battery/plug	M	I
	7	Angle tolerance of measurement	+/-0.1 degrees	up to +/-0.5 degrees	H	T,A,I
	8	Total Cost	<$2600	0$ < cost<$2600	M	A
	9	Damage caused to club	zero	none	M	A,I
	10	Lifetime	10,000 measurements	- 5,000 measurements maximum	M	A

* Risk of meeting specification: (H) High, (M) Medium, (L) Low

** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

1. The time to take all measurements for one club is deemed high risk because this is one of the main design focuses given by our sponsor and will be measured through testing of our final project.

2. The minimum number of measurements taken by the device is three, including loft, lie and face angle. Keel point, bounce angle, and hosel length may also be included but are not required. This is deemed low risk because we are not required to include additional measurements.

3. The device must be easy to use. One of the main issues with the existing "Green Gauge" is user error, so we deemed this high risk and will be reviewed through testing and analysis.

4. The time to calibrate the device for different clubs is deemed medium risk because it contributes to the total time but is not as consuming as taking actual measurement. This will be reviewed through testing.

5. Ideally, the device would consist of a single interconnected mechanical system. This would contribute to ease of use. However, separate devices such as protractors may be included with a maximum of 3 different components to measure loft, lie, and face angle so is deemed low risk.

6. If the device can be created to be purely mechanical it would be beneficial because it would not require a power source. However, if it is more user friendly and assists with increasing precision to have digital measurements, this may be a necessary trade-off, so is deemed low risk.

7. The tolerance of each angle measurement should be at largest, +/-0.5 degrees, with a goal of +/0.1 degrees. This is deemed high risk as it is the pinnacle of our design goals given by our sponsor. We will demonstrate our device's precision with analysis, testing, and inspection.

8. The total cost to manufacture the device should be under $2600, but we will aim to keep costs as low as possible while meeting the other parameters. This is considered low risk because keeping the device under $2600 should not be very difficult if we are using a mostly mechanical system.

9. The device must cause zero damage to the clubs being measured. This is deemed medium risk because it should not be very hard to execute, however it is very important.

10. The device should last between 5,000 to 10,000 measurements. It is deemed medium risk because it is important that the device is long-lasting and durable but should not be too difficult if we utilize strong materials that resist corrosion.

5. Project Management

Our plan for this project consists of various parts that will come together and build off each other to complete our project. Getting to know our team was the first step in our process; this assists in making everything more efficient and enjoyable. Next, conducting research and background research to get a better idea of the project helped to create our problem statement as well as this scope of work which will be presented to our sponsor for review. Once approved, our group will move into the ideation portion, using techniques such as brainstorming and models to produce a concept. To help with this we will visit the Callaway Headquarters in Carlsbad, CA on February 22, 2022. This concept will be refined and analyzed using CAD and handmade models. From here we will develop a concept prototype for our preliminary design review (PDR) presentation which will be our next major milestone. From here we will move to our next milestones, sequentially including the Interim Design Review, the Critical Design Review, building, testing, signoffs, and finally the EXPO and Final Design Review.

The scope of this project includes no small number of significant challenges. The main challenge we face is finding a method to make the measurement process more consistent without increasing the time for each measurement or the cost of the device itself. Another issue that we face is finding cheap but reliable electronic components if we choose to implement a digital solution. Finally, we are located at a significant distance from our sponsor's office so any face-to-face meeting will require a significant amount of time and money.

Table 3 outlines deadlines for the main milestones of our project. For a more detailed outline of milestone due dates and time periods, see Appendix C: Gantt Chart.

Table 3: Project Timeline.

Deliverable	Description	Due Date
Scope of Work	Outline of the Project	2/2/22
Preliminary Design Review (PDR)	Review of our initial design solutions for problem	3/1/22
Critical design review (CDR)	Document of complete idea and process	5/3/22
EXPO	Show off the final prototype	11/18/22
Final Design Review (FDR)	Final Design Report, Senior Project showcase with final prototype	12/2/22

6. Conclusion

The goal of our senior design project is to create a measurement device for Callaway that improves upon the current "Green Gauge" Callaway uses to test the tolerances of their newly manufactured clubs. This Scope of Work outlines what our team has already conducted in the design process as well as what we plan to do. We identified who the stakeholders are and what is most important to them. We conducted background research on existing products, where they meet our design criteria, and where they are lacking. We investigated relevant technologies that we may want to implement into our design. We dove into the scope of our project by creating a boundary sketch and defining the basic goals of our design. We analyzed the objectives on a more detailed scale by creating a QFD (see Appendix B) which led to detailed specification goals and the corresponding tolerances. These specifications and tolerances were organized into a table (see Table 2) where we analyzed the difficulty and importance of executing each specification goal and how they will be reviewed on our prototype. Finally, we outlined the major milestone deadlines we plan to reach which can be seen in Table 3 and Appendix C.

Once our sponsor gives us feedback and approval on this Scope of Work, we will be conducting our preliminary design phase. The PDR will be completed and ready for review by our sponsor on March 1, 2022.

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PART II: PRELIMINARY DESIGN REPORT (PDR)

Abstract

This Preliminary Design Review outlines the design selection process for the Callaway Golf measuring device that was executed by four mechanical engineering students attending California Polytechnic State University, San Luis Obispo. The main goal of this report is to give the reader an understanding of the ideation process as well as an understanding of why the final design was chosen. The Concept development section dives into the ideation process to compare different design ideas to come up with what will complete the job the best. The Concept Design section will explain why the concept design was chosen as well as provide a computer-aided design "CAD" model and a picture of a concept prototype. The concept justification portion will go into detail through hand calculations and engineering judgement on why the concept design is believed to be the best idea that was thought of. Lastly, the Project Management section will show an overview of the plan to take on the rest of this project through a description of milestones and the corresponding completion date.

1. Introduction

When golf clubs are manufactured it is important that multiple dimensions and attributes of the head component are measured and meet the necessary tolerance. These attributes include the loft, lie, face angle, keel point, and F1 length. One method of measurement uses a Coordinate Measuring Machine "CMM" which is a very high-tech and expensive device. While these machines are extremely accurate, they are slow to operate. Another device is called the "Green Gauge" which is a term used by Callaway for their most common gauge. The "Green Gauge" is a cheaper and quicker method to measure loft, lie, and face angle; however, it lacks accuracy and consistency.

The goal is to design a device that is inexpensive and fast like the "Green Gauge" but improves the accuracy and consistency of measurement across different operators, while also incorporating the measurement of the F1 length to save time in the overall process. Since the Scope of Work, the main change to this project is incorporating a way to set the datum in a more reliable and consistent fashion as well as measure the F1 length of the club head. The additional requirements to the Scope of Work led to extra ideation and adjustments to the final concept. Currently, the Datum on the "Green Gauge" can be inconsistent and prone to user error because the club head is not locked in place during measurements. Also, the F1 length is currently measured on a separate device which leads to an overall longer measurement time. Adding another measurement requirement, F1 length, to the device does not change the boundary diagram because the F1 measurement will be attached to the portion of the device locking the mandrel or shaft to the device.

Since the Scope of Work, the functional diagram, found in Appendix H, has been updated to include measuring the F1 length and changes to the subfunctions, making them more specific. On the other hand, the house of quality and engineering specification table did not undergo changes since the completion of the Scope of Work.

This project will be taken on by Blake Sousa, Grant Gabrielson, Roman Hays, and Andre Fisher. They are all fourth-year mechanical engineers attending California Polytechnic University, San Luis Obispo. This document will outline their design selection process.

2. Concept Development

To develop a more efficient and precise measurement process of golf clubs, the overall measurement was outlined under five main functions:

- Setting a consistent and reliable datum.
- Measuring the face angle.
- Measuring the loft angle.
- Measuring the lie angle.
- Measuring the F1 length.

Setting a consistent and reliable datum is the most important step in a measurement process. Measuring with an inconsistent datum increases the tolerance of every measurement. In effect, the measurements are less consistent and precise than desired. Setting a datum of measurement for a golf club requires orienting the club consistently and using a reference measurement before taking additional measurements.

Setting the datum for a golf club is dependent on the keel point. The keel point is where the club face makes its first point of contact with ground as can be seen in Figure 1. The keel point for each specific club can be obtained from the manufacturer's specifications sheet. To obtain accurate measurements, the club head must be rotated so that its first point of contact with ground is at the manufacturer's keel point distance from the centerline of the gage (see Figures 2 and 3). By setting a consistent datum about the keel point, all other measurements can be properly obtained.

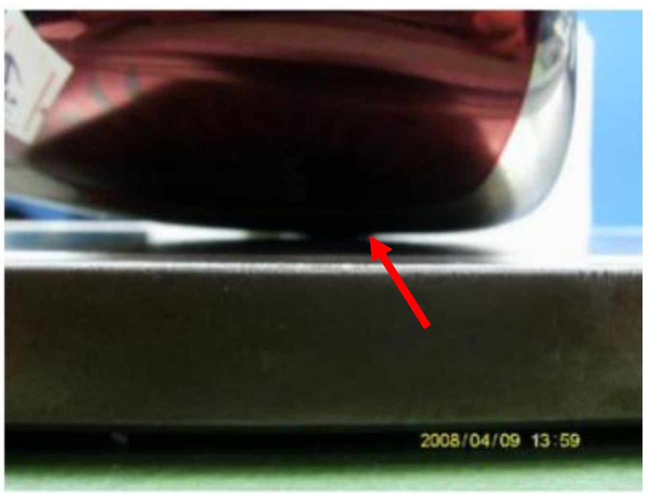

Figure 1: Keel Point of a Golf Club

Figure 2: Manufacturer's Keel Point Distance from Centerline of Gage

Figure 3: Rotating Club to Make First Point of Contact with Manufacturer's Keel Point Distance

The face angle, seen in Figure 4, is the direction that the club face is pointed, which can typically be referred to as an open or closed club face. The face angle is measured using the club's design lie measurement. The design lie measurement is the angle the club is designed to have that was made by the team designing the club.

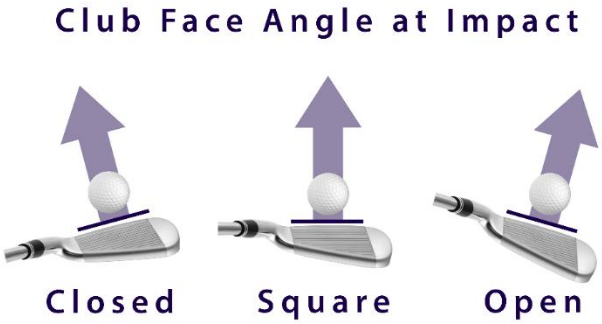

Figure 4: Visual Depiction of the Face Angle Measurement [1].

The loft angle of the golf club, seen in Figure 5, is the angle of the clubface as positioned to the shaft which is relative to the vertical plane of the club rather than the ground. The loft angle is measured using the club's design lie measurement.

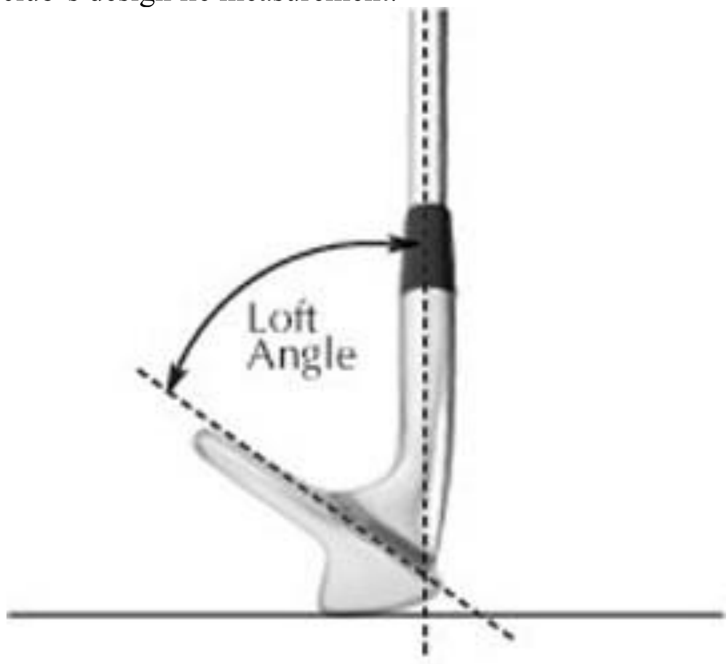

Figure 5: Visual Depiction of the Loft Angle Measurement [2].

The lie angle of the golf club, seen in Figure 6, is defined by the angle created between the center of the shaft and the ground when the clubhead is resting flush against the ground.

Figure 6: Visual Depiction of the Lie Angle Measurement [3].

The F1 measurement, seen in Figure 4, may be measured by Callaway Golf standards or by United States Golf Association "USGA" standards. The USGA measurement takes place when the lie angle is set to 60 degrees and measures the length from the tip of the hosel to the first point of contact between the clubhead and the set, 60-degree plane. The Callaway Golf standard measures the F1 measurement after the lie measurement is made. Using the lie measurement as its reference measurement, the F1 length is defined along a plane parallel to the shaft, measuring from the tip of the hosel to the base plate.

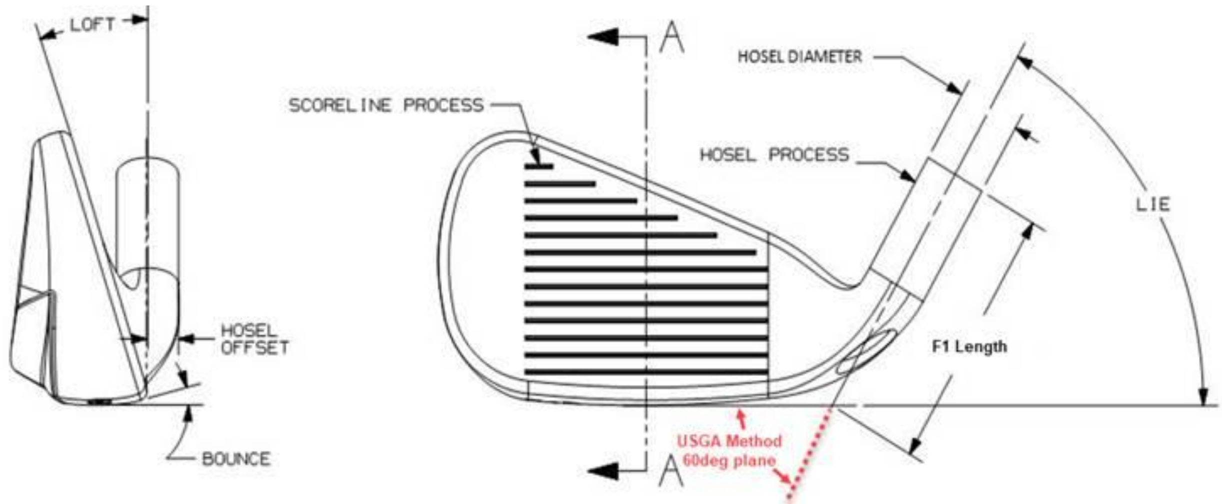

Figure 7: Visual Depiction of the F1 Measurement [2].

Before concept ideation, ideation was performed per function, based on criteria addressing the sponsor's wants and needs. The criteria are stated in the list below:

1. Low cost
2. Resolution
3. Size
4. Manufacturability
5. Ease of use
6. Measurement speed
7. Weight
8. Durability
9. Transportability
10. Assembly
11. Consistency

Throughout the function ideation process, the first focus was to increase the resolution, therefore increasing the precision, of each measurement. One of the largest flaws in the current device, the "Green Gauge," is the increase in tolerance due to human error. To minimize the effects of human error, different methods of digital measurements were brainstormed to replace the current, mechanical measurements. Digital measurements use higher precision technology and a user interface is more intuitive than mechanical interfaces. As a result, digital measurements increase the measurement's precision while minimizing human error.

Throughout the brainstorming process, different ideas were proposed. For example, LiDAR, laser measurements, photo measurements, and encoders. Based on the technology currently available to the public, encoders were decided to be the best method of measurement because they are capable of outputting high precision and are relatively inexpensive when compared to high precision lasers and LiDAR options.

Furthermore, ideation was completed per function, resulting in five different sketches per function along with an analysis of each ideas effectiveness in accomplishing the criteria stated above The ideation process per function is summarized in Pugh Matrices, which can be found in Appendix C. Please visit Appendix C to see the proposed solutions to accomplish each function along with their analysis of accomplishing the previously stated criteria.

Figure 8 show an ideation model that allows us to be successful in the function of maintaining our datum with different measurements. The track system modeled taught us that we can allow the clubhead to be secured without having to be moved for different measurements.

Figure 8: Track System that slides to contact the secured club face.

In the ideation model shown in Figure 9, we explored using one component to measure both loft and face angle. After creating this model, we realized this may not be feasible because the claw would have to be different sizes for varying club heads, such as irons and driver. Irons are much smaller so a smaller claw would be required.

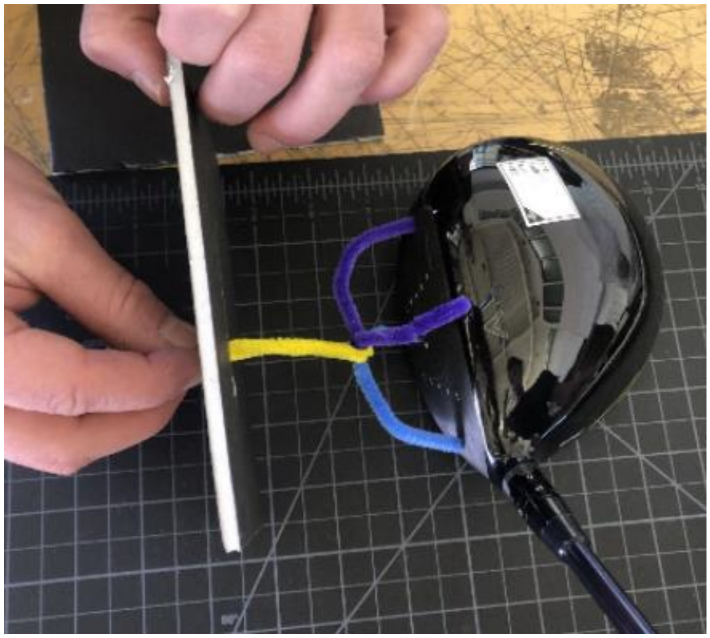

Figure 9: Claw-like mechanism to measure loft and face angle.

For the function of measuring the lie angle, we created an ideation model, found in Figure 10, that allows the shaft to rotate when measuring the lie angle at the clamping mechanism where it is secured.

Figure 10: Rotating shaft connection for measuring lie angle.

The ideation models were compared for each function in Pugh Matrices, which can be found in Appendix C. In each Pugh Matrix for the corresponding function, each model was compared by how they performed in the desired subfunction, such as cost and resolution. Whichever model for each function performed the best overall for all the subfunctions was brought to the next phase.

After creating the Pugh Matrices, a Morphological Matrix, found in Appendix D, was created to summarize each possible solution of the functions in one figure. Using the Morphological Matrix, five concept models were created combining the most effective solutions of each function. The five concept models are found in figures five, six, seven, eight, and nine. An analysis of how each concept design coincides with the criteria may be found in the Decision Matrix in Appendix E.

As seen in Figure 11, this design is purely mechanical. A tightening, metal clamp is used to fix the club shaft to the mechanism. The clamp lies on a flat plane that can be adjusted angularly using a worm-gear and is measured using a protractor. The loft and face angle of the clubhead is measured using one rotating component with two points of contact that contacts the clubhead at point, adjusting the other point until it meets the opposite side of the clubhead. The function of this measurement technology is like that of the micrometer. The F1 length is measured using a drop-down ruler that contacts the bottom of the hosel and the base plate, measured at the design lie angle. The benefit to this design is the simplicity of having fewer components as there is only one component to measure both the face and loft angle; the drawback is that the points of contact for these two measurements must be adjusted for different club types. Additionally, there are pre-existing attachments for loft that could not be implemented with this system.

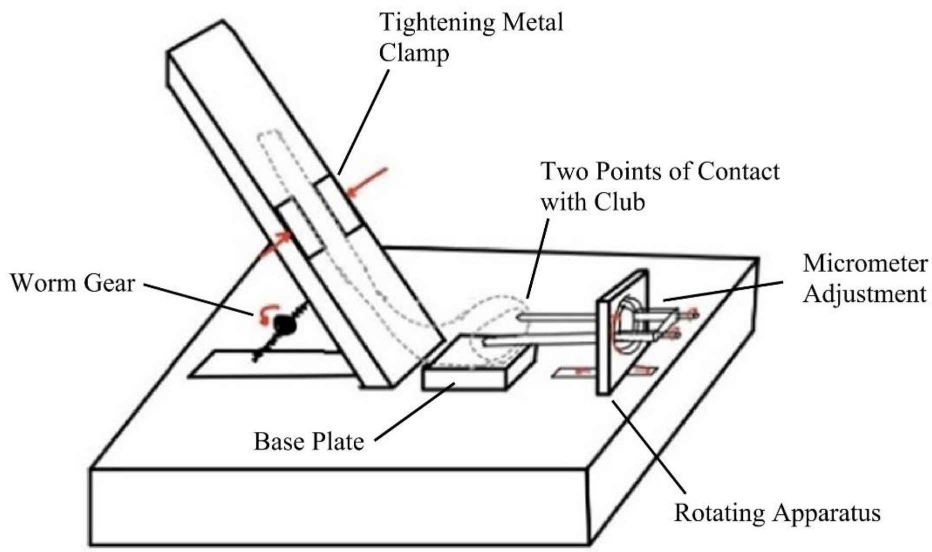

Figure 11: Concept Design 1.

Figure 12 also shows a purely mechanical device. The club head attaches to a mandril, and elastic straps are used to secure the shaft to the rotating datum that is used for the lie measurement. A worm gear is used to adjust the datum and a mechanical protractor is used to measure the loft. The face angle is measured with a turn dial on an apparatus that can interface with the club. This will ensure a high resolution with a low potential for wear-and-tear. The F1 length is measured using a drop-down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate. The drawback to this design is having to convert a distance reading to an angle measurement, which increases complexity. Also, the elastic straps may wear out over time, having to be replaced, and the loft angle does not have interchangeable parts for all types of clubs.

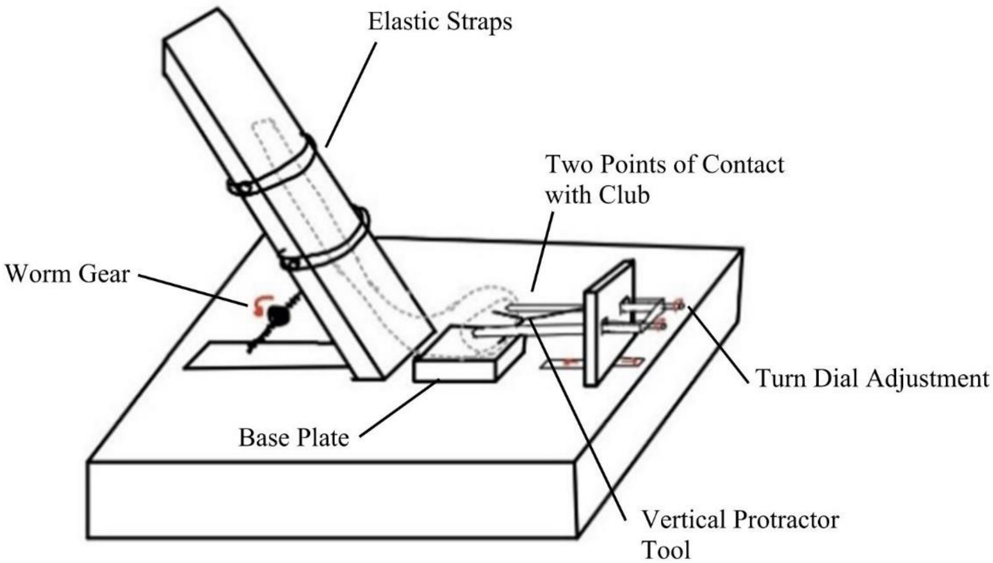

Figure 12 Concept Design 2.

The design in Figure 13 implements laser technology with mechanical components. The club head attaches to a mandril that is clamped to the measurement datum. A LidDAR is used to measure the plane of the club face to generate a profile that can evaluate the loft and lie with a single measurement. The F1 length is measured using a drop-down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate. This design has quite of bit of potential, however further research into LiDAR indicates that it would be expensive to implement and could require quite a bit of complexity in generating measurements from the outputted plane.

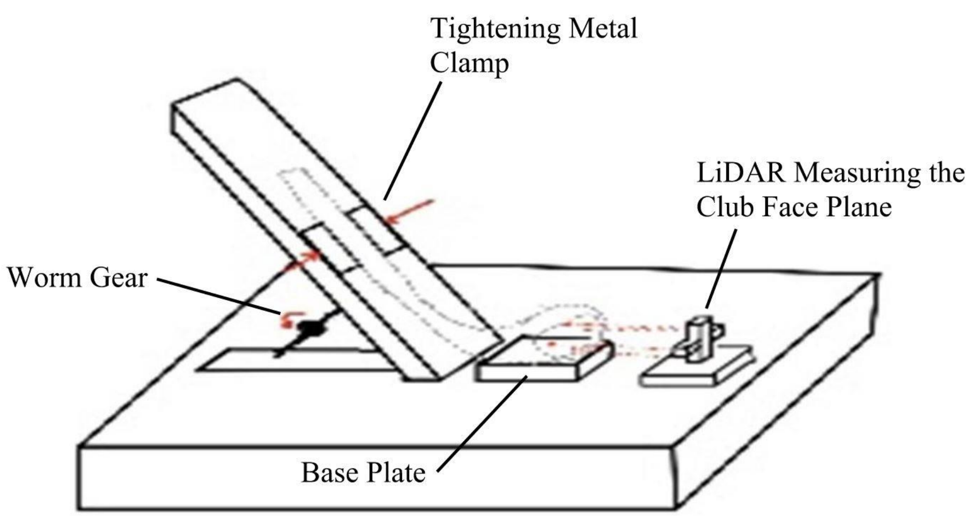

Figure 13: Concept Design 3.

The design in Figure 14 shows a design that implements a laser centering component as well as more datum securing mechanisms. The club head attaches to a mandril which then is clamped to a worm gear measuring the lie angle. The lie angle is set and changed by adjusting the worm gear with the output connected to an encoder. A mold of the club sets the face angle to its "zero" orientation. A cross laser is used to center the head on the flat plate. Securing the head in its "zero" orientation, the head is locked in place using set screws and three points of contact. Face and loft angles are measured using similar devices to the "Green Gauge" connected to encoders. The F1 length is measured using a drop-down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate. This design has many components that are advantageous such as the laser-setting datum, a locking mechanism adding more security throughout the measurement process, and simplicity by implementing pre-existing components.

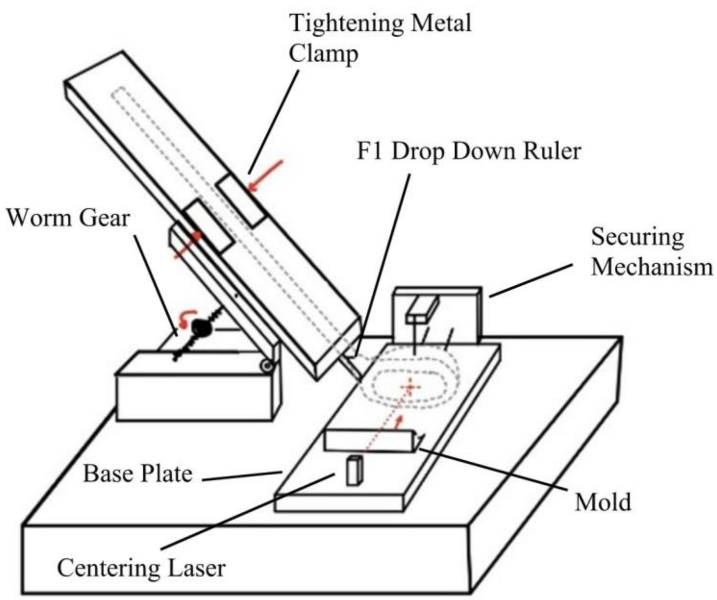

Figure 14: Concept Design 4.

Figure 15 depicts a universal measuring mechanism for loft. A mandril is placed inside a club head which is then clamped to a measuring datum. A worm gear will be used to adjust the lie angle which can make for easy adjustability and a high resolution if done correctly. The loft will be measured using two points of contact which can be implemented for all the clubs. This eliminates the need to switch to a different method for drivers. Face angle will be measured using a set point on the clubhead, and then a micrometer will read how far off the other point is. This method creates a measurement for the face angle. The F1 length is measured using a drop-down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate. This design does not allow for the use of pre-existing components.

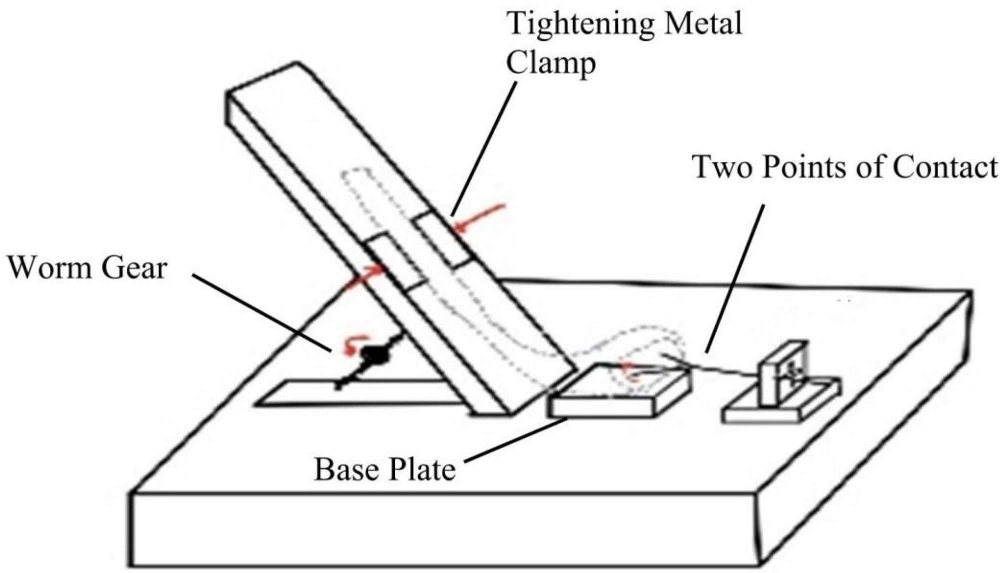

Figure 15: Concept Design 5.

Design 4 ranked the highest in the Decision Matrix, found in Appendix E. This design uses encoders and microcontrollers to output high tolerance measurements to an easily understand interface, decreasing human error, therefore decreasing the tolerance of the measurements. Design 4 must be plugged in to the wall or connected to batteries. The main factors helping this design rank the highest is the method of setting the datum. By using a mold of the clubhead's face and a cross laser, the clubhead will be centered precisely and set in its "zeroed" position with ease. Once set to its "zero" position, the head will be locked into place using three points of contact via set screws. This minimizes the possibility of altering the club's position during the measurement processes. Additionally, the face and loft angles will be measured using fixtures like those used currently with the addition of encoders to minimize the tolerance of the measurement while increasing the intuitiveness of the measurement device. The implementation of encoders will fulfill two important stakeholder needs: mitigation of human error and minimization of tolerance. Human error will be reduced because the digital display is easier to read from when compared to a mechanical device. Encoders will help to lower the measurement tolerance because the encoders are capable of a very high resolution, as discussed in section 4.1.1. This is the best design possible when taking budget and knowledge into account. The design will be modified as necessary during the prototyping and testing stages.

3. Concept Design

The selected design will be the most efficient and consistent in taking all the measurements necessary. Starting with the lie angle, a threaded bolt on a plate will be utilized. Using a threaded handle, the plate will be pushed up and down, adjusting the lie angle. For a visual aid of this system, refer to the compass in Appendix A that served as the inspiration for this component. This should allow for a tight tolerance of measurement as a protractor will be attached to the end of the plate to read measurements manually as well as a microcontroller and encoder to take the measurement electronically.

One of the most key features of the design is setting the datum of the club. To do this the club will be set to the design lie for the club and then approached by a mold on a slider to ensure that the face angle is set well and not at an angle that will mess up the measurement of the club. After this is done a clamping slider is set over the club and then the club is secured with clamping screws at three points to ensure the club face does not pivot during measurements of the club.

The loft and face angle will incorporate microcontrollers and encoders as well. For the loft angle, an arm will extend off a shaft attached to the controller. At the end of the shaft there will be an arm with a female fixture. This fixture allows the attachment of interchangeable, male components that extend to the clubface, measuring the loft angle. Different attachments, already used by Callaway, can be connected to this fixture by means of a set screw. By selecting the correct attachment, the loft angle, measuring device can measure all types of clubs. The different attachments are important because different clubs have different faces, such that one attachment is unable to measure more than one type of club. The loft measurement will be taken only electronically and displayed on a screen which will help with user error and time of measurement.

Additionally, the face angle will be measured in a similar fashion. A two-pronged piece will slide towards the club to contact the club face. As it adjusts so that both prongs are hitting, the end of the device, a straight piece of metal, will pivot about a single point, moving slightly. This movement will be captured by the encoder and microcontroller, outputting the measurement to a digital display. The digital display will decrease measurement time and user error compared to reading a mechanical gauge’s output.

To measure the F1 length, a pointed ruler will be used that drops down parallel to the club’s shaft. The ruler will pivot with the lie angle so the F1 distance can be measured at any angle. This angle may be the design lie angle or the USGA standard angle of 60 degrees. The ruler will have a set screw allowing it to secure at an upwards position or drop down to take a given measurement. There will be a small mechanism that drops with the ruler that can be adjusted to interface with the top of the hosel to get a more accurate measurement on the ruler. An alternative method of measuring the F1 length is to alter the configuration of digital calipers such that the moving component of the caliper will align with the hosel to record the measurement.

The procedure for measuring a golf club will be done in nine steps.

Step 1: Zero the measurement device.

Figure 16: Shown above is how the current device interface is set to 0, a flat plate is pushed against the face and loft measuring devices and then the lie angle is set to 90 degrees. After the zero button is hit on the controller so that all angle measurements will be correct. Our design will be done in a similar fashion to this set-up as it is an efficient way to ensure the controllers read the measurements correctly.

Step 2: Set the lie angle to the design specifications.

Step 3: Attach and clamp the club and shaft to the fixture measuring the lie angle.

Step 4: Align the club head to its zero position.

By sliding the mold towards the

club until contact is made. This sets the face angle to its zero position. Use the cross laser to ensure the center of the club is aligned with the center of the plate.

Step 5: Fix the clubhead in place.

Clamp down the clubhead from the back and top of the club by using three set screws. This ensures there is no movement of the clubhead during the measurement process.

Step 6: Measure the face angle.

Slide the loft and face angle apparatus towards the clubhead. Using the two points of contact from the face angle measuring device, the measurement will be output to the digital display.

Step 7: Measure the loft angle.

Using the same apparatus and choosing the proper attachment for the clubhead type being measured, contact the clubhead. The measurement will be output to the digital display.

Step 8: Measure the lie angle.

Align the horizontal cross laser with the horizontal grooves on the club face by adjusting the lie angle. Once aligned, the measurement will be output to the digital display.

Step 9: Measure the F1 length.

Release a ruler off the mounting plate so that it drops down and contacts the base plate. From here a measurement device on the ruler can be adjusted so that it aligns with the top of the hosel and the measurement can be taken manually off the ruler.

The main material used in the design will be stainless steel and possibly aluminum for some of the special parts. This was chosen because it is a strong material and because this device will be used in a shop setting and it needs to be anticorrosive. It will be made of steel plates, bars, and sheets. The main processes to build this product will be milling and plasma cutting. With these two processes all the components should be possible to make plus there is access to both machining methods at Cal Poly and at Callaway. Thus, this method works compared to a different process such as casting. A total of about 40 of these products will be made by Callaway so it makes more sense to go with these machining processes for such a low quantity.

Figures 17, 18, 19, and 20 depict the basic mechanical components of the top design gauge working together in a solid-model prototype that does not yet include the digital readout components, gears, laser-level, and some fasteners.

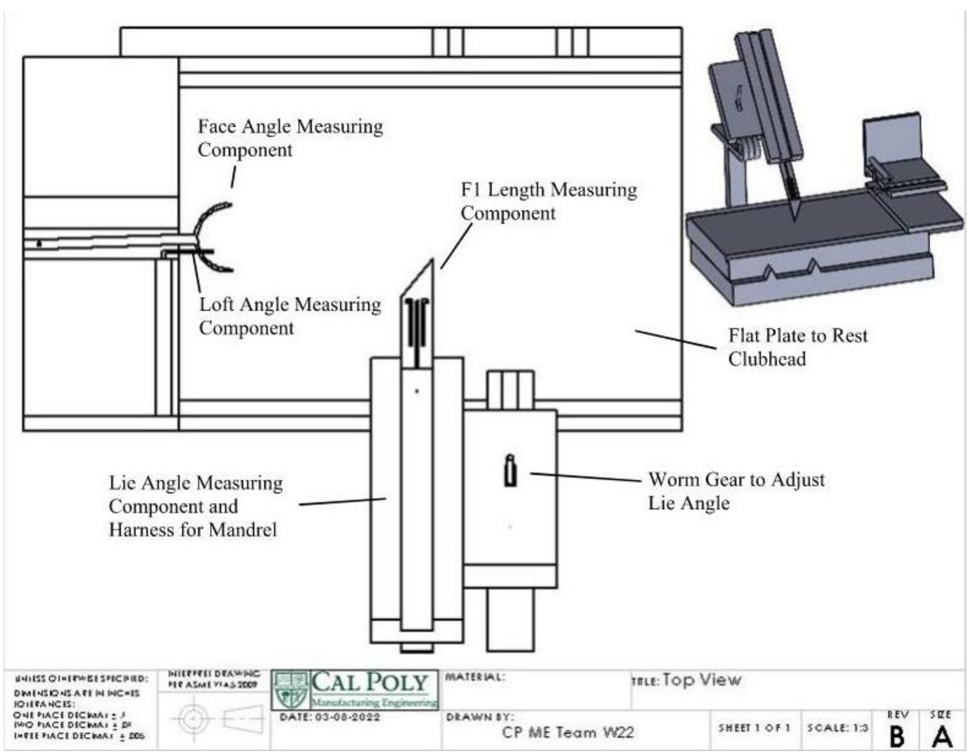

Figure 17: Top View of Solidworks Prototype Gauge.

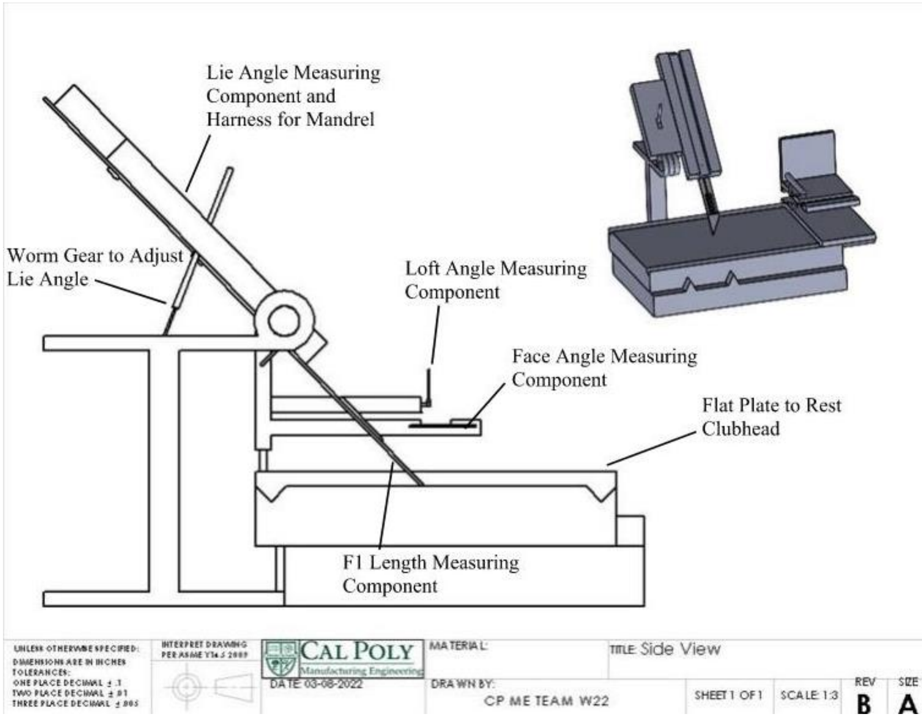

Figure 18: Side View of Solidworks Prototype Gauge.

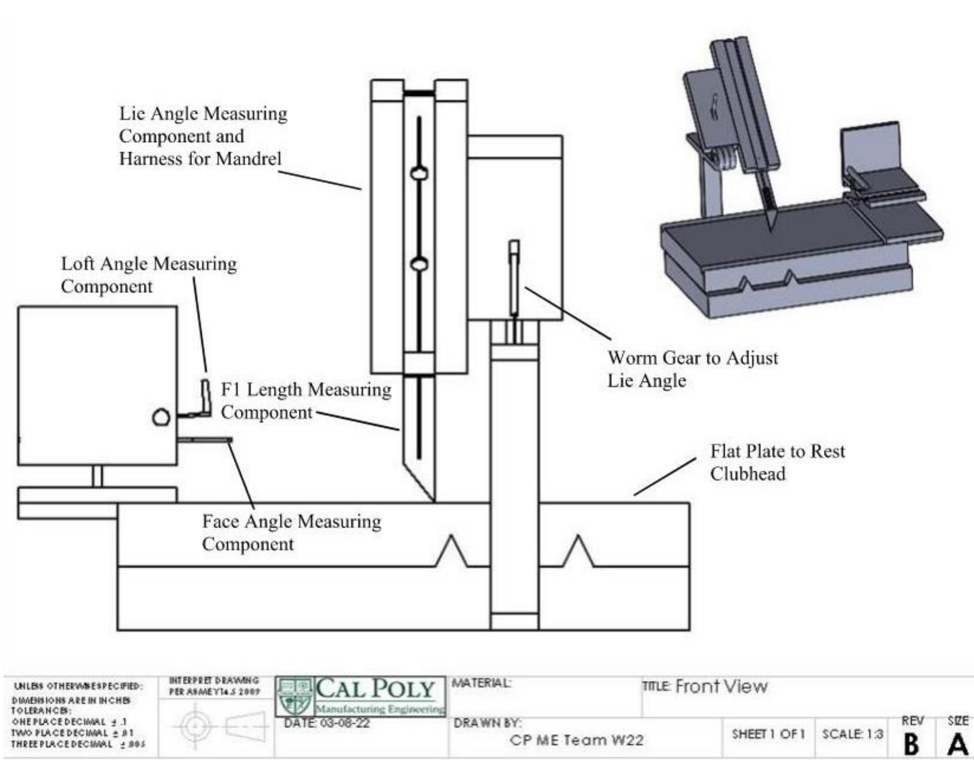

Figure 19: Front View of Solidworks Prototype Gauge.

Figure 20: Isometric View of Concept Prototype.

4. Concept Justification

The following section explains how concept justification was executed for this project and what is needed for further validation during testing and manufacturing. Section 4.1 explains the methods that were already used to justify the model. Section 4.2 discusses some safety concerns that will be addressed in all stages of the process. Finally, Section 4.3 discusses any further problems and concerns that the team anticipates will become relevant going forward.

4.1 Justification Methodology

The design that was created has been verified to be both feasible and effective to the best of the group's collective engineering knowledge. The design was evaluated using the following methods:

- Preliminary hand calculations
- Experimental trials
- Prototyping/engineering judgment
- Callaway factory visit

4.1.1 Preliminary Hand Calculations

The hand calculations that have been executed for the design justification involve justifying the use of encoders to achieve the resolution that the stakeholders desire. For this design 4000 PPR encoders will be used, meaning that the encoders can take 4000 unique measurements for each full rotation. The angular tolerance is required is +/- 0.1 degrees. In addition, angular measurements will be taken over a maximum of a 90-degree span. Because of this, the following equations were derived to determine the resolution that is possible for these encoders:

$$90\ deg \cdot \frac{1\ rotation}{360\ deg} \cdot \frac{4000\ ticks}{1\ rotation} = 1000\ measurements$$

$$\frac{90\ deg}{1000\ measurements} = 0.09\ \frac{deg}{measurement}$$

This means that the resolution that can be achieved with the desired encoders is 0.09 degrees, with a tolerance of +/- 0.045 degrees. This should be more than acceptable for the scope of this design.

4.1.2 Experimental Trials

Like the hand calculations, the experimental trials have primarily involved the implementation of encoders for the design solution. For these trials a simple microcontroller unit called a Nucleo was used to interface with firmware that was designed to execute the function of angular measurement. This was accomplished using a Python file that converts the tick value that is read from the encoder to an angular measurement value and repeatedly presents it to the user via the simple user interface.

Appendix G displays some sample code from the Python file that will be used to collect data from the encoders and translate them to the digital display. This is executed using object-oriented programming with cooperative multitasking between two tasks: Task User and Task Encoder. Task User is what interacts directly with the digital display, while Task Encoder records encoder measurements to the microcontroller for translation and processing. Please note that the printed strings “stopping” and “end of data collection” as well as the time array are used for testing but will not be included in the final code.

While this trial has proven the group’s capability of implementing this technology, further testing is required using different microcontrollers and encoders to decide upon the final model for use. Table 1 shows questions about the technology used alongside methods to obtain answers and justification needed in the future.

Table 1: Justification Table.

Question	Method of Justification
Does the encoder work for angular measurements when the rotating axis has a significant length?	First, securely attach a long piece of material to the axis of the encoder that will serve as a datum. An angular measurement device will then be placed on top of the datum and rotate the system to ensure that the two measurements are consistent.
What material will be used for each individual component?	Justification will be executed using a multi-step process: • Execute preliminary hand calculations to narrow down the materials list to five potential candidates. • Run Finite Element Analysis (FEA) for the SolidWorks model using a variety of different materials • For the materials that perform sufficiently, research aspects of the material such as density, price, and elastic modulus and create a table of attributes • Create a weighted decision matrix for the materials to find one that best suits the needed functionality
How will Callaway manufacture the different components of the design?	For the components that are intended for in-house manufacturing, execute the manufacturing process in the shop to evaluate the time and effort required to manufacture the design. This will likely be executed with the help of shop techs.

4.1.3 Prototyping and Engineering Judgment

A primary outcome of the prototyping process was to justify the design idea in more of a "real world" context. The prototype that was generated led to the following conclusions:

1. The device will not carry much of a load outside of the threaded components, meaning that they will be the primary point of concern for FEA and material decision making.
2. Many effective components were like those on the current green gauge, further validating the strategy of optimizing the current design instead of starting completely from scratch.
3. There is a wide array of possibilities for datum setting if the system utilized holds the back of the club head perfectly stationary.

4.1.4 Callaway Factory Visit

During the Callaway factory visit, the group gained invaluable hands-on experience with the green gauge. Conversations with Juan, Ricky, and Graham provided insight as to whether the design ideas were feasible from the outset. This sort of "filtering" process allowed the disposal of certain ideas from the outset like the light-based measurement system.

The group was able to get some important validation for datum setting ideas particularly. By getting hands on experience using the current design's methods, the group was able to formulate ideas to improve upon the process (further discussed in Section 3) while obtaining immediate feedback on the constraints and feasibility for each new idea. The mold idea garnered the most positive feedback from the Callaway representatives, so it was selected as the most promising avenue going forward. After a fully functional prototype is manufactured, a mold will be 3D printed to execute a final working justification based on a given club's design schematics.

4.2 Hazard Analysis

The design hazard analysis was conducted to identify potential safety concerns and find ways that they can be prevented. The primary safety concerns include the following:

1. Electrical components that can introduce a shocking hazard.
2. Pinch points on pivoting components.
3. Sharp edges on the device.
4. The weight of the device, especially while being transported.

For more information on the potential safety concerns and an outline of the prevention methods, please refer to Appendix F.

4.3 Further Challenges

There is a wide array of further challenges beyond what has already been discussed throughout this section of the PDR. First, there will be trouble during the prototyping process due to the size and number of components for the design. This means that 3D printing, or machining, will be a lengthy process and will be very material intensive.

Another significant problem is that datum setting will be different for each of the different club types, and each type may require a unique solution. Because of this, there is a chance that a new datum setting device must be created for each design specification which may be material and time intensive. This is another reason why the mold idea is very appealing to sponsors and group members alike, but as mentioned before more testing is required going forward.

Finally, a significant issue is that San Luis Obispo is located far from the Callaway factory so in-person visits are both time and resource intensive. The first visit provided invaluable information and hands-on experience that could not have been acquired otherwise. The visit required a 12-hour round trip for driving, however, so subsequent visits will only be made if they are entirely necessary.

5. Project Management

The plan for this project consists of various parts that will build off each other to fulfill the scope. Getting to know the team was the first step in the process; this assists in making everything more efficient and enjoyable. Next, conducting research and background research to get a better idea of the project helped to create a problem statement as well as the scope of work which was presented to the sponsor for review. Once approved, the group moved into the ideation portion, using techniques such as brainstorming and models to produce a concept. To help with this the group visited the Callaway Headquarters in Carlsbad, CA on February 22, 2022. This concept was refined and analyzed using CAD and handmade models. From here a concept prototype was developed for this preliminary design review (PDR) presentation which is one of the primary milestones. From here, the next milestones will include the Interim Design Review, the Critical Design Review, building, testing, signoffs, and finally the EXPO and Final Design Review.

The next step for this process is preparing for the Critical Design Review which will involve research into the best materials to use for this build as well as purchasing for the prototype as well as what encoders will work the best for the design. This will involve comparing different machining processes as well as material costs to keep the overall build of this project at a relatively low cost. The current consensus is that stainless steel will be the best material being that it is noncorrosive and handles tooling processes well. Stainless is also a common material making it easier to get in certain sizes and can be on the cheaper side in comparison to a material such as aluminum. Once this is done the materials can be ordered and the machining and assembly portion for the prototyping process will begin, which will take a lot of shop time. The reason for the long shop time will be because the measurements must be taken at a tight tolerance so the parts will need to be machined to a tight tolerance as well. Once all the machining is complete assembly and testing will begin.

Table 2 outlines deadlines for the main milestones of the project. For a more detailed outline of milestone due dates and time periods, see Appendix B: Gantt Chart.

Table 2: Project Timeline.

Deliverable	Description	Due Date
Scope of Work	Outline of the Project	2/2/22
Preliminary Design Review (PDR)	Review of the initial design solutions for the problem	3/1/22
Critical design review (CDR)	Document of complete idea and process	5/3/22
EXPO	Show off the final prototype	11/18/22
Final Design Review (FDR)	Final Design Report, Senior Project showcase with final prototype	12/2/22

6. Conclusion

The goal of the senior design project is to create a measurement device for Callaway that improves upon the current "Green Gauge" Callaway uses to test the tolerances of their newly manufactured clubs. This Preliminary Design Review went into detail on the ideation process that took place as well as how the group came to the consensus of the final design decision. All the matrices to go through the design as well as the Gantt chart to show the plan going forward can be found in Appendix B. This also includes an explanation of the design that was selected by going into each function and explain why each design will be the most efficient followed by a section to justify the design through hand calculations and engineering judgements. The last portion of this document was the Project Management portion which explained the plan moving forward involving purchasing and testing.

After reading through this the group would like to ask permission to move forward with this design as well as request any insight that may be of use.

7. References

BB. “Club Face Angle.” *Leo Tarrant Golf*, https://leotarrantgolf.com/swing-path-club-face/club-face-angle/.

CC. “Clubfitting: Turtle Cove Golf Center.” *Turtle Cove Golf Center | Turtle Cove Golf Center*, 29 Oct. 2020, https://turtlecovegolfcenter.com/clubfitting/.

DD. Kelley, Brent. “The Truth about Lie Angle in Golf Clubs: What It Is, Why It Matters.” *TripSavvy*, TripSavvy, 22 May 2018, https://www.tripsavvy.com/the-truth-about-lie-angle-1563330.

PART III: CRITICAL DESIGN REVIEW (CDR)

Abstract

This document outlines the final design alongside the design verification and justification for the Callaway Measurement Device senior project. The purpose of this design is to measure the loft, lie, face angle, keel point, and F1 length of Callaway's full spectrum of golf clubs using a single integrated measurement gauge. This document covers a detailed outline of the chosen design alongside justifications for each subsystem based on analyses, similar designs, and prototype testing. Next the document provides a plan for design testing and verification. Finally, an indented bill of materials, drawing package, and other analyses are provided in the appendices.

1. Introduction

The Callaway Measurement Team has made progress on their design and manufacturing plan since the Preliminary Design Review. The design progress involves a firmer, more precise system for setting the lie angle, a shaft clamping system with increased degrees of freedom allowing additional measurements, a damage-resistant club head clamping system, testing justification for the encoder, and precision setting of the keel point. The new system for setting the lie angle involves a jacking bolt and nut, allowing the user to adjust the angle of the clubhead with more precision and makes the manufacturing of the system more feasible. The shaft clamping system was redesigned to gain an accurate datum to measure the F1 length. The clamping system is more complicated than the clamping method used by other devices but remains intuitive and is a consistent centering system for the shaft of the golf club. Testing the encoder provides justification of the precision generated using this measurement device.

In addition to the team's design progress, a manufacturing plan has been created and includes the sourcing and modification of materials and assembly instructions. The progress made by the Callaway Measurement Team provides justification for the precision and manufacturability of the team's project and proves the team is ready to purchase the materials and manufacture the prototype.

2. System Design

The golf club measurement device was designed to measure the lie angle, face angle, loft angle, and F1 length of a golf club. To create this device, it was necessary to develop a more efficient and precise measurement system. Therefore, the overall measurement was outlined under five main functions:

- Setting a consistent and reliable datum.
- Measuring the face angle.
- Measuring the loft angle.
- Measuring the lie angle.
- Measuring the F1 length.

Setting a consistent and reliable datum is the most important step in a measurement process. Measuring with an inconsistent datum increases the tolerance of every measurement. In effect, the measurements are less consistent and precise than desired. Setting a datum of measurement for a golf club requires orienting the club consistently and using a reference measurement before taking additional measurements.

Setting the datum for a golf club is dependent on the keel point. The keel point is where the club face makes its first point of contact with ground as can be seen in Figure 2.1. The keel point for each specific club can be obtained from the manufacturer's specifications sheet. To obtain accurate measurements, the club head must be rotated so that its first point of contact with ground is at the manufacturer's keel point distance from the centerline of the gage (see Figures 2.2 and 2.3). By setting a consistent datum about the keel point, all other measurements can be properly obtained.

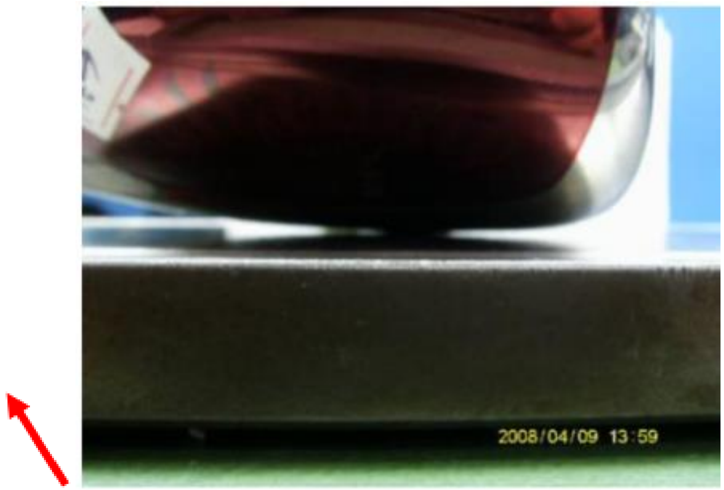

Figure 2.1: Keel Point of a Golf Club

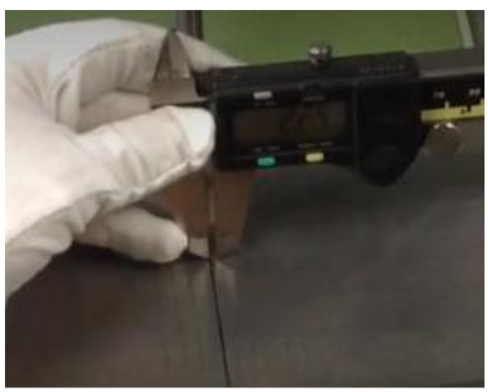

Figure 2.2: Manufacturer's Keel Point Distance from Centerline of Gage

Figure 2.3: Rotating Club to Make First Point of Contact with Manufacturer's Keel Point Distance

The face angle, seen in Figure 2.4, is the direction that the club face is pointed, which can typically be referred to as an open or closed club face. The face angle is measured using the club's design lie measurement. The design lie measurement is the angle the club is designed to have that was made by the team designing the club.

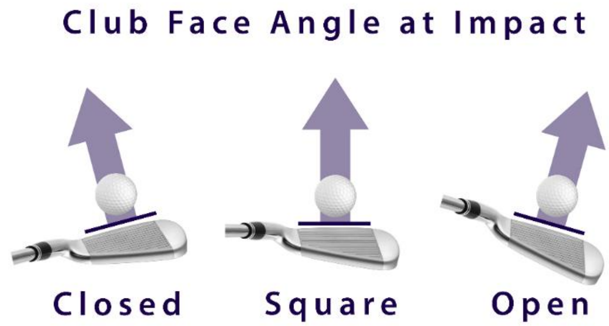

Figure 2.4: Visual Depiction of the Face Angle Measurement [1].

The loft angle of the golf club, seen in Figure 2.5, is the angle of the clubface as positioned to the shaft which is relative to the vertical plane of the club rather than the ground. The loft angle is measured using the club's design lie measurement.

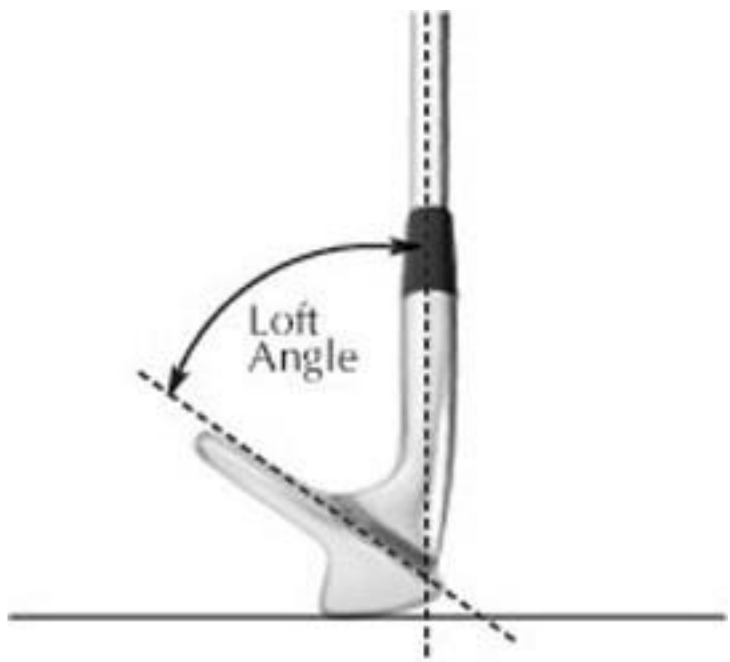

Figure 2.5: Visual Depiction of the Loft Angle Measurement [2].

The lie angle of the golf club, seen in Figure 2.6, is defined by the angle created between the center of the shaft and the ground when the clubhead is resting flush against the ground.

Figure 2.6: Visual Depiction of the Lie Angle Measurement [3].

The F1 measurement, seen in Figure 4, may be measured by Callaway Golf standards or by United States Golf Association "USGA" standards. The USGA measurement takes place when the lie angle is set to 60 degrees and measures the length from the tip of the hosel to the first point of contact between the clubhead and the set, 60-degree plane. The Callaway Golf standard measures the F1 measurement after the lie measurement is made. Using the lie measurement as its reference measurement, the F1 length is defined along a plane parallel to the shaft, measuring from the tip of the hosel to the base plate.

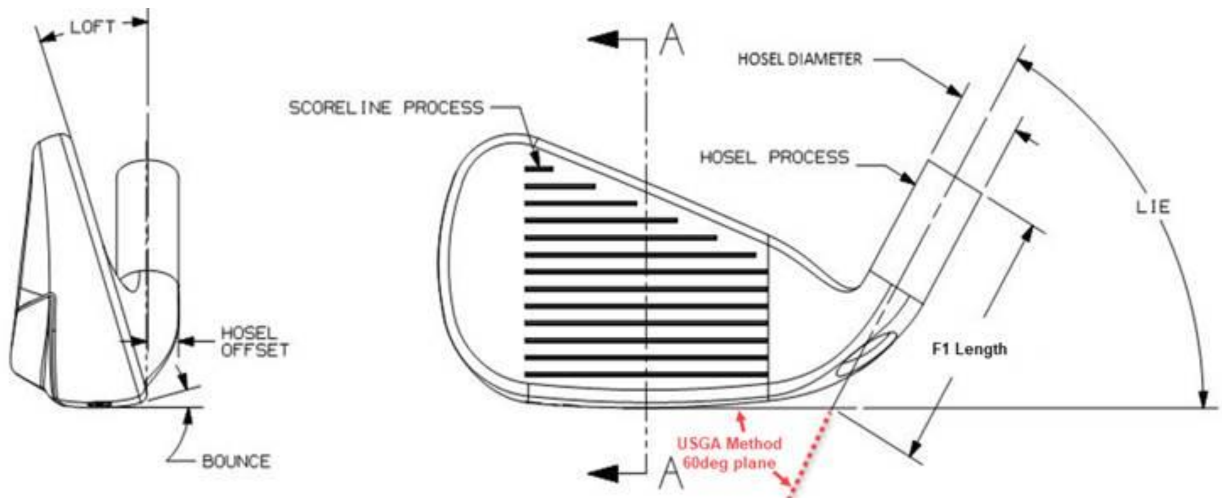

Figure 2.7: Visual Depiction of the F1 Measurement [2].

The keel point slider will be used to simplify the keel point location process for the device. The keel point is a design specification that is used to "zero" the club in order to take measurements. Currently, the keel point is set by simply "eyeballing" based on marks that are set on the base plate. This is a problem because the keel point's location is covered by the club which makes it hard to locate via vision alone. The new keel point slider will allow for better keel point location by using contact rather than sight. This is visualized in Figure 2.8.

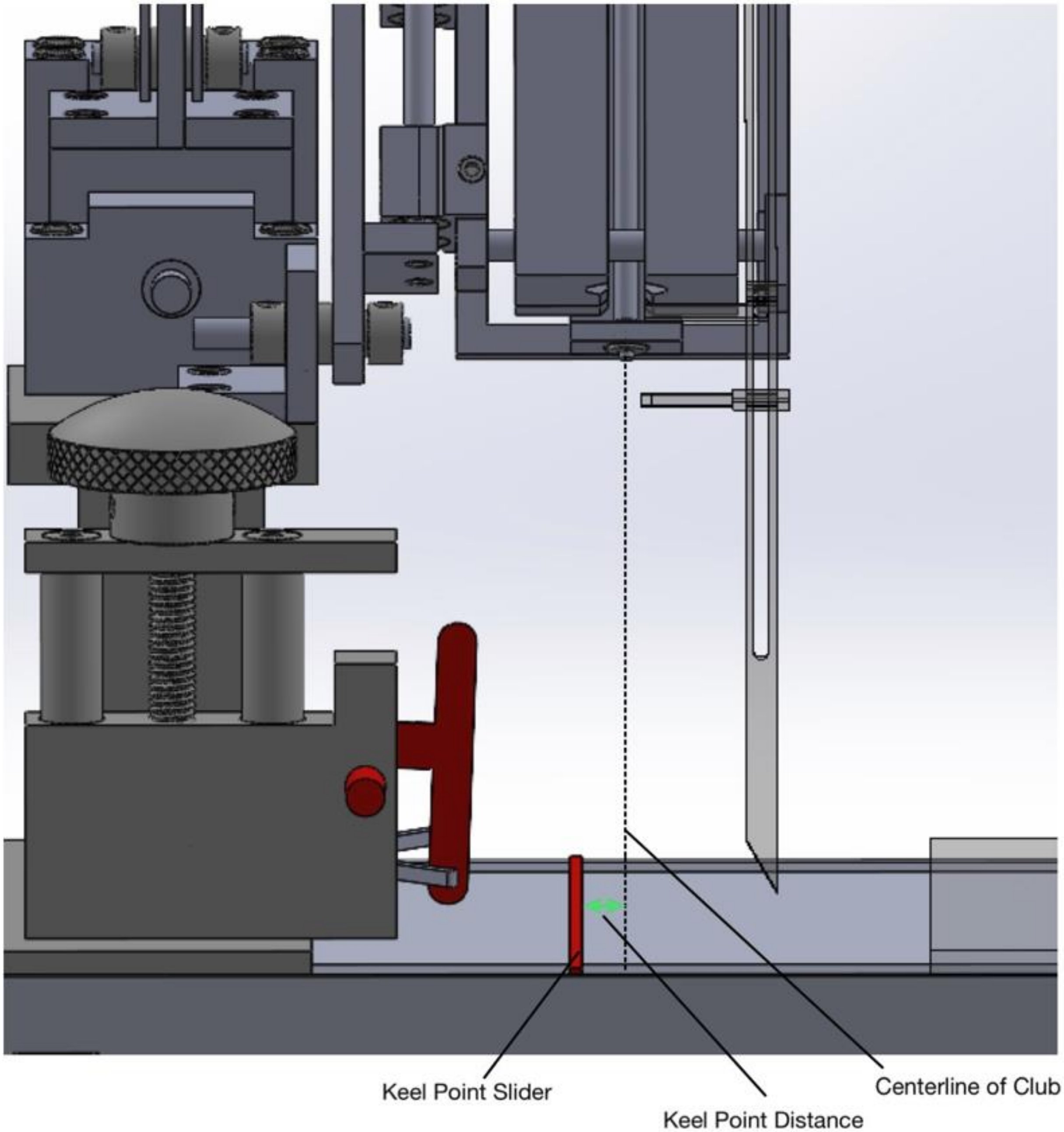

Figure 2.8: Visual Depiction of the Keel Point Slider from the SolidWorks Model.

The loft and face angle apparatuses are very similar to those that are in use for the current green gauge. The key difference in implementation will be the encoders, which are not a part of the SolidWorks model. These are shown in Figure 2.9.

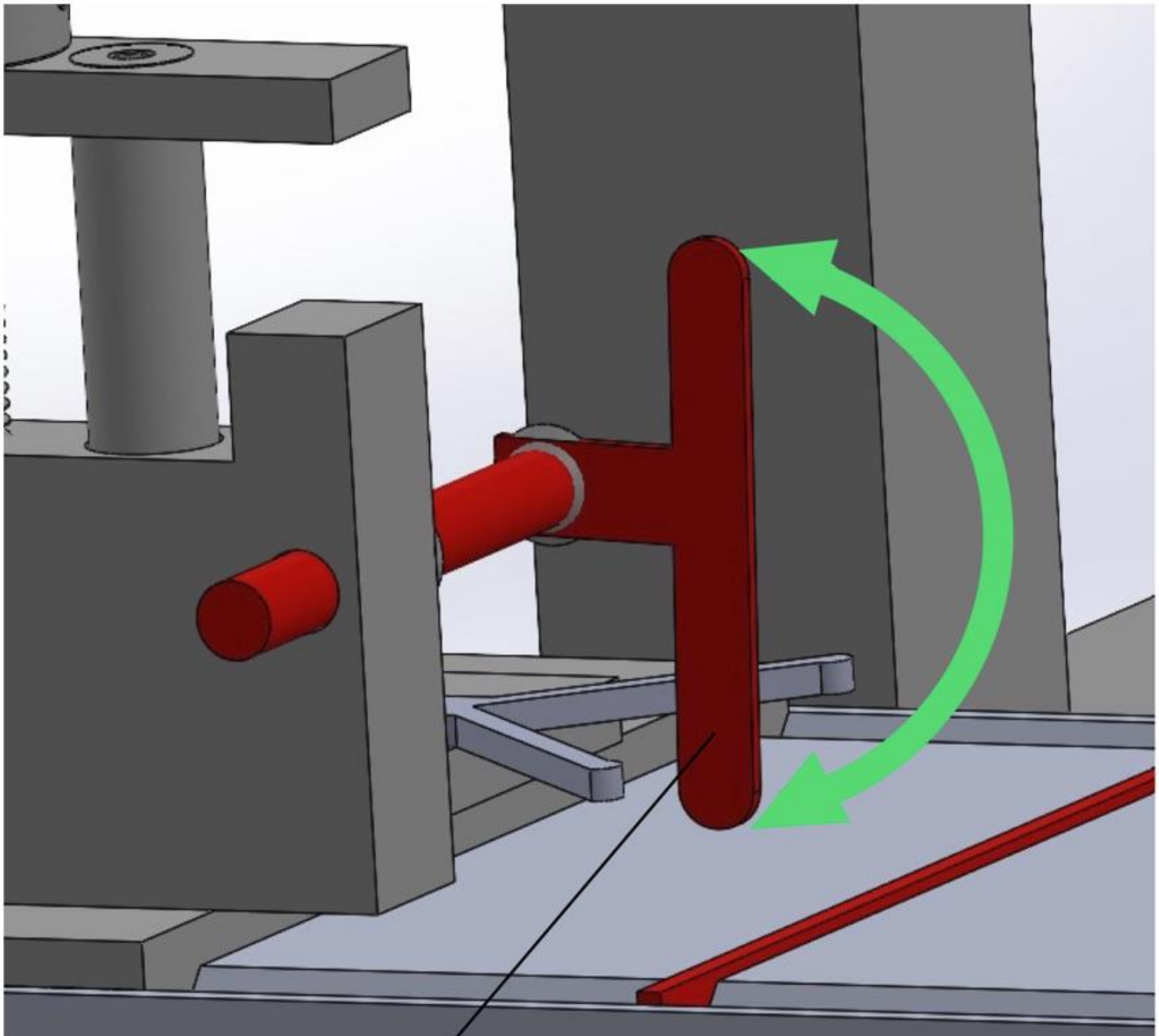

Figure 2.9A: Visual Depiction of the Loft Angle Arm from the SolidWorks Model

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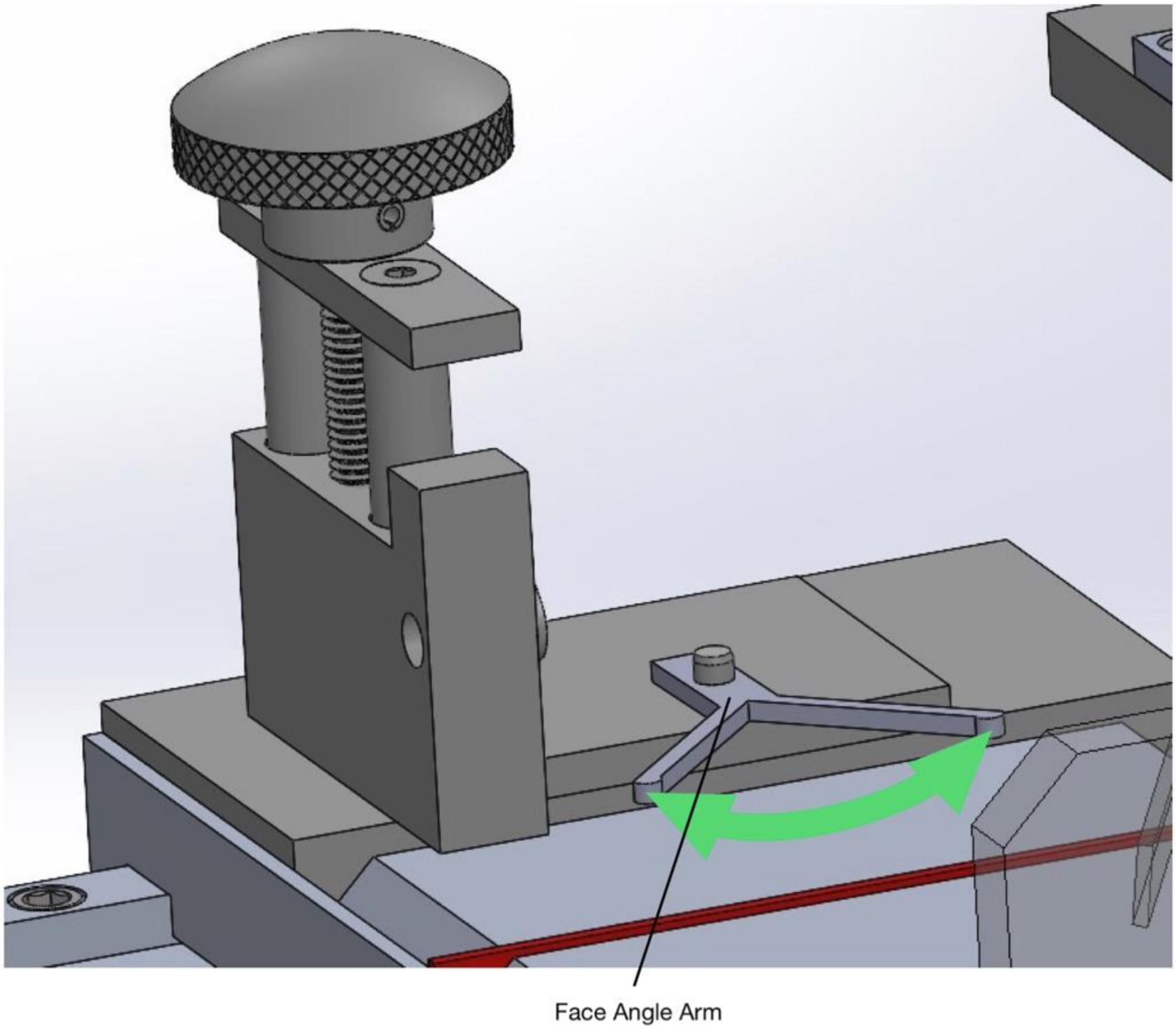

Figure 2.9B: Visual Depiction of the Face Angle Arm from the SolidWorks Model

The F1 slider was a difficult consideration to implement since it needs to be aligned with the back of the club shaft. The slider is designed to drop down from the lie plane in order to measure the F1 length at any angle that is desired. Measurements will be taken from this slider using simple ticks like a ruler, although the implementation of linear encoders to digitize the process is being investigated. A small fixture can slide down the rod in order to interface with the mandrel for more accurate readings, as seen in Figure 2.10.

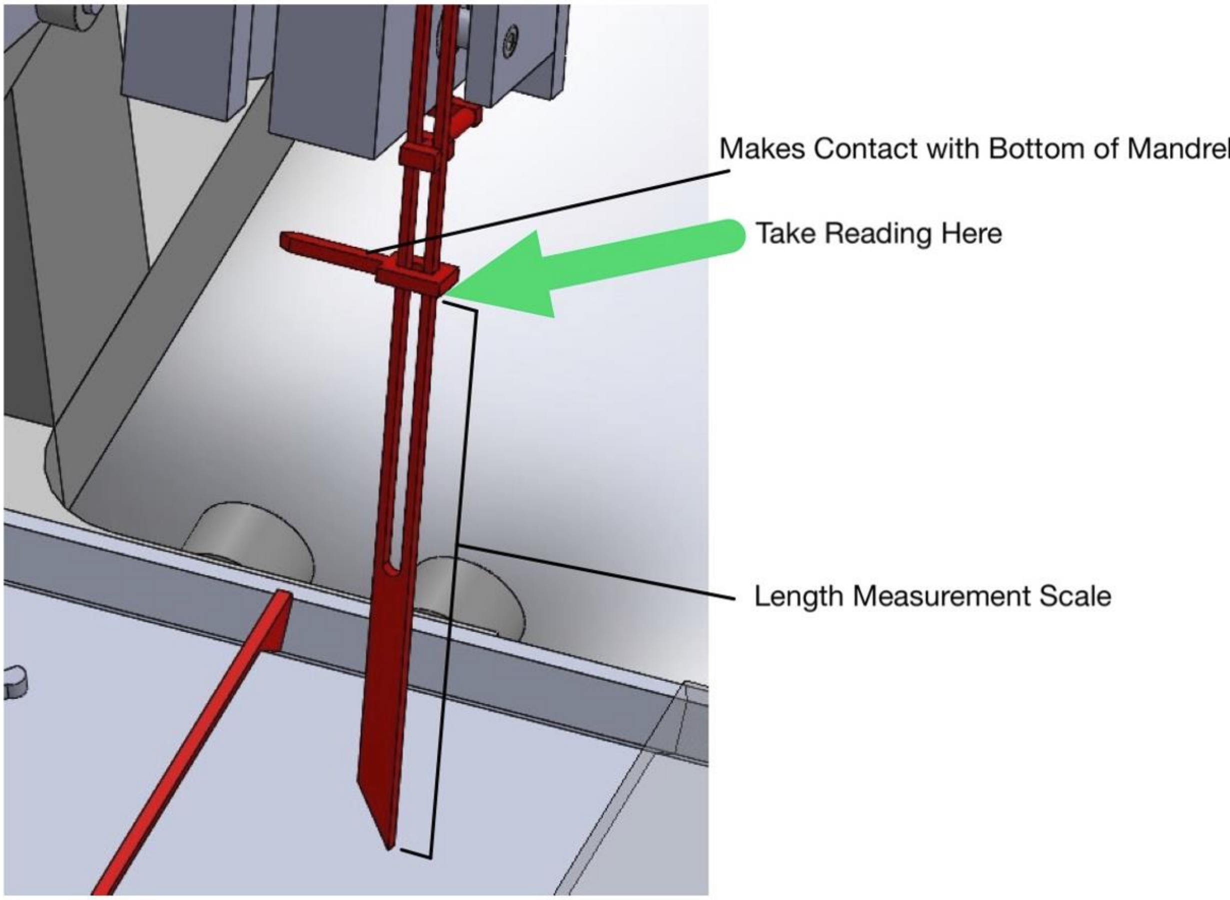

Figure 2.10: Visual Depiction of the F1 Slider from the SolidWorks Model

The loft measurement apparatus was changed significantly to incorporate a crank for more accurate measurement. As the crank turns, the threaded shaft moves the base along the length of the shaft to pivot the lie apparatus upwards and downwards. This leads to only small changes in angle for large turns from the crank. This is useful both for ease of operation and for resolution for the total measurement.

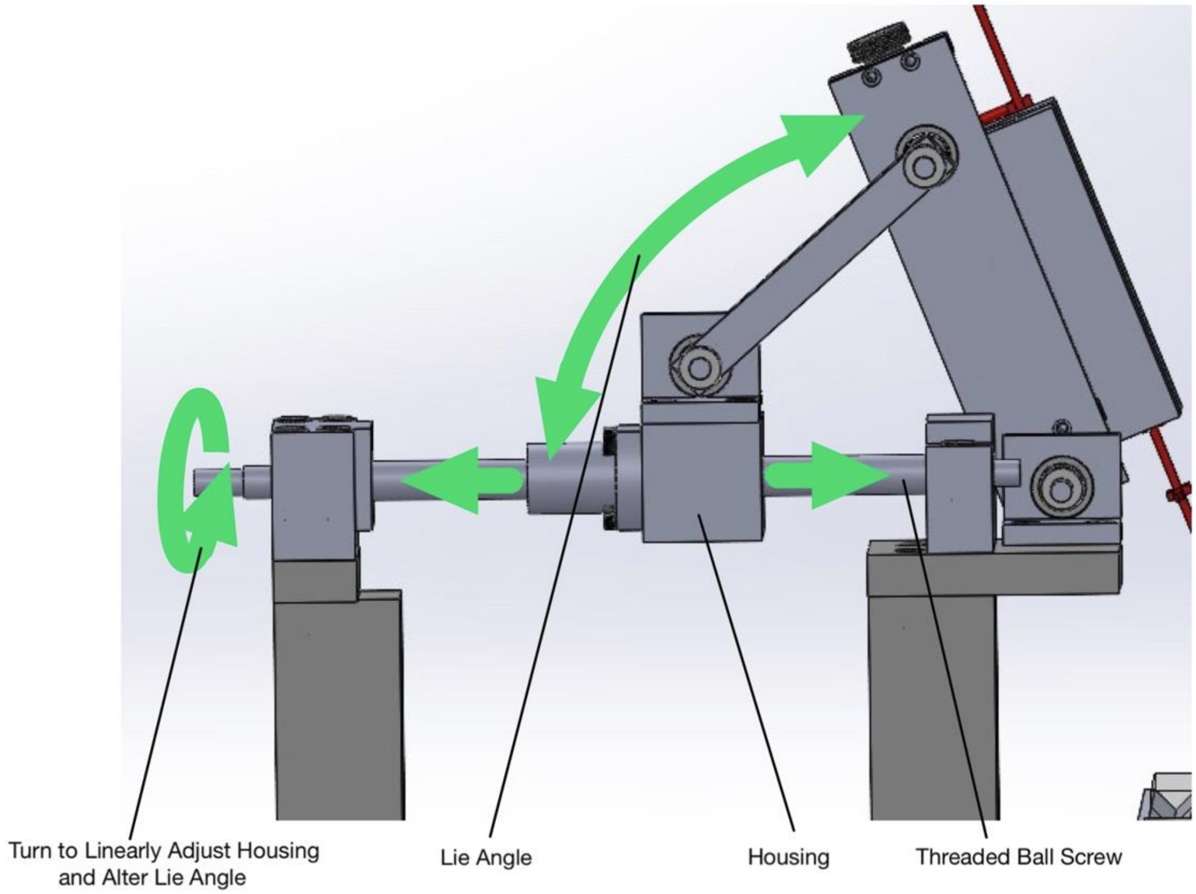

Figure 2.11: Visual Depiction of the Loft Apparatus from the SolidWorks Model

3. Design Justification

The design justification process is discussed throughout this section. This section will primarily outline the solutions that were developed for the following design specifications:

- Measurement tolerance (loft, lie, and face angle)
- Set up time (keel point)
- Amount of unique measurement types (keel point and F1 length)
- Damage to club (FMEA and safety)

A complete list of design specifications can be referenced in Table 1 of Section 5. Primary justification modes include 3D modeling and dimensioning, physical prototyping, and FMEA (Failure Modes and Analysis). Each of these justification modes will be discussed further in the coming subsections.

3.1 Lie Angle

The lie angle needs to be read down to 0.5 degrees from an angle range of 55 to 90 degrees from horizontal. Our design which implements a ball screw lift mechanism, pictured in Figure 3.1A and Figure 3.1B, allows two arms to be moved. We optimized these arms in SolidWorks to obtain an angle range just below 55 degrees to just past 90 degrees.

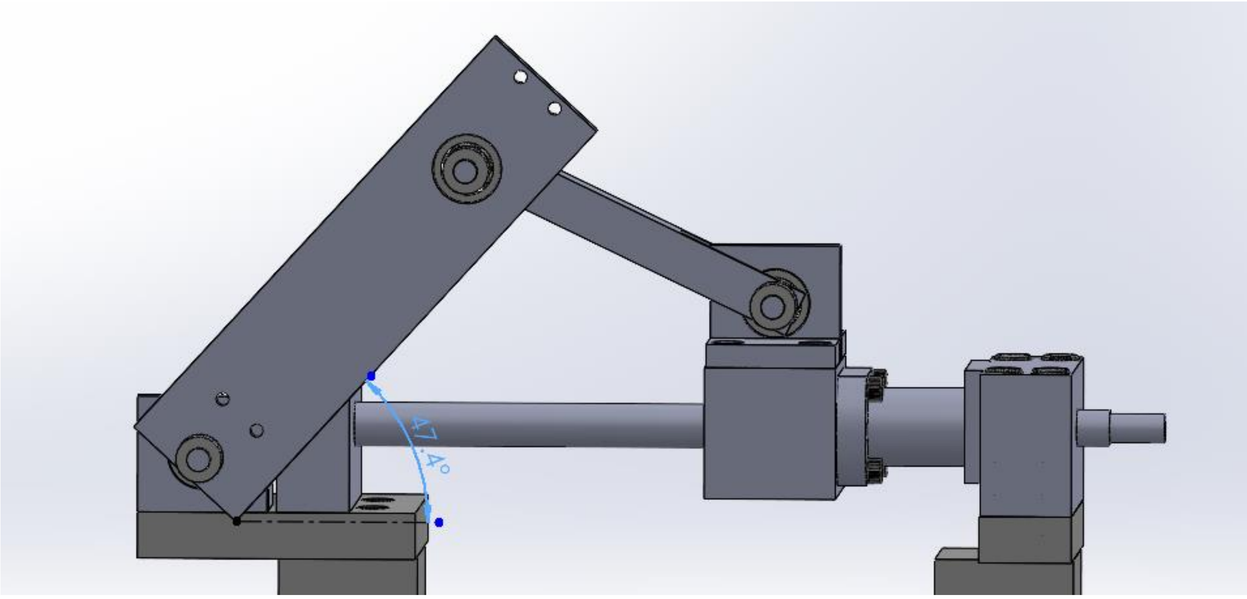

Figure 3.1A: Lie Arm positioned at one extreme.

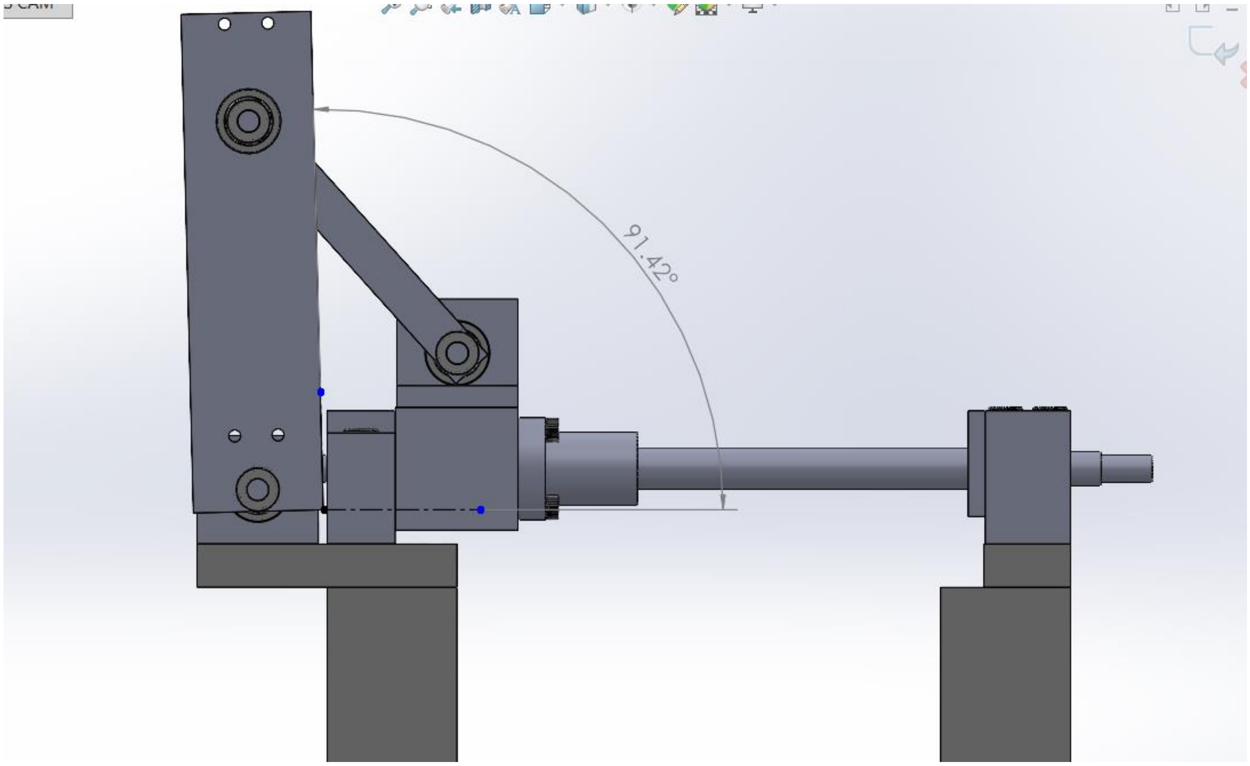

Figure 3.1B: Lie Arm positioned at other extreme.

Figure 3.1A and Figure 3.1B show that our design can be adjusted from 47.4 degrees to 91.4 degrees, which encompasses the desired range.

To meet the specification of getting changes of precision within 0.5 degrees, we ordered the ball screw that we will be using in our final prototype. Using wood, we connected arms and built a preliminary prototype to test how minor of adjustments could be made with the ball screw (see Figure 3.1C).

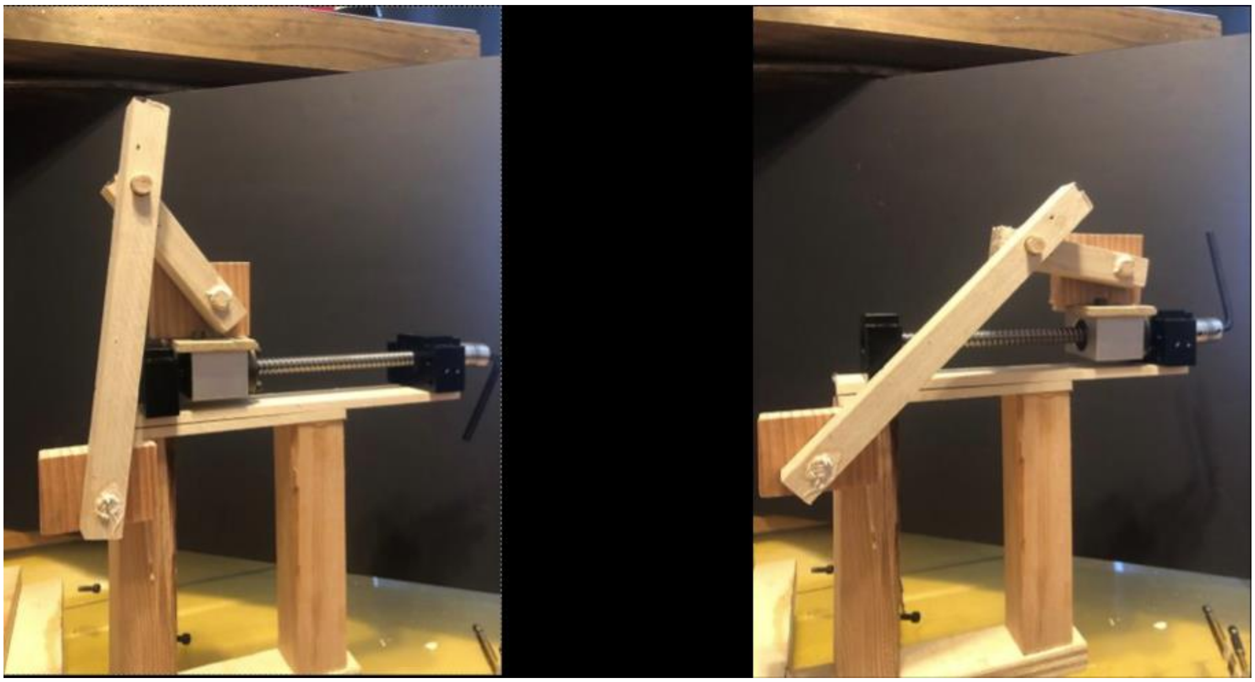

Figure 3.1C: Prototype for testing ball screw adjustment.

After creating this prototype, we saw that large rotations of the Allen wrench resulted in small linear movement of the mounting block, and therefore very small changes in angle. When tested, we could obtain changes in lie angle of less than 0.25 degrees. Therefore, this part we purchased will be sufficient for obtaining changes in lie angle less than 0.5 degrees.

3.2 Loft Angle and Face Angle

The current measuring device Callaway uses is produced by Golf works which is shown below in Figures 3.A and 3.2B. The pictures show the measuring components used to obtain the loft and face angles of the clubs which are extremely accurate and can be consistent if used right so for our design we decided to go with the same concept utilizing encoders and contact points to measure the angles. Our design upgrades the loft arm by allowing it to measure all clubs and not just irons by having a groove where different devices can slip on that are specific to drivers and woods. Currently these clubs are measured using a protractor so this should increase the accuracy of measurement as well as the time it takes to measure these clubs.

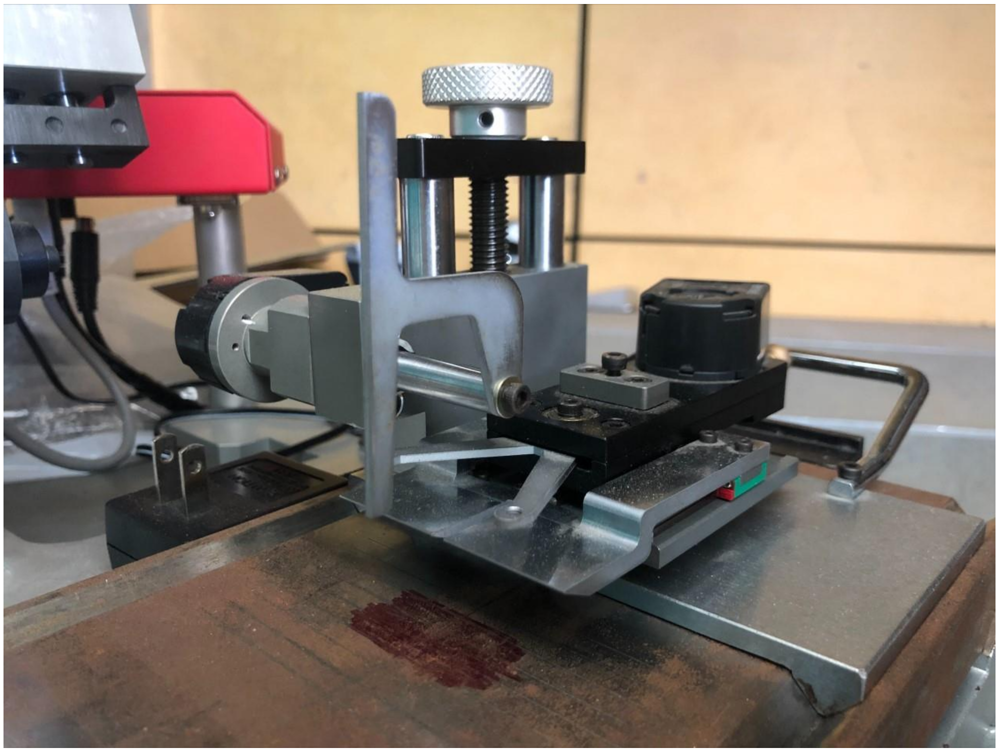

Figure 3.2A: Isometric View of Current Measuring Device for Callaway

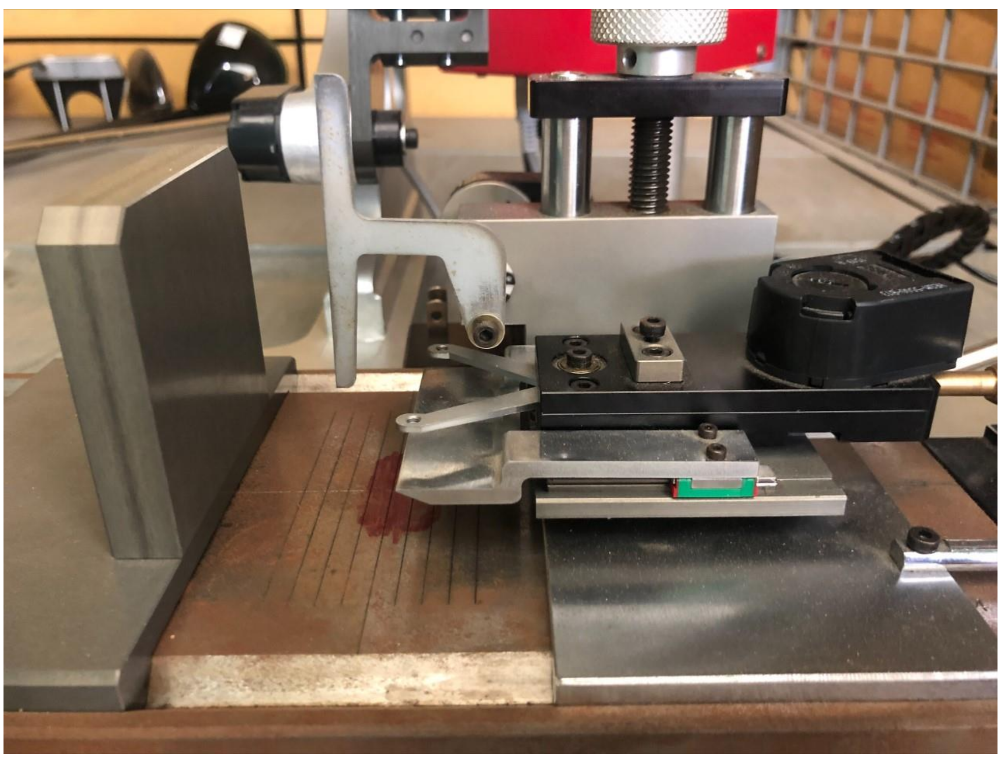

Figure 3.2B: Side View of Current Measuring Device for Callaway.

3.3 Keel Point (Datum Setting)

The keel point slider zeros along the center of the long axis of the shaft or mandrel that is clamped, regardless of the thickness. The slider will either be adjusted along a printed out scale and locked into place with a spring set screw, or if possible will be connected to an encoder. The thickness of the slider will be the same as the plate that Callaway golf currently tapes down after the keel point measurement is marked with a digital caliper.

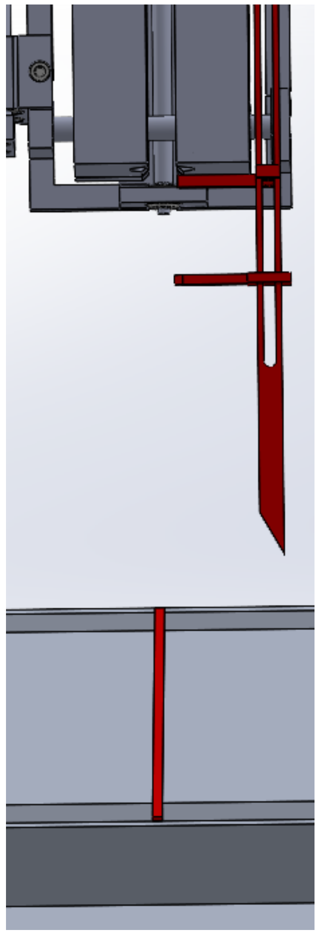

Figure 3.3A: Keel Point Slider zeros at shaft/mandrel centerline.

3.4 F1 Length

The most challenging constraint when implementing F1 Length into the design is maintaining the long axis of the F1 Measurement coincident with the center plane of the shaft. As a result, we designed a clamping mechanism that maintains the same center plane of the shaft or mandrel regardless of the thickness (see Figure 3.4A).

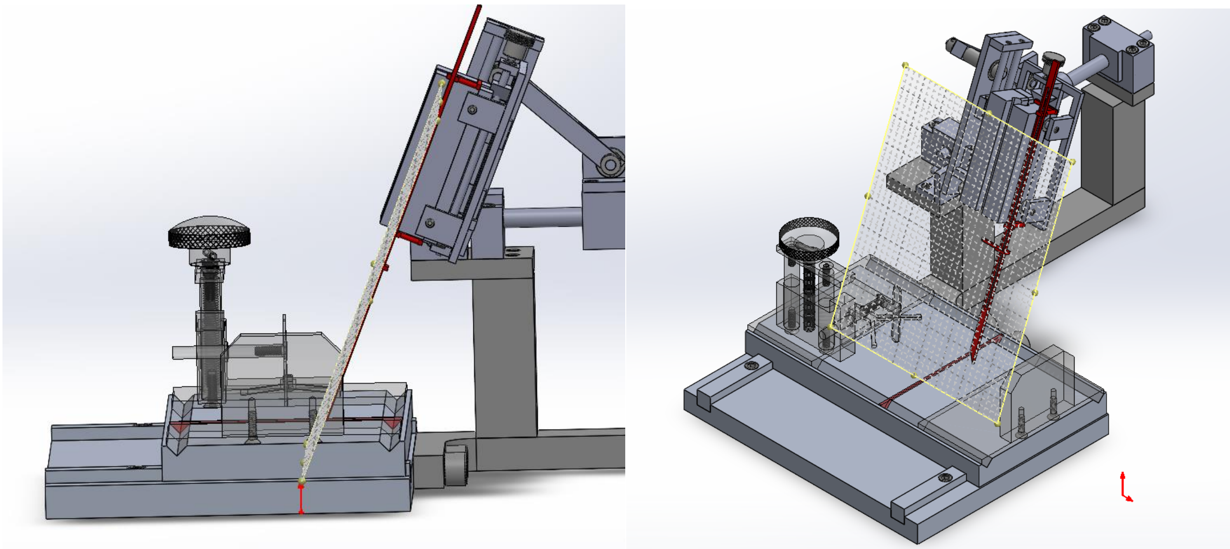

Figure 3.4A: The plane of the F1 Length contacting the base coincides with center plane of shaft clamping mechanism.

Because the F1 maintains coincidence with the center plane of any size shaft measured, our design allows for the implementation of quick F1 measurement without having to reposition the club into a separate measuring device, as in other designs.

To this point, we have not been able to implement a digital encoder for this measurement. At the very least, we will have a similar measurement readout scale for the F1 length as the Callaway's existing F1 measuring device, however ours will have the advantage of being implemented in one cohesive device.

3.5 Safety Maintenance and Repair

Overall this product is built to last and contains little safety and maintenance problems. One problem we can foresee for safety is the possibility of pinching fingers when adjusting certain angles but that is about the extent of how one could hurt themselves while operating this product. Maintenance will consist of changing bearings and any parts that may become worn overtime, we do not expect this to happen very often and the product should last many years before having to undergo maintenance if built correctly.

3.6 FMEA

As a part of design justification, the group completed FMEA to discern the possible modes of failure for the system. To view the full FMEA table, please refer to Appendix D. The group does not anticipate any mechanical failings, as the FEA that was conducted did not show any significant loads throughout the system as anticipated. The primary failure concern is on the electrical side. This is because the digital components will rely on a multitude of connections in order to function so they are prone to a broken connection that can lead to failure. To visualize this concern, the group created the wiring diagram in Appendix H. After consideration and discussion with peers who have extensive electronics experience, a few solutions to this problem are set for implementation:

- Use heat shrink to wrap wire ports for proper and complete insulation
- Create electrical housing so that wiring is not tugged unnecessarily
- Use a single microcontroller for all encoders instead of one for each
    - This will require an MCU with many pins
    - SPI encoders make this easy to implement

3.7 Unresolved Issues

The main unresolved issue with this design currently is getting our code to perform properly with the encoders so that we can finish the design. The encoders have been selected, but the new SPI data type is leading to complications as far as pins are concerned. As a result, the group is investigating new options for larger controllers. This is expected to be resolved soon and once completed the design can move into production and testing.

4. Manufacturing Plan

This section outlines the manufacturing plan that was developed for the device. Because the device requires a lot of manufactured components, the manufacturing plan is divided into subassemblies which are then divided into individual parts and components. The section will discuss the following subassemblies, as well as their individual components:

1. Base subassembly
2. Electrical system
3. Lie subassembly
4. Shaft clamping subassembly
5. Loft and face angle subassembly
6. Zero slider subassembly
7. Keel point zeroing subassembly
8. F1 subassembly
9. Laser subassembly

This section will also outline assembly instructions that will be used once the components have been manufactured. Between this section and the drawing package in Appendix A, a reader should have everything that they need to recreate the design.

4.1 Base Subassembly

The following section will describe the manufacturing plans for each component in the base assembly and then end with a description on how to assemble this sub assembly.

4.1.1 Base Plate

The Base Plate raw material is bought from MetalsDepot.com. 1st it is cut to size using a water jet and then two slots will be milled into it to hold the key stock that will be used as sliders. 4 holes will be tapped to connect the two slides.

4.1.2 Slider Plate

The Slider Plate Raw material is bought from MetalsDepot.com. 1st it is cut to size using a water jet and then it is milled down to create the slide grooves on both sides.

4.1.3 Slide Plate Stoppers (Optional)

4.1.4 Stopper Connecting Bolts (Optional)

Purchased from McMaster

4.1.5 Base Plate Slides

Raw material is bought from MetalsDepot.com then cut to size using a band saw. Two holes will be tapped to connect to the base plate.

4.1.5 Base Assembly Instructions

To assemble first attach the base slides to the base plate by bolting down each slide using countersunk bolts. Then attach the Slide Plate stoppers to the Slider Plate using the connecting bolts. Place the slider plate onto the base plate and it then this sub assembly is complete.

4.2 Electrical System

The following section will describe the manufacturing plans for each part in the Electrical System and then end with a description on how to assemble this sub assembly.

4.2.1 Microcontroller

This part will be bought from pi-plates.com

4.2.2 Digital Interface

This part will be bought from digikey.com

4.2.3 Interface Base

The interface base raw material will be bought from MetalsDepot.com and then cut to size using a water jet. From here two holes will be tapped to connect it to the main base

4.2.4 Interface Base Bolts

Purchased from McMaster

4.2.5 Interface Height Tube

The height tube raw material will be ordered from MetalsDepot.com and then cut to size using a band saw. From here a hole will be tapped on both ends to connect it to the mount plate as well as the Interface Base

4.2.6 Interface Mount Plate

Raw Material will be bought from MetalsDepot.com. The plate will then be cut to size using a water jet as well as have 4 mounting holes put in using the water jet

4.2.7 Interface Mount Bolts

Purchased from McMaster

4.2.10 Interface Buttons/Manual Controller

This part will be bought from digikey.com

4.2.11 Encoder Connecting Cables

This part will be bought from Coast Electronics

4.3 Lie Subassembly

The following section will describe the manufacturing plans for each part in the lie assembly and then end with a description on how to assemble this sub assembly.

4.3.1 Lie Base Subassembly

4.3.1.1 Lie Base

The interface base raw material will be bought from MetalsDepot.com and then cut to size using a water jet. From here two holes will be tapped to connect it to the main base

4.3.1.2 Lie Base to Base Bolts

Purchased from McMaster

4.3.1.3 Lie Stand 1

Raw Material purchased from metalsdepot.com and then cut to length using a band saw. From here two holes will be drilled and tapped to allow connection to Lie Base and Bolting end plate 1.

4.3.1.4 Lie Stand 2

Raw Material purchased from metalsdepot.com and then cut to length using a band saw. From here two holes will be drilled and tapped to allow connection to Lie Base and Bolting end plate 1.

4.3.1.5 Bolting End Plate 1

Raw Material purchased from metalsdepot.com and then laser cut to size and then drill and tap holes to allow connection to Lie Stand 1.

4.3.1.6 Bolting End Plate 2

Raw Material purchased from metalsdepot.com and then laser cut to size and then drill and tap holes to allow connection to Lie Stand 1.

4.3.2 Lie Arm Subassembly

4.3.2.1 Main Arm

Raw material purchased from metalsdepot.com and then cut to size using water jet. After drill holes to allow shaft connections

4.3.2.2 Small Arm

Raw Material purchased frommetalsdepot.com. Cut to size using a band saw, use a drill to make holes for shaft connections. Lastly mill the groove to allow clearance for the bearing.

4.3.2.3 Main Arm Shaft

Raw Material purchased from metalsdepot.com and then lathed to proper diameter. After cut to size using a band saw.

4.3.2.4 Small to Main Shaft

Raw Material purchased from metalsdepot.com and then lathed to proper diameter and cut to size using a band saw.

4.3.2.5 Small Arm Shaft

Raw Material purchased from metalsdepot.com and then lathed to proper diameter and cut to size using a band saw.

4.3.2.6 Bearing Plate 1

Raw Material purchased from metalsdepot.com. Cut to size using a water jet and then drill holes for mounting.

4.3.2.7 Bearing Plate 2

Raw Material purchased from metalsdepot.com. Cut to size using a water jet and then drill holes for mounting.

4.3.2.8 Bearing Plate 3

Raw Material purchased from metalsdepot.com. Cut to size using a water jet and then drill holes for mounting and bearing insert.

4.3.2.9 Flange 1

Raw Material purchased frommetalsdepot.com. Cut to size using a bandsaw and then drill holes to use for mounting.

4.3.2.10 Flange 2

Raw Material purchased frommetalsdepot.com. Cut to size using a bandsaw and then drill holes to use for mounting.

4.3.2.11 Flange 3

Raw Material purchased frommetalsdepot.com. Cut to size using a bandsaw and then drill holes to use for mounting.

4.3.2.12 Small to Main Arm Spacer

Raw materials purchased metalsdepot.com and then cut to size using a band saw.

4.3.2.13 Main Arm Spacer

Raw materials purchased metalsdepot.com and then cut to size using a band saw.

4.3.2.14 Small Arm Spacer

Raw materials purchased metalsdepot.com and then cut to size using a band saw.

4.3.2.15 Lie Arm Ball Bearing

Purchased from mcmaster.com

4.3.2.16 Lie Plastic Washers

Purchased from mcmaster.com

4.3.2.17 Lie Shaft Collars

Purchased from mcmaster.com

4.3.3 Ball Screw Subassembly

Purchased from amazon.com

4.3.4 Assembly of Lie Subassembly

This system contains three separate sub-subassemblies and all of these will be connected together through bolts and shaft collars.

4.4 Shaft Clamping Subassembly

The following section will describe the manufacturing plans for each part in the Clamping assembly and then end with a description on how to assemble this sub assembly.

4.4.1 Mounting Subassembly

4.4.1.1 Sliding Shaft End

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.1.2 Sliding Shaft

Raw materials purchased from mcmaster.com and then cut to size using a band saw. Part will be turned on a lathe, drilling and tapping the holes.

4.4.1.3 Sliding Shaft to Shaft End Bolts

Bolts will be purchased from a local hardware supplier or off mcmastercar.com

4.4.1.4 Linear Bearing Subassembly

4.4.1.4.1 Bearing Housing Bottom

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.1.4.2 Bearing Housing Top

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.1.4.3 Linear Ball Bearing

Purchased from mcmastercar.com

4.4.1.4.4 Bottom to Top Housing Bolts

Bolts will be purchased from a local hardware supplier or off mcmastercar.com

4.4.1.5 Linear Bearing Subassembly to Clamp Housing Bolts

Bolts will be purchased from a local hardware supplier or off mcmastercar.com

4.4.2 Clamp Housing Subassembly

4.4.2.1 C-Clamp Housing Subassembly

4.4.2.1.1 Slider Base Plate

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.2.1.2 C-Clamp Shaft

Raw materials purchased from mcmaster.com and then cut to size using a band saw. Part will be turned on a lathe, drilling and tapping the holes.

4.4.2.1.3 Housing Slider-Backing

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.2.1.4 Shaft End

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.2.1.5 Bolts

Bolts will be purchased from a local hardware supplier or off mcmastercar.com

4.4.2.2 Symmetrical Separator Subassembly

4.4.2.2.1 Symmetric Separator

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.2.2.2 Symmetric Screw

Raw materials purchased from mcmaster.com and then cut to size using a band saw. Part will be turned on a lathe, drilling and tapping the holes.

4.4.2.2.3 Ball Bearing

Purchased of mcmastercar.com or off local supplier

4.4.2.2.4 Retaining Ring

Purchased of mcmastercar.com or off local supplier

4.4.2.2.5 Plastic Washer

Purchased of mcmastercar.com or off local supplier

4.4.2.2.6 Knob

Purchased of mcmastercar.com or off local supplier

4.4.2.2.7 Symmetric Screw Housing

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.2.2.8 Bolts

Bolts will be purchased from a local hardware supplier or off mcmastercar.com

4.4.2.3 C-Clamp Subassembly

4.4.2.3.1 C-Clamp Top

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.2.3.2 C-Clamp Bottom

Raw materials purchased from metalsdepot.com and then cut to size use a water jet. Holes drilled and tapped using hand or CNC mill.

4.4.2.3.3 Linear Ball Bearing

Purchased of mcmastercar.com or off local supplier

4.4.2.3.4 Retaining Ring

Purchased of mcmastercar.com or off local supplier

4.4.2.3.5 Top to Bottom Bolts

Purchased of mcmastercar.com or off local supplier

4.5 Loft and Face Angle Subassembly

The following section will describe the manufacturing plans for each part in the loft and face angle assembly and then end with a description on how to assemble this sub assembly.

4.5.1 Loft/Face Base

4.5.1.1 Loft/Face Slide Plate

Raw Material will be bought from MetalsDepot.com and then it will be cut to length using a bandsaw. From here it will be milled down to create its slide grooves and then two holes will be drilled on the bottom.

4.5.1.2 Vertical Adjustment Base

Raw Material will be bought from MetalsDepot.com and then the piece will be milled down to meet specifications. Two holes will be drilled to allow it to adjust vertically. One hole will be tapped to allow the knob to adjust its height

4.5.1.3 Slide Shafts

Raw Material will be bought from MetalsDepot.com. The material will then be cut to size using a band saw and then holes will be tapped on the top and bottom of the tube to allow it to connect to the slide plate and the height cap

4.5.1.4 Height Cap

Raw material will be bought from MetalsDepot.com. The material will then be cut to size with three holes using a water jet.

4.5.1.5 Slide Shaft Connecting Bolts

Purchased from McMasters

4.5.1.6 Height Knob

Purchased from McMasters

4.5.1.7 Slide Handle Bolts (Optional)

Purchased from McMasters

4.5.1.8 Loft/Face Base Assembly

This assembly starts by attaching the two slide shafts to the Slide plate using the connecting bolts. From here the Adjustment base can slide onto the tubes. Next the height cap is attached to the tubes using bolts and the height knob is screwed into the adjustment base.

4.5.2 Loft Angle Measurement Subassembly

4.5.2.1 Encoder

Purchased from P3 America

4.5.2.2 Encoder Female Housing

Raw material will be bought from MetalsDepot.com. The material will then be cut with a CNC mill.

4.5.2.3 Encoder Connecting Bolts

Purchased from McMasters

4.5.2.4 Loft Shaft

Raw Material bought from MetalsDepot.com. The part will then be cut to size using a band saw. From here a hole will be tapped on the end to allow connection to the loft contact piece

4.5.2.5 Loft Contact Piece

Raw Material bought from MetalsDepot.com. The piece will then be cut to size using a water jet with a hole to a low a bolt to the Loft Shaft

4.5.2.6 Club adjustment Slides

Part will be provided to us by Callaway Golf to allow for interchangeability between clubs.

4.5.2.7 Loft Contact to Loft Shaft Bolts

Purchased from McMasters

4.5.2.8 Shaft Snap ring

Purchased from McMasters

4.5.2.9 Snap ring Washer

Purchased from McMasters

4.5.2.10 Assembly for Loft Subassembly

This assembly starts by attaching the snap ring onto the shaft, then slide the shaft into the base. From here the contact piece can be attached with a bolt. Last is bolting the encoder housing and then the encoder.

4.5.3 Face Angle Measurement Subassembly

4.5.3.1 Encoder

Purchased from P3 America

4.5.3.2 Encoder Female Housing

Raw material will be bought from MetalsDepot.com. The material will then be cut with a CNC mill.

4.5.3.3 Encoder Connecting Bolts

Purchased from McMasters

4.5.3.4 Face Angle Arm

Raw Material bought from MetalsDepot.com. The piece will then be cut to size using a water jet with a hole to a low a bolt to the Face Encoder Shaft.

4.5.3.5 Face Encoder Shaft

Purchased from P3 America

4.5.3.6 Face Arm to Cylinder Bolts

Purchased from McMasters

4.5.3.7 Snap ring

Purchased from McMasters

4.5.4.8 Snap ring Washer

Purchased from McMasters

4.5.4.9 Assembly of Face Subassembly

This assembly involves attaching the encoder to the angle arm through bolting the female encoder housing to base.

4.6 Zero Slider Subassembly

The following section will describe the manufacturing plans for each part in the zero-slider assembly and then end with a description on how to assemble this sub assembly.

4.6.1 Slide Plate

Raw Material will be bought from MetalsDepot.com and then it will be cut to length using a bandsaw. From here it will be milled down to create its slide grooves.

4.6.2 Loft Face Zero Plate

Raw Material will be bought from MetalsDepot.com and then it will be cut to size using a water jet.

4.6.3 Connecting Bolts

Purchased from McMasters

4.6.4 Assembly of Zero Slider

To assemble connect the slide plate to the zero-plate using the two connecting bolts

4.7 Keel Point Zeroing

The following section will describe the manufacturing plans for each part in the keel point assembly and then end with a description on how to assemble this sub assembly.

4.7.1 Keel Slider Plate

Raw Material will be bought from MetalsDepot.com and then it will be cut to size using a water jet.

4.7.2 Linear Encoder (Tentative)

Purchased from P3 America

4.8 F1 Subassembly

The following section will describe the manufacturing plans for each part in the F1 assembly and then end with a description on how to assemble this sub assembly.

4.8.1 F1 Slider

4.8.1.1 Slider Housing

Raw Material will be bought from MetalsDepot.com and then it will be cut to size using a water jet.

4.8.1.2 Sliding Plate

Raw Material will be bought from MetalsDepot.com and then it will be cut to size using a water jet. High precision tick marks will be machined using CNC. Hole for set screw will be drilled on metal drill press.

4.8.1.3 Set Screw

Purchased from McMaster

4.8.1.4 Set Screw Bolt

Purchased from McMaster

4.8.2 Linear Encoder (Tentative)

Purchased from P3 America

4.9 Laser Subassembly

The following section will describe the manufacturing plans for each part in the laser assembly and then end with a description on how to assemble this sub assembly.

4.9.1 Leveling Laser

Purchased from quarton.com

4.9.2 Sliding Plate

Raw Material will be bought from MetalsDepot.com and then it will be cut to length using a bandsaw. From here it will be milled down to create its slide grooves.

4.9.3 Securing Bolts

Purchased from McMasters

5. Design Verification Plan

To execute design verification, the team intends to test each specification with the newly created gauge and compare the values to those from the provided design values and those collected from the digital gauge. Table 1 outlines the specifications that will be tested during design verification:

Table 1: Measurement device specifications table

			Target	Tolerance	Risk *	Compliance **
Specification	1	Time to measure a club	< 2 minutes	+ 8 minutes	H	T
	2	Amount of measurement types	3 minimum	+ 3	L	I
	3	Is it intuitive?	zero training required	10 minute demonstation	H	T,A
	4	Set up time	< 1 minute	+3 minutes	M	T
	5	Amount of components	one component	+2 components	L	A,I
	6	Battery/Plug Required?	not required	1 battery/plug	M	I
	7	Angle tolerance of measurement	+/-0.1 degrees	up to +/-0.5 degrees	H	T,A,I
	8	Total Cost	<$2600	0$ < cost<$2600	M	A
	9	Damage caused to club	zero	none	M	A,I
	10	Lifetime	10,000 measurements	- 5,000 measurements maximum	M	A

* Risk of meeting specification: (H) High, (M) Medium, (L) Low

** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

The following sections will discuss specifications that require further testing along with the testing methodology, equipment needed, and results processing for the corresponding specification. To reference the complete design verification plan, please refer to Appendix F. The following specifications will be discussed in depth:

- Measurement time (Section 5.1)
- Intuitiveness (Section 5.2)
- Setup time (Section 5.3)
- Angular tolerance (Section 5.4)

To reference the complete design verification plan, please refer to Appendix F.

5.1 Measurement Time

Measurement time is characterized as the amount of time that it takes to take all measurements after the club is properly set up in the clamp. The target measurement time is less than 2 minutes, and the tolerance includes an additional 8 minutes. The wide tolerance results from the fact that measurement time is far from the most important specification and is eclipsed by specifications such as tolerance and cost.

5.1.1 Measurement Time - Testing Methodology

Before testing measurement time, one of the provided clubs will be attached to the measurement device with the clamp. For the first part of the test, lie will be measured. To begin lie measurement, the club face will be levelled using the laser and keel point will be set. A stopwatch will begin counting as soon as the user begins levelling the club. The lie portion of this test will finish as soon as the user is able to call out a value that is accurate with respect to the specifications. The threshold for accuracy will be discussed further in the angle tolerance portion of this report (Section 5.7). After the first portion is complete, the user will then proceed to take the measurements for loft and face angle. As soon as loft and face angle are measured, the stopwatch will be stopped and the time will be recorded.

5.1.2 Measurement Time - Equipment Needed

The following equipment will be required to test for this specification:

- 1 existing club with available measurement specs
- 1 [phone] stopwatch

5.2 Intuitiveness

Intuitiveness is the measure of how quickly someone can learn to use the device. The initial target of having no training required is far from realistic for a complete layman, so the tolerance specification of a short demonstration will be employed for this testing.

5.2.1 Intuitiveness - Testing Methodology

To execute testing for intuitiveness, the group will provide a short demonstration to Coach Rossman and then ask her to attempt to take a series of measurements using the device. Coach Rossman was selected as the subject because she signed the NDA and has a level of familiarity but has never personally used the device. As a result, she can act as a stand-in for the Callaway employees who will use the new device. To execute the test, she will be asked to measure loft, lie, and face angle while using the newly created device.

5.2.2 Intuitiveness - Equipment Needed

The following equipment will be required to test for this specification:

- 1 existing club with available measurement specs

5.3 Setup Time

Setup time is the measurement of how long it takes to change one club out for another once measurements have been completed.

5.3.1 Setup Time - Testing Methodology

To test setup time, the group will begin after a club has been measured for another test. One member will begin the stopwatch while another member proceeds to remove the initial club from the clamp and replace it with another. The timing will be complete when the second club is firmly secured by the clamp and ready to be measured.

5.3.2 Setup Time - Equipment Needed

The following equipment will be required to test for this specification:

- 1 existing club with available measurement specs
- 1 [phone] stopwatch

5.4 Angular Tolerance

Angular tolerance is the tolerance for angular measurements that is found after uncertainty analysis is conducted. This is perhaps the most important design specification and requires a value of +/- 0.1° for each angular measurement.

5.4.1 Angular Tolerance - Testing Methodology

To test angular tolerance, the group will obtain a digital angular measurement level with a tolerance of +/- 0.05° from Digi-key Electronics. The digital level will be placed on top of the lie measurement apparatus in line with the rotating plane. Readings will be taken both using the digital level and the measurement device's digital display. Ten measurements will be taken in a range between 55 and 85° and recorded into a table.

5.4.2 Angular Tolerance - Equipment Needed

The following equipment will be required to test for this specification:

- 1 existing club with available measurement specs
- 1 Digi-key angular measurement device

Project Management

6. Conclusion

This document reviewed the key design steps and decisions that have been made since the PDR. The main milestones that were reached were the completion of drawings, the development of a DVP, and the completion of the bill of materials. These are significant steps because they allow the group to order components needed to begin manufacturing the device. Going forward, the group will begin manufacturing the prototype for testing. In addition, electrical components will be completed and assembled entering the fall quarter of 2022. Directly following, the group will carry out the design verification plan. Do you agree with the purchasing, testing, and building plans?

PART IV: FINAL DESIGN REVIEW (FDR)

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1. Design Updates

Since the CDR, the design changed drastically. Upon completion of the CDR, the team met with their sponsor, Callaway. Prior to the meeting, the team believed they would be designing a gauge for production and therefore, designed the prototype out of metal to be machined by a mill or lathe. The design, drawing package, and manufacturing plan in the CDR section was based on this concept. During the meeting, miscommunication was identified, and due to costs and ease of manufacturability, the team pivoted their design goal to create a proof-of-concept prototype.

1.1 From metal to 3-D Prints

In the initial design, the team aimed to minimize material costs by using fasteners to connect many smaller machined metal parts, rather than wasting large amounts of material using material removal processes on large chunks of metal. Since transitioning to 3-D prints, this restriction was no longer the case. Instead, many parts and subassemblies were combined into single parts to be 3-D printed. This began a new iterative design process, where through trial and error, the team could settle on the best design without worrying about cost. The transition from the production designs to the proof-of-concept designs may be compared between the CDR Appendices: Appendix A and the prototype's drawing package. In summary, the final prototype simplified the design drastically, combining and deleting components for ease of manufacturability and assembly purposes.

1.2 Digital Assembly

Due to many issues with the digital script, encoders, and redefining the goal of the project, the team transitioned into using a Raspberry Pie. Though more expensive, the digital aspect of the concept prototype is one of the highest priorities because it enables the final prototype to measure golf clubs to a resolution of 0.07°. The Raspberry Pie is more user friendly and allowed the team to successfully interface the encoders. Once the digital interface was integrated and completed, the team designed housings for the digital components and display. These were designed to be 3-D printed and mounted to the base assembly.

1.3 Base Assembly

One of the most expensive material costs in the CDR model was the base assembly. This assembly required large chunks of metal to be stable and support subassemblies without movement. The team reduced this cost by changing the base to be made from aluminum extrude. Though not as strong nor stiff as a metal plate, aluminum extrude is more durable and reliable than 3D printed components.

1.4 Clamping Assembly

The original clamping assembly was overly complicated, with many components requiring extensive machining and assembling. The clamping assembly was originally designed to maintain a centerline datum along the shaft of the golf club to allow integration of an F1 gauge measuring along this datum. To simplify the design, springs with equivalent spring constants replaced the complicated symmetrical separator in the CDR's design.

2. Manufacturing

This section outlines the manufacturing process for the device that was created. Because the device requires a lot of manufactured components, the manufacturing process is divided into subassemblies. The section will discuss the following subassemblies, as well as their individual components:

1. Changes from Manufacturing Plan
2. Base subassembly
3. Lie subassembly
4. Shaft clamping subassembly
5. Zero slider subassembly
6. Loft and face angle subassembly
7. Digital subassembly
8. Laser subassembly

This section also outlines how the components were procured, manufactured, and assembled. In addition, the group included challenges and recommendations for future manufacturing.

2.1 Changes from Manufacturing Plan

A key difference between the manufacturing plan and the final manufacturing process is the materials used. For the manufacturing plan, the group intended to build and machine the device using aluminum. Callaway informed the group that proof of concept was acceptable instead of a device that was ready for mass-production, so the group pivoted to using 3D printed parts instead. Because the group gets free 3D printing as Cal Poly students, this change saved a lot of time and money for everyone involved.

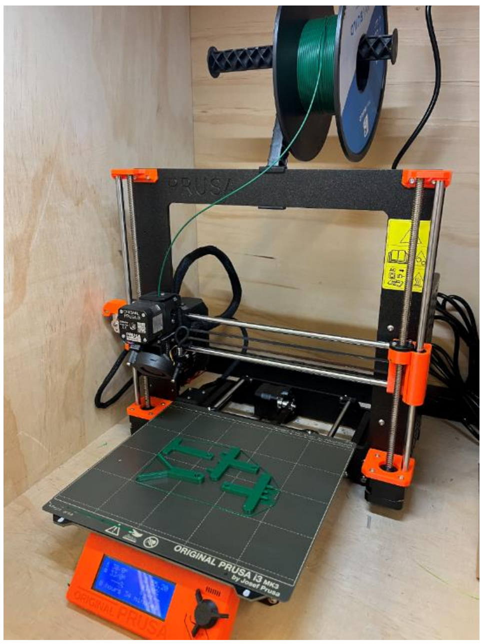


Figure 2.1: 3D Printer with Test Loft and Face Angle Arms

Another key budgetary change was the use of quadrature encoders rather than SPI, and the use of a Raspberry Pi 4 rather than an Arduino board. This was chosen because it allowed for the use of Python, which the group is more familiar with than C++. In addition, the additional cost of the Raspberry Pi was mitigated by the reduced cost of the 3 new encoders. The total cost falls within the budget of $1000 with a total of $764.02. For a more detailed breakdown of the budget, please refer to the bill of materials in Appendix C.

2.2 Base Subassembly

The following section will describe the manufacturing plans for each component in the base assembly and then end with a description on how to assemble this sub assembly.

2.2.1 Base Plate

2.2.1.1 T-Slotted Framing

This was purchased from McMaster and cut with a band saw.

2.2.1.2 Diagonal Brace

This was purchased from McMaster and cut with a band saw.

2.2.1.3 Silver Corner Bracket

This was purchased from McMaster.

2.2.1.4 Silver Corner Surface Bracket

This was purchased from McMaster.

2.2.1.5 End-Feed Nut

A pack of four was purchased from McMaster

2.2.2 Slider Plate

This was 3D printed at Mustang 60.

2.2.3 Base Assembly Instructions

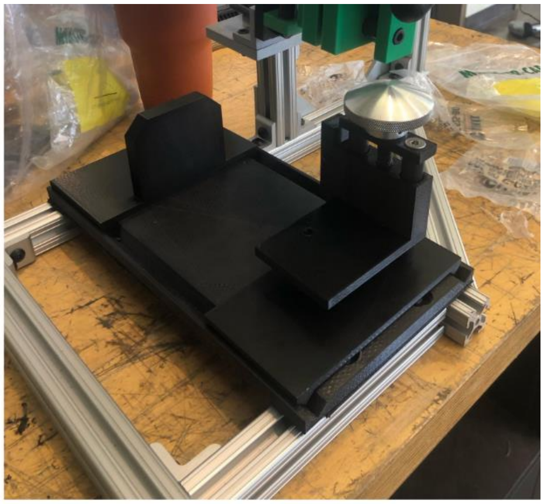


Figure 2.2: Base Subassembly

Cut the T-Slotted framing into 7 different pieces. 4 pieces will be used as the base, below the slider point and will be joined together through brackets and bolts coming from McMaster. Then, the slider base plate will be bolted into the slots while being able to shift around.

2.3 Lie Subassembly

The following section will describe the manufacturing plans for each part in the lie assembly and then end with a description on how to assemble this sub assembly.

2.3.1 Lie Base Subassembly

2.3.1.1 Lie Base

This was 3D printed at Mustang 60.

2.3.1.2 Lie Base to Stand Bolts

This was purchased from McMaster.

2.3.1.3 Bolting End Plate 1

This was 3D printed at Mustang 60.

2.3.1.4 Bolting End Plate 2

This was 3D printed at Mustang 60.

2.3.1.5 Bolting End Plate Bolts

This was purchased from McMaster.

Figure 2.3: Lie Base Subassembly

2.3.2 Lie Arm Subassembly

2.3.2.1 Main Arm

This was 3D printed at Mustang 60.

2.3.2.2 Small Arm

This was 3D printed at Mustang 60.

2.3.2.3 Main Arm Shaft

This was purchased from McMaster and cut to size using a band saw.

2.3.2.4 Small to Main Shaft

This was cut from same material used for the main arm shaft using a band saw.

2.3.2.5 Small Arm Shaft

This was cut from same material used for the main arm shaft using a band saw.

2.3.2.6 Bearing Plate 1

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

Figure 2.4: Tapping a 3D Printed Part

2.3.2.7 Bearing Plate 2

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.3.2.8 Flange 1

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.3.2.9 Flange 2

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.3.2.10 Flange 3

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.3.2.11 Lie Arm Ball Bearing

This was purchased from McMaster.

2.3.2.12 M6 x 1.00 x 20mm

A set of 25 was purchased from McMaster.

2.3.2.13 Lie Shaft Collar

This was purchased from McMaster.

2.3.2.14 Aluminum Spacer

This was purchased from McMaster.

Figure 2.5: Lie Arm Subassembly

2.3.3 Ball Screw Part

This was purchased from amazon.com


Figure 2.6: Ball Screw

2.3.4 Lie Bolts A
This was purchased from McMaster.

2.3.5 Lie Bolts B
This was purchased from McMaster.

2.3.6 Lie Bolts C
This was purchased from McMaster.

2.3.7 Lie Bolts D
This was purchased from McMaster.

2.3.8 Lie Assembly Instructions
The lie base assembly must be put together as seen in figure 2. After securing the assembly with the proper joints and bolts, the ball screw may be attached to the device. The ball screw sits on 3D printed material. Next, the lie arm may be added to the device by heating the 3D printed part to be attached to allow for the ball bearing to insert into the interference fit. Using the same heating process, heat the 3D printed lie arm to allow for the bearing to be installed into the interference fit. Connect the lie arm to the ball bearing, via the 3D printed small arm to main shaft, and install the shaft through both ball bearings.

2.4 Shaft Clamping Subassembly
The following section will describe the manufacturing plans for each part in the Clamping assembly and then end with a description on how to assemble this sub assembly.

2.4.1 C Clamp Base
This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.4.2 C Clamp

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.4.3 Vertical Slide Base

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.4.4 Lie to Clamp Adaptors

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.4.5 ½ Aluminum Rod

This was purchased from McMaster and cut to size using a band saw. This was then predrilled and tapped on a lathe for a M6x1.00 thread.

2.4.6 Connecting Bolts M6 x 1.00 x 10mm

A pack of 100 was purchased from McMaster.

2.4.7 ½" Double Sided Bolt

This was purchased from McMaster.

2.4.8 Two Arm Knob ¼"-20x1/2" Long

This was purchased from McMaster.

2.4.9 Shaft Clamping Assembly Instructions

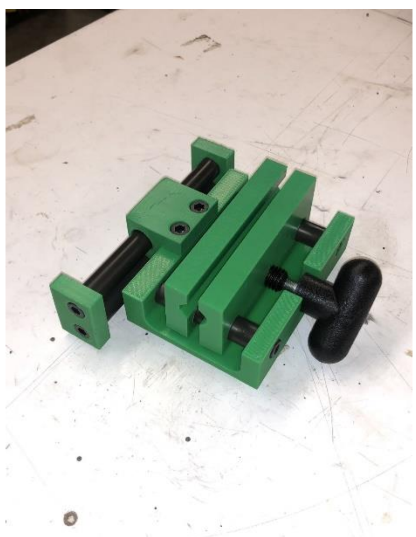


Figure 2.7: Shaft Clamping Subassembly

First, slide the shafts through the vertical slide base before bolting the lie to clamp adaptors in place with M6 bolts. Then, bolt the vertical slide base to the C-Clamp Base. Install the double-sided screw and sliding shafts into the C-Clamps. Install all at once into the C-Clamp Base and bolt them down. Finally, coat with Loctite and screw the knob into the double-sided screw.

2.5 Zero Slider Subassembly

The following section will describe the manufacturing for the slide plate. Assembly instructions are not included because it is only a single part.

2.5.1 Slide Plate

This was 3D printed at Mustang 60.

2.6 Loft and Face Angle Subassembly

The following section will describe the manufacturing plans for each part in the loft and face angle assembly and then end with a description on how to assemble this sub assembly.

2.6.1 Loft/Face Slider

This was 3D printed at Mustang 60. M6x1.00 holes were tapped as shown on drawings.

2.6.2 Vertical Adjustment Base

This was 3D printed at Mustang 60.

2.6.3 Slide Shafts

The raw material was purchased from McMaster and cut to size using a band saw. It was then predrilled and tapped on a lathe for a M6x1.00 thread.

2.6.4 Slide Shaft to Slider Plate Bolts

The same bolts from the zero-slider subassembly were used.

2.6.5 Slide Shaft to Height Cap Bolts

This was purchased from McMaster.

2.6.6 Height Cap

This was 3D printed at Mustang 60.

2.6.7 Height Knob

This was purchased from McMaster.

2.6.8 Flat Iron Contact

The raw material was purchased from McMaster and machined using water cutting.

2.6.9 Wood Contact Piece

This was provided by Callaway.

2.6.10 Driver Contact Piece

This was provided by Callaway.

2.6.11 Loft Encoder Shaft

The ¼" shaft from the lie subassembly was used and cut to size using a band saw.

2.6.12 Loft Arm to Cylinder Bolts

A set of 25 was purchased from McMaster.

2.6.13 Snap Rings for Loft and Face

A set of 10 was purchased from McMaster.

2.6.14 Washers for Loft and Face

A set of 25 was purchased from McMaster.

2.6.15 Face Angle Arm

The raw material was purchased from McMaster and cut using water cutting in the machine shop.

2.6.16 Face Encoder Shaft

The ¼" shaft from the lie subassembly was used and cut to size using a band saw.

2.6.17 Loft and Face Angle Assembly Instructions

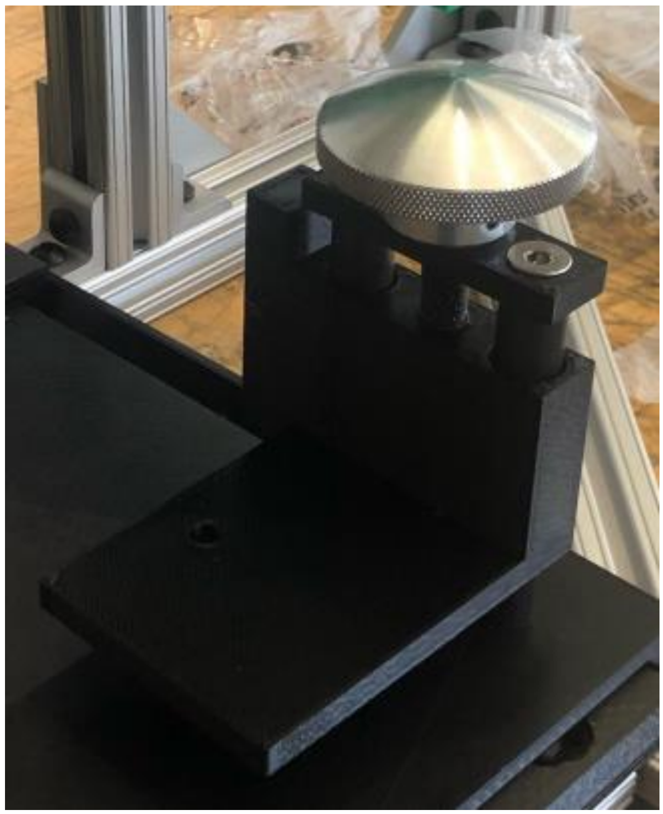


Figure 2.8: Loft and Face Angle Subassembly

First, bolt the shafts into the base plate. Next, slide the vertically adjustable slider onto the shafts. Bolt the top face onto the shafts and insert the knob, screwing it into the vertically adjustable slider. Once complete, join the contact plate to the ¼" shaft by heating them up to account for the interference fit. Then, set onto the face angle side and install encoder by bolting it to the plate. Finally, slide the loft angle shaft through the slot and set up the encoder on the outside of the part by bolting it in.

2.7 Digital Subassembly

The following section will describe the procurement and assembly instructions for the digital systems.

2.7.1 Encoders

A set of 3 was purchased from CUI Devices.

2.7.2 Display Screen

This was purchased from Amazon.com.

2.7.3 Raspberry Pi 4

This was purchased from Amazon.com.

2.7.4 Female-to-Female Wiring connections

This was purchased from Coast Electronics.

2.7.5 Digital Subassembly Instructions

Detach a 5-wire strip of female-to-female wiring connections for the lie encoder and attach each connector to the five pins on the bottom of the encoder under the case. For the lie encoder, attach the power to PIN 1, GND to PIN 9, A to PIN 3, B to PIN 5, and Index to PIN 7.

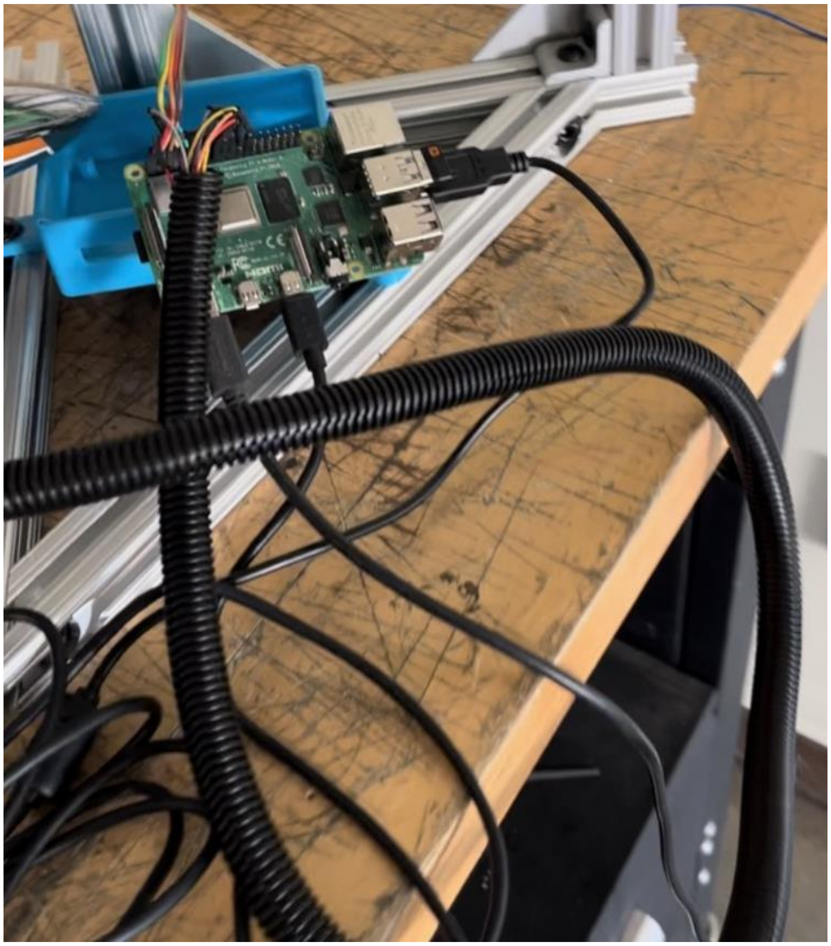


Figure 2.9: Wiring Setup

For the loft and face angle encoders, obtain 10 strands of 48” female to female wiring. Group five wires for each encoder and run them all through tubing similar to that in Figure 6.8. For the loft encoder, attach the power to PIN 17, GND to PIN 25, A to PIN 19, B to PIN 21, and Index to PIN 723. For the face angle encoder, attach the power to PIN 4, GND to PIN 6, A to PIN 12, B to PIN 16, and Index to PIN 18. Finally, attach the display screen to the Raspberry Pi using the HDMI terminal. Plug the Raspberry Pi to any 5V compatible source with a USB-C cable. For a complete wiring diagram, please refer to FDR Appendix B.

2.8 Laser Subassembly

The following section will describe the manufacturing plans for each part in the laser assembly and then end with a description on how to assemble this sub assembly.

2.8.1 Leveling Laser

This was purchased from amazon.com.

2.8.2 Leveling Laser Bracket

This was purchased from amazon.com.

2.8.3 Sliding Plate

This was 3D printed at Mustang 60.

2.8.4 Securing Bolts

This was purchased from McMaster.

2.8.5 Power Supply

2.8.5.1 Universal Regulated AC-DC Power Adaptor

This was purchased from Coast Electronics.

2.8.5.2 2.5 mm Solderless DC Plug

This was purchased from Coast Electronics.

2.8.6 Laser Subassembly Instructions

Insert the laser into the bracket using the securing screws that come with the bracket. Next, use the securing bolts to attach the bracket to the sliding plate. Attach the positive and negative ends of the laser’s wiring to the positive and negative terminals in the solderless DC plug and secure them with a screwdriver. Finally, insert the plug into the appropriate site at the end of the power adapter. Plug the power adaptor into a wall to power the laser and unplug it to turn the laser off.

2.9 Challenges

For the electronics, a major challenge was that the Raspberry Pi did not have enough voltage supply ports to power the laser subassembly, so the group was forced to use a second power adapter.

A challenge that the group ran into was the ball screw jamming and stopping it from rotating. The ball screw did not have a constraint other than the small arm connecting the top of the ball screw to the large, lie arm, allowing it to rotate radially about 10 degrees per direction. Because the shaft clamping system has weight, it caused a moment about the ball screw, making the shaft clamping subassembly sit at an angle. To combat this, we printed out rails to hold the ball screw in place and made the shaft clamping assembly sit straighter.

3. Design Verification

This section covers the design verification procedure the group used to test the prototype against the specifications. By following the test procedures designed by the team, they were able to evaluate the success of the project. Table 3.1 displays the specifications.

Table 3.1: Measurement device specifications table

Specification		Target	Tolerance	Risk *	Compliance **	Pass/Fail?
1	Time to measure a club	< 2 minutes	+ 8 minutes	H	T	Pass
2	Number of measurement types	3 minimum	+ 3	L	I	Pass
3	Is it intuitive?	zero training required	≤ 5 demonstrations	H	T,A	Pass
4	Set up time	< 1 minute	+3 minutes	M	T	Pass
5	Amount of components	1 component	+4 components	L	A,I	Fail
6	Battery/Plug Required?	N/A	1 battery/plug	M	I	Pass
7	Angle tolerance of measurement	+/-0.1 degrees	up to +/-0.5 degrees	H	T,A,I	Pass
8	Total Cost	<$2600	0$ < cost<$2600	M	A	Pass
9	Damage caused to club	zero	none	M	A,I	Pass
10	Lifetime	10,000 measurements	5,000 measurements maximum	M	A	Fail

* Risk of meeting specification: (H) High, (M) Medium, (L) Low

** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

The team evaluated the project’s completion of the specifications through observation, testing, and statistical analysis. The following sections will introduce each observation/test conducted, explain each procedure, discuss, and explain the results. For more information on the tests, see Appendix E and F for complete descriptions of the test procedures and their results.

3.1 Time to Measure a Club

The team created a test to determine how long it takes to measure a golf club by calculating the average amount of time it took to measure the lie, loft, and face angle across the 3 club types: woods, drivers, and irons. Each club was tested 3 times for a total of 9 samples.

The samples began with the club set up in the measurement device, with each encoder "zoroed" and ready for measuring. Starting the clock, Roman followed the user manual to take measurements of each club. Table 3.2 includes a summary of the team's data.

Table 3.2: Data summary of the measurement time test.

Data Specification	Time [min:sec]
Mean	2:18
Standard Deviation	0:32
Maximum Time	3:15
Minimum Time	1:24

The team targeted a time of 2 minutes to measure a club but found it acceptable if a club takes less than 8 minutes to measure. Therefore, the prototype passed this specification. Roman, the person manually conducting this test, found it difficult to measure the woods and drivers because of the flexibility of the 3D printed keel point slider. By improving the rigidity with higher percentage infill or making it out of stiffer materials, it will take less time to measure the woods and drivers.

3.2 Number of Measurement Types

The final prototype was able to measure 3 different angles, lie, loft, and face angle. At the beginning of the project, the team planned to measure the F1 length and install a system to easily set the keel point but did not have enough time to accomplish this task. As a result, the final prototype can measure 3 key angles of a golf club, and therefore, passes the specification.

3.3 Is it Intuitive?

To determine the intuitiveness of the final prototype, the team approached 5 random people to participate in the test. Once a volunteer was selected, Roman explained the project and showed the volunteer how to zero the device and measure a golf club in accordance with the user manual. Once shown, each participant tried to operate the device unaided. If aid were required, Roman and Grant answered their questions and then repeated the demonstration. The intuitiveness of the prototype was judged on the number of additional demonstrations the participant required before measuring a golf club unaided. Table 3.3 contains a summary of the data gathered.

Table 3.3: Data summary of intuitive test.

Data Specification	Number of Additional Demonstrations
Mean	3.4
Standard Deviation	0.89
Maximum Time	4
Minimum Time	2

The volunteers required an average of 3.4 additional demonstrations to successfully measure a golf club unaided. With a maximum of 4 additional demonstrations, the prototype passed this specification because it took less than 5 demonstrations.

3.4 Set Up Time

The team created a test to determine how long it takes to set up a golf club to be measured by calculating the average amount of time it took to set up woods, drivers, and irons. Each club was tested 3 times for a total of 9 samples.

The samples began with the prototype plugged in and the golf club separated from the machine. Starting the clock, Roman attached the golf club to the machine and followed the user manual to set up the club properly. Table 3.4 includes a summary of the team's data.

Table 3.4: Data summary of the set-up time test.

Data Specification	Time [min:sec]
Mean	2:01
Standard Deviation	0:49
Maximum Time	2:51
Minimum Time	0:49

The team targeted a time of 1 minute to set up a club but found it acceptable if a club takes less than 3 minutes to set up. Therefore, the prototype passed this specification. Roman, the person manually conducting this test, found it difficult to open and close the shaft clamping system, increasing the time it takes to set up the club. By using springs with lower spring constants and using snap ring pliers, or a similar tool, the amount of time required to set up the club will decrease.

3.5 Amount of Components

The number of components was targeted to be 1 machine/assembly to measure the required angles of the club. This was not possible in the design of the team’s prototype because subassemblies were needed to support the club and the encoders needed to measure the different angles. The prototype has 7 subassemblies and therefore, fails the specification. Though the number of components does not align with the specifications the team created at the beginning of the project, the number of components may be simplified in future design iterations and does not affect the functionality of the measurement device.

3.6 Battery/Plug Required?

The prototype requires 1 plug into the wall and therefore, passes the specification. A wall outlet powers 3 encoders, a raspberry pi, and the user interface display. No plug in required would be the preferred method of powering the prototype but isn’t required.

3.7 Angle Tolerance of Measurement

The team created multiple tests to determine the angle tolerance the prototype can measure too. To analyze the effectiveness of the prototype, the tests focus on accuracy and precision. To determine the accuracy of the device, measurements must be compared to a known measurement. For the lie and loft angles, Callaway provided golf clubs with known angles. For the face angle, a known 5° angled plate was used. To determine the precision of the device, the measurements were compared to each by analyzing the standard deviations of the samples.

To test the device, the team designed 3 tests, 1 test per angle. An iron with known measurements was selected for the lie and loft angle tests. In all 3 tests, a sample size of 32 was chosen to gain the best understanding of the deviation within the system without taking multiple hours to complete each test. Each test began with the golf club fixed in the clamping system and "zeroed" encoders. Then following the user manual, the lie, loft, or face angle was measured. In between measurements, the system was "zeroed" between measurements. Tables 3.5 - 3.6 include a summary of the lie, loft, and face angle data.

Table 3.5: Accuracy analysis of the samples.

Accuracy			
Angle	**Mean**	**Target**	**Pass/Fail?**
Lie Angle	62.73°	61.00° ± 0.50°	Fail
Loft Angle	26.75°	23.50° ± 0.50°	Fail
Face Angle	5.01°	5.00° ± 0.50°	Pass

Table 3.6: Precision analysis of the samples.

Precision			
Angle	**Standard Deviation**	**Target**	**Pass/Fail**
Lie Angle	0.30°	< 0.60°	Pass
Loft Angle	0.84°	< 0.60°	Fail
Face Angle	0.33°	< 0.60°	Pass

To pass the angle tolerance specification, the prototype must pass in both accuracy and precision for all test angles. The prototype's accuracy generally fails due to the imperfections in 3D printed materials. It is close to impossible to control GD&T and tolerances to high precision tolerances resulting in misalignment between mating parts in the system. Furthermore, the 3D printed components in the prototype have 15% infill rates, making them less stiff. The team selected this infill density to minimize overall weight and lower print times, allowing the team to use an iterative design process. As a result, most components in the design are subject to bending. Manufacturing the prototype with stiffer materials, such as aluminum or any metal, and using CNC machining or hand milling would fix this problem immediately and should make the machine accurate to the specifications required.

On the other hand, the prototype's precision generally passes the specifications, being more precise than necessary. Having a high precision means the device is repeatable and requires further design iterations and calibration to become more accurate. The loft angle failed the accuracy and precision test and therefore requires the most attention. The loft angle deviates substantially from the target mean and standard deviation because the most imperfections occur along the axis the loft angle is measured at. Figure 3.1 displays the deviation of the device along the loft angle.

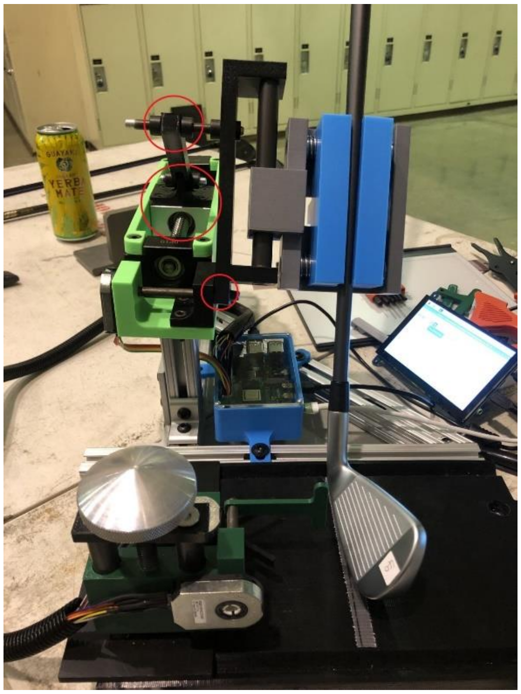


Figure 3.1: Deviation in axis of loft angle.

The red circles in figure 3.1 mark the points of the design subject to the most rotational bending. The shaft clamping assembly branches out from these points, resulting in a large deviation in the clockwise direction when viewed from the orientation in figure 3.1. This deviation translates to the face of the club, rotating it in the same direction. To understand how large the deviation was, Andre conducted another test as seen in figure 3.2.

Figure 3.2: Deviation test of the loft angle.

In figure 3.2, a clamp minimizes the deviation between the shaft clamping system and the lie arm. This allows the team to measure the deviation of the loft angle due to the imperfections of the manufacturing process and material. The tests began by zeroing the lie and loft angle according to the user manual. Then, the loft angle was measured in 2 cases when the golf club reaches the design lie angle for measurements. In the first case, the shaft clamping system was rotated in the clockwise direction until it stopped rotating and then recorded the loft angle. In the second case, the shaft clamping system was rotated in the counterclockwise direction until it stopped rotating and then recorded the loft angle again. Once both values were recorded, the difference was calculated to explain the amount of deviation present along the same axis as the loft angle. With 19 samples, table 3.7 summarizes the data.

Table 3.7: Prototype deviation along the loft angle.

Data Specification	**Angle [°]**
Mean	6.13°
Standard Deviation	0.60°
Maximum Angle	7.31°
Minimum Angle	4.99°

Table 3.7 displays a large variation along the loft angle axis. As a result of manufacturing choices, this deviation may be minimized by machining the prototype’s components with a CNC machine and using higher stiffness materials. This will minimize the prototype’s deviation along the loft angle axis and result in higher accuracy and precision for the design.

3.8 Total Cost

The total cost specification establishes a target of less than $2,600. Founded off the retail value of similar products, the prototype’s final cost was $1,107.77, passing the specification. A future iteration of the team’s prototype will be made from metal and have a higher total cost.

3.9 Damage Caused to Club

The team found no signs of damage to the club. Using 3D printed material to manufacture the product drives the success of this specification because the metal and titanium clubs used in the tests is stronger and harder than 3D printed material. In future, metallic iterations of the team’s prototype, the machine will not damage the club because of the lack of moving parts. To damage the clubs, the operator must consciously attempt to damage the club because the prototype does not have the capability to damage a golf club on its own.

3.10 Lifetime

The prototype failed the lifetime specification because of the design and design for manufacturing decisions the team made. The team used 3D printing to quickly make the prototype and allowed for quick and cheap design iterations. This method has a defect because 3D printed material is not durable enough to withstand 10,000 measurements. Though the prototype failed in this specification, altering the manufacturing process to include metal in place of 3D material will fix this issue.

3.11 Ball Screw Analysis

The team conducted two more tests to analyze the ball screws effect on the lie angle. The first test the team conducted analyzed the ball screws rotation impact on the change in lie angle. To do this, the lie angle started at 90°, vertical, and after rotating the ball screw 1 revolution, the angle displacement was recorded. This test was then repeated for 5, 10, and 15 revolutions. The second test conducted measured the maximum and minimum angles the lie angle may achieve. Table 3.8 summarizes the data from these two tests.

Table 3.8: Ball screw analysis data.

Data Specification	Angle
Mean	1.82°/revolution
Standard Deviation	0.10°/revolution
Maximum Angle	89.50°
Minimum Angle	30.23°

The tests pass the specifications outlined in the DVPR and test plans found in Appendix E and F. The prototype's maximum and minimum lie angles enables the machine to measure any golf club because all golf clubs fall within these bounds. Furthermore, the low change in degree per revolution provides the operator sufficient precision to achieve whatever lie angle they desire. This positively impacts the prototype because it takes less time to achieve the desired angle.

4. Discussion and Recommendations

This design challenge was difficult for the team because they had too large of a scope to design a clear path to success. One of the biggest lessons the team faced was solving the question, "How do you measure an object without a consistent datum?" Humans post process each golf club, making every club slightly different than the last. In addition, the team found the best path to designing a solution, short of creating a new scanning method was to seek mechanical and electromechanical alternatives. Additionally, the team found it easier to create a repeatable and reproducible measuring device by isolate movement along as many axes as possible.

After deliberation, the group has assembled the following list of recommendations for improvements on the device going forward:

- Manufacture the device using aluminum or steel.
- Use linear and rotational bearings to allow the design to operate more fluidly and resist friction forces.
- Use springs with lower spring constants in the shaft clamping assembly to make unclamping and clamping a golf club easier.
- Redesign the link connecting the ball screw to the lie angle to minimize rotation around the ball screw.
- Redesign the user interface housing to double as a brace against the shaft clamping assembly. Operating as a brace would restrict the shaft clamping system from leaning from side-to-side.

- Consider absolute encoders, they may be more expensive, but they are less likely to drift compared to incremental encoders.
- Support the shafts on both sides of the encoders to further reduce the chance of shaft deflection.
- Implement a split power supply for the leveling laser and Raspberry Pi so that only one outlet is required.
- Purchase a high-quality crosshair laser with a thin beam for leveling.
- Design a spring-loaded clamp to hold the golf club in place while taking measurements.
- Attach a more ergonomic knob to operate the ball screw.
- Implement an additional encoder to mount to the base plate to track the location of the keel point slider. This would make setting up the machine to measure woods and drivers significantly quicker and more precise.
- Tighten component tolerances to allow for more precise fits.
- Design loft adapters used to measure woods and drivers to be attached via a nut and threaded shaft to the loft and face angle housing.
- Design an adapter to add to the shaft clamping assembly to measure the F1 length. This addition to the system would add another encoder to the system.

After the group gives the project to Callaway, there are a few next steps that they must take to implement the device for their factories. First, a final prototype needs to be machined using aluminum or steel components with some minor testing to ensure all components are up to standard. The provided drawing packages are sufficient to help the machinists complete all required processes. Callaway can use the same Raspberry Pi and encoders for the final device, but if they desire to try other encoders and microcontrollers, the group recommends implementing a script using C++ rather than Python if their engineers have experience with the software.

The Raspberry Pi is convenient because it removes the necessity for a computer connection, but if this is not an issue a cheaper microcontroller such as an ESP32 can be used. The Raspberry Pi is also convenient if Callaway wants to implement the same script that the group provided due to the use of internal Raspberry Pi libraries and Thonny for the implementation. If the Raspberry Pi is used, a UI can be developed for the device so the script is not directly pulled up. This would be helpful because it would disallow the user from accidentally changing values in the script when operating the device. This is far from necessary, however, and does not change any of the base functionality for the system.

5. Conclusion

This document reviewed the final design for the Callaway measurement device senior project. This document went over the changes in design that developed since the CDR and provided explanations to the major developments that were made. In addition, the effectiveness of the device and full manufacturing process were reviewed.

Looking back along the timeline of the project, the team is proud of what they accomplished. The team ran into their biggest difficulties because of miscommunication. If the correct questions were asked from the beginning, the team would have saved time designing their prototype and would be able to spend more time manufacturing and testing.

After completing the project testing, the group reached many conclusions for the effectiveness and shortcomings of the final design. The device passed the criteria for all requested measurement times and passed all intuitiveness trials with desirable values. Precision testing was successful for the lie and face angles, and the face angle passed the accuracy tests. The group was also proud about how the use of the digital system allowed for quicker and easier measurements while keeping the prototype's price below competitor's pricing.

The only tested specifications the device fell short of were the precision testing for loft and the accuracy testing for loft and lie. These criteria were not met because of certain mechanical failings due to the use of 3D printing rather than aluminum manufactured parts. The 3D printed material was prone to significant flexing which would allow the encoder shafts to deflect substantially. This deflection would cause drift over time for encoder measurements that would mess up the calibration and skew some results. This is because the encoders are only designed to account for rotational motion and are unable to properly process linear translation. This was only an issue for accuracy and one of the precision tests because the imperfections of the prototype mainly stacked up along one axis, the same axis the loft angle is measured in.

If the group were to do the project over again, they would have made a few major changes. They would have decided to 3D print all parts far earlier into the process to better optimize the device for PLA's material properties, taking more advantage of the iterative design process. In addition, they would have used quadrature encoders with a Raspberry Pi earlier into the process. This was because the group was only familiar with Python at the time and the prospect of needing to learn C++ alongside implement SPI encoders simultaneously introduced far too many variables to execute the solution in a prompt manner. Had the group committed to the Raspberry Pi sooner, the digital system would have been ready months earlier. This may have allowed the group more time to develop a UI for the device and find a way to implement a linear encoder for F1 measurements. In addition to saving money, switching to the raspberry pi would enable the team to begin prototype testing earlier.

SOW Appendices

A. Relevant Patent List
B. QFD House of Quality
C. Gantt Chart

Appendix A: Relevant Patent List

1. https://patents.google.com/patent/US6430829B1/en
2. https://patents.google.com/patent/US6508007B1/en
3. https://patents.google.com/patent/US4858332A/en
4. https://patents.google.com/patent/US5105550A/en
5. https://patents.google.com/patent/US20120090186A1/en
6. https://patents.google.com/patent/US20140352162A1/en
7. https://patents.google.com/patent/US20090144997A1/en
8. https://patents.google.com/patent/US4817294A/en
9. https://patents.google.com/patent/US4875293A/en
10. https://patents.google.com/patent/US4094072A/en

Appendix B: QFD House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

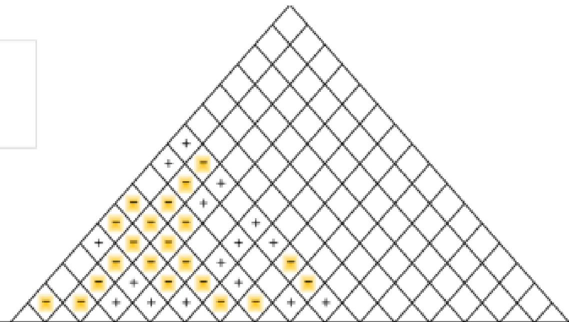
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Callaway Measurement Device

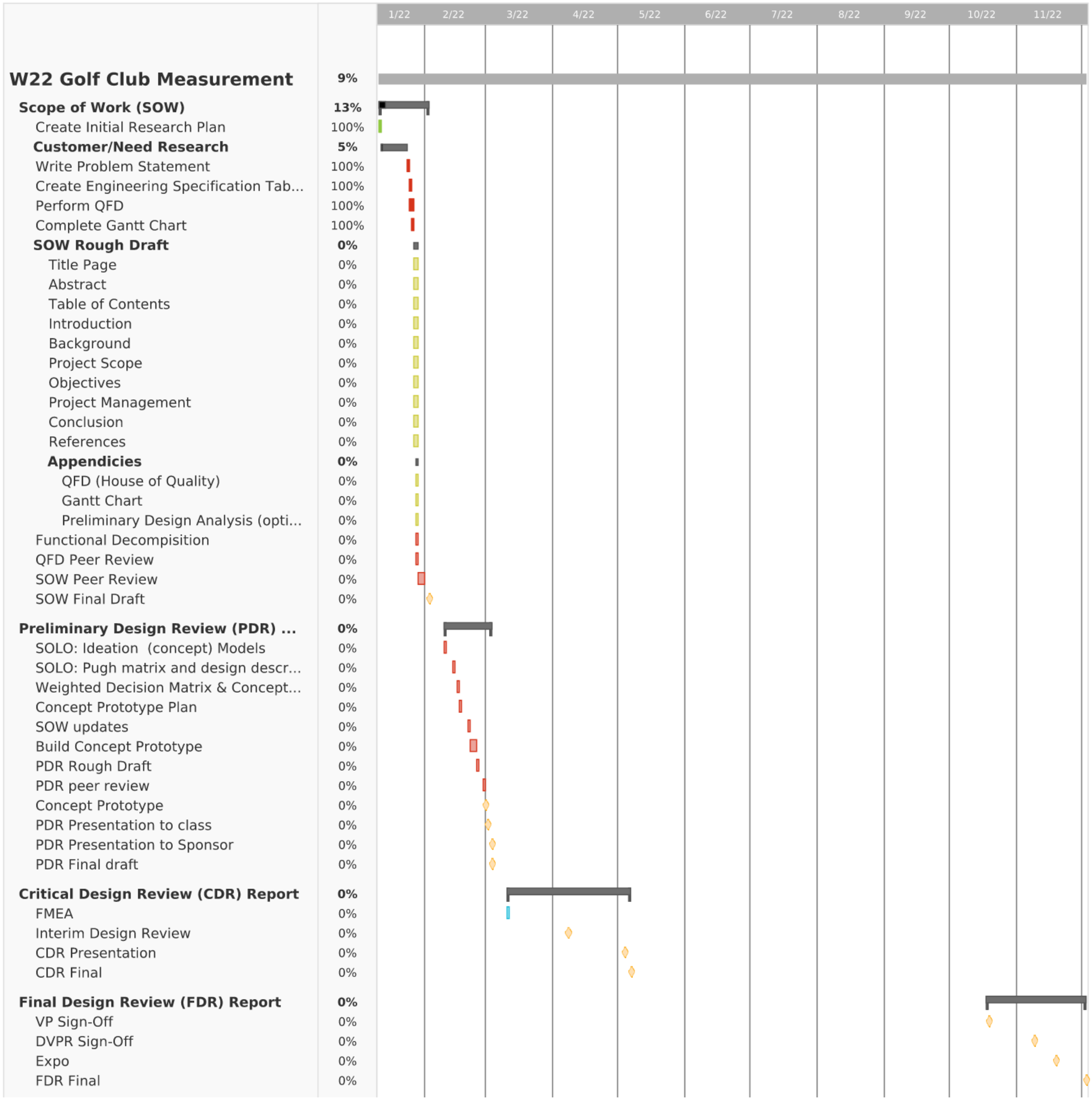
Revision Date: 1/25/22



Row #	Weight Chart	Relative Weight	Quality Assurance Dept.	R&D	Sponsor		Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	1 Time to measure a clubhead	2 Amount of measurement types	3 Is it intuitive? Survey	4 Set up time	5 Amount of components	6 Battery/plug required?	7 Tolerance of angle measurement	8 Total cost	9 Damage Caused to Club	10 Lifetime	11	12	13	14	15	16	NOW: Curr. Products Green Gage	Green Gage - digital	CMM - Laser			Row #
								Direction of Improvement	▼	▲	◇	▼	▼	▼	▼	▼	▼	▲												
1		7%	4	1	10		9	Low Cost					○	●		●									5	3	1			1
2		16%	10	10	10		9	Resolution		▽	●			○	●	○									2	3	5			2
3		4%	2	4	2		9	Size		▽			●	▽	○	○									5	5	1			3
4		13%	8	8	10		9	Manufacturability		▽			●	○	●	●									4	4	2			4
5		16%	10	10	10		9	Ease of Operation	●	●	●	●	●	▽	○		●	○							3	5	4			5
6		11%	8	5	8		9	Speed of Measurement	●	○	○	●	○		○		○	●							4	4	1			6
7		4%	2	2	3		9	Weight			▽		●	●	○	●									4	4	1			7
8		11%	7	7	7		9	Durability		○			○	○	●	●		●							5	3	1			8
9		4%	2	4	2		9	Transportability			▽		●	●				●							3	3	1			9
10		3%	2	2	2		9	Assembly		▽	●		●	●	●	○		▽							4	3	2			10
11		12%	10	5	8		9	Repeatability/Consistency	●	●	●	▽	●	○	●		●								2	3	5			11
12		0%																												12
13		0%																												13
14		0%																												14
15		0%																												15
16		0%																												16

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	< 2 minutes	3 minimum	0 training required	< 1 minute	One component	Not required	< +/-0.1 degrees	<$2600	No noticeable damage	10,000 measurements						
	Max Relationship	9	9	9	9	9	9	9	9	9	9						
	Technical Importance Rating	341	345.7	452.2	247.4	587.7	337.5	592.5	383.6	276.9	281.7	0	0	0	0	0	0
	Relative Weight	9%	9%	12%	6%	15%	9%	15%	10%	7%	7%	0%	0%	0%	0%	0%	0%
Curr. Products	Green Gage	3	4	3	3	2	5	2	5	3	4						
	Green Gage - digital	4	3	4	4	2	1	3	3	3	4						
	CMM - Laser	1	5	3	1	3	1	5	1	5	2						
	0																
	0																
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix C: Gantt Chart



PDR Appendices

A. Ideation
B. Gantt Chart
C. Pugh Matrices
D. Morphological Matrix
E. Weighted Decision Matrix
F. Design Hazard Checklist
G. Experimental Results and Details
H. Functional Decomposition

Appendix A: Ideation

Figure 1: Worm gear technology to be implemented in adjusting the lie angle.

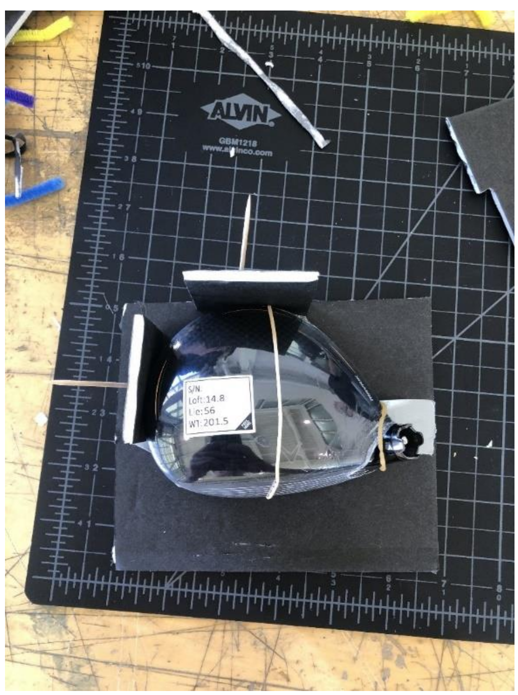


Figure 2: Sliding clamps to secure club head for purpose of central datum. Not seen is the shaft connected to the clubhead to secure it from a third location.

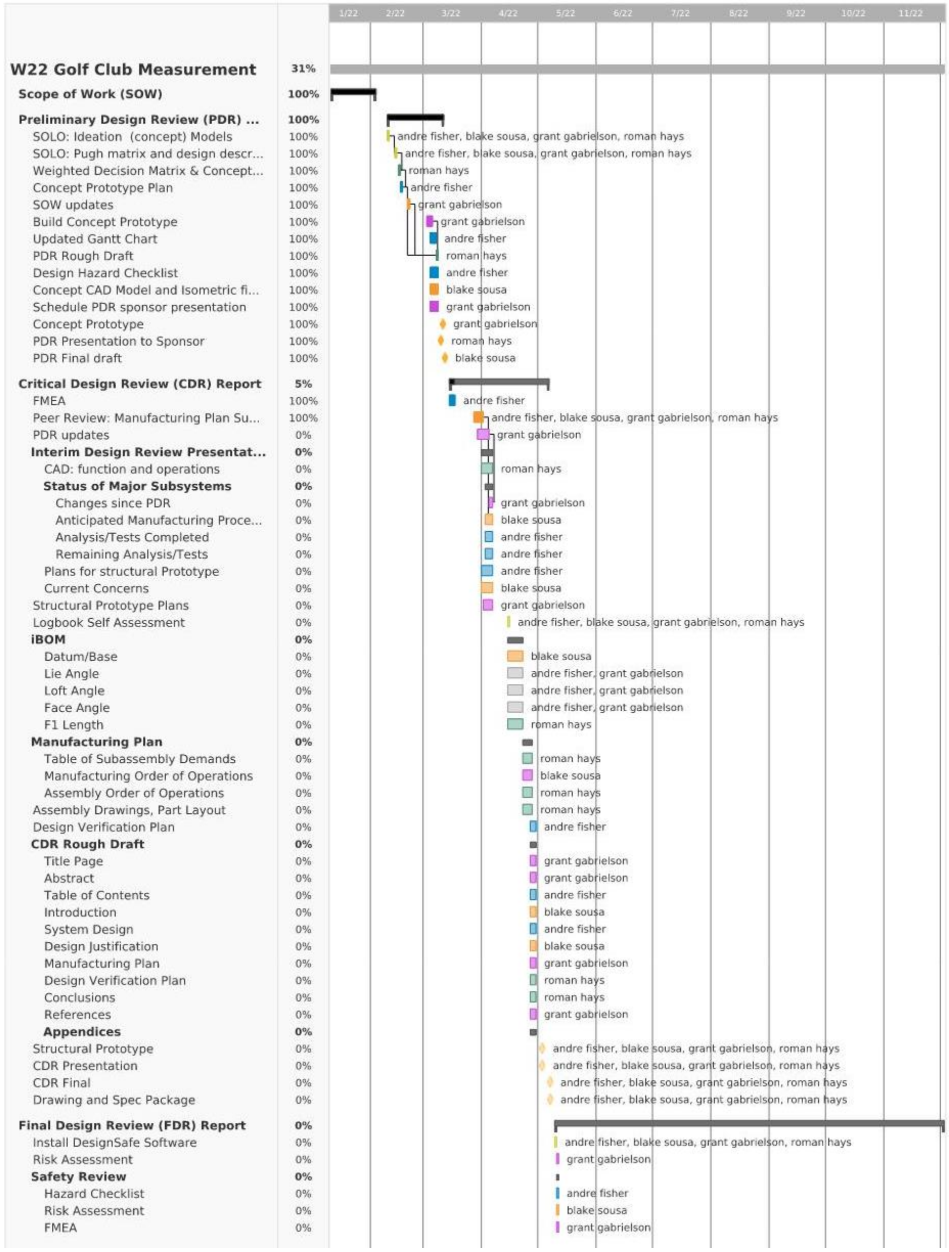
Figure 3: Setting the clubhead down on a flat datum and measuring the loft angle by putting a grid behind the clubhead and taking a picture. The grid is made up of squares and when photo is taken, the computer will calculate the slope made by the club and convert it to an angle from the Zenith. We think it is a good idea, but we think it may take a lot of research to figure out the correct way to make this solution feasible.

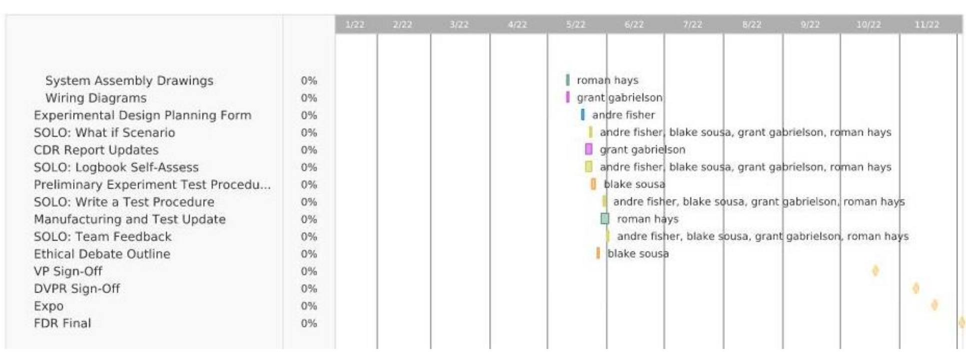
Figure 4: 4-point laser contact to establish distances for angle conversions of loft and face angle. The red dashed lines signify distances calculated using laser-distance technology. By measure from the reference plane on the left-hand side, the four measurements from the laser-distance scanner will define the measurements of the plane. From here, software can be used to calculate the face angle and loft of the clubhead. We really like this idea because this kind of measurement technology is versatile and can be used for every club. Furthermore, this technology already exists, so we would just need to figure out a way to extract the data and run calculations from it.

Figure 5: Clamping mechanism that tightens down with screws (represented with toothpicks) to securely hold mandrel or shaft in place. Loosen screws to change shaft or mandrel out or to adjust position of club.

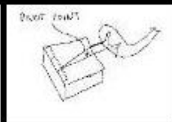
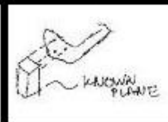
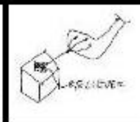
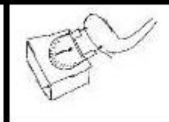
Figure 6: Mechanical system with constant vertical height contact with mandrel or shaft. The horizontal second contact point with the bottom of the shaft or mandrel is adjustable. With trigonometry, will yield lie angle based on constant height and adjusted horizontal distance contact to mandrel or shaft.

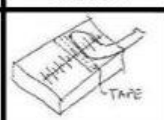
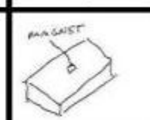
Appendix B: Gantt Chart

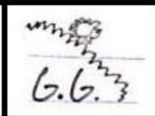
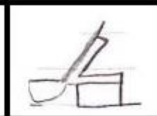
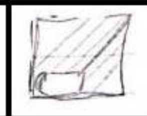
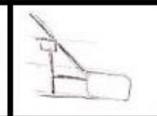
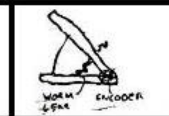


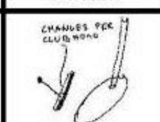
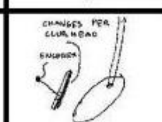
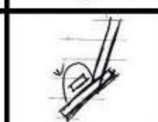
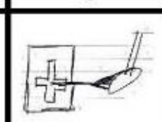
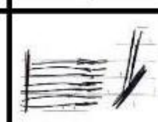


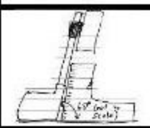
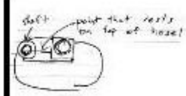
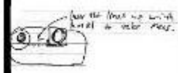
Appendix C: Pugh Matrices

Function	Face Angle					
Datum/Idea	Datum	1	2	3	4	5
Sketch						
Description	Protractor with mechanical measurement	Laser mapping of club face plane	Mechanical Mapping of club face plane	Protractor with protractor measurement	Encoder measuring angle to digital display	Micrometer measurement of angle
Criteria						
Low Cost		-	-	+	-	-
Resolution		+	+	S	+	+
Size		+	-	-	-	-
Manufacturability		-	-	+	+	-
Ease of Use		+	+	S	+	-
Measurement Speed		+	+	S	+	-
Weight		S	-	S	-	-
Durability		-	-	-	-	-
Transportability		S	S	S	S	S
Assembly		-	-	S	+	S
Consistency		+	+	S	+	+
Total		1	-2	0	2	-5

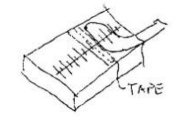
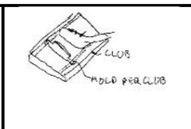
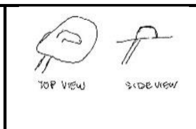
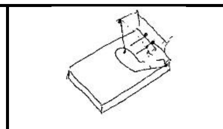
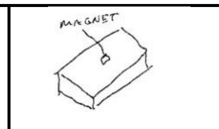
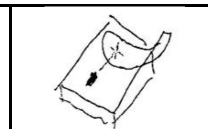
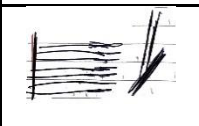
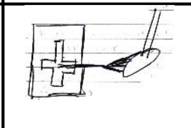
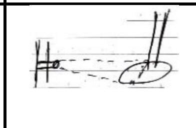
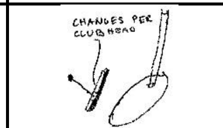
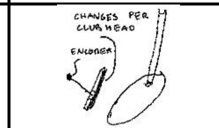
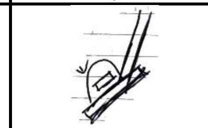
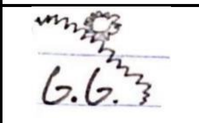
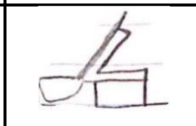
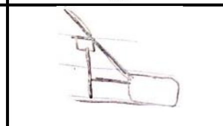
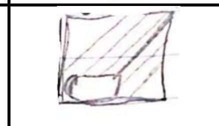
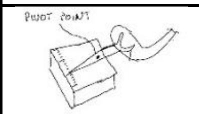
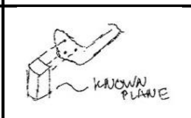
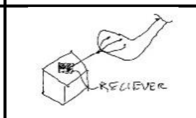
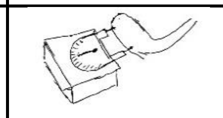
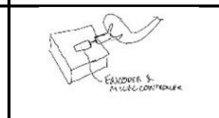
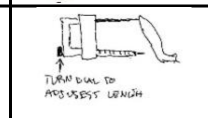
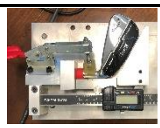
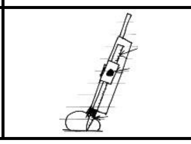
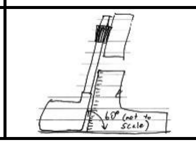
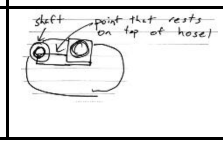
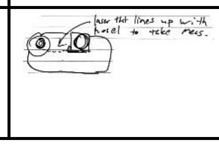
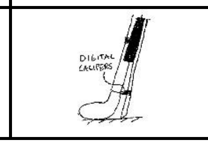
Function	Setting the Datum					
Datum/Idea	Datum	1	2	3	4	5
Sketch						
Description	Mark keel measurement with tape	Align clubface with a mold	Rest top of head in a mold, upside down	Clamp clubjead at 3 points	Magnetic datum	Cross laser to align vert. and horiz.
Criteria						
Low Cost		-	-	-	-	-
Resolution		+	-	+	-	+
Size		-	-	-	S	-
Manufacturability		-	-	-	-	-
Ease of Use		+	+	+	+	+
Measurement Speed		+	+	+	S	+
Weight		S	S	S	S	S
Durability		-	-	+	S	S
Transportability		S	S	S	S	S
Assembly		+	+	+	+	+
Consistency		+	+	+	S	+
Total		1	-1	3	-1	2

Function	Lie Angle					
Datum/Idea	Datum	1	2	3	4	5
Sketch						
Description	Adjustable gear rack with protractor	Adjustable worm gear with protractor	Separate Protractor	Angle backdrop, catches picture and calc. angle	Set a vert. dist. and changing horiz. Distance	Worm gear with encoder
Criteria						
Low Cost		+	+	-	+	+
Resolution		+	-	-	S	+
Size		+	+	-	-	+
Manufacturability		+	+	+	+	+
Ease of Use		S	-	+	-	+
Measurement Speed		S	-	+	-	+
Weight		+	+	S	S	+
Durability		-	+	S	-	S
Transportability		S	S	-	S	S
Assembly		S	-	+	+	S
Consistency		S	-	+	-	+
Total		4	0	1	-2	8

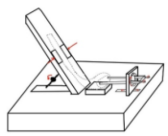
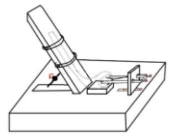
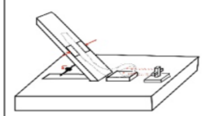
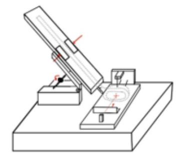
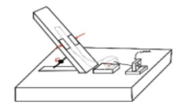
Function	Loft Angle					
Datum/Idea	Datum	1	2	3	4	5
Sketch						
Description	Protractor with interchangeable bits per club	Encoder with interchangeable bits per club	Angle measuring level	4 points of contact to measure loft and face angle	Narrow rods attached to displacement	Laser measurement zeroed on vert.
Criteria						
Low Cost		-	+	-	+	-
Resolution		+	-	+	S	+
Size		-	S	-	S	S
Manufacturability		-	+	-	+	+
Ease of Use		+	+	-	-	+
Measurement Speed		+	+	+	-	+
Weight		-	+	+	S	+
Durability		S	S	-	-	S
Transportability		S	+	S	-	S
Assembly		+	+	S	-	+
Consistency		+	-	+	+	+
Total		1	5	-1	-2	6

Function	F1 Measurement					
Datum/Idea	Datum	1	2	3	4	5
Sketch						
Description	Fixture clamping head to a 60° plane	Ruler with marker attached to side of fixture	60° block with ruler on it	Arm extending from ruler to contact the hosel	Laser extending from ruler to line up with the hosel	Digital caliper attached behind fixture
Criteria						
Low Cost		+	+	+	-	+
Resolution		-	-	-	+	+
Size		+	-	+	+	+
Manufacturability		+	+	+	+	+
Ease of Use		+	+	+	+	+
Measurement Speed		S	+	S	S	+
Weight		+	-	+	+	+
Durability		-	+	-	+	S
Transportability		S	S	S	S	S
Assembly		S	S	S	S	S
Consistency		+	+	-	+	+
Total		4	3	2	6	8

Appendix D: Morphological Matrix

Morphological Matrix						
Function	Function Ideas					
Setting the Datum						
Loft Angle						
Lie Angle						
Face Angle						
F1 Length						

Appendix E: Decision Matrix

Specification	Weight	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
		Design 1		Design 2		Design 3		Design 4		Design 5	
											
		Use a tightening, metal clamp to fix the club shaft to the mechanism. The clamp lies on a flat plane that can be adjusted angularly using a worm-gear and is measured using a protractor. The loft and face angle of the clubhead is measured using one rotating component with two points of contact that contacts the clubhead at point, adjusting the other point until it meets the opposite side of the clubhead. The function of this measurement technology is like that of the micrometer. The F1 length is measured using a drop down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate.		The club head attaches to a mandril, and elastic straps are used to secure the shaft to the rotating datum that is used for lie measurement. A worm gear is used to adjust the datum and a mechanical protractor is used to measure the loft. The face angle is measured with a turn dial on an apparatus that can interface with the club. This will ensure a high resolution with a low potential for wear-and-tear. The F1 length is measured using a drop down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate.		The club head attaches to a mandril that is clamped to the measurement datum. A lidar is used to measure the plane of the club face to generate a profile that can evaluate the loft and lie with a single measurement. The F1 length is measured using a drop down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate.		The club head attaches to a mandril which then is clamped worm hear driven measuring the lie angle. The lie angle is set and changed by adjusting a worm gear with the output connected to an encoder. A mold of the club sets the face angle to its "zero" orientation. A cross laser is used to center the head on the flat plate. Securing the head in its "zero" orientation, the head is locked in place using set screws and 3 points of contact. Face and loft angles are measured using similar devices to the green gage connected to encoders. The F1 length is measured using a drop down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate.		A mandril is placed inside a club head which is then clamped to a measuring datum. A worm gear will be used to adjust the lie angle which can make for easy adjustability and a high resolution if done right. The loft will be done by 2 points of contact method which can be used for all the clubs eliminating the need to switch to a different method for drivers. Face angle will be done using a set point a then a micrometer will read how far off the other point is which will allow us to calculate face angle. The F1 length is measured using a drop down ruler that contacts the hosel, providing the measurement from the hosel to the flat plate.	
Time to measure a clubhead	4	3	12	3	12	5	20	5	20	2	8
is it intuitive	3	4	12	4	12	2	6	4	12	4	12
set up time	1	3	3	4	4	3	3	4	4	3	3
Amount of components	3	2	6	2	6	5	15	2	6	2	6
Battery/Plug in required	1	5	5	5	5	1	1	1	1	5	5
Tolerance of measurement	5	4	20	2	10	3	15	5	25	4	20
Total cost	5	4	20	4	20	2	10	2	10	3	15
Damage inflicted on clubhead	5	4	20	4	20	5	25	5	25	4	20
Lifetime	4	4	16	4	16	5	20	5	20	4	16
Feasibility	3	5	15	5	15	3	9	5	15	5	15
Total			129		120		124		138		120

Appendix F: Design Hazard Checklist

PDR Design Hazard Checklist **W22 – Callaway Measurement Device**

Y	N	
×		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	×	2. Can any part of the design undergo high accelerations/decelerations?
	×	3. Will the system have any large moving masses or large forces?
	×	4. Will the system produce a projectile?
×		5. Would it be possible for the system to fall under gravity creating injury?
	×	6. Will a user be exposed to overhanging weights as part of the design?
×		7. Will the system have any sharp edges?
	×	8. Will any part of the electrical systems not be grounded?
	×	9. Will there be any large batteries or electrical voltage in the system above 40 V?
×		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	×	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	×	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	×	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	×	14. Can the system generate high levels of noise?
	×	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
	×	16. Is it possible for the system to be used in an unsafe manner?
	×	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:
(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
There is a battery and electrical components that have potential to induce electrical shocks	• Ground electrical components • Create a housing for electronics • Insulate any remaining wiring	4-3-22	
There are components that can pinch a user's fingers	• Put a sign on the device that warns of a pinching hazard • Implement a plate that blocks off the pivot point of the device	4-3-22	
There are sharp edges that may cut the user	• Put a rubber covering on any sharp external components	4-3-22	
The device can be dropped and crush a user's foot	• Reduce the weight of the device as much as possible during the materials selection process	3-28-22	

Appendix G: Experimental Results and Details

```
if __name__ == '__main__':
    ## @brief List containing taskUser and taskEncoder functions
    #
    tasklist = [taskUser.taskUserFunction('Task User', 10_000, zFlag, position, delta),
                taskEncoder.taskEncoderFunction('Task Encoder', 10_000, zFlag, position, delta)]

    while True:
        try:
            for task in tasklist:
                next(task)
        except KeyboardInterrupt:
            break
```

This is an excerpt of the main file that constantly synthesizes data from both tasks using a series of shared variables.

```
if __name__ == '__main__':
    # Sets up an encoder hooked up to pins B6 and B7 and calls for it to update
    # and return its position every second.
    _encoder_1 = Encoder(pyb.Pin.cpu.B6, pyb.Pin.cpu.B7, 4)

    while True:
        try:
            _encoder_1.update()
            _encoder_1.get_position()
            time.sleep(1)
        except KeyboardInterrupt:
            break

    print('stopping')
```

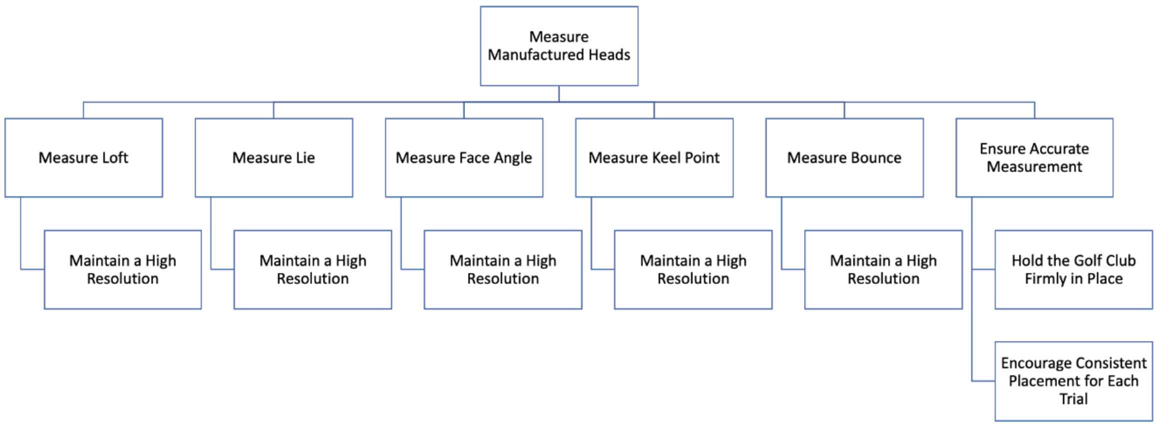
This is a part of task encoder that records the value based on readings generated by the hardware. The rest of this file includes the function definitions that we use to run these lines of code.

```
# Data printing state
elif state == S6_PRINT:
    if numPrinted == idx:
        print(f'{timeArray[numPrinted]:.2f}, {posArray[numPrinted]}')
        state = S1_CMD
        print('End of Data Collection')
        _printHelp()
        yield None

    else:
        print(f'{timeArray[numPrinted]:.2f}, {posArray[numPrinted]}')
        numPrinted += 1
        yield None
```

This code is the section of Task User that prints the encoder position values that are sent over from Task User.

Appendix H: Functional Decomposition



CDR Appendices

A. Drawing and Specification Package
B. Project Budget
C. Structural Prototypes
D. Failure Modes and Analysis
E. Design Hazard Checklist
F. Design Verification Plan
G. Gantt Chart
H. Wiring Diagrams

Appendix A: Drawing and Specification Package

100000 – Main Assembly

- 100000E – Top Level Assembly Exploded
- 110000 – Base Subassembly
  - 110000E – Base Subassembly Exploded
  - 111000 – Base Plate Drawing
  - 112000 – Slider Plate Drawing
- 120000 – Lie Subassembly
  - 120000E – Lie Subassembly Exploded
  - 121000 – Lie Base Subassembly
    - 121100 – Lie Base Drawing
    - 121200 – Lie Base to Stand Bolts*
    - 121300 – Lie Stand 1
    - 121400 – Lie Stand 2
    - 121500 – Bolting End Plate 1
    - 121600 – Bolting End Plate 2
    - 121700 – Bolting End Plate Bolts*
  - 122000 – Lie Arm Subassembly
    - 122000E – Lie Arm Subassembly Exploded
    - 122-1-00 – Main Arm Drawing
    - 122-2-00 – Small Arm Drawing
    - 122-3-00 – Main Arm Shaft Drawing
    - 122-4-00 – Small to Main Shaft
    - 122-5-00 – Small Arm Shaft
    - 122-6-00 – Bearing Plate 1
    - 122-7-00 – Bearing Plate 2
    - 122-8-00 – Flange 1
    - 122-9-00 – Flange 2
    - 122-10-00 – Flange 3
    - 122-11-00 – Small to Main Arm Spacer*

122-12-00 – Main Arm Spacer*

122-13-00 – Small Arm Spacer*

122-14-00 – Lie Arm Ball Bearing*

122-15-00 – Lie Plastic Washer*

122-16-00 – Lie Shaft Collar*

123000 – Ball Screw Part*

124000 – Lie Bolts A*

125000 – Lie Bolts B*

126000 – Lie Bolts C*

127000 – Lie Bolts D*

130000 – Shaft Clamping Assembly

131000 – Mounting Subassembly

131100 – Sliding Shaft End

131200 – Sliding Shaft

131300* – Sliding Shaft to Shaft End Bolts

131400 – Linear Bearing Subassembly

131410 – Bearing Housing Bottom

131420 – Bearing Housing Top

131430* – Linear Ball Bearing

131440* – External Retaining Ring

131450* – Bottom to Top Housing Bolt

131500* – Linear Bearing Subassembly to Clamp Housing Bolts

132000 – Clamp Housing Subassembly

132100 – C-Clamp Housing Subassembly

132110 – Slider Base Plate

132120 – C-Clamp Shaft

132130 – Housing Slider Backing

132140 – Shaft End

132150* – Bolts

132200 – Symmetrical Separator Subassembly

        - 132210 – Symmetric Separator
        - 132220* – Symmetric Screw
        - 132230* – Ball Bearing
        - 132240* – Retaining Ring
        - 132250* – Plastic Washer
        - 132260 – Knob*
        - 132270 – Symmetric Screw Housing
        - 132280* – Bolts
    - 132300 – C-Clamp Subassembly
        - 132310 – C-Clamp Top
        - 132320 – C-Clamp Bottom
        - 132330* – Linear Ball Bearing
        - 132340* – Retaining Ring
        - 132350* – Top to Bottom Bolts
- 140000 – Zero Slider Subassembly
    - 140000E – Zero Slider Subassembly Exploded
    - 141000 – Slide Plate Drawing
    - 142000 – Loft Face Zero Plate Drawing
- 150000 – Loft & Face Angle Subassembly
    - 150000E – Loft & Face Subassembly Exploded
    - 15-01-000 – Loft/Face Slider
    - 15-02-000 – Vertical Adjustment Base
    - 15-03-000 – Slide Shafts
    - 15-04-000 – Slide Shaft to Slider Plate Bolts*
    - 15-05-000 – Slide Shaft to Height Cap Bolts*
    - 15-06-000 – Height Cap*
    - 15-07-000 – Height Knob
    - 15-08-000 – Height Knob Set Screw*
    - 15-09-000 – Height Bolt*
    - 15-10-000 – Slide Handle*

- 15-11-000 – Slide Handle Bolts*
- 15-12-000 – Encoder
- 15-13-000 – Female Housing to Encoder
- 15-14-000 – Housing to Loft Face Base Bolts
- 15-15-000 – Flat, Iron Contact
- 15-16-000 – Wood Contact Piece
- 15-17-000 – Driver Contact Piece
- 15-18-000 – Loft Encoder Shaft Drawing
- 15-19-000 – Loft Arm to Cylinder Bolts*
- 15-20-000 – Snap Ring for Loft and Face*
- 15-21-000 – Washer for Loft and Face*
- 15-22-000 – Face Angle Arm
- 15-23-000 – Face Encoder Shaft

160000 – Digital Subassembly

- 160000E – Digital Subassembly Exploded
- 161000 – Microcontroller Unit*
- 162000 – Encoder Connecting Cables*
- 163000 – I2C Digital Interface*

170000 – Keel Point “Zeroing” Subassembly

- 171000 – Keel Slider Plate Drawing

180000 – F1 Subassembly

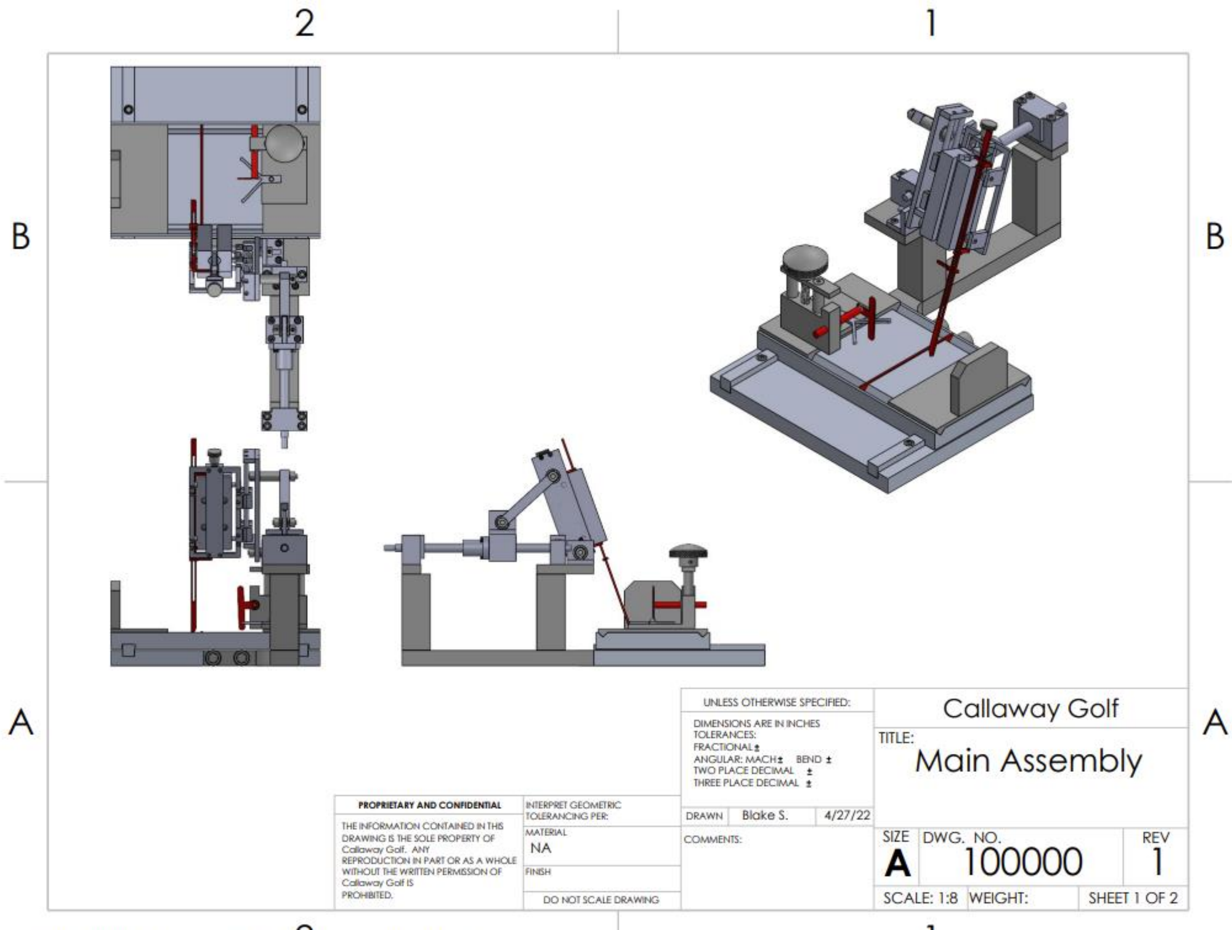
- 180000E – F1 Subassembly Exploded
- 181000 – F1 Base Contact Slider Drawing
- 182000 – F1 Mandrel Contact Drawing
- 183000 – F1 Mounts Drawing
- 184000 – F1 Bolts*

190000 – Laser Subassembly

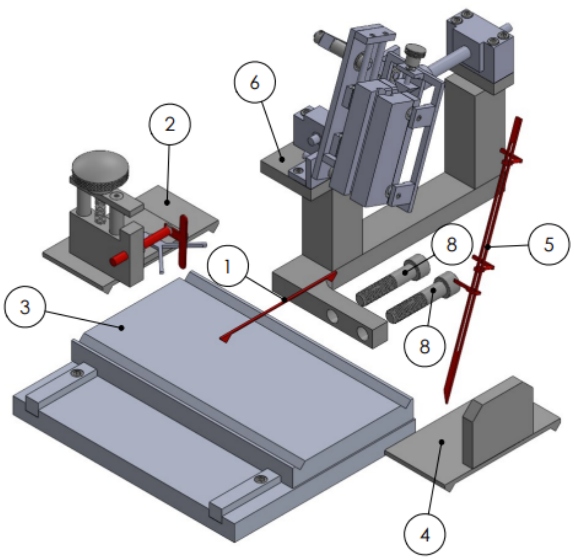
- 190000E- Laser Subassembly Exploded
- 191000 – Leveling Laser*
- 192000 – Sliding Plate Drawing*

193000 – Bolts*

*Note: no drawing included



SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	170000	Keel Point "Zeroing" SubAssembly	1
2	150000	Loft & Face Angle Subassembly	1
3	110000	Base Subassembly	1
4	140000	Zero Slider Subassembly	1
5	180000	F1 Subassembly	1
6	120000	Lie Subassembly	1
7	130000	Shaft Clamping Subassembly	1
8	1-10-0000	Base Plate to Lie Base Bolts	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

DRAWN Blake S. 4/27/22

COMMENTS:

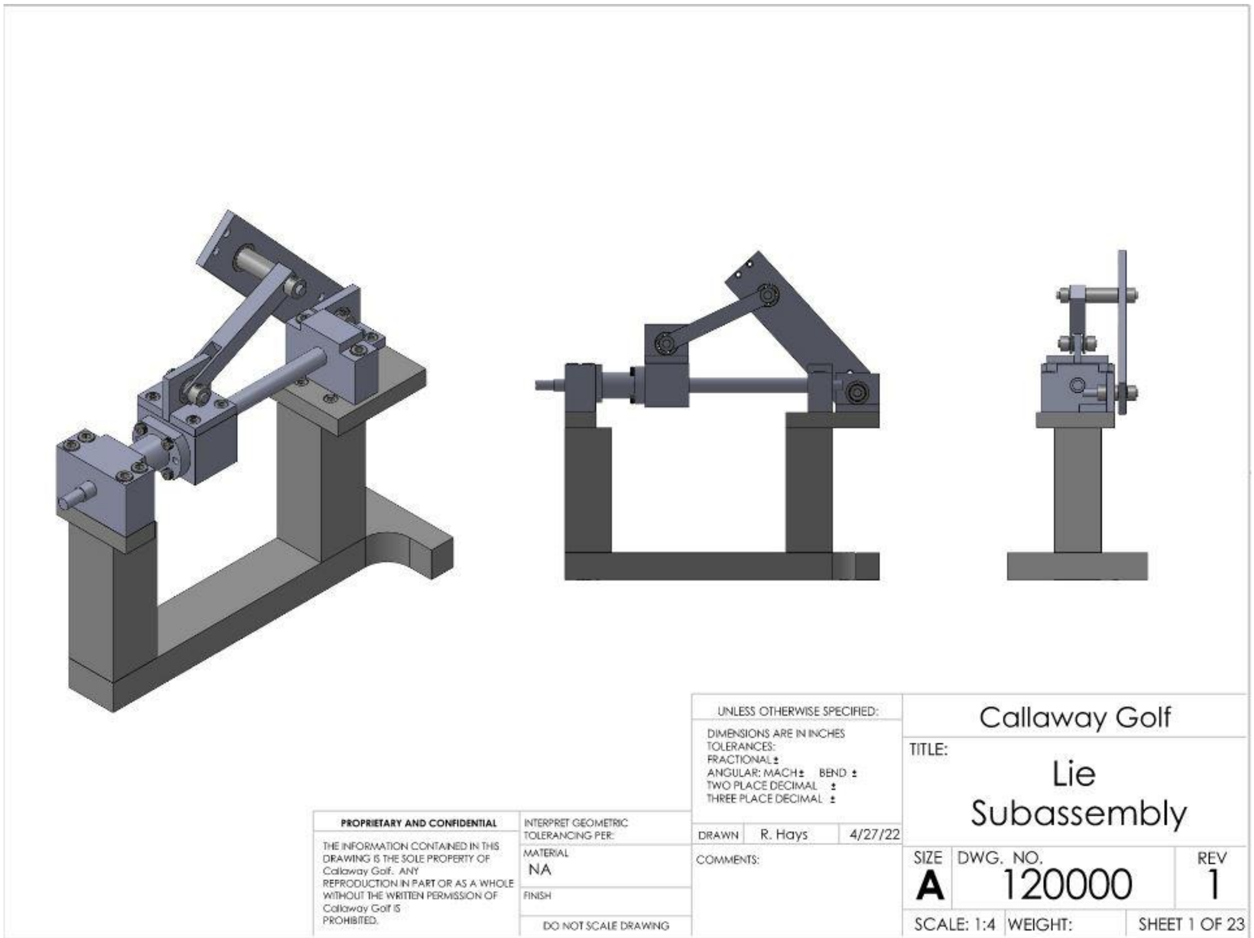
Callaway Golf

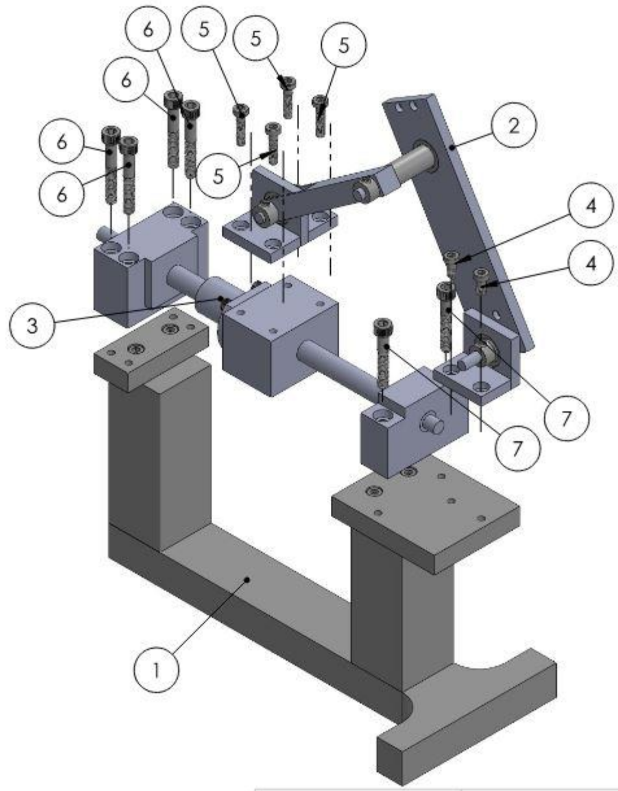
TITLE: Main Assembly Exploded

SIZE A | DWG. NO. 100000E | REV 1

SCALE: 1:8 | WEIGHT: | SHEET 2 OF 2

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL NA
FINISH
DO NOT SCALE DRAWING


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Lie
Subassembly
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING
DRAWN
R. Hays
4/27/22
COMMENTS:
SIZE
A
DWG. NO.
120000
REV
1
SCALE: 1:4
WEIGHT:
SHEET 1 OF 23



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	121000	Lie Base Subassembly	1
2	122000	Lie Arm Subassembly	1
3	123000	Lie Ball Screw Part	1
4	124000	Lie Bolts A	2
5	125000	Lie Bolts B	4
6	126000	Lie Bolts C	4
7	127000	Lie Bolts D	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

PROPRIETARY AND CONFIDENTIAL

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INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL NA
FINISH
DO NOT SCALE DRAWING

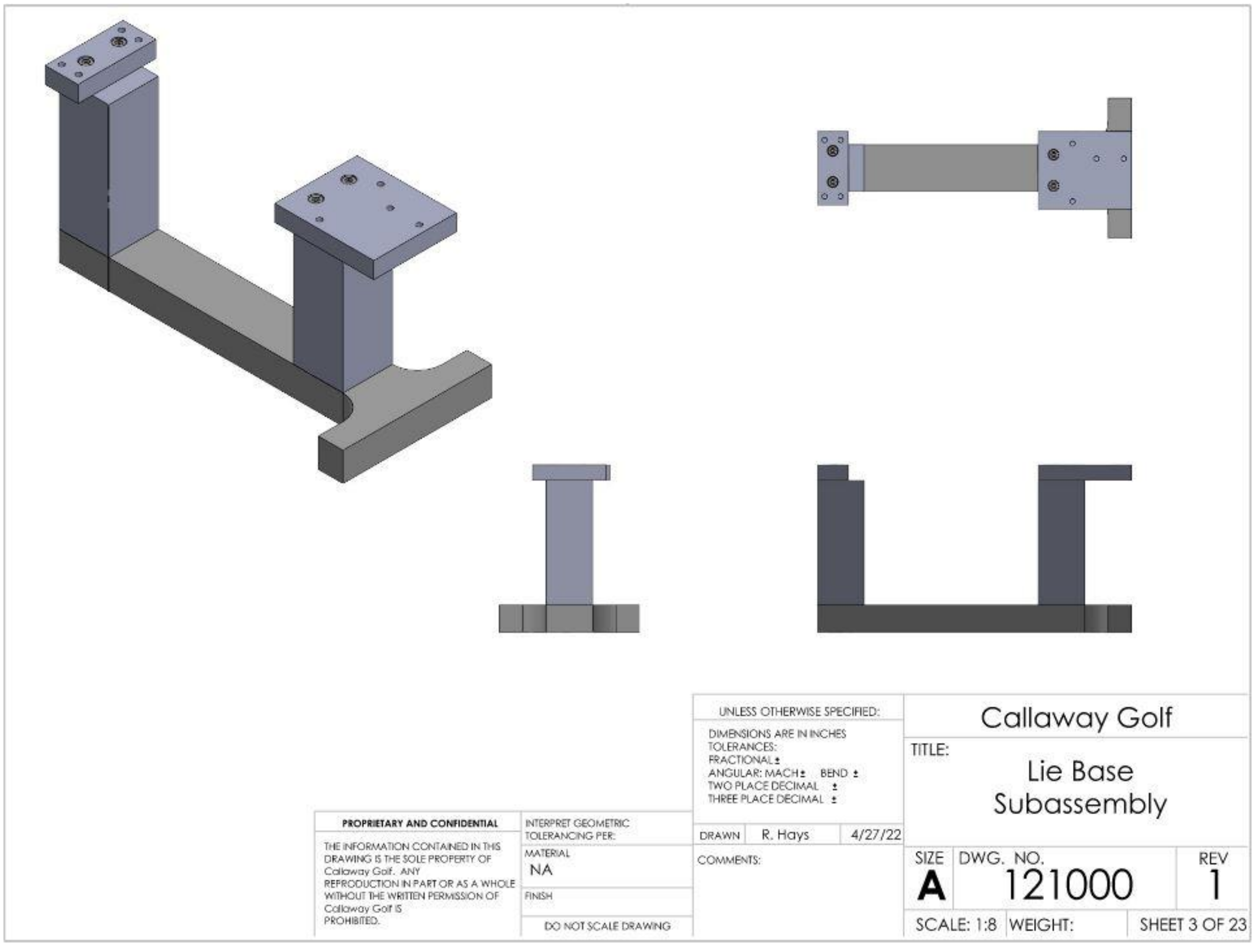
DRAWN R. Hays 4/27/22
COMMENTS:

Callaway Golf

TITLE: Lie Subassembly

SIZE A | DWG. NO. 120000E | REV 1

SCALE: 1:8 | WEIGHT: | SHEET 2 OF 23


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Lie Base
Subassembly
PROPRIETARY AND CONFIDENTIAL
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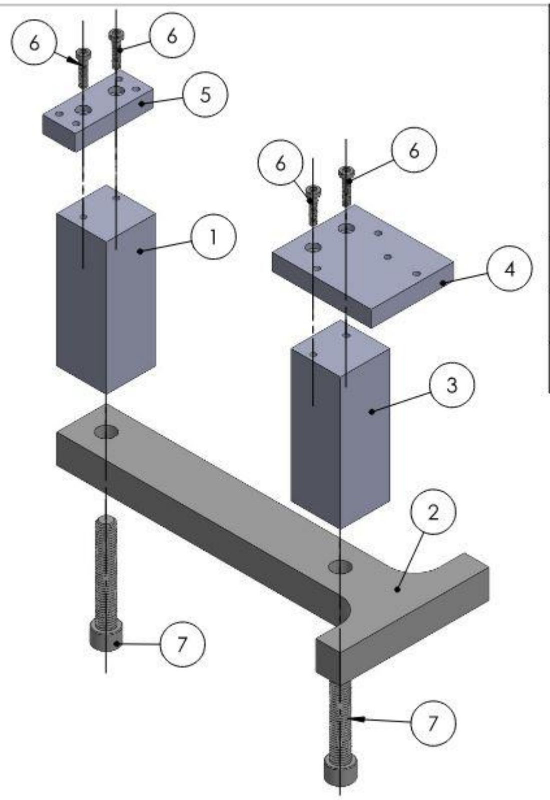
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS:
SIZE A
DWG. NO. 121000
REV 1
SCALE: 1:8
WEIGHT:
SHEET 3 OF 23



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	121400	Lie Stand 2	1
2	121100	Lie Base	1
3	121300	Lie Stand 1	1
4	121500	Bolting End Plate 1	1
5	121600	Bolting End Plate 2	1
6	125000	Lie Bolts B	4
7	121200	Lie Base to Lie Stand Bolt- 91290A235	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

Callaway Golf

TITLE: Lie Base Subassembly Exploded

PROPRIETARY AND CONFIDENTIAL

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INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: NA

FINISH

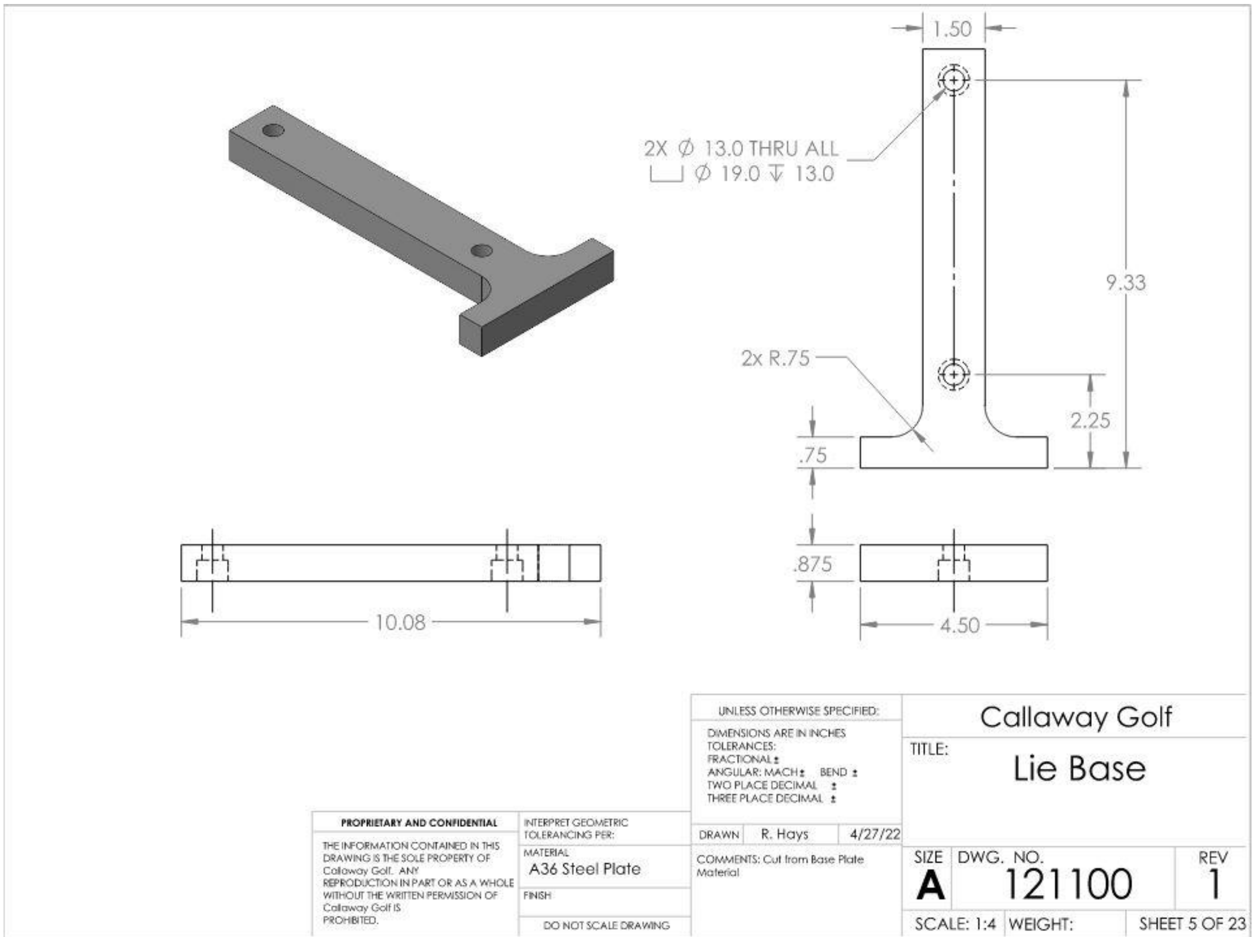
DO NOT SCALE DRAWING

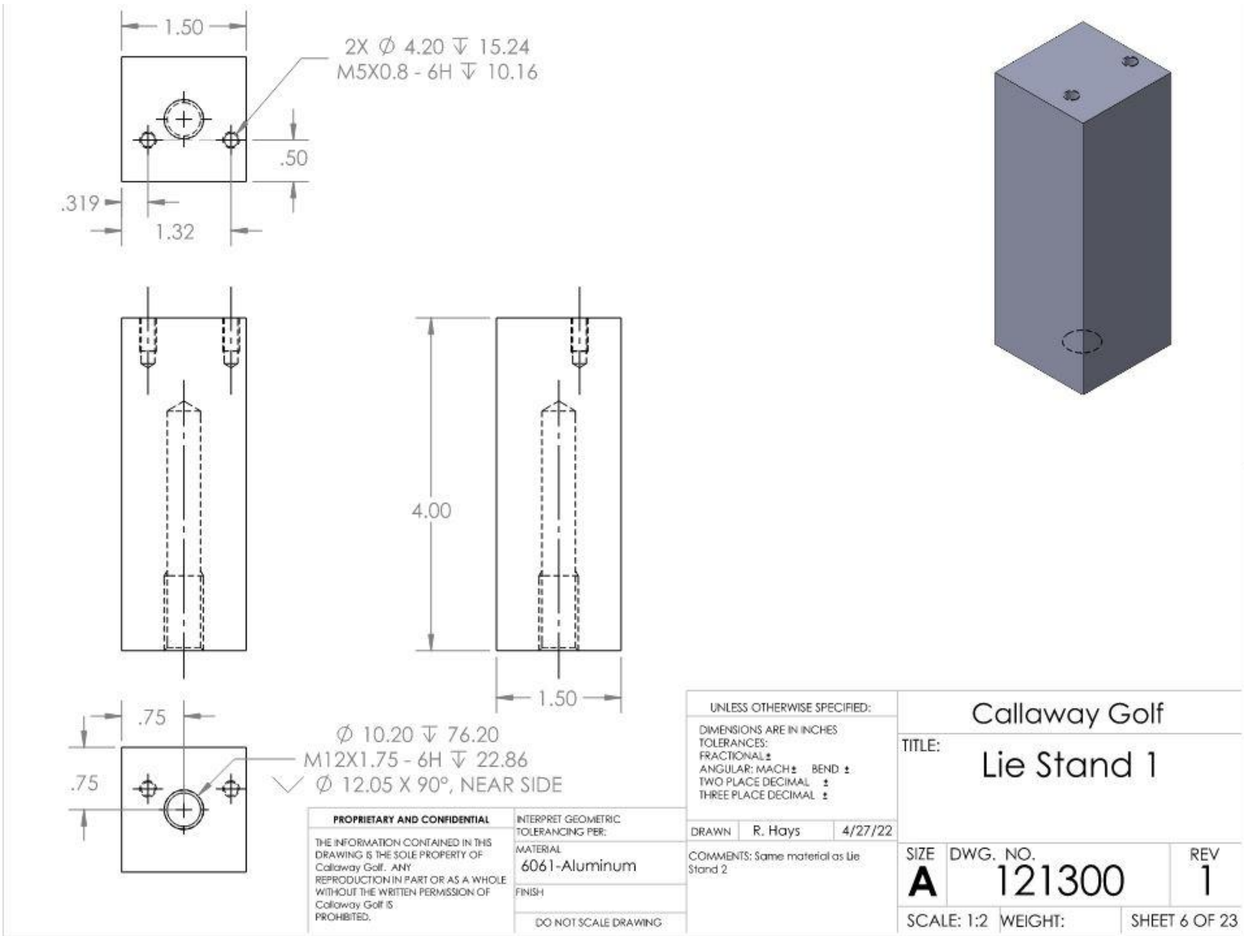
DRAWN: R. Hays 4/27/22

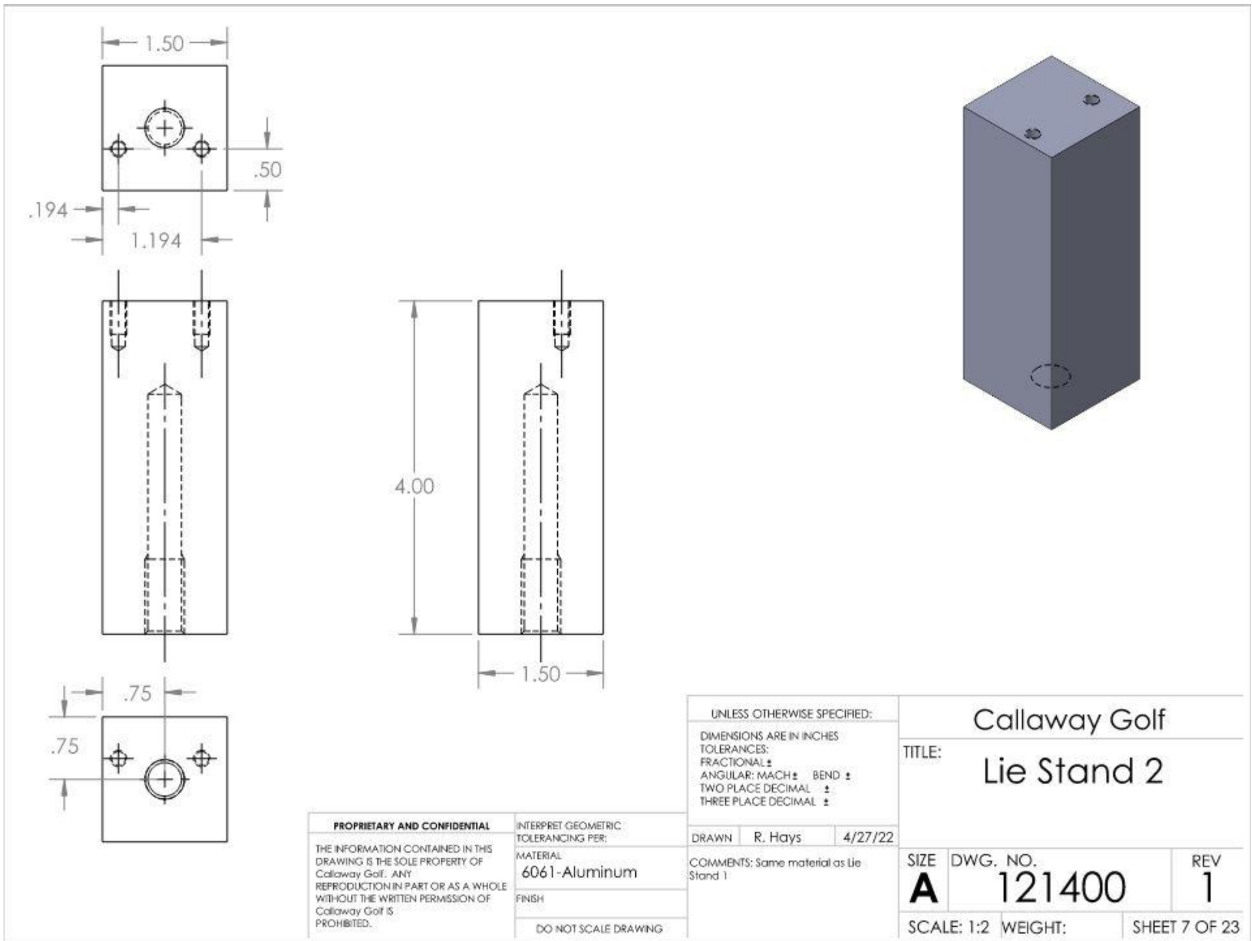
COMMENTS:

SIZE: A DWG. NO. 121000E REV 1

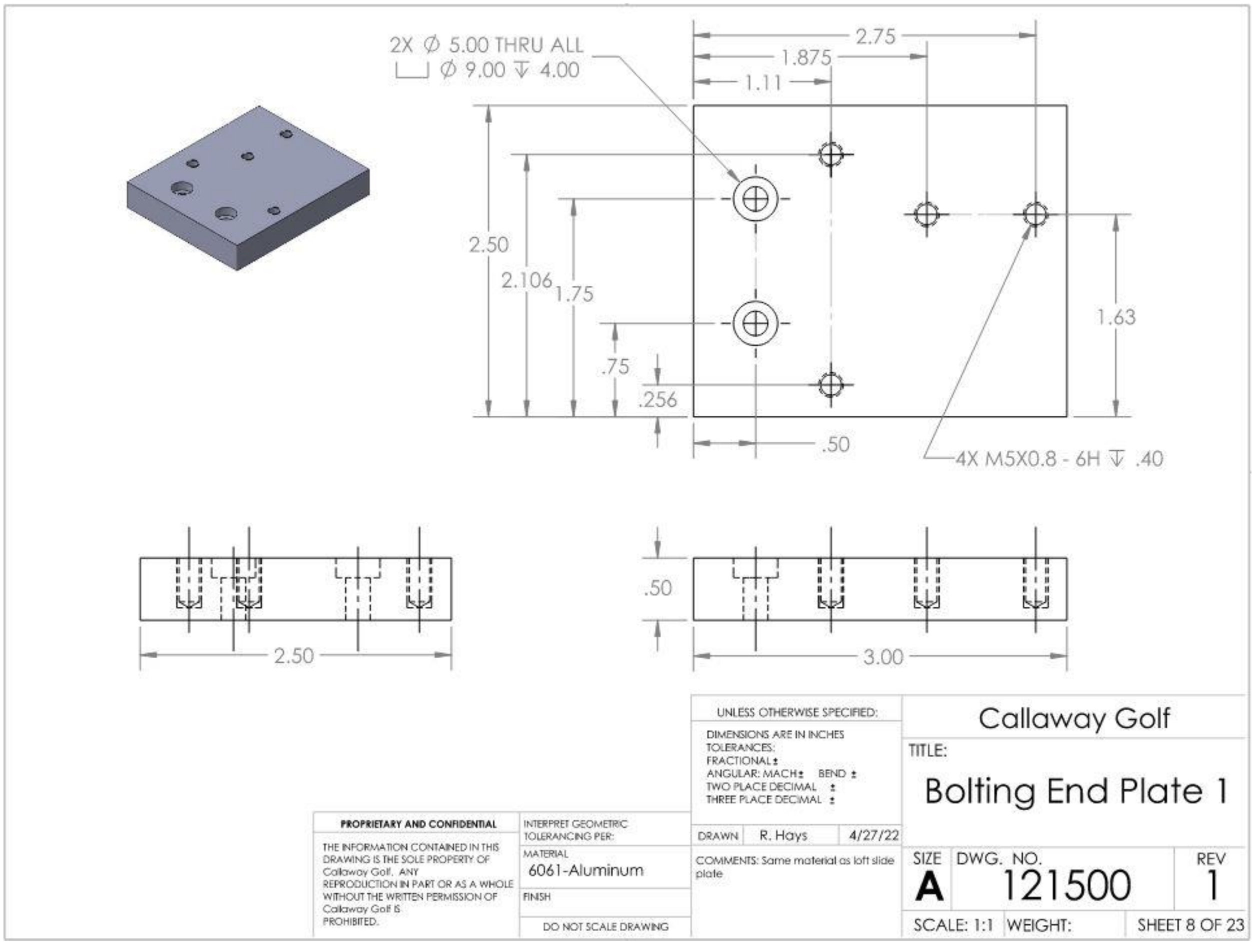
SCALE: 1:8 WEIGHT: SHEET 4 OF 23


1.50
2X ∅ 13.0 THRU ALL
⌴ ∅ 19.0 ↧ 13.0
9.33
2x R.75
2.25
.75
.875
10.08
4.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Lie Base
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
A36 Steel Plate
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Cut from Base Plate Material
SIZE DWG. NO. REV
A 121100 1
SCALE: 1:4 WEIGHT: SHEET 5 OF 23

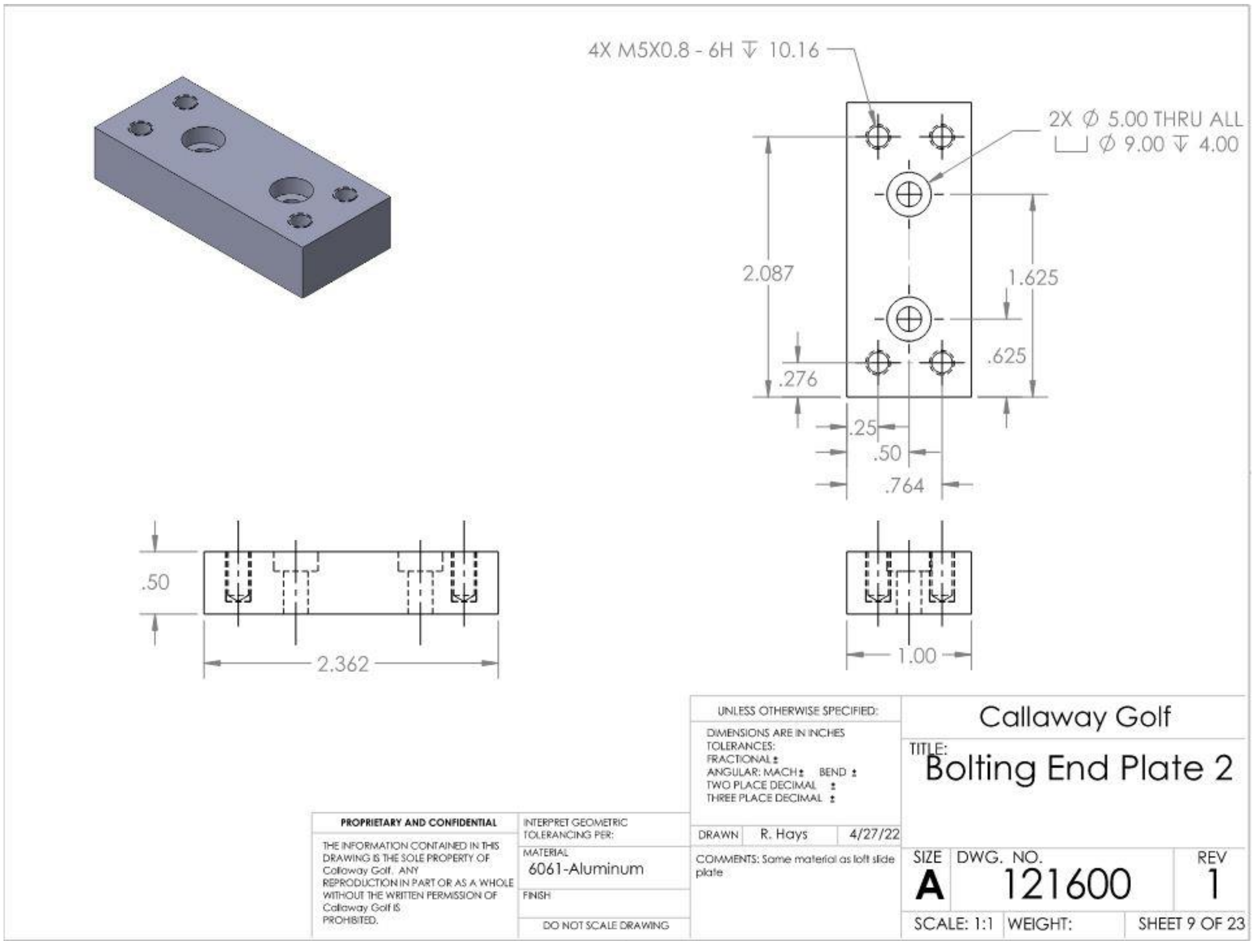

1.50
2X Ø 4.20 ↧ 15.24
M5X0.8 - 6H ↧ 10.16
.50
.319
1.32
4.00
1.50
.75
.75
Ø 10.20 ↧ 76.20
M12X1.75 - 6H ↧ 22.86
⌵ Ø 12.05 X 90°, NEAR SIDE
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN R. Hays 4/27/22
COMMENTS: Same material as Lie Stand 2
Callaway Golf
TITLE:
Lie Stand 1
SIZE A
DWG. NO. 121300
REV 1
SCALE: 1:2
WEIGHT:
SHEET 6 OF 23



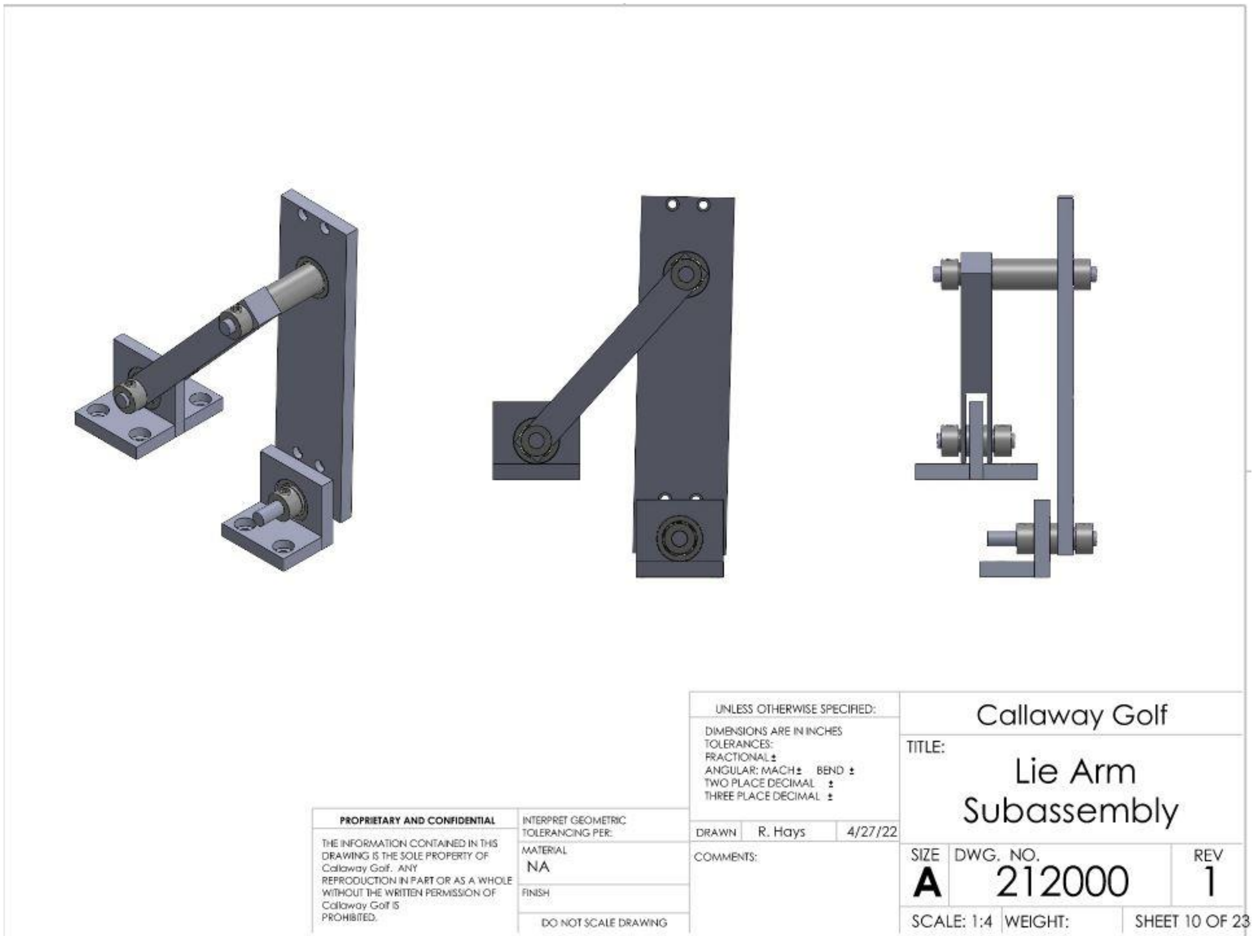
1.50
.50
.194
1.194
4.00
1.50
.75
.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Lie Stand 2
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Same material as Lie Stand 1
SIZE A
DWG. NO. 121400
REV 1
SCALE: 1:2 WEIGHT:
SHEET 7 OF 23



2X Ø 5.00 THRU ALL
⌴ Ø 9.00 ↧ 4.00
2.75
1.875
1.11
2.50
2.106
1.75
.75
.256
.50
1.63
4X M5X0.8 - 6H ↧ .40
.50
2.50
3.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Bolting End Plate 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Same material as loft slide plate
SIZE A
DWG. NO. 121500
REV 1
SCALE: 1:1 WEIGHT: SHEET 8 OF 23



4X M5X0.8 - 6H ↧ 10.16
2X Ø 5.00 THRU ALL
⌴ Ø 9.00 ↧ 4.00
2.087
1.625
.625
.276
.25
.50
.764
.50
2.362
1.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE: Bolting End Plate 2
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Calloway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Calloway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Same material as loft slide plate
SIZE A
DWG. NO. 121600
REV 1
SCALE: 1:1
WEIGHT:
SHEET 9 OF 23


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Lie Arm Subassembly
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS:
SIZE A
DWG. NO. 212000
REV 1
SCALE: 1:4
WEIGHT:
SHEET 10 OF 23

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	122-9-00	Flange 2	1
2	122-10-00	Flange 3	1
3	122-3-00	Main Arm Shaft	1
4	122-16-00	Lie Shaft Collar- 9414T6	6
5	122-15-00	Lie Plastic Washer- 95606A421	6
6	122-14-00	Lie Arm Ball Bearing- 2342K164	3
7	122-12-00	Main Arm Spacer- 92510A760	1
8	122-6-00	Bearing Plate 1	1
9	122-1-00	Main Arm	1
10	122-4-00	Small To Main Arm Shaft	1
11	122-11-00	Small to Main Arm Spacer- 92511A057	1
12	122-2-00	Small Arm	1
13	122-7-00	Bearing Plate 2	1
14	122-13-00	Small Arm Spacer- 92510A398	2
15	122-5-00	Small Arm Shaft	1
16	122-8-00	Flange 1	1

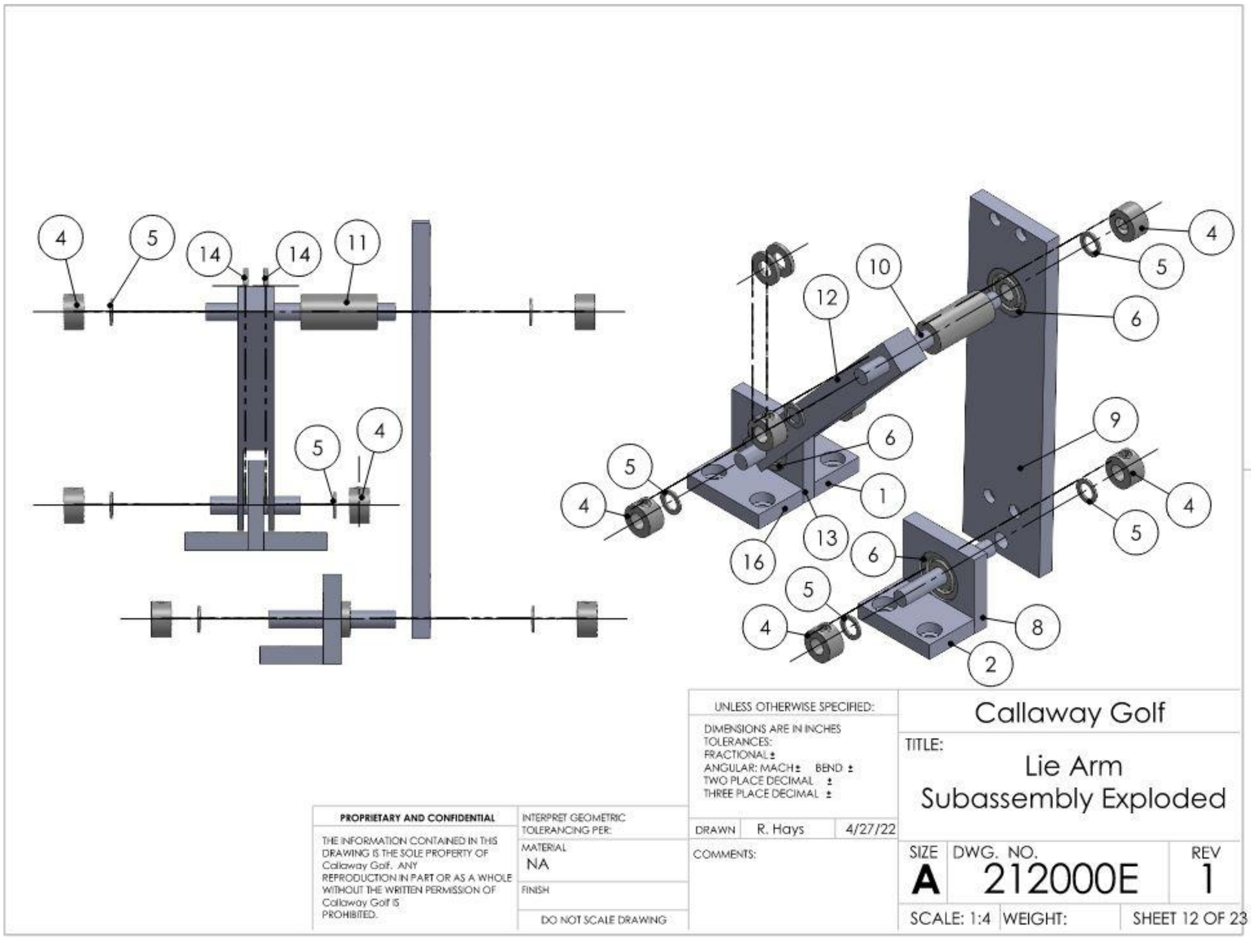
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

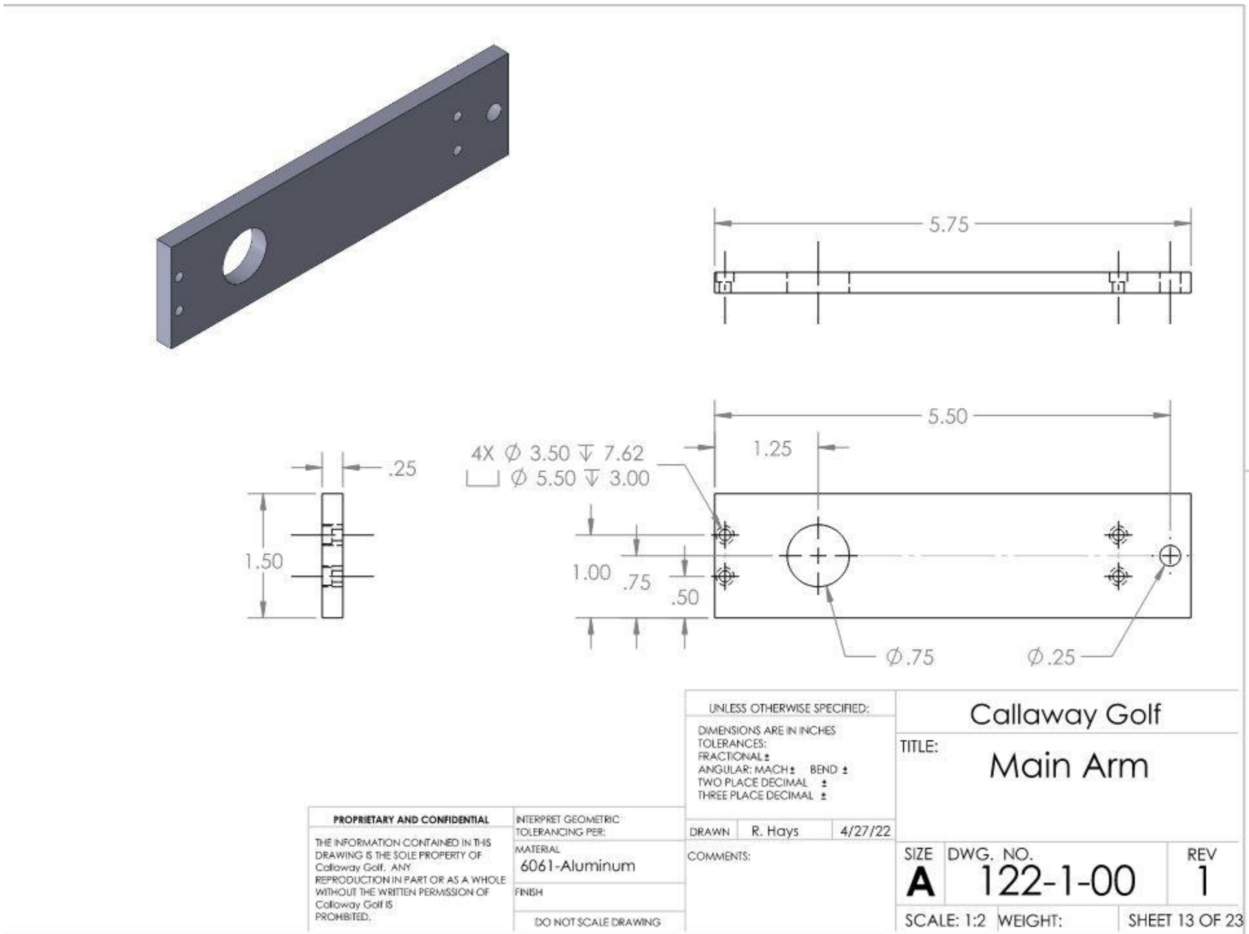
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.

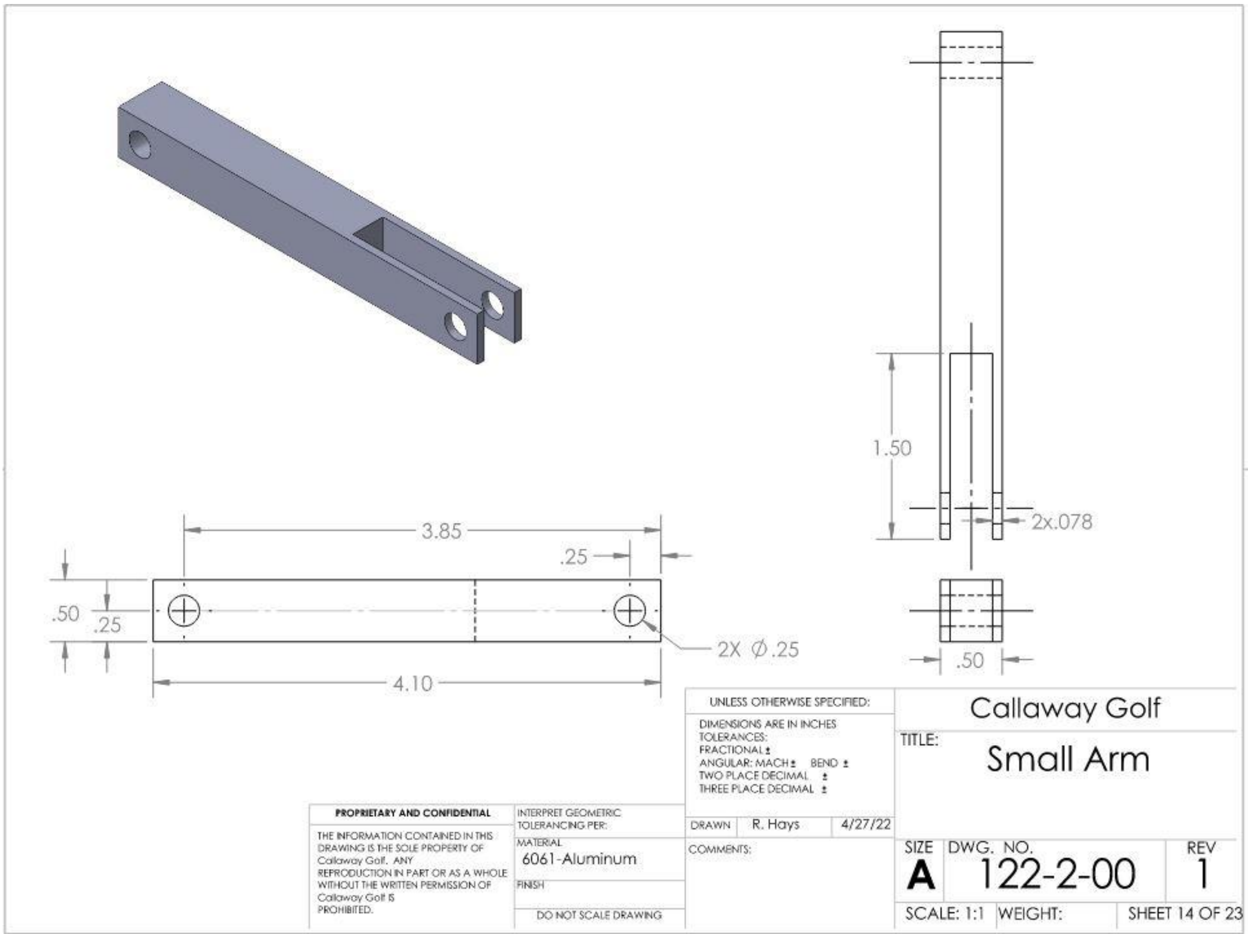
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING

DRAWN R. Hays 4/27/22
COMMENTS:

Callaway Golf
TITLE:
Lie Subassembly
SIZE A | DWG. NO. 1 | REV 1
SCALE: 1:4 | WEIGHT: | SHEET 11 OF 23

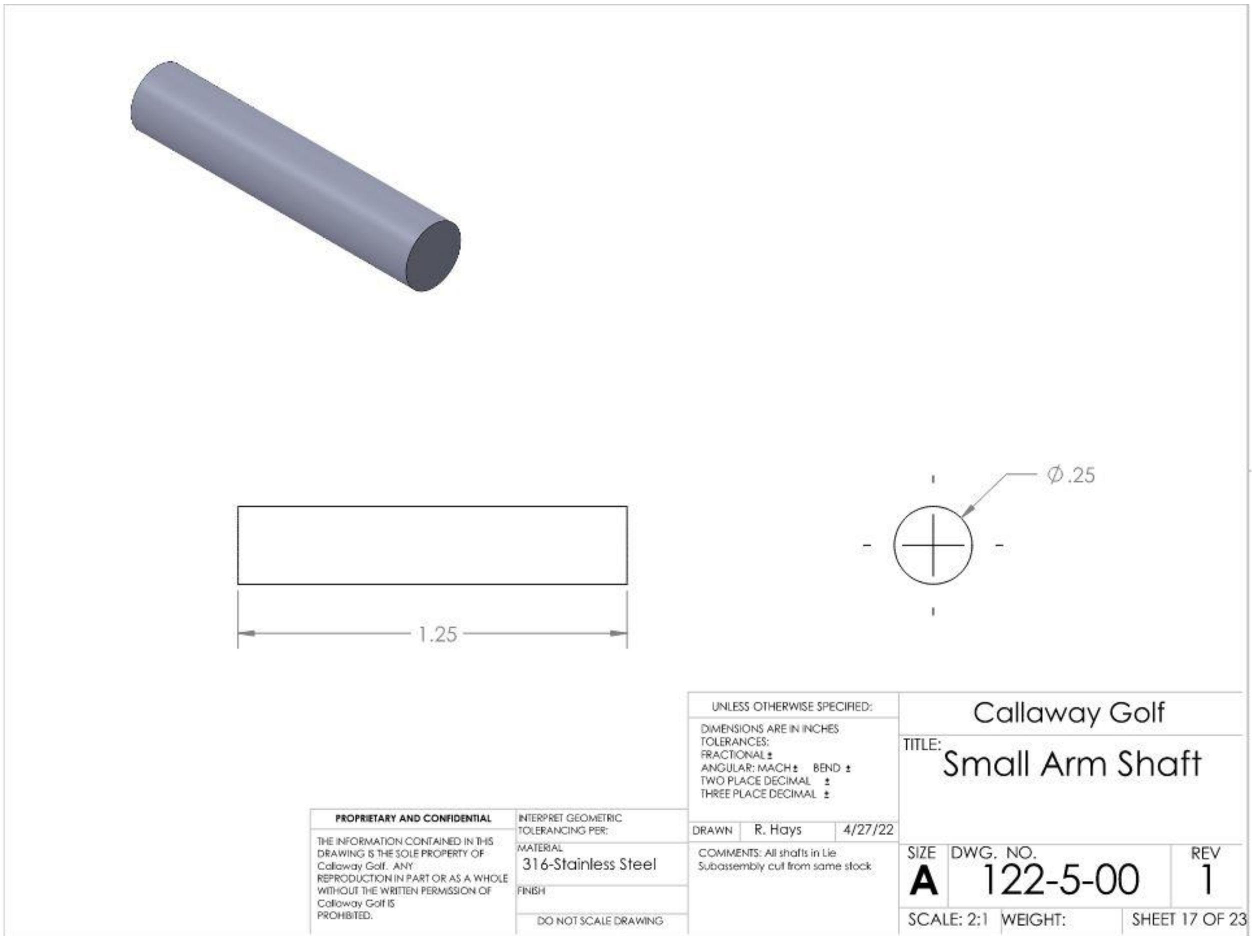

4
5
14
14
11
5
4
10
12
6
9
6
5
4
1
13
16
4
5
6
5
4
8
2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Lie Arm
Subassembly Exploded
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS:
SIZE A
DWG. NO. 212000E
REV 1
SCALE: 1:4
WEIGHT:
SHEET 12 OF 23


5.75
5.50
1.25
4X Ø 3.50 ↧ 7.62
⌴ Ø 5.50 ↧ 3.00
.25
1.50
1.00
.75
.50
Ø.75
Ø.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Main Arm
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Calloway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Calloway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS:
SIZE A
DWG. NO. 122-1-00
REV 1
SCALE: 1:2
WEIGHT:
SHEET 13 OF 23

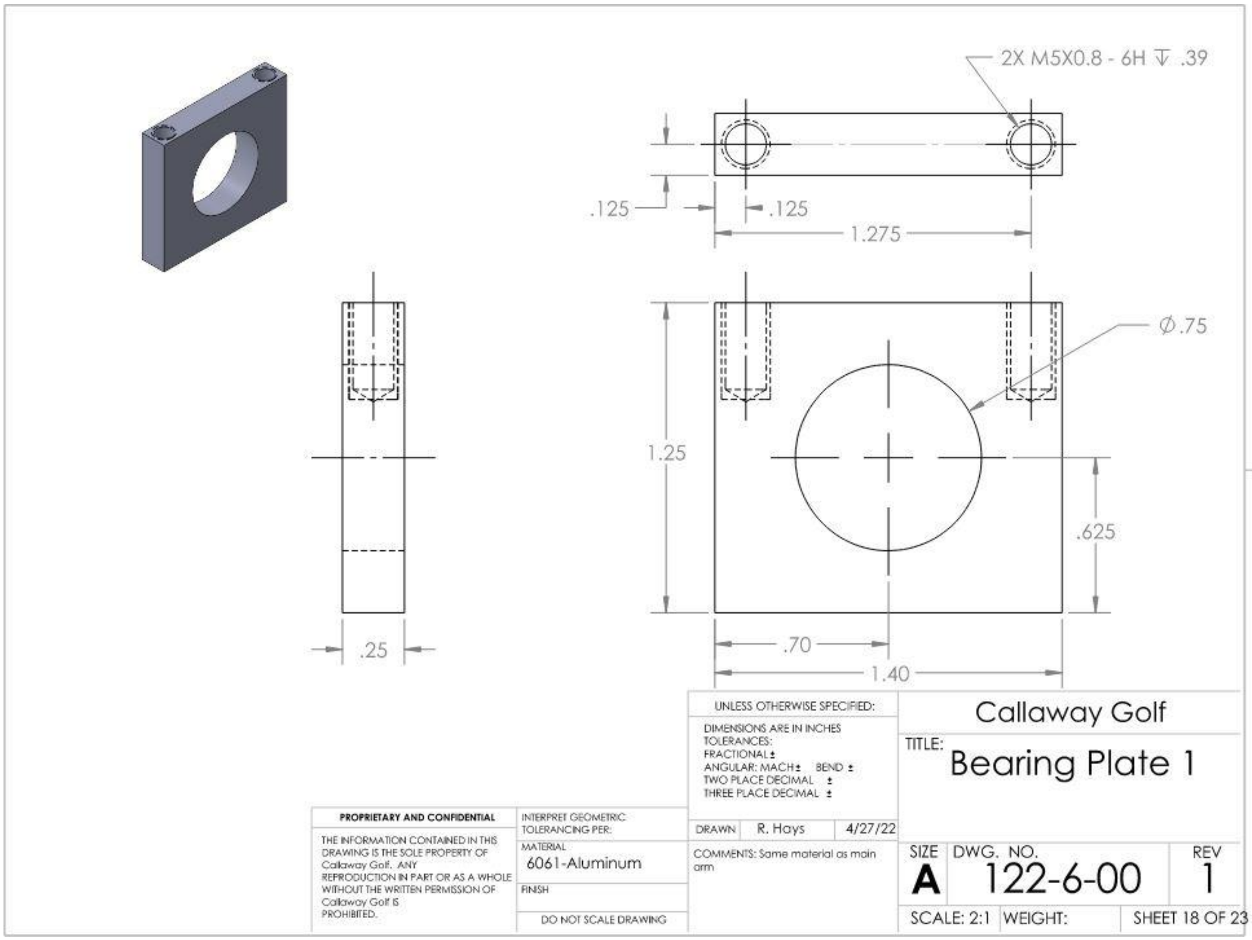

3.85
.25
.50
.25
2X Ø.25
4.10
1.50
2x.078
.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Small Arm
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS:
SIZE A
DWG. NO. 122-2-00
REV 1
SCALE: 1:1 WEIGHT: SHEET 14 OF 23

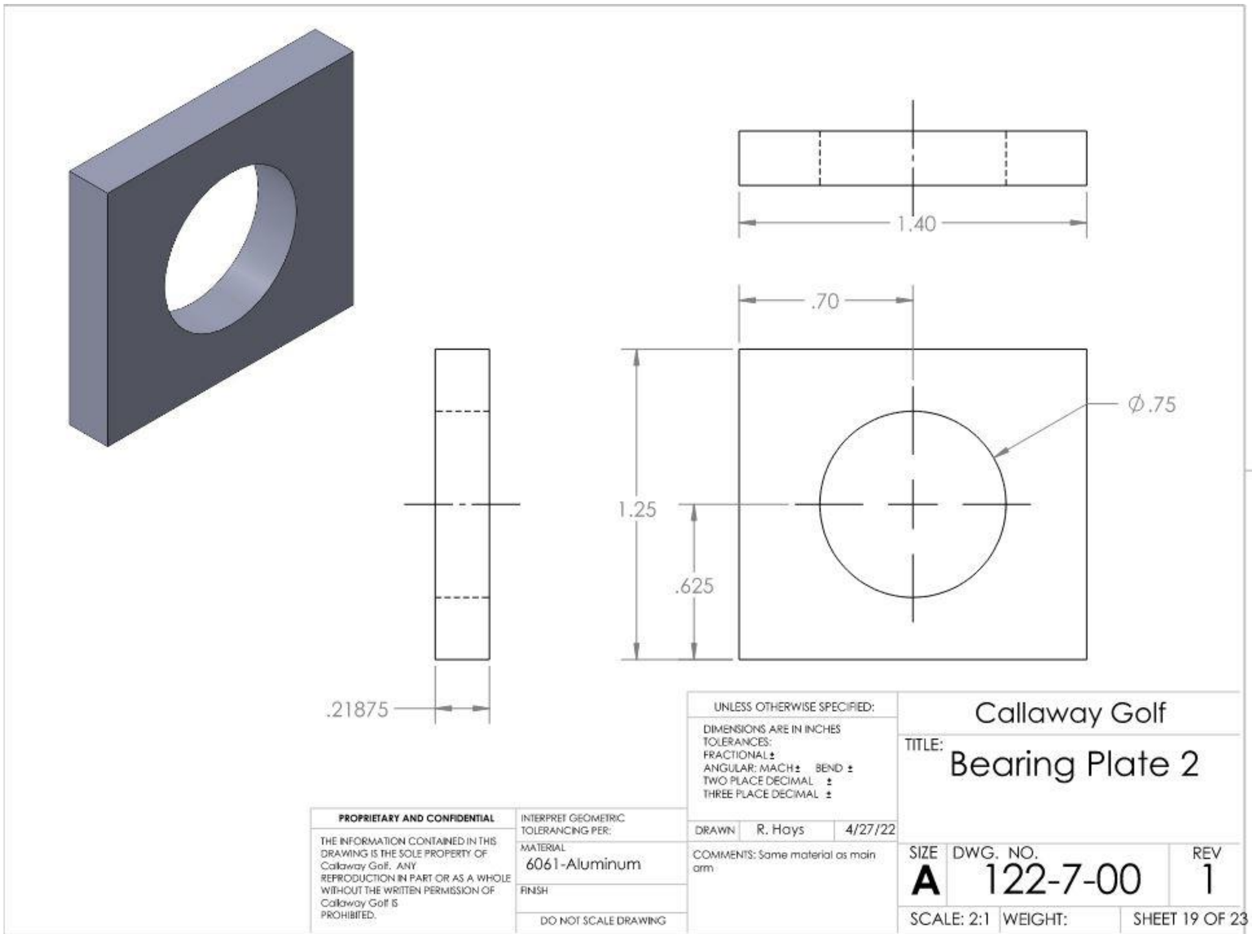

1.75
Ø.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Main Arm Shaft
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
316-Stainless Steel
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: All shafts in Lie Subassembly cut from same stock
SIZE A
DWG. NO. 122-3-00
REV 1
SCALE: 2:1
WEIGHT:
SHEET 15 OF 23

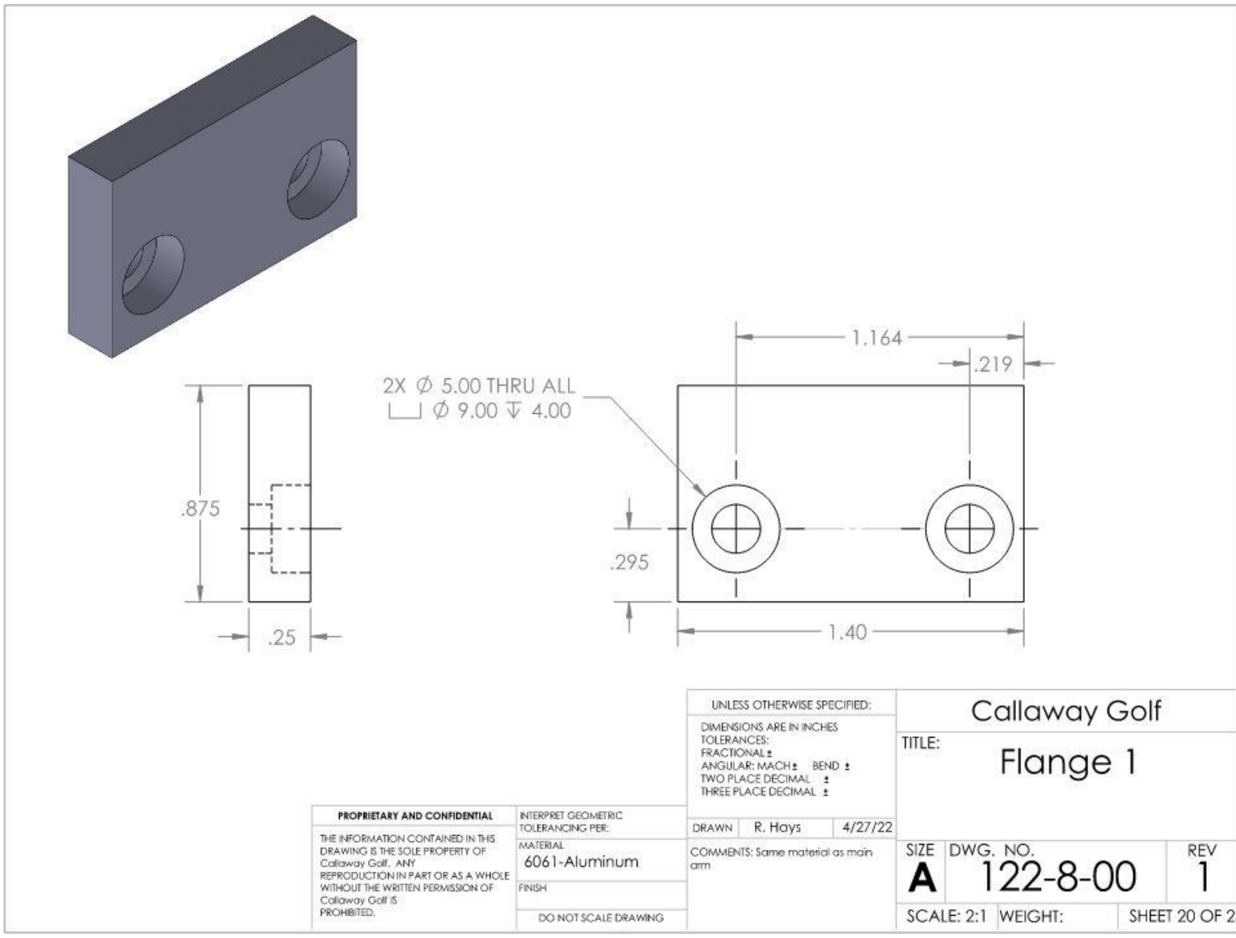
2.625
Ø.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Small to Main Arm Shaft
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
316-Stainless Steel
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS All shafts in Lie Subassembly cut from same stock:
SIZE A
DWG. NO. 122-4-00
REV 1
SCALE: 1:1 WEIGHT:
SHEET 16 OF 23



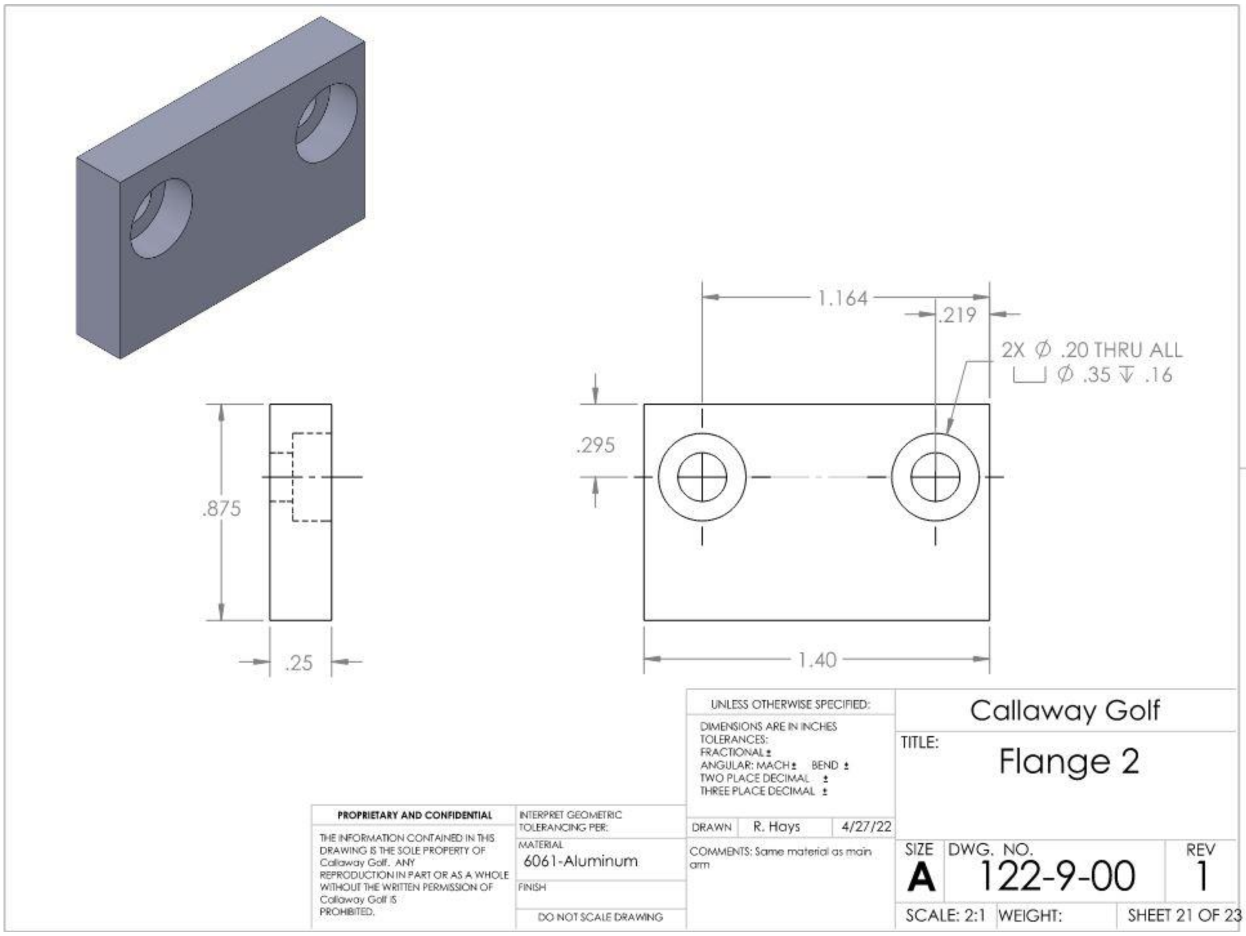
Ø.25
1.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE: Small Arm Shaft
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
316-Stainless Steel
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: All shafts in Lie Subassembly cut from same stock
SIZE A
DWG. NO. 122-5-00
REV 1
SCALE: 2:1 WEIGHT:
SHEET 17 OF 23

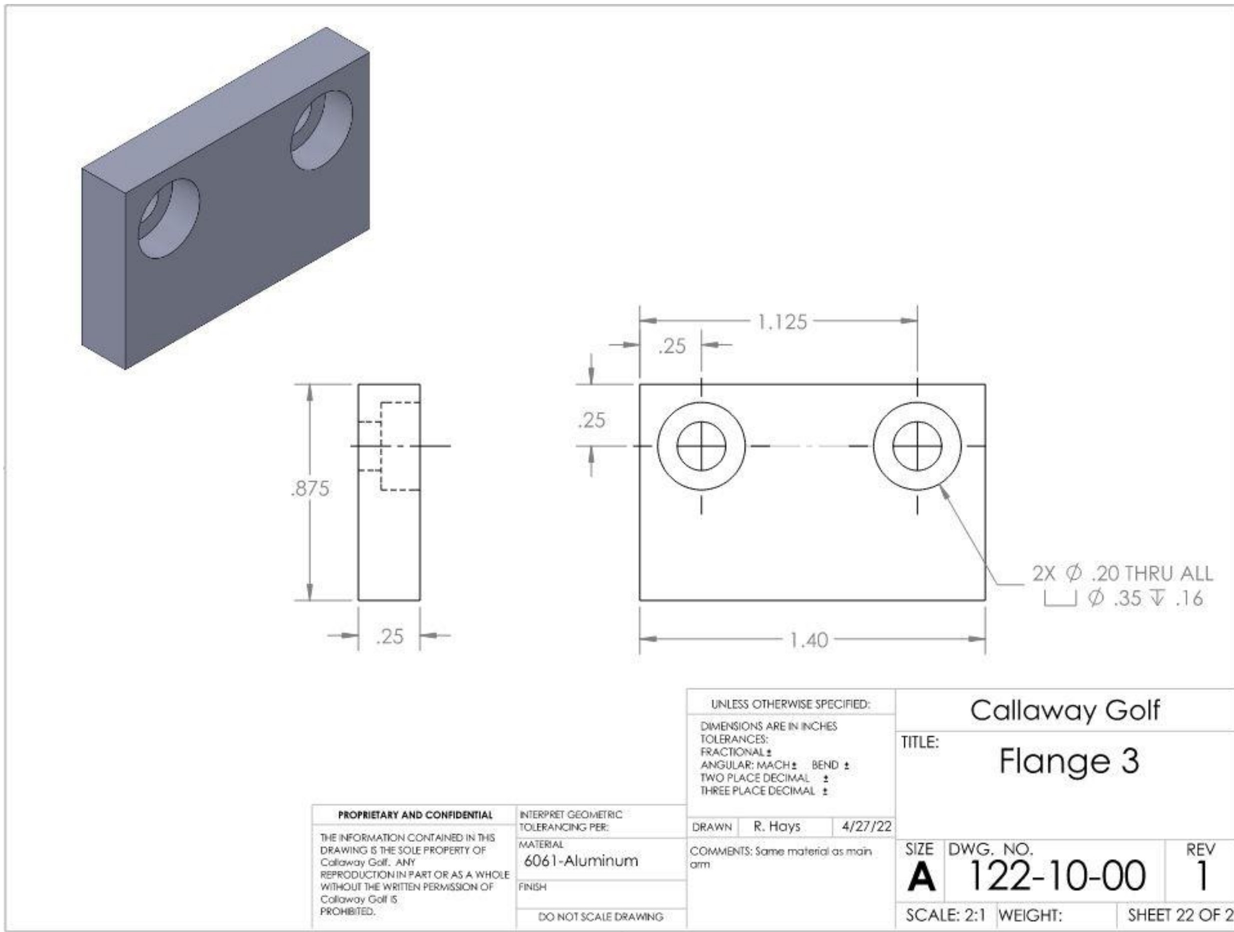

2X M5X0.8 - 6H ↧ .39
.125
.125
1.275
Ø.75
1.25
.625
.25
.70
1.40
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Bearing Plate 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Same material as main arm
SIZE A
DWG. NO. 122-6-00
REV 1
SCALE: 2:1
WEIGHT:
SHEET 18 OF 23

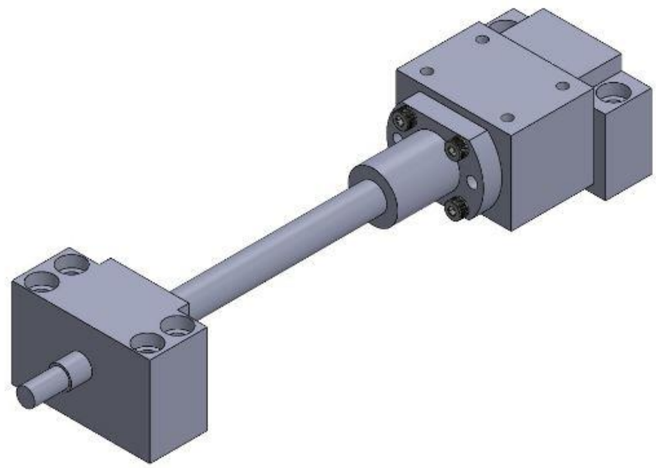

1.40
.70
Ø.75
1.25
.625
.21875
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Bearing Plate 2
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Same material as main arm
SIZE
A
DWG. NO.
122-7-00
REV
1
SCALE: 2:1
WEIGHT:
SHEET 19 OF 23



1.164
.219
2X Ø 5.00 THRU ALL
⌴ Ø 9.00 ↧ 4.00
.875
.295
.25
1.40
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Flange 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Same material as main arm
SIZE A
DWG. NO. 122-8-00
REV 1
SCALE: 2:1
WEIGHT:
SHEET 20 OF 23


1.164
.219
2X Ø .20 THRU ALL
⌴ Ø .35 ↧ .16
.295
.875
.25
1.40
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Flange 2
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Same material as main arm
SIZE A
DWG. NO. 122-9-00
REV 1
SCALE: 2:1
WEIGHT:
SHEET 21 OF 23


1.125
.25
.25
.875
.25
1.40
2X Ø .20 THRU ALL
⌴ Ø .35 ↧ .16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
Flange 3
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061-Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN R. Hays 4/27/22
COMMENTS: Same material as main arm
SIZE A
DWG. NO. 122-10-00
REV 1
SCALE: 2:1 WEIGHT:
SHEET 22 OF 23



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

Callaway Golf

TITLE:
Lie Ball Screw Part

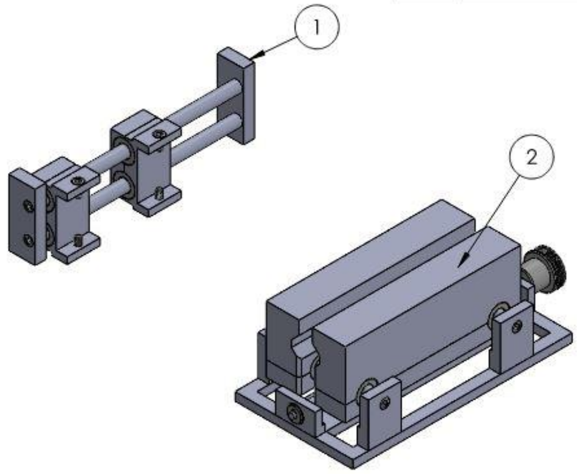
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING

DRAWN R. Hays 4/27/22
COMMENTS:
Purchase from Amazon.com

SIZE A
DWG. NO. 213000
REV 1
SCALE: 1:4 WEIGHT: SHEET 23 OF 23

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	131000	MOUNTING SUBASSEMBLY	1
2	13200	CLAMP HOUSING SUBASSEMBLY	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

Callaway Golf

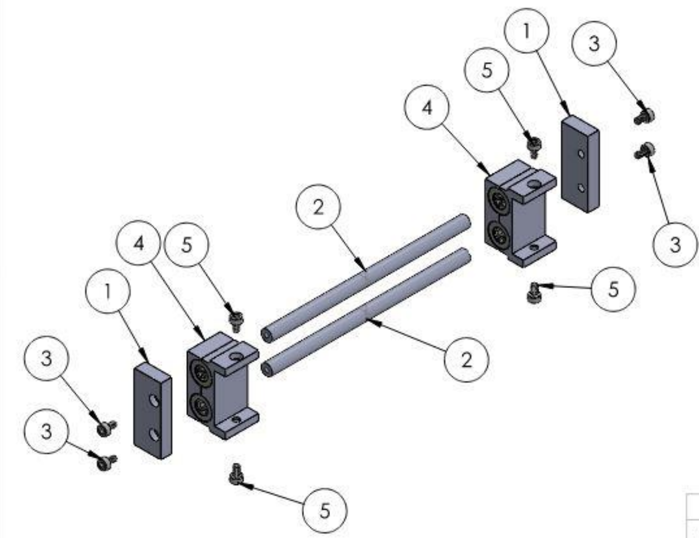
TITLE:
SHAFT CLAMP SUBASSEMBLY

PROPRIETARY AND CONFIDENTIAL

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: NA
FINISH
DO NOT SCALE DRAWING

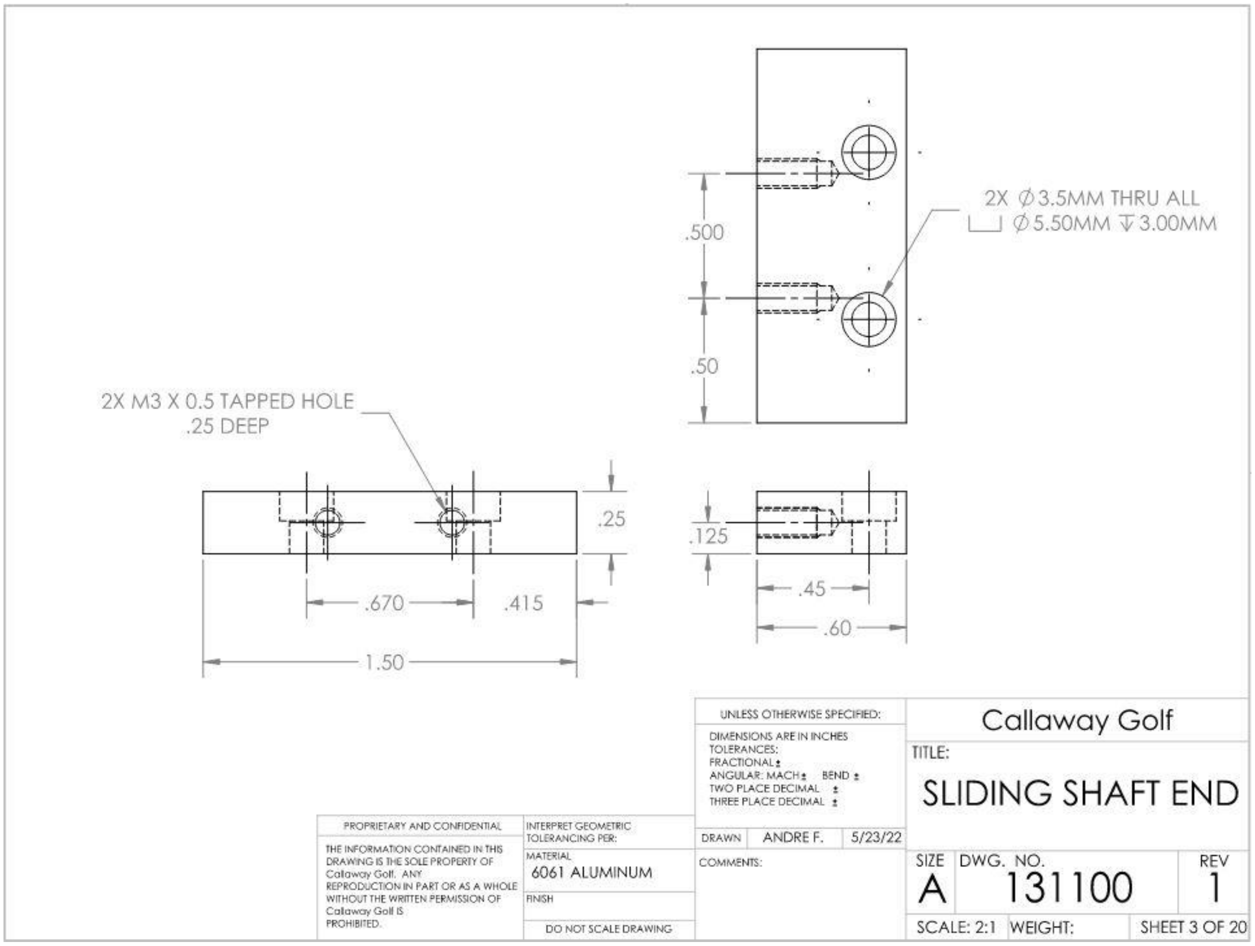
DRAWN: ANDRE F. 5/23/22
COMMENTS:

SIZE: A
DWG. NO. 130000
REV: 1
SCALE: 1:2 WEIGHT: SHEET 1 OF 20

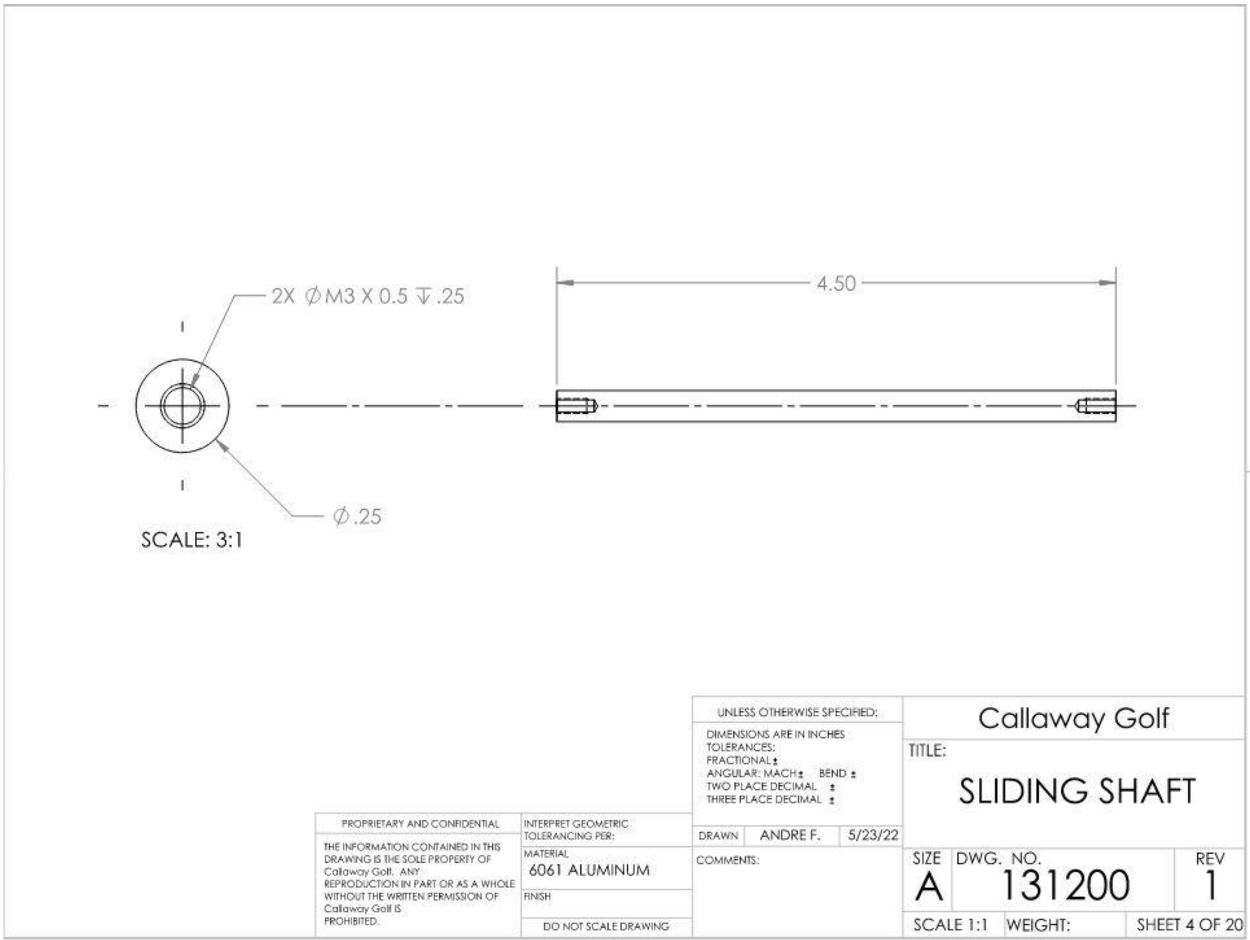


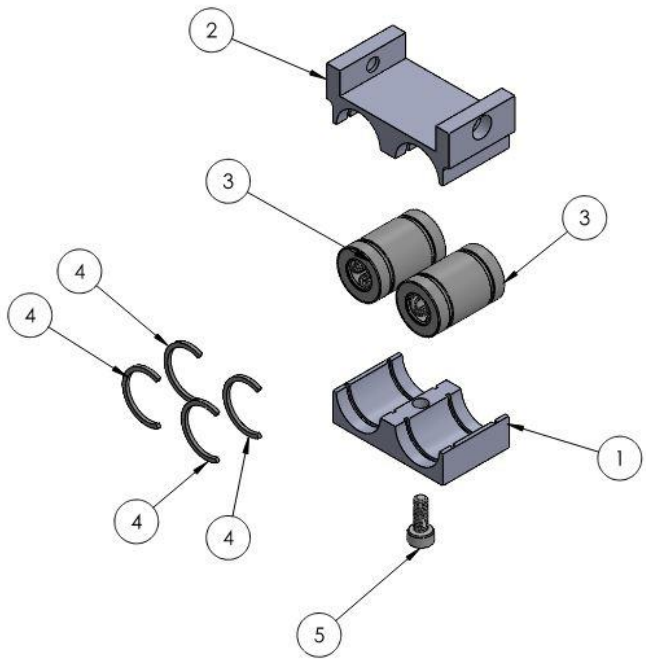
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	131100	SLIDING SHAFT END	2
2	131200	SLIDING SHAFT	2
3	131300	SLIDING SHAFT TO SHAFT END BOLTS 9129A110	4
4	131400	LINEAR BEARING SUBASSEMBLY	2
5	131500	LINEAR BEARING SUBASSEMBLY TO CLAMP HOUSING BOLTS 9129A110	4

PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.	INTERPRET GEOMETRIC TOLERANCING PER: MATERIAL NA FINISH DO NOT SCALE DRAWING	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ± DRAWN ANDRE F. 5/23/22 COMMENTS:	Callaway Golf TITLE: MOUNTING SUBASSEMBLY SIZE A DWG. NO. 131000 REV 1 SCALE: 1:2 WEIGHT: SHEET 2 OF 20



2X ∅3.5MM THRU ALL
⌴ ∅5.50MM ↧ 3.00MM
.500
.50
2X M3 X 0.5 TAPPED HOLE
.25 DEEP
.25
.125
.670
.415
.45
.60
1.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
SLIDING SHAFT END
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 131100
REV 1
SCALE: 2:1 WEIGHT: SHEET 3 OF 20


2X ∅M3 X 0.5 ↧.25
4.50
∅.25
SCALE: 3:1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
SLIDING SHAFT
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN
ANDRE F.
5/23/22
COMMENTS:
SIZE
A
DWG. NO.
131200
REV
1
SCALE 1:1
WEIGHT:
SHEET 4 OF 20



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	124141	BEARING HOUSING BOTTOM	1
2	124142	BEARING HOUSING TOP	1
3	124143	LINEAR BALL BEARING 60595K11	2
4	124144	EXTERNAL RETAINING RING 9968K22	4
5	124145	BOTTOM TO TOP HOUSING BOLT 91292A112	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

PROPRIETARY AND CONFIDENTIAL

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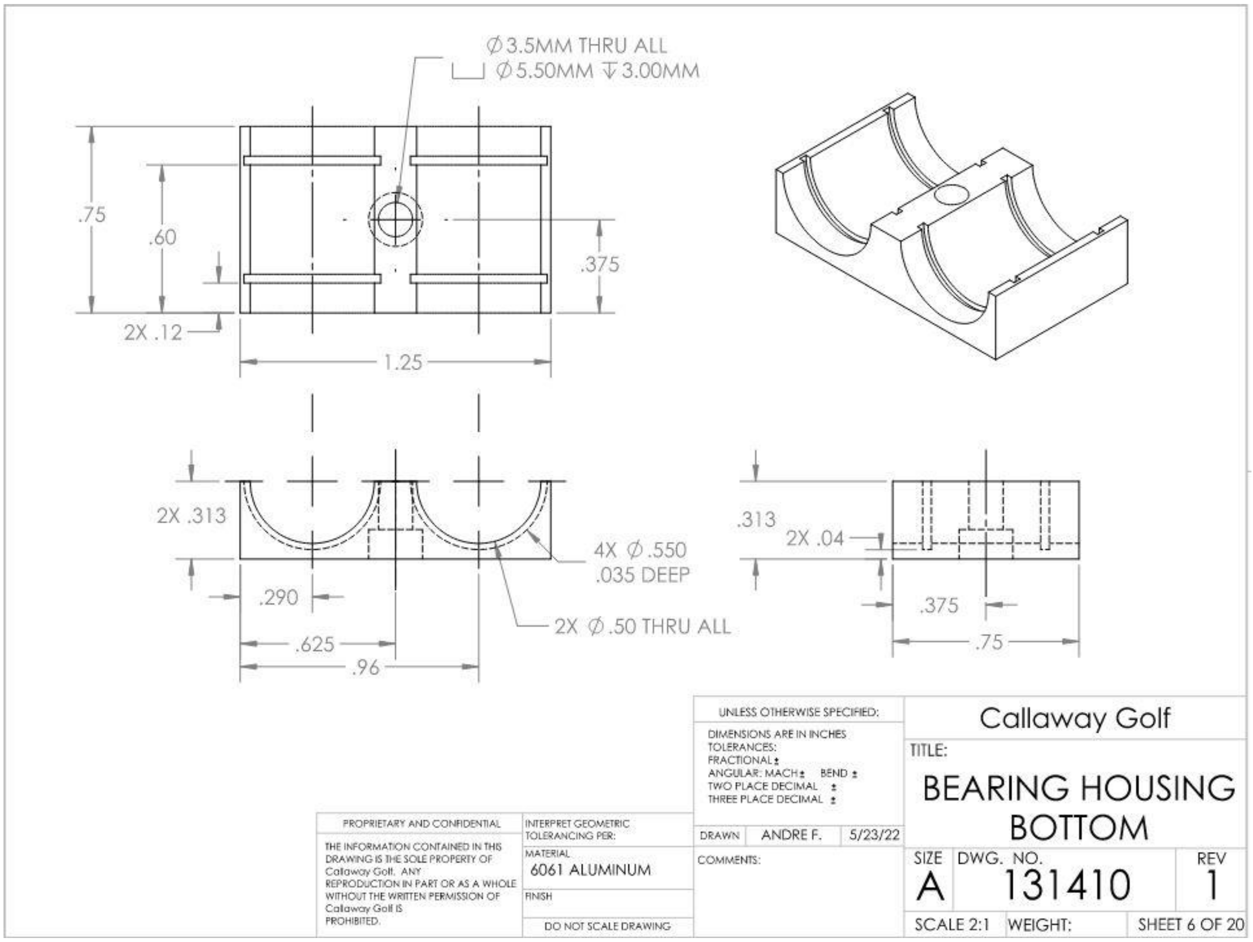
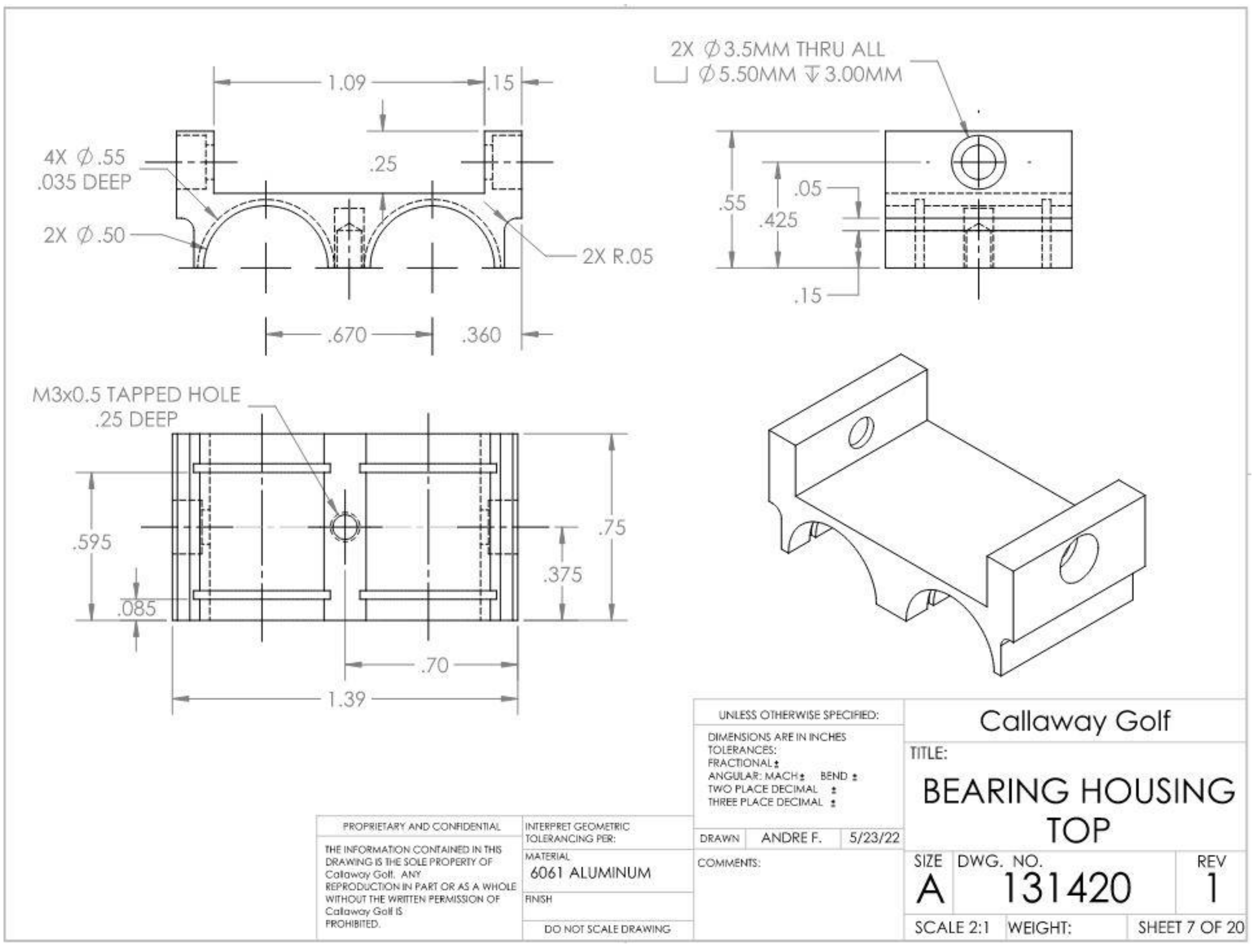
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL NA
FINISH
DO NOT SCALE DRAWING

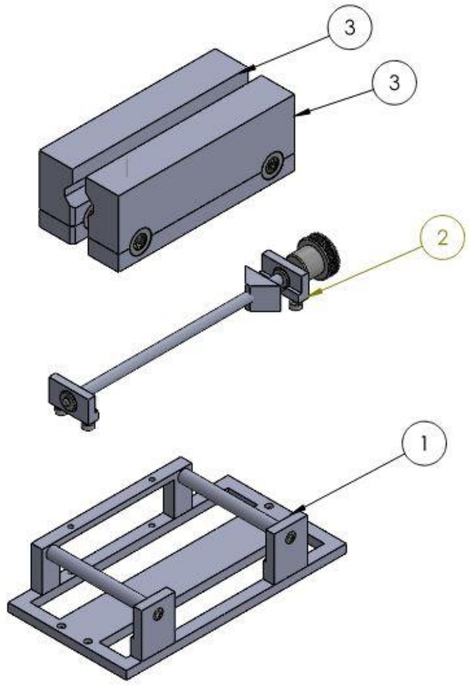
DRAWN ANDRE F. 5/23/22
COMMENTS:

Callaway Golf
TITLE: LINEAR BEARING SUBASSEMBLY
SIZE A DWG. NO. 131400 REV 1
SCALE 1:1 WEIGHT: SHEET 5 OF 20



Ø3.5MM THRU ALL
⌴ Ø5.50MM ↧3.00MM
.75
.60
.375
2X .12
1.25
2X .313
4X Ø.550
.035 DEEP
.290
2X Ø.50 THRU ALL
.625
.96
.313
2X .04
.375
.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
BEARING HOUSING BOTTOM
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 131410
REV 1
SCALE 2:1
WEIGHT:
SHEET 6 OF 20


2X ⌀3.5MM THRU ALL
⌴ ⌀5.50MM ↧3.00MM
1.09
.15
.25
4X ⌀.55
.035 DEEP
2X ⌀.50
2X R.05
.55
.05
.425
.15
.670
.360
M3x0.5 TAPPED HOLE
.25 DEEP
.595
.085
.75
.375
.70
1.39
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
BEARING HOUSING TOP
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 131420
REV 1
SCALE 2:1
WEIGHT:
SHEET 7 OF 20



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	132100	C-CLAMP HOUSING SUBASSEMBLY	1
2	132200	SYMMETRICAL SEPARATOR SUBASSEMBLY	1
3	132300	C-CLAMP SUBASSEMBLY	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

Callaway Golf

TITLE:

CLAMP HOUSING SUBASSEMBLY

PROPRIETARY AND CONFIDENTIAL

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL NA

FINISH

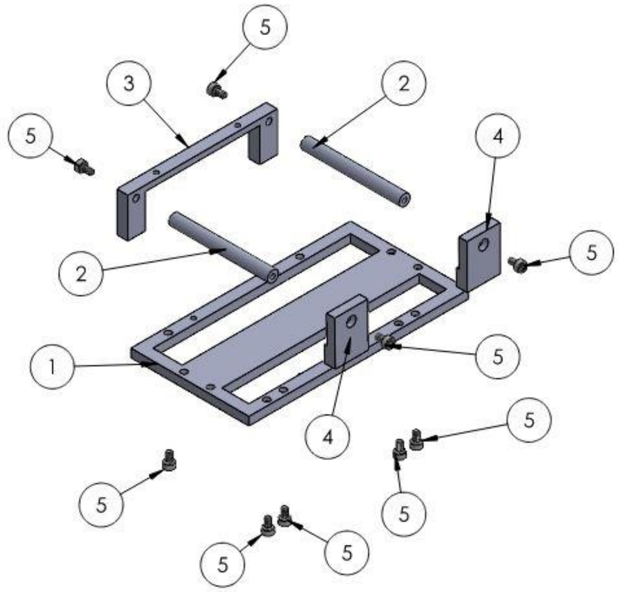
DO NOT SCALE DRAWING

DRAWN ANDRE F. 5/23/22

COMMENTS:

SIZE A DWG. NO. 132000 REV 1

SCALE 1:2 WEIGHT: SHEET 8 OF 20



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	132110	SLIDER BASE PLATE	1
2	132120	C-CLAMP SHAFT	2
3	13130	HOUSING SLIDER BACKING	1
4	13140	SHAFT END	2
5	13150	BOLTS 9129A110	10

PROPRIETARY AND CONFIDENTIAL

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INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: NA

FINISH

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

DRAWN: ANDRE F. 5/23/22

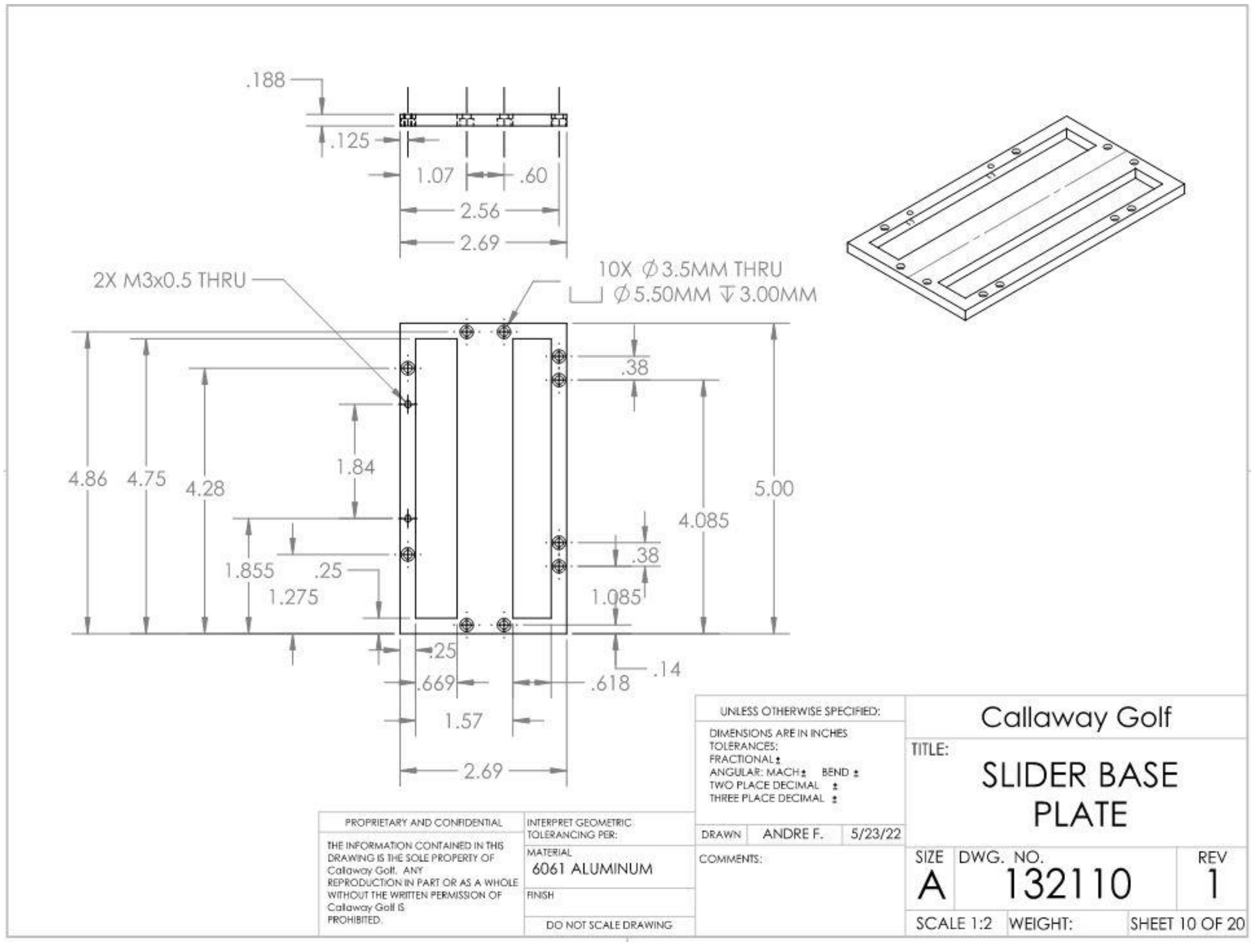
COMMENTS:

Callaway Golf

TITLE: C-CLAMP HOUSING SUBASSEMBLY

SIZE: A | DWG. NO. 132100 | REV 1

SCALE 1:2 | WEIGHT: | SHEET 9 OF 20


.188
.125
1.07
.60
2.56
2.69
2X M3x0.5 THRU
10X ∅3.5MM THRU
⌴ ∅5.50MM ↧ 3.00MM
4.86
4.75
4.28
1.84
1.855
.25
1.275
.38
4.085
5.00
.38
1.085
.14
.25
.669
.618
1.57
2.69
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
SLIDER BASE PLATE
PROPRIETARY AND CONFIDENTIAL
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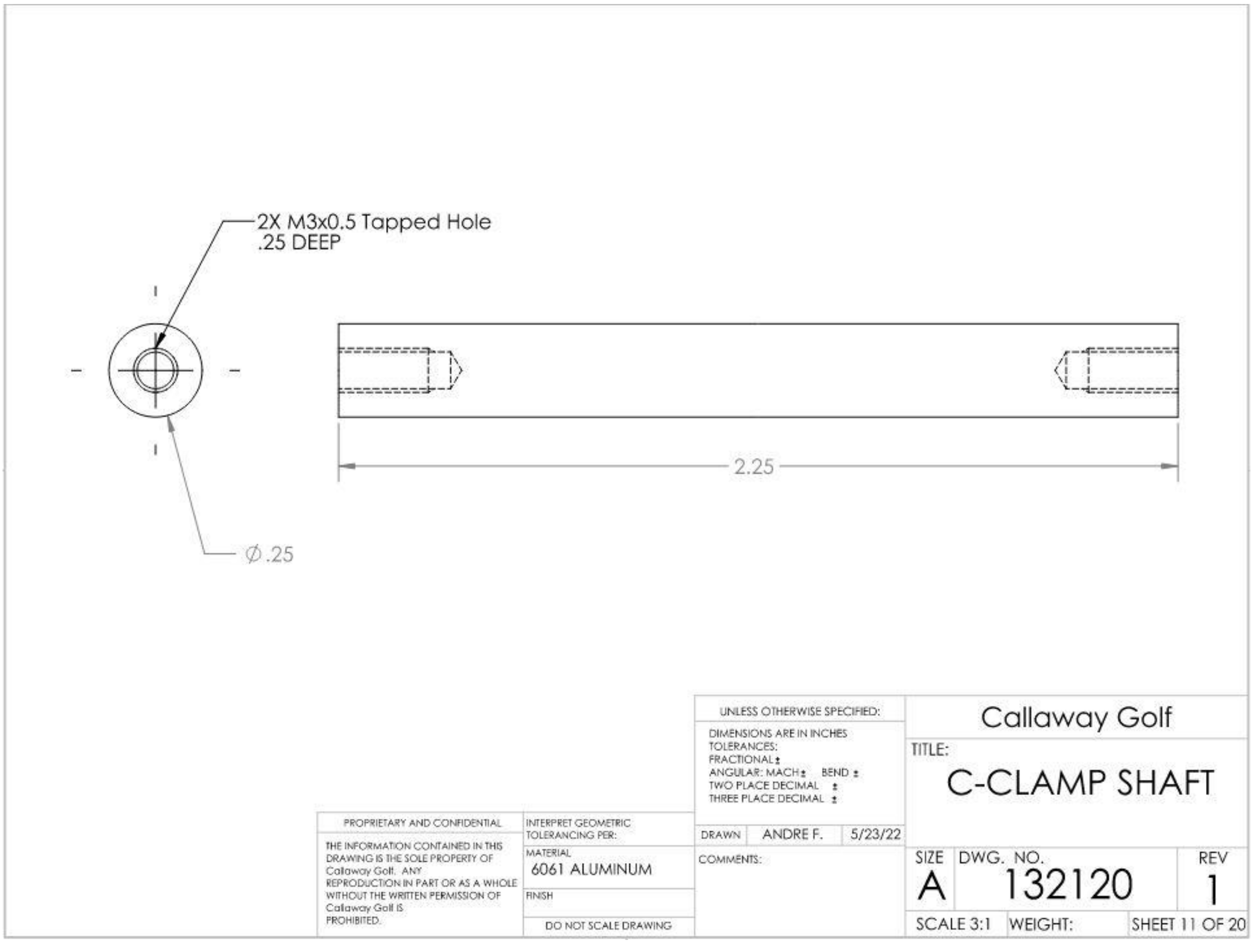
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 132110
REV 1
SCALE 1:2
WEIGHT:
SHEET 10 OF 20


2X M3x0.5 Tapped Hole
.25 DEEP
Ø.25
2.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
C-CLAMP SHAFT
PROPRIETARY AND CONFIDENTIAL
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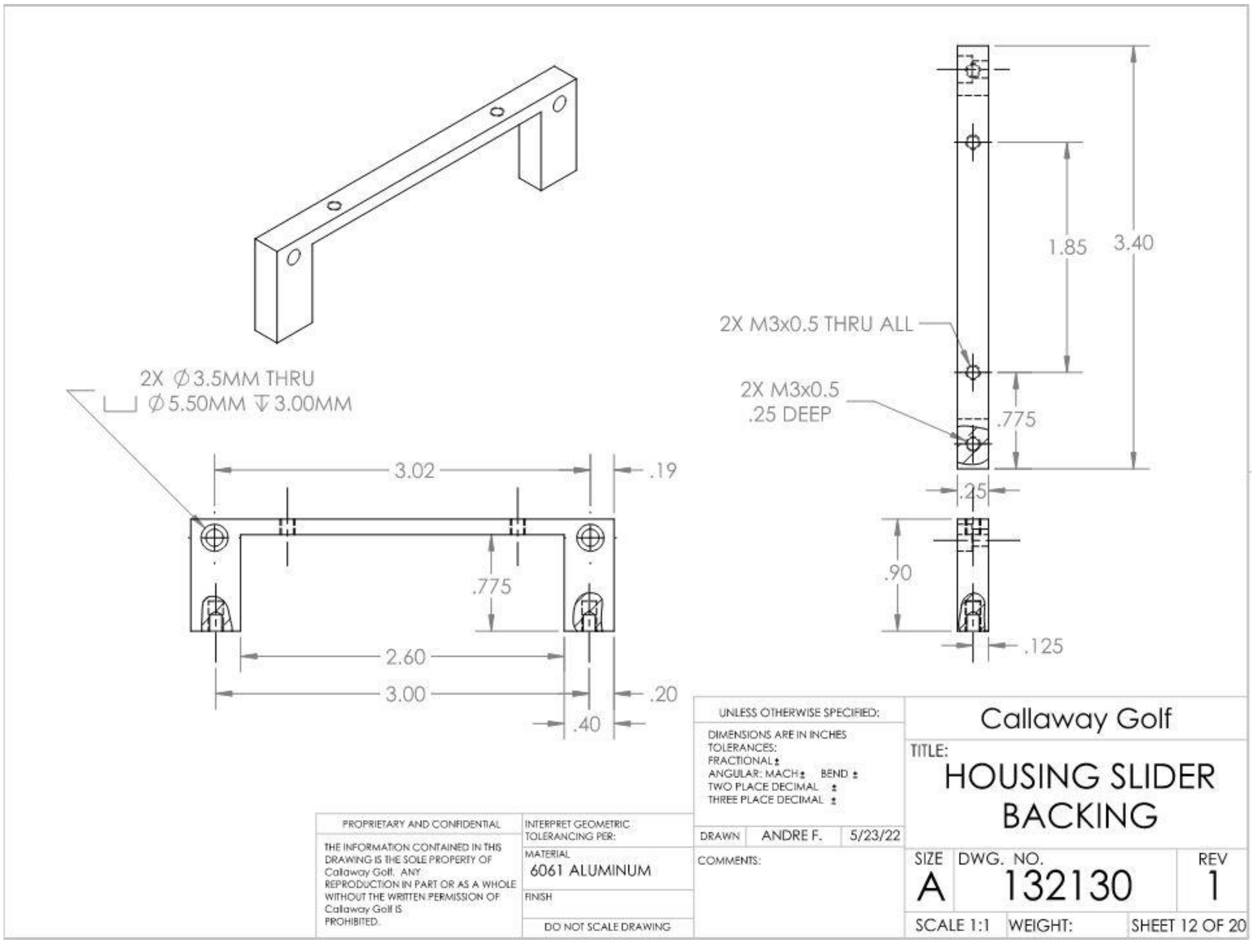
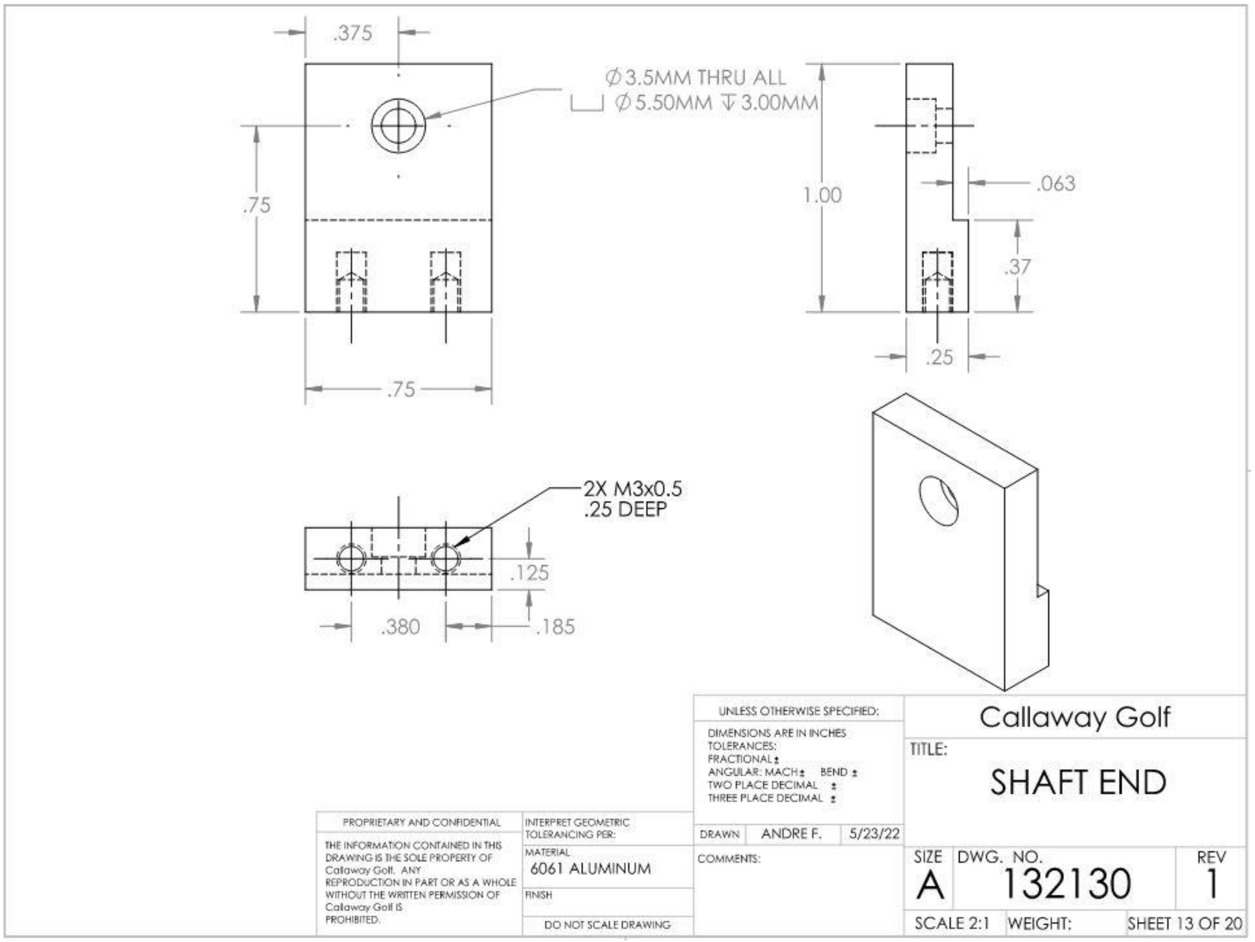
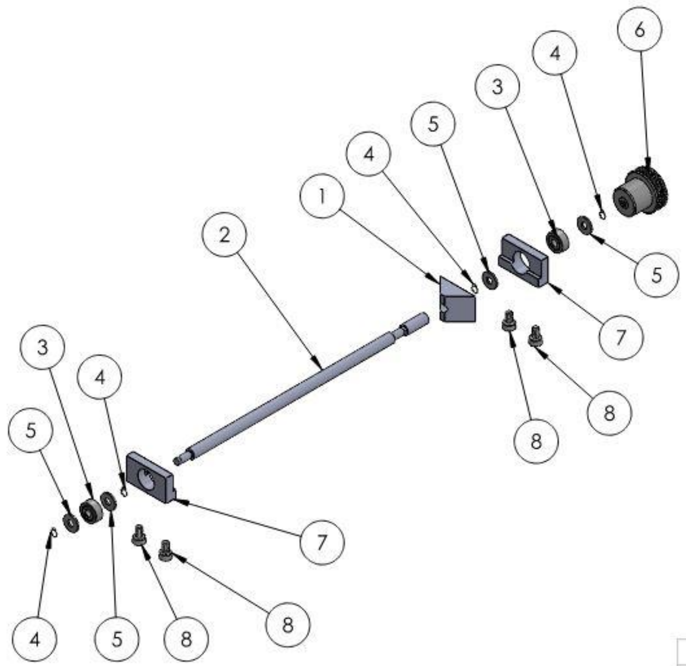
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 132120
REV 1
SCALE 3:1
WEIGHT:
SHEET 11 OF 20


2X ∅3.5MM THRU
⌴ ∅5.50MM ↧ 3.00MM
3.02
.19
.775
2.60
3.00
.20
.40
2X M3x0.5 THRU ALL
2X M3x0.5
.25 DEEP
1.85
3.40
.775
.25
.90
.125
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
HOUSING SLIDER BACKING
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 132130
REV 1
SCALE 1:1
WEIGHT:
SHEET 12 OF 20


.375
Ø3.5MM THRU ALL
⌴ Ø5.50MM ↧3.00MM
.75
1.00
.063
.37
.25
.75
2X M3x0.5
.25 DEEP
.125
.380
.185
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
SHAFT END
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE
A
DWG. NO.
132130
REV
1
SCALE 2:1
WEIGHT:
SHEET 13 OF 20



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	132210	SYMMETRIC SEPARATOR	1
2	132220	SYMMETRIC SCREW 98861A060	1
3	132230	BALL BEARING 60355K851	2
4	132240	RETAINING RING 98410A111	4
5	132250	PLASTIC WASHER 95649A120	4
6	132260	KNOB 60765K12	1
7	132270	SYMMETRIC SCREW HOUSING	2
8	132280	BOLTS 9129A110	4

PROPRIETARY AND CONFIDENTIAL

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INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: NA

FINISH

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

DRAWN ANDRE F. 5/23/22

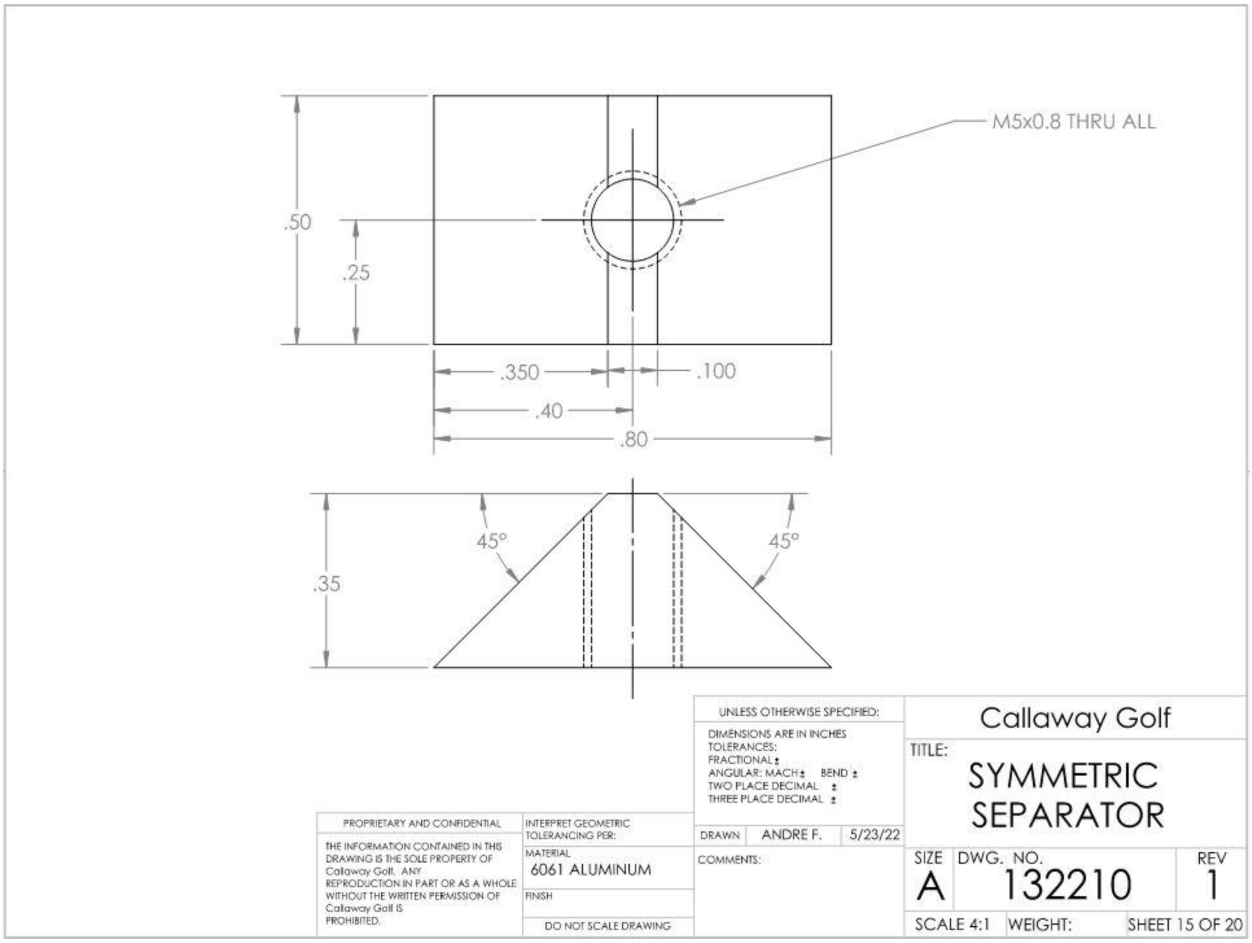
COMMENTS:

Callaway Golf

TITLE: SYMMETRIC SEPARATOR SUB ASSEMBLY

SIZE A DWG. NO. 132200 REV 1

SCALE 1:2 WEIGHT: SHEET 14 OF 20



M5x0.8 THRU ALL
.50
.25
.350
.100
.40
.80
45°
45°
.35
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
SYMMETRIC SEPARATOR
PROPRIETARY AND CONFIDENTIAL
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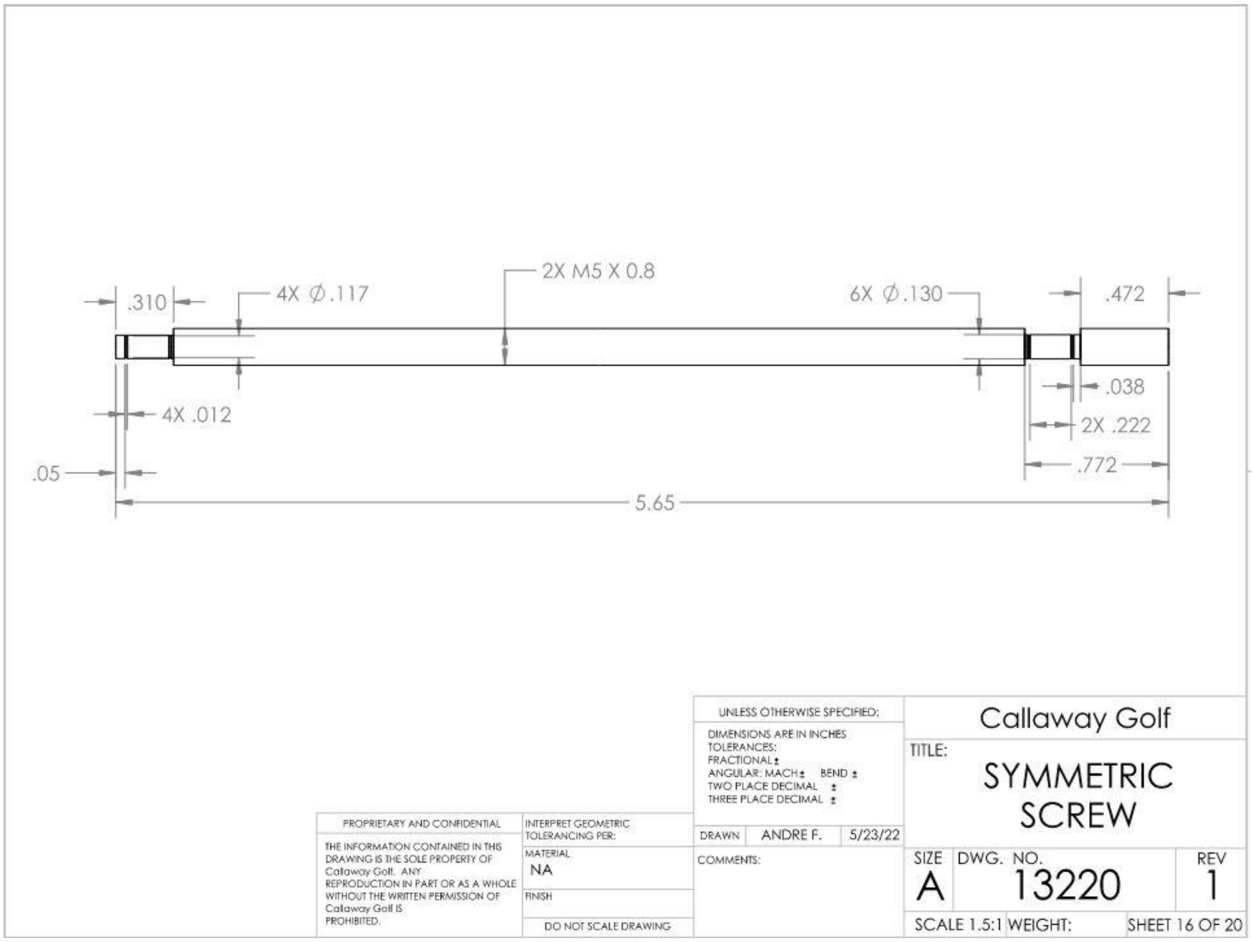
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 132210
REV 1
SCALE 4:1
WEIGHT:
SHEET 15 OF 20


.310
4X ∅.117
2X M5 X 0.8
6X ∅.130
.472
.038
2X .222
.772
4X .012
.05
5.65
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
SYMMETRIC SCREW
PROPRIETARY AND CONFIDENTIAL
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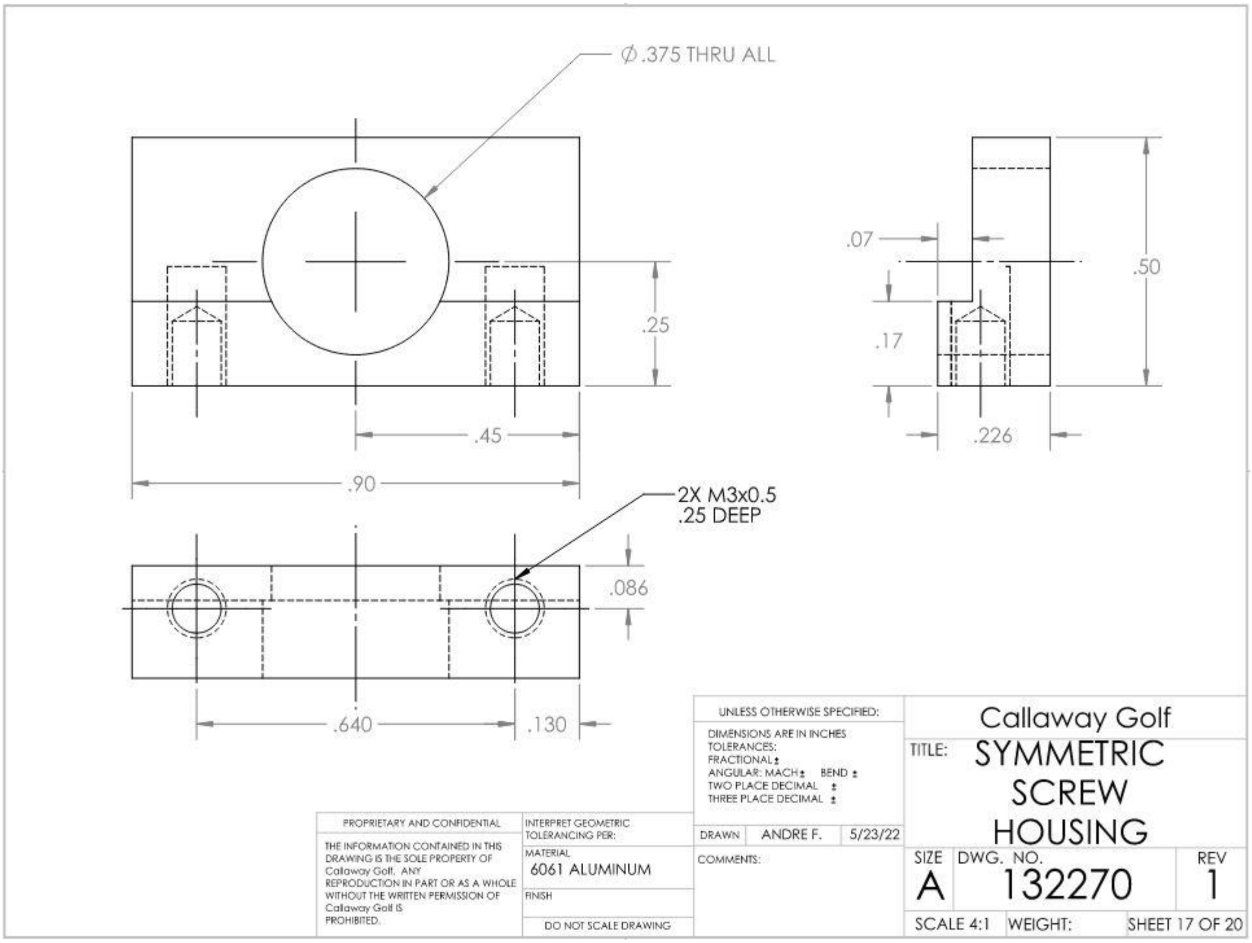
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 13220
REV 1
SCALE 1.5:1
WEIGHT:
SHEET 16 OF 20


Ø.375 THRU ALL
.07
.50
.25
.17
.45
.226
.90
2X M3x0.5
.25 DEEP
.086
.640
.130
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE: SYMMETRIC SCREW HOUSING
PROPRIETARY AND CONFIDENTIAL
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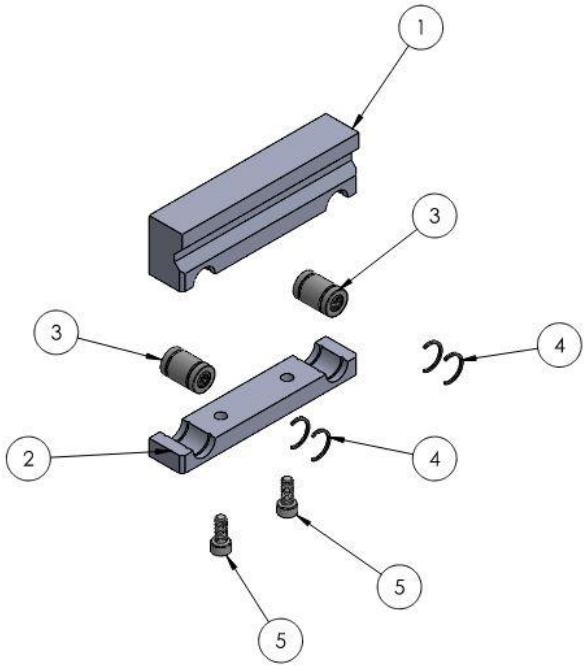
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 132270
REV 1
SCALE 4:1
WEIGHT:
SHEET 17 OF 20



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	132310	C-CLAMP TOP	1
2	132320	C-CLAMP BOTTOM	1
3	132330	LINEAR BALL BEARING 60595K11	2
4	132340	RETAINING RING 9968K22	4
5	132350	TOP TO BOTTOM BOLT 9129A125	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

Callaway Golf

TITLE: C-CLAMP SUBASSEMBLY

PROPRIETARY AND CONFIDENTIAL

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INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: NA

FINISH

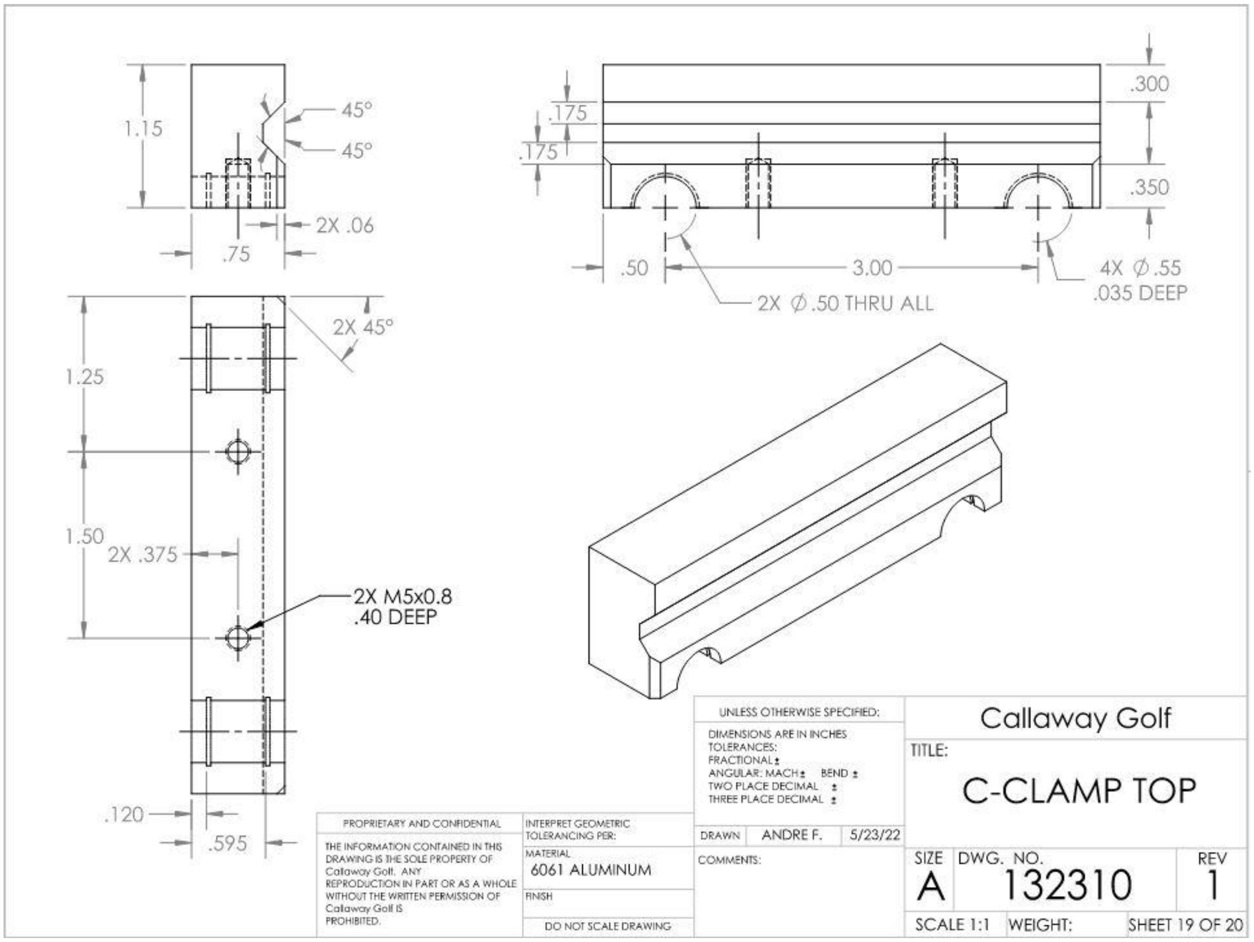
DO NOT SCALE DRAWING

DRAWN: ANDRE F. 5/23/22

COMMENTS:

SIZE: A | DWG. NO.: 132300 | REV: 1

SCALE 1:2 | WEIGHT: | SHEET 18 OF 20


1.15
45°
45°
2X .06
.75
.175
.175
.300
.350
.50
3.00
4X ∅ .55
.035 DEEP
2X ∅ .50 THRU ALL
2X 45°
1.25
1.50
2X .375
2X M5x0.8
.40 DEEP
.120
.595
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
C-CLAMP TOP
PROPRIETARY AND CONFIDENTIAL
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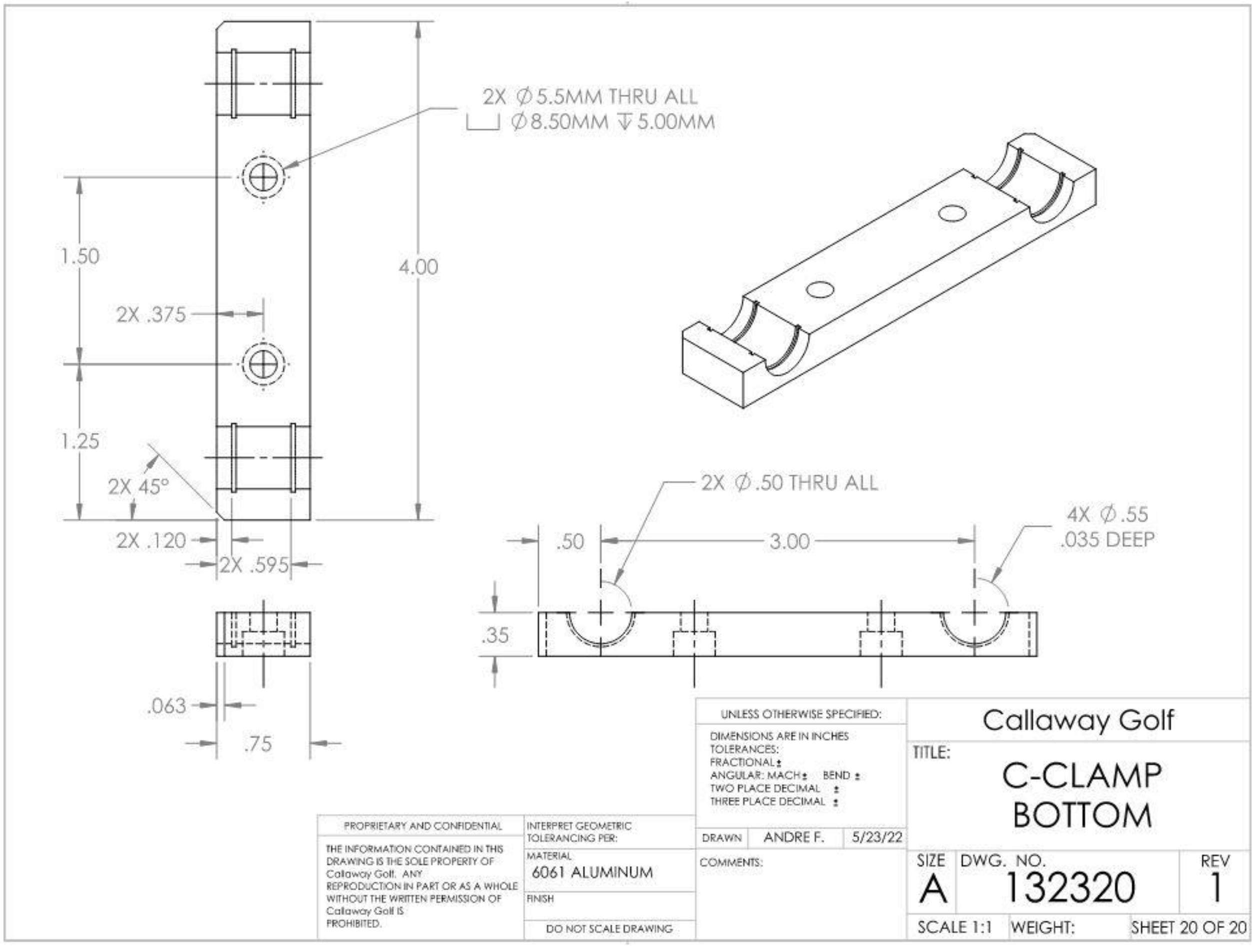
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 132310
REV 1
SCALE 1:1
WEIGHT:
SHEET 19 OF 20


2X ∅5.5MM THRU ALL
⌴ ∅8.50MM ↧ 5.00MM
1.50
4.00
2X .375
1.25
2X 45°
2X .120
2X .595
2X ∅.50 THRU ALL
4X ∅.55
.035 DEEP
.50
3.00
.35
.063
.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
Callaway Golf
TITLE:
C-CLAMP
BOTTOM
PROPRIETARY AND CONFIDENTIAL
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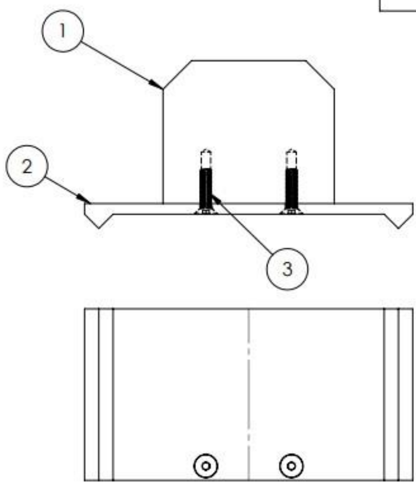
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 ALUMINUM
FINISH
DO NOT SCALE DRAWING
DRAWN ANDRE F. 5/23/22
COMMENTS:
SIZE A
DWG. NO. 132320
REV 1
SCALE 1:1
WEIGHT:
SHEET 20 OF 20

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Loft Face Zero Plate	141000	1
2	Slide Plate	142000	1
3	93395A310	143000	2



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

PROPRIETARY AND CONFIDENTIAL

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INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: NA
FINISH
DO NOT SCALE DRAWING

DRAWN: Blake S. 4/27/22
COMMENTS:

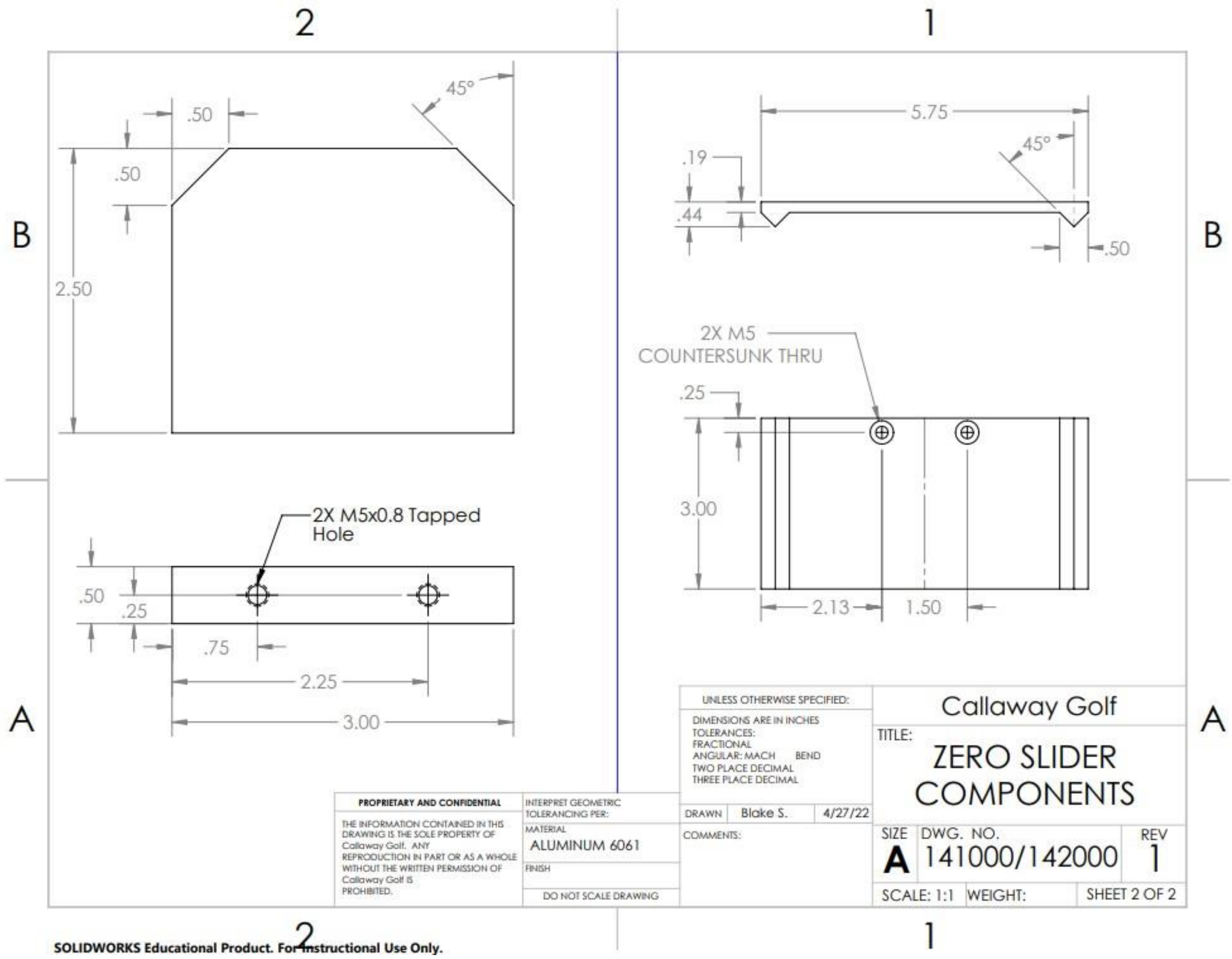
Callaway Golf

TITLE: Zero Slider Subassembly

SIZE: A | DWG. NO. 140000 | REV 1

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 2

SOLIDWORKS Educational Product. For Instructional Use Only.


2X M5x0.8 Tapped Hole
2X M5 COUNTERSUNK THRU
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
Callaway Golf
TITLE:
ZERO SLIDER COMPONENTS
PROPRIETARY AND CONFIDENTIAL
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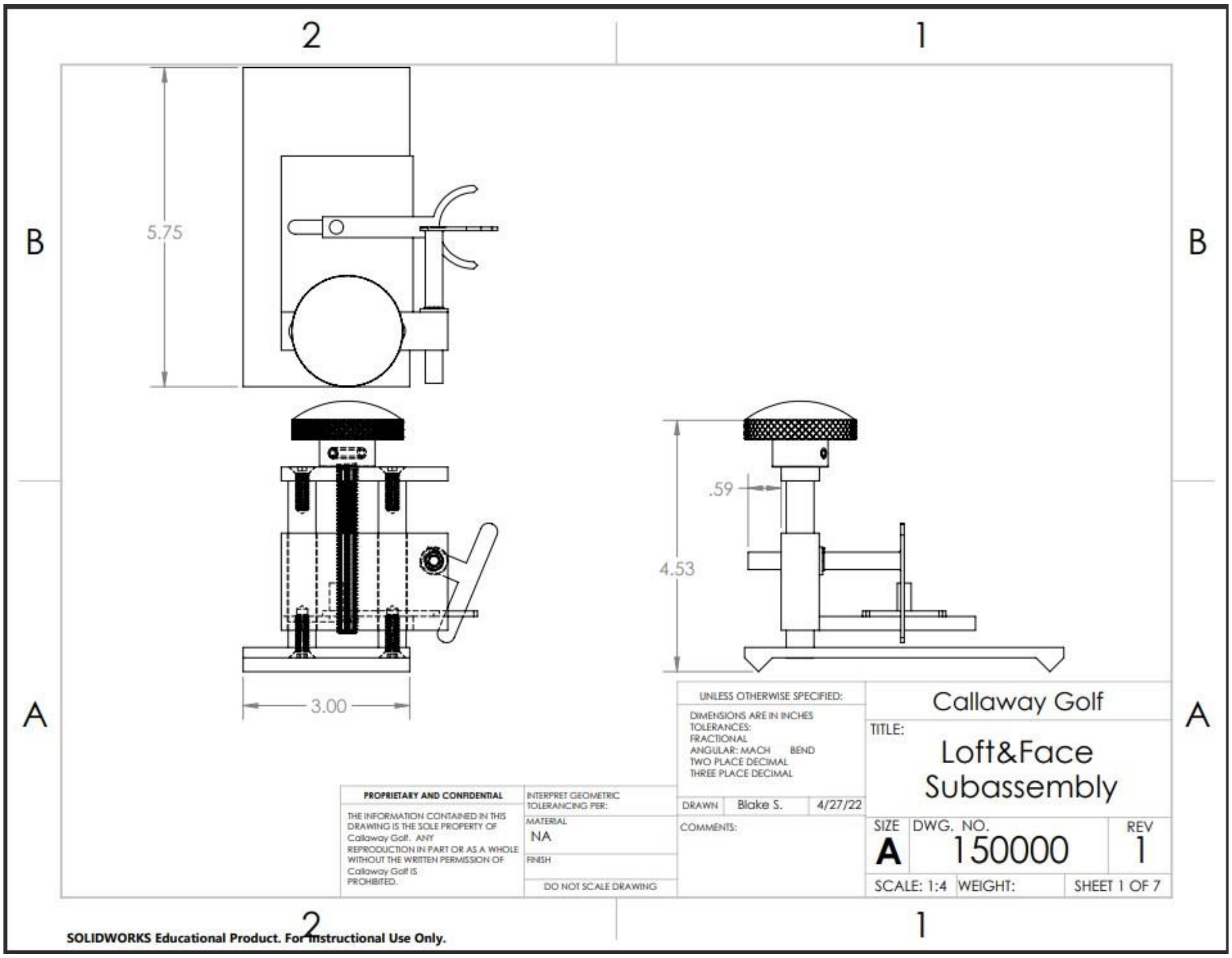
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM 6061
FINISH
DO NOT SCALE DRAWING
DRAWN Blake S. 4/27/22
COMMENTS:
SIZE A
DWG. NO. 141000/142000
REV 1
SCALE: 1:1 WEIGHT: SHEET 2 OF 2
SOLIDWORKS Educational Product. For Instructional Use Only.



2
1
B
A
5.75
.59
4.53
3.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
Callaway Golf
TITLE:
Loft&Face Subassembly
PROPRIETARY AND CONFIDENTIAL
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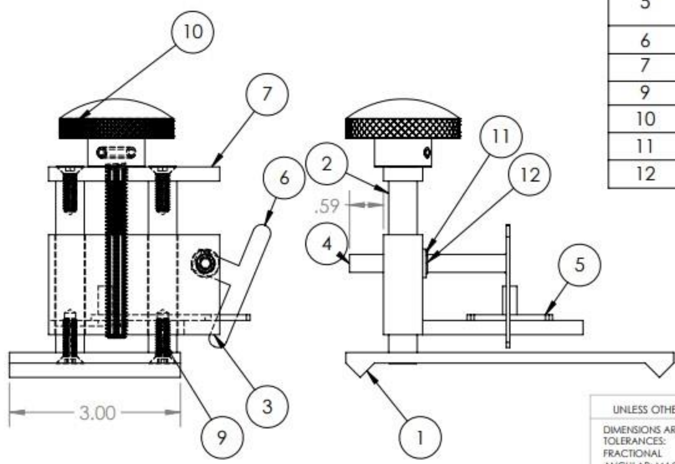
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING
DRAWN Blake S. 4/27/22
COMMENTS:
SIZE A
DWG. NO. 150000
REV 1
SCALE: 1:4
WEIGHT:
SHEET 1 OF 7
SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	15-01-000	Measuring Slide Plate	1
2	15-03-000	Loft_Face Vertical adjust tube	2
3	15-02-000	Loft_Face Base	1
4	15-18-000	Loft Shaft	1
5	15-22-000	Face Angle Arm	1
6	15-15-000	Iron Contact	1
7	15-06-000	Height Cap	1
9	15-04-000	93395A360	5
10	15-07-000	7762K103	2
11	15-21-000	90940A015	1
12	15-20-000	91590A115	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

PROPRIETARY AND CONFIDENTIAL
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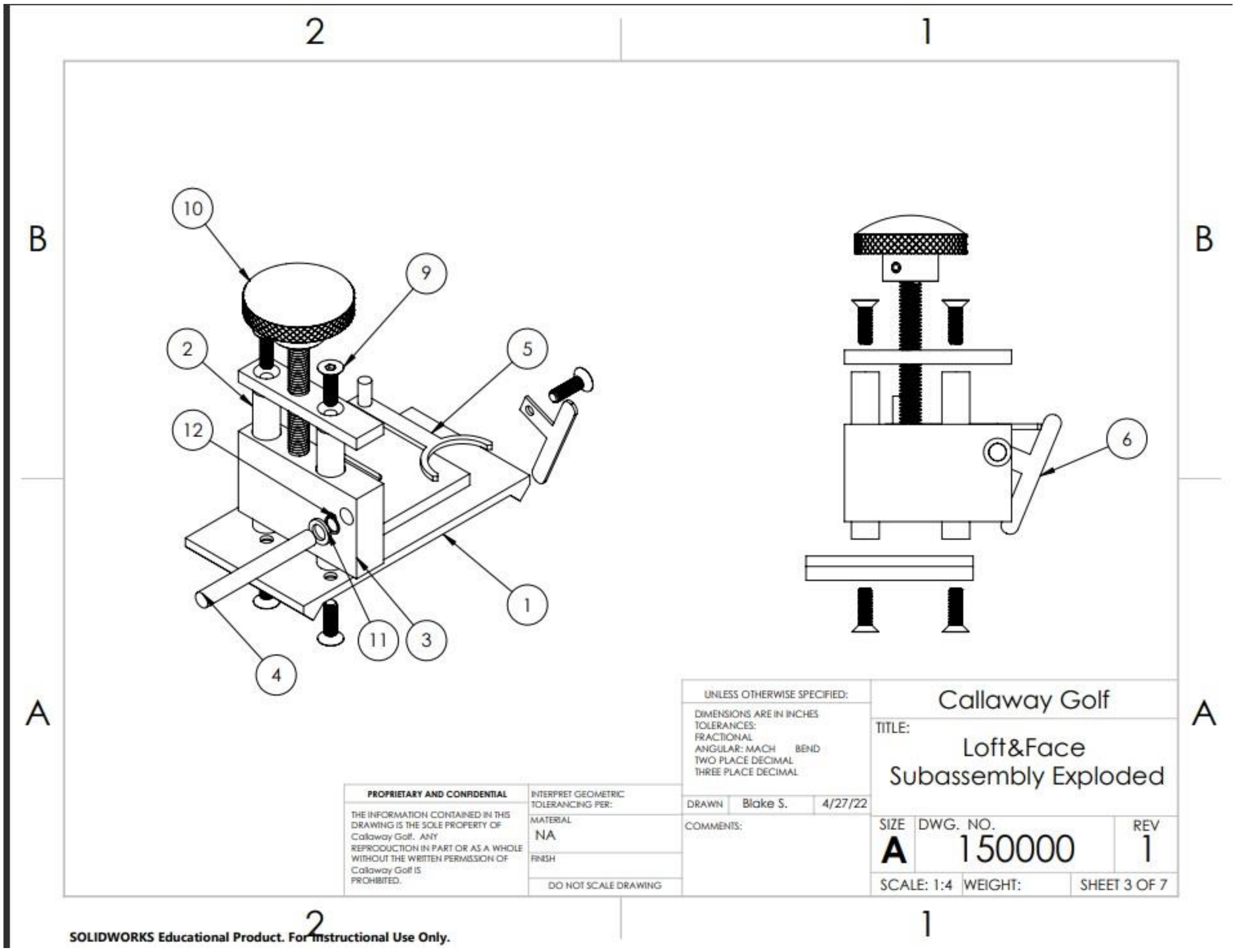
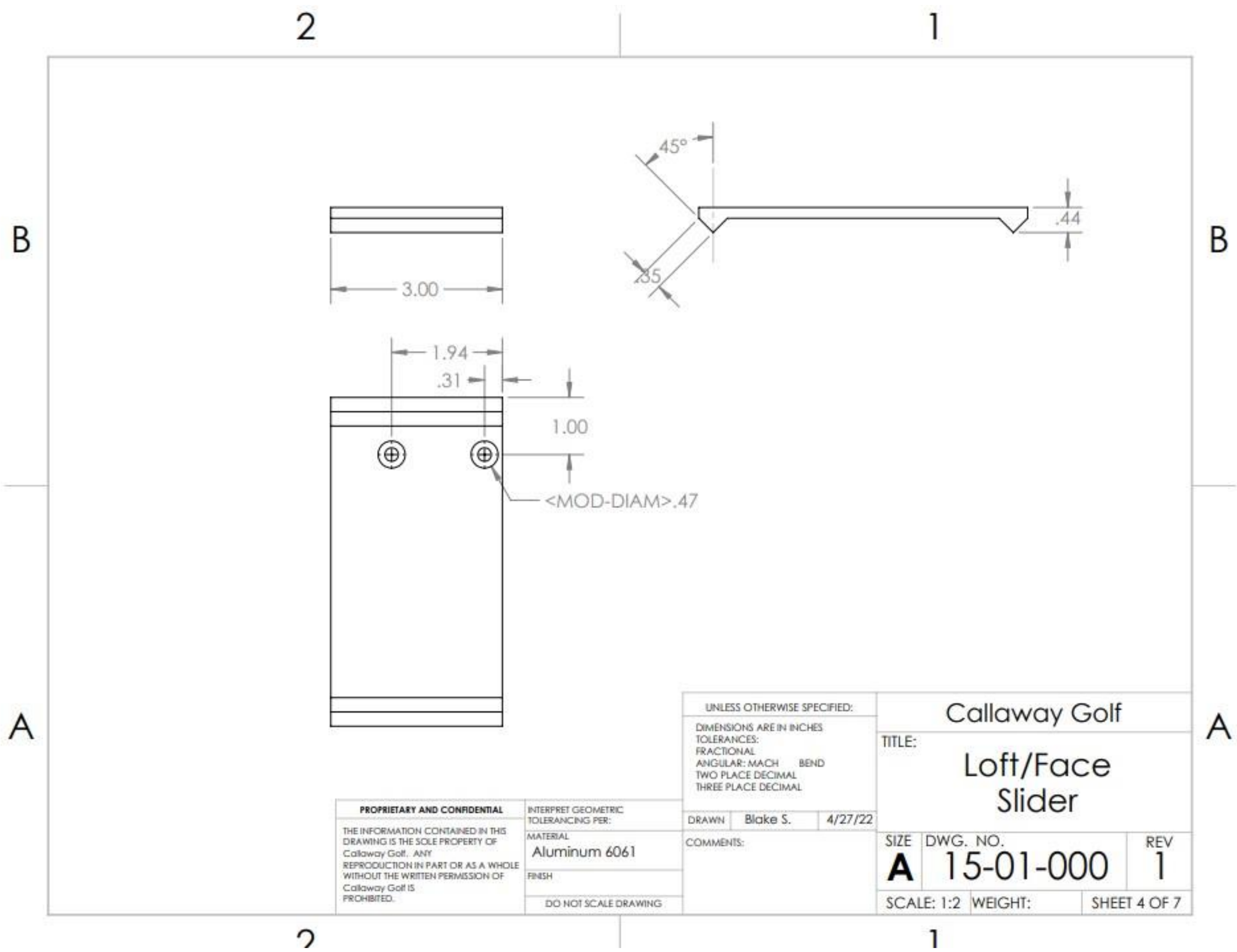
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL NA
FINISH
DO NOT SCALE DRAWING

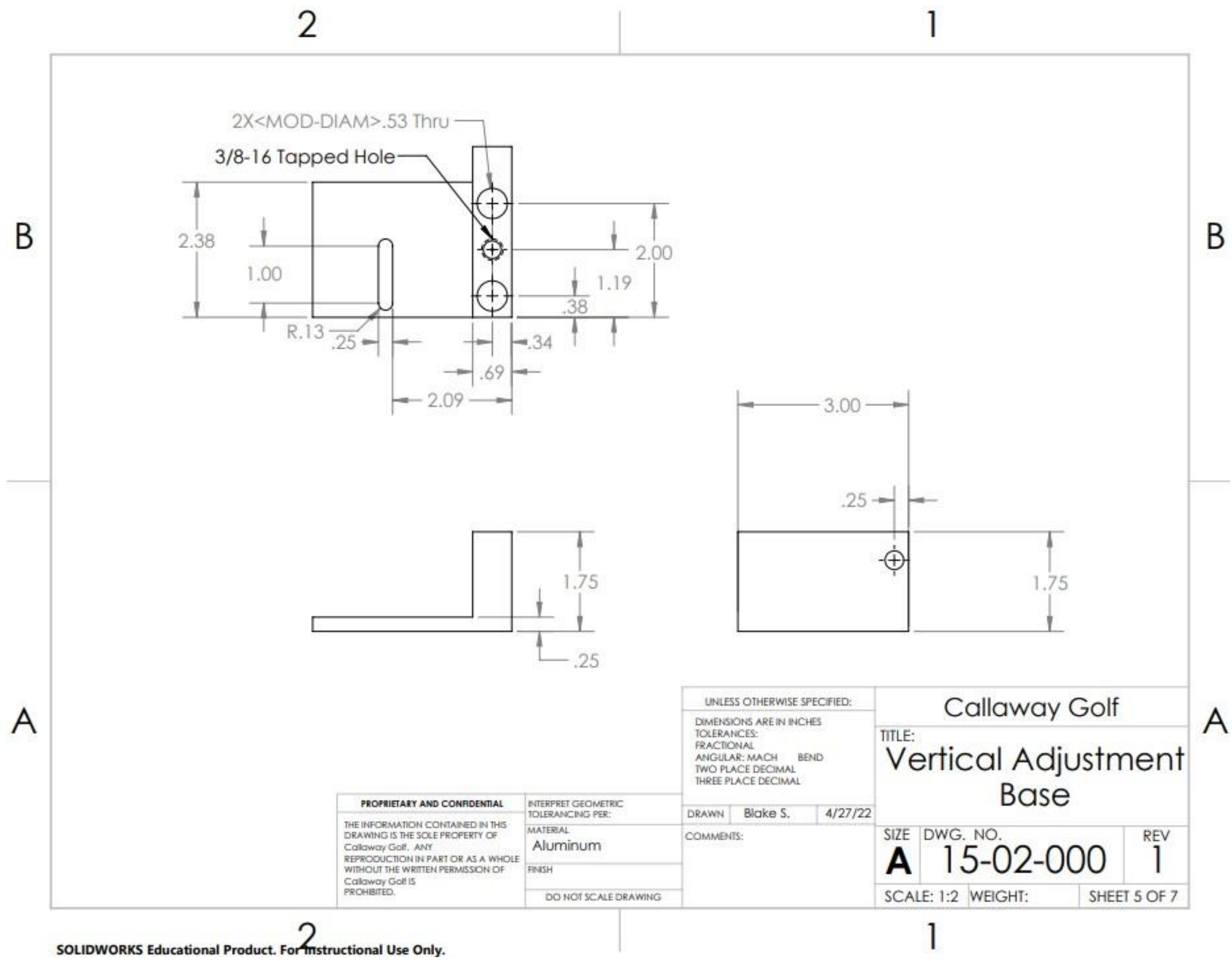
DRAWN Blake S. 4/27/22
COMMENTS:

Callaway Golf
TITLE: Loft&Face Subassembly
SIZE A DWG. NO. 150000 REV 1
SCALE: 1:4 WEIGHT: SHEET 2 OF 7


2
1
B
A
10
9
2
5
12
1
11
3
4
6
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
Callaway Golf
TITLE:
Loft&Face
Subassembly Exploded
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
NA
FINISH
DO NOT SCALE DRAWING
DRAWN Blake S. 4/27/22
COMMENTS:
SIZE A
DWG. NO. 150000
REV 1
SCALE: 1:4 WEIGHT:
SHEET 3 OF 7
SOLIDWORKS Educational Product. For Instructional Use Only.



2
1
B
A
45°
.44
.35
3.00
1.94
.31
1.00
<MOD-DIAM>.47
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum 6061
FINISH
DO NOT SCALE DRAWING
DRAWN
Blake S.
4/27/22
COMMENTS:
Callaway Golf
TITLE:
Loft/Face Slider
SIZE
A
DWG. NO.
15-01-000
REV
1
SCALE: 1:2
WEIGHT:
SHEET 4 OF 7


2X<MOD-DIAM>.53 Thru
3/8-16 Tapped Hole
2.38
1.00
2.00
1.19
.38
R.13
.25
.34
.69
2.09
3.00
.25
1.75
1.75
.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
Callaway Golf
TITLE:
Vertical Adjustment Base
PROPRIETARY AND CONFIDENTIAL
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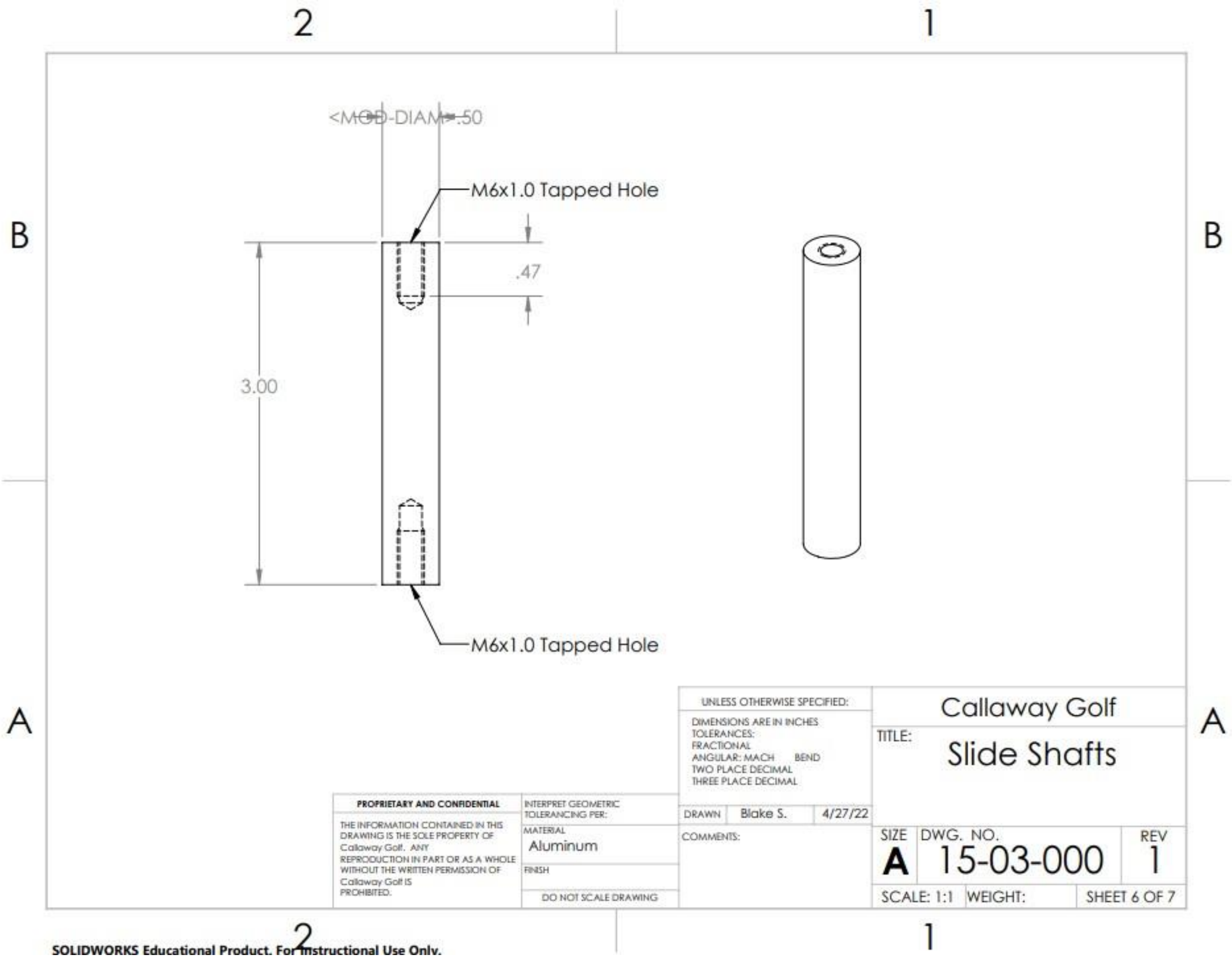
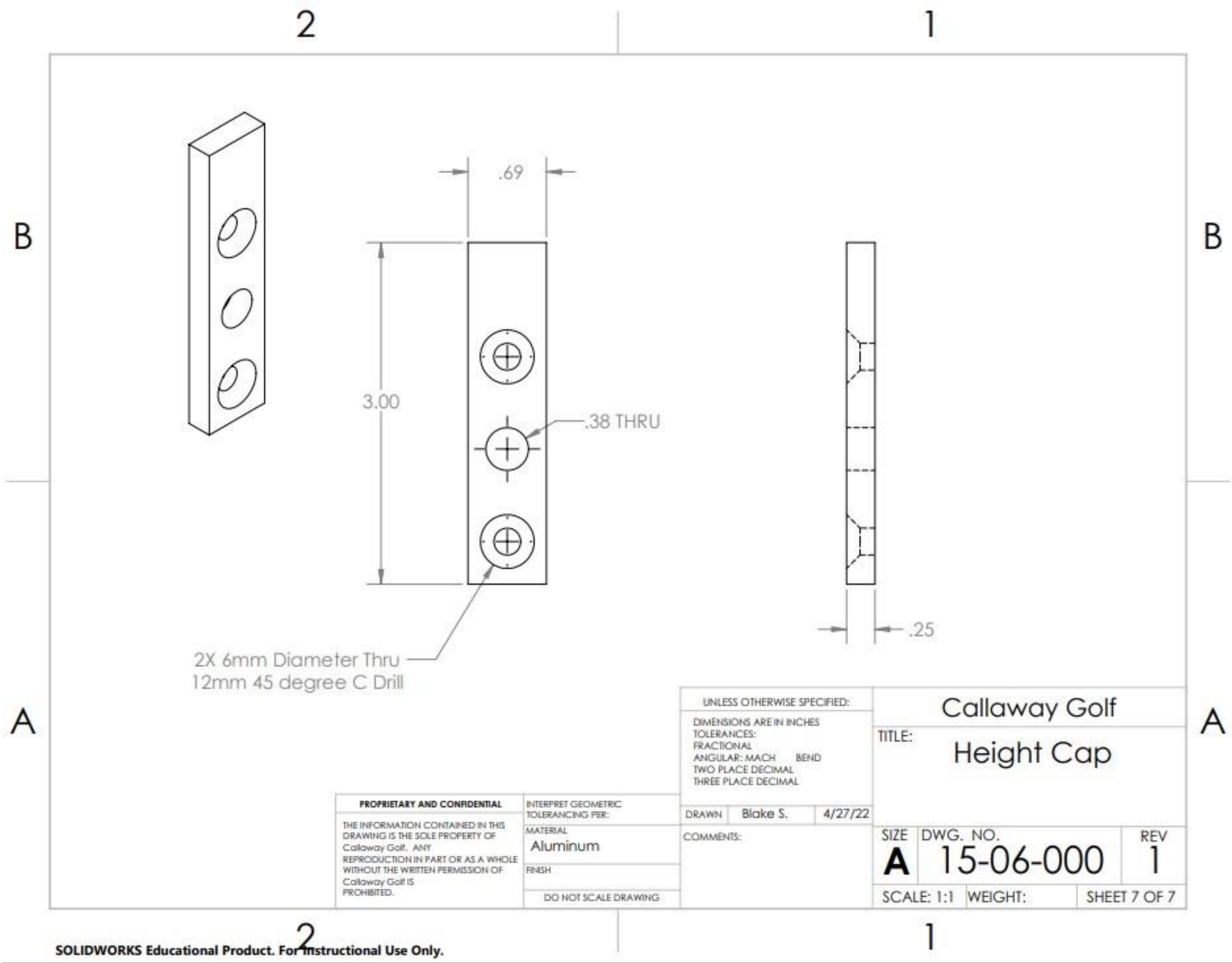
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN Blake S. 4/27/22
COMMENTS:
SIZE A
DWG. NO. 15-02-000
REV 1
SCALE: 1:2 WEIGHT: SHEET 5 OF 7
SOLIDWORKS Educational Product. For Instructional Use Only.



<MOD-DIAM>.50
M6x1.0 Tapped Hole
.47
3.00
M6x1.0 Tapped Hole
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
Callaway Golf
TITLE:
Slide Shafts
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN Blake S. 4/27/22
COMMENTS:
SIZE DWG. NO. REV
A 15-03-000 1
SCALE: 1:1 WEIGHT: SHEET 6 OF 7
SOLIDWORKS Educational Product. For Instructional Use Only.


2
1
B
.69
3.00
.38 THRU
.25
2X 6mm Diameter Thru
12mm 45 degree C Drill
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
Callaway Golf
TITLE:
Height Cap
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Callaway Golf. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Callaway Golf IS PROHIBITED.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN Blake S. 4/27/22
COMMENTS:
SIZE A
DWG. NO. 15-06-000
REV 1
SCALE: 1:1
WEIGHT:
SHEET 7 OF 7
SOLIDWORKS Educational Product. For Instructional Use Only.

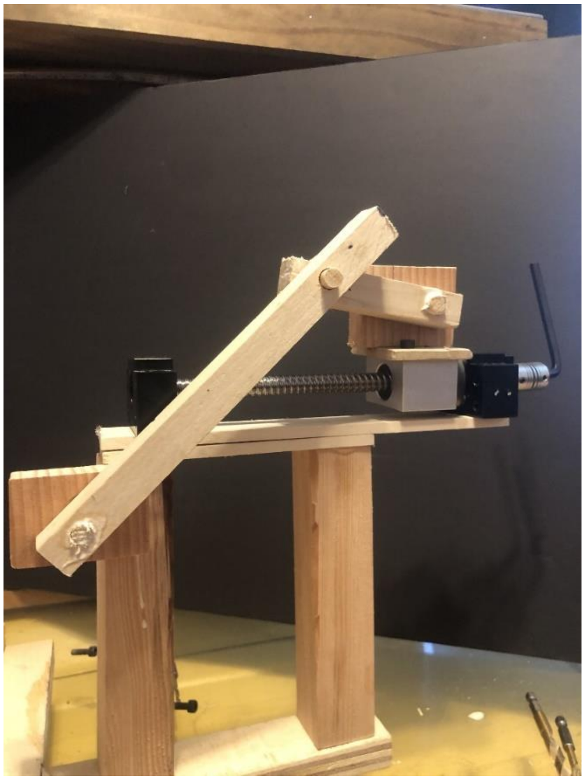
Appendix B: Project Budget

Callaway Golf Head Measuring Device														
Indented Bill of Material (iBOM)														
Assy Level	Part Number	Descriptive Part Name						Qty	Part Cost	Tax Cost	Total Cost	Source	More Info	Additional Notes
		Lvl0	Lvl1	Lvl2	Lvl3	Lvl4	Lvl5							
0	100000	Final Assembly						-				------		
1	110000		Base Assembly					-				------		
2	111000			Base Plate				1	$ 211.68	$ 19.05	$ 230.73	metalsdepot.com	P3114	
2	112000			Base Slider Assembly				-						
3	112100				Slider Plate			1	$ 119.12	$ 10.72	$ 129.84			
3	112200				Slider Stopper Plate			2	-	-	-	3D Print		
3	112300				Stopper Plate Bolts			4	$ 4.18	$ 0.38	$ 18.22	mcmaster.com	8286	
1	120000		Lie Assembly					-						
2	121000			Lie Base Assembly				-						
3	121100				Base Assembly			-						
4	121110					Lie Base		1	$ 94.51	$ 8.51	$ 103.02	metalsdepot.com	P378-6061	
4	121120					Lie Base to Base Plate Bolts		2						
4	121130					Base Stands		2	$ 16.16	$ 1.45	$ 17.61	metalsdepot.com	SQ334	One metal stock, cut in half
4	121140					Gear Rack Mounting Plate		1	$ 42.60	$ 3.83	$ 46.43	metalsdepot.com	F4123	
4	121150					Base Stand Bolts		4			$ -			
3	121200				Pivot Point Assembly			-			$ -			
4	121210					Mounting Arm		1	$ 8.00	$ 0.72	$ 8.72	metalsdepot.com	F418114	Both arms cut from the same metal stock.
4	121220					Pinion Arm		1						
4	121230					Gear Rack Base and Mounting Arm Joint		-						
5	121231						Encoder	1	$ 55.00	$ 4.95	$ 59.95			
5	121232						Shoulder Bolt	2						
5	121233						Washer	1						
5	121234						Nut	1						
5	121235						Deep Groove Bearing	1						
4	121240					Mounting and Pinion Arm Joint		-						
5	121241						Shoulder Bolt	1						
5	121242						Spacer	1						
5	121243						Washer	1						
5	121244						Nut	2						
5	121245						Thrust Bearing	1						
5	121246						Deep Groove Bearing	1						
2	122000			Shaft Clamping				-						
3	122100				Slider Housing			-						
4	122110					Mounting Bolts		12						
4	122120					Sliding Plates		1	$ 58.12	$ 5.23	$ 63.35	metalsdepot.com	F4185	Aluminum will be used for all aluminum components in the assembly.
4	122130					Sliding Rods		1	$ 23.47	$ 2.11	$ 25.58	mcmaster.com	2655N11	Four rods are cut from 1 three foot long piece of material
4	122140					Linear Bearings		4	$ 17.57	$ 1.58	$ 76.61	mcmaster.com	60595K11	
4	122150					External Retaining Rings		4	$ 0.36	$ 0.03	$ 1.57	mcmaster.com	9968K22	
4	122160					Bearing Housing		1	31.51	$ 2.84	$ 34.35	mcmaster.com	895K233	6x4x0.75" plate, can be used for all bearing components, also used for clamping plates

3	122200				C-Clamp Housing									
4	122210					Sliding Plates		2	NA	NA	NA	metalsdepot.com		Included in metal stock bought for the slider housing
4	122220					Sliding Rods		2	NA	NA	NA	metalsdepot.com		Included in the sliding rods bought for the slider housing
3	122300				C-Clamp									
4	122310					Linear Bearings		4	$ 17.57	$ 1.58	$ 76.61	mcmaster.com	60595K11	
4	122320					External Retaining Rings		4	$ 0.36	$ 0.03	$ 1.57	mcmaster.com	9968K22	
4	122330					Clamps		2	NA	NA	NA	metalsdepot.com		Stock purchased with the bearing housing metal
2	123000			Zero Slider Assembly				-						
3	123100				Slide Plate			1	NA	NA	NA	metalsdepot.com		Material from base assemply slide plate
3	123200				loft face zero plate			1	$ 33.15	$ 2.98	$ 36.13	metalsdepot.com	F4343	
3	123300				Connecting Bolts			2	$ 10.89	$ 0.98	$ 11.87	mcmaster.com	93395A360	PKQ. QTY. 25
1	130000		Loft & Face Angle Assembly					-						
2	131000			Base Assembly				-						
3	131100				Slider Plate Assembly			-						
4	131110					Loft/Face Slider		1	NA	NA	NA	metalsdepot.com		from gear rack mounting plate
4	131120					Vetrical Adjustment Base		1	NA	NA	NA	metalsdepot.com		same material as zero plate
4	131130					Slide shafts		2	$ 6.16	$ 0.55	$ 6.71	metalsdepot.com	R312	
4	131140					Slide Shaft to slider plate bolts		2	NA	NA	NA	mcmaster.com	93395A360	same bolts from zero slider assembly
3	131200				Height adjustment Assembly			2						
4	131210					Slide Shaft to height cap bolts		1	$ 13.12	$ 1.18	$ 14.30	mcmaster.com	92290A868	PKQ. QTY 5
4	131220					Height Cap		1	$ 22.44	$ 2.02	$ 24.46	mcmaster.com	7762K103	
4	131230					Height Knob		1	NA	NA	NA	metalsdepot.com		'material from slider plates
4	131240					Height Knob Set Screw		1				mcmaster.com		
4	131250					Height Bolt		-				mcmaster.com		
4	131260					Slide Handle		1				mcmaster.com		
4	131270					Slide Handle Bolts		2	NA	NA	NA	mcmaster.com		from small bolt package
2	132000			Loft Angle Measurement Assembly				-						
3	132100				Encoder			1	$ 55.00	$ 4.95	$ 59.95			
3	132200				Female Housing to Encoder			1						
3	132300				Housing to Loft Face Base Bolts			2						
3	132400				Loft Arm Assembly			-						
4	132410					Flat, Iron Contact		1	$ 24.00	$ 2.16	$ 26.16	metalsdepot.com	F5116112	
4	132420					Wood Contact Piece		1	NA	NA	NA	Callaway		
4	132430					Driver Contact Piece		1	NA	NA	NA	Callaway		
4	132440					Loft Encoder Shaft		1	$ 6.28	$ 0.57	$ 6.85	metalsdepot.com	R35616	
4	132450					Loft Arm to Cylinder Bolts		1	$ 12.00	$ 1.08	$ 13.08	mcmaster.com	93395A296	M5x.088 PKQ 25
4	132460					Snapring		1	$ 10.73	$ 0.97	$ 11.70	mcmaster.com	91590A115	PKG. QTY. 10
4	132470					Washer		2	$ 13.91	$ 1.25	$ 15.16	mcmaster.com	90940A015	PKG. QTY. 25
2	133000			Face Angle Measurement Assembly				-						
3	133100				Encoder			1	$ 55.00	$ 4.95	$ 59.95			
3	133200				Female Housing to Encoder			1						
3	133300				Housing to Loft Face Base Bolts			2						
3	133400				Loft Arm Assembly			-						
4	133410					Face Angle Arm		1	NA	NA	NA	metalsdepot.com		same material as loft arm
4	133420					Face Encoder Shaft		1	NA	NA	NA	metalsdepot.com		same material as Loft Encoder Shaft

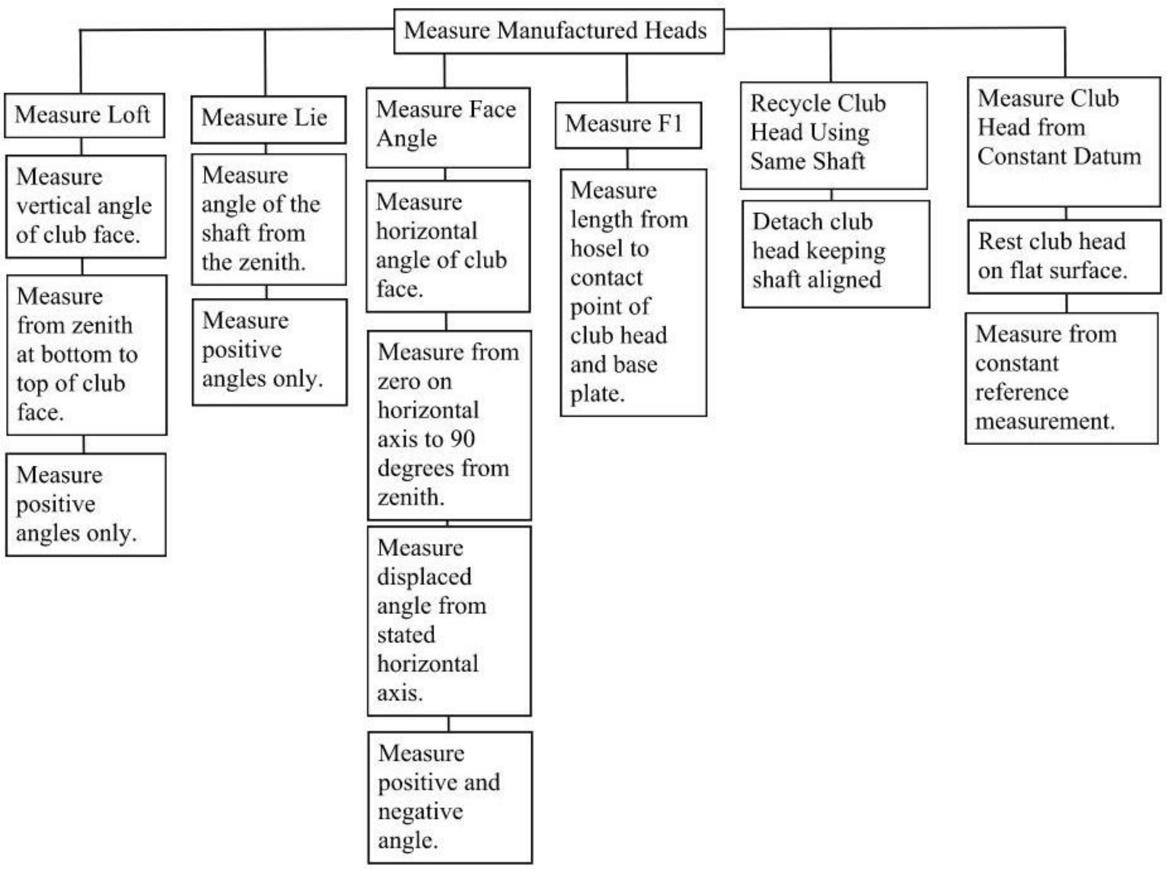
4	133430					Face Arm to Cylinder Bolts		1	NA	NA	NA	mcmaster.com		from loft package
4	133440					Snapring		1	NA	NA	NA	mcmaster.com		from loft package
4	133450					Washer		2	NA	NA	NA	mcmaster.com		from loft package
1	140000		Digital Assembly											
2	141000			Microcontroller Unit				1	$ 17.50	$ 1.58	$ 19.08	adafruit.com		
2	142000			Encoder Connecting Cables				3	$ 5.00	$ 0.45	$ 16.35	robotshop.com		
2	143000			I2C Digital Interface				1	$ 12.99	$ 1.17	$ 14.16	adafruit.com		
1	150000		Keel Point "Zeroing" Assembly					-						
2	151000			Keel Slider Plate				1	NA	NA	NA	metalsdepot.com		from slider plates material
1	160000		F1 Assembly											
2	161000			F1 base contact slider				1	$ 14.12	$ 1.27	$ 15.39	metalsdepot.com	F4183	
2	162000			F1 mandrel contact				1	NA	NA	NA	metalsdepot.com		from F1 contact slider
2	163000			F1 mounts				1	NA	NA	NA	metalsdepot.com		from F1 contact slider
2	164000			F1 bolts				5	NA	NA	NA	mcmaster.com		from small bolt package
1	170000		Laser Assembly					-						
2	171000			Leveling Laser				1	22.5	2.025	24.525	amazon.com		
2	172000			Sliding plate				-	NA	NA	NA	metalsdepot.com		from F1 contact slider
2	173000			Bolts				-	NA	NA	NA			
1	180000		Club Head Clamping Assembly					-						
	Total Parts							126		Total:	$ 1,269.98			

Appendix C: Structural Prototypes



Appendix D: Failure Modes and Analysis

FMEA W22 Callaway Golf Head Measuring Device									
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurrence	Current Detection Activities	Detection	RPN
Lie Meausrement	Strip Threads	Inoperable/ Not Precise	1	Improper Use/Wear over time	Proper Strength Bolt	5	Visual	2	10
Loft Measurement	Can deform or break over time	Inoperable	1	Improper Use/Wear over time	Proper strength Plate	6	Visual	2	12
Face Angle Measurement	Can deform or break over time	Inoperable	1	Improper Use/Wear over time	Proper strength Plate	7	Visual	2	14
F1 Length	Measurement tool is extended before setting lie	Inoperable	1	Improper Use	Clear Procedure	8	Visual	2	16
Datum Set	Wear on molds	Certain Clubs can not be measured	2	Wear over time	Strength of Mold	4	Visual	2	16
Electrical interface	Functioning Lifetime & Pinching wires Scratched Screen	Inoperable/ Difficulty Reading	2	Wear over time	Proper selection of components Wrapping the wires	1	Visual	2	4
Laser	Functioning Lifetime	Inoperable	2	Wear over time	Proper Slection of Laser	2	Visual	2	8
Encoders	Adjusted too fast Too much torque applied	Not as precise	3	Improper Use/ Dropping	Clear Procedure on how to operate	3	Visual	2	18



Appendix E: Design Hazards Checklist

PDR Design Hazard Checklist **W22 – Callaway Measurement Device**

Y	N	
×		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	×	2. Can any part of the design undergo high accelerations/decelerations?
	×	3. Will the system have any large moving masses or large forces?
	×	4. Will the system produce a projectile?
×		5. Would it be possible for the system to fall under gravity creating injury?
	×	6. Will a user be exposed to overhanging weights as part of the design?
×		7. Will the system have any sharp edges?
	×	8. Will any part of the electrical systems not be grounded?
	×	9. Will there be any large batteries or electrical voltage in the system above 40 V?
×		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	×	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	×	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	×	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	×	14. Can the system generate high levels of noise?
	×	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
	×	16. Is it possible for the system to be used in an unsafe manner?
	×	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:
(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
There is a battery and electrical components that have potential to induce electrical shocks	• Ground electrical components • Create a housing for electronics • Insulate any remaining wiring	4-3-22	
There are components that can pinch a user's fingers	• Put a sign on the device that warns of a pinching hazard • Implement a plate that blocks off the pivot point of the device	4-3-22	
There are sharp edges that may cut the user	• Put a rubber covering on any sharp external components	4-3-22	
The device can be dropped and crush a user's foot	• Reduce the weight of the device as much as possible during the materials selection process	3-28-22	

Appendix F: Design Verification Plan

DVP&R - Design Verification Plan (& Report)

Project: W22 Callaway Measurement Device | Sponsor: Callaway | Edit Date: 5/6/2022

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
1	Time to measure a club	Once the club is set in the fixture: 1. Start time. 2. Take measurements of all dimensions. 3. Stop time. 4. Repeat for a total of 5 trials. 5. Average times.	Time it takes to measure each club.	"+"8 minutes	Complete prototype and timer.	Complete prototype and timer.	Andre Fisher	5/29/2022			
2	Amount of measurement types	Analyze number of measurements needed to create to measure the desired aspects of the clubhead once the design is finalized in the CDR.	Sum the number of measurement types per process.	"+" 3	Finalized design.	Finalized design.	Roman Hays	5/16/2022			
3	Intuitiveness	1. Demonstrate how to measure a golf club to a person with zero knowledge. 2. Time the amount of time it takes for a person to gather said measurements. 3. Repeat for a total of 5 time measurements. 4. Average the results.	Measure the time it takes for a new person to operate the device.	10 minute demonstration	Complete prototype and timer.	Complete prototype and timer.	Blake Sousa	5/29/2022			

DVP&R - Design Verification Plan (& Report)

Project: W22 Callaway Measurement Device | Sponsor: Callaway | Edit Date: 5/6/2022

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
4	Set up time	1. Start a stopwatch. 2. Set up the golf club in the fixture, zeroing out all measurement devices. 3. Stop timer. 4. Repeat process for a total of 5 trials with different people every time. 5. Average measurements.	Measure the time it takes to set up a new golf club in the measuring instrument.	"+" 3 minutes	Lie angle subassembly, datum, club clamping mechanism, keel point measurement.	Lie angle subassembly, datum, club clamping mechanism, keel point measurement.	Grant Gabrielson	5/29/2022			
5	Number of components	Counting the datum and lie angle/clamping mechanism as one (because they are connected), analyze the number of additional subassemblies required to measure the golf club.	Count the number of subassemblies.	"+4" components	Finalized design.	Finalized design.	Andre Fisher	5/16/2022			
6	Batter/plug-in required?	Will the measurement device have any sort of electricity necessary, or is it all mechanical?	Note if there are electronics.	1 battery/plug in	Finalized design.	Finalized design.	Roman Hays	5/29/2022			
7	Angle tolerance of Measurement	Using golf clubs sent from Callaway with already measured elements of the clubhead, take measurements of the clubhead. Take 5 separate measurements and average the results.	Tolerance stacks of datums, backlash in gears, and tolerances of encoders.	Up to +/- 0.5 degrees	Encoder and microcontroller working.	Encoder and microcontroller working.	Grant Gabrielson	5/29/2022			

DVP&R - Design Verification Plan (& Report)

Project: W22 Callaway Measurement Device | Sponsor: Callaway | Edit Date: 5/6/2022

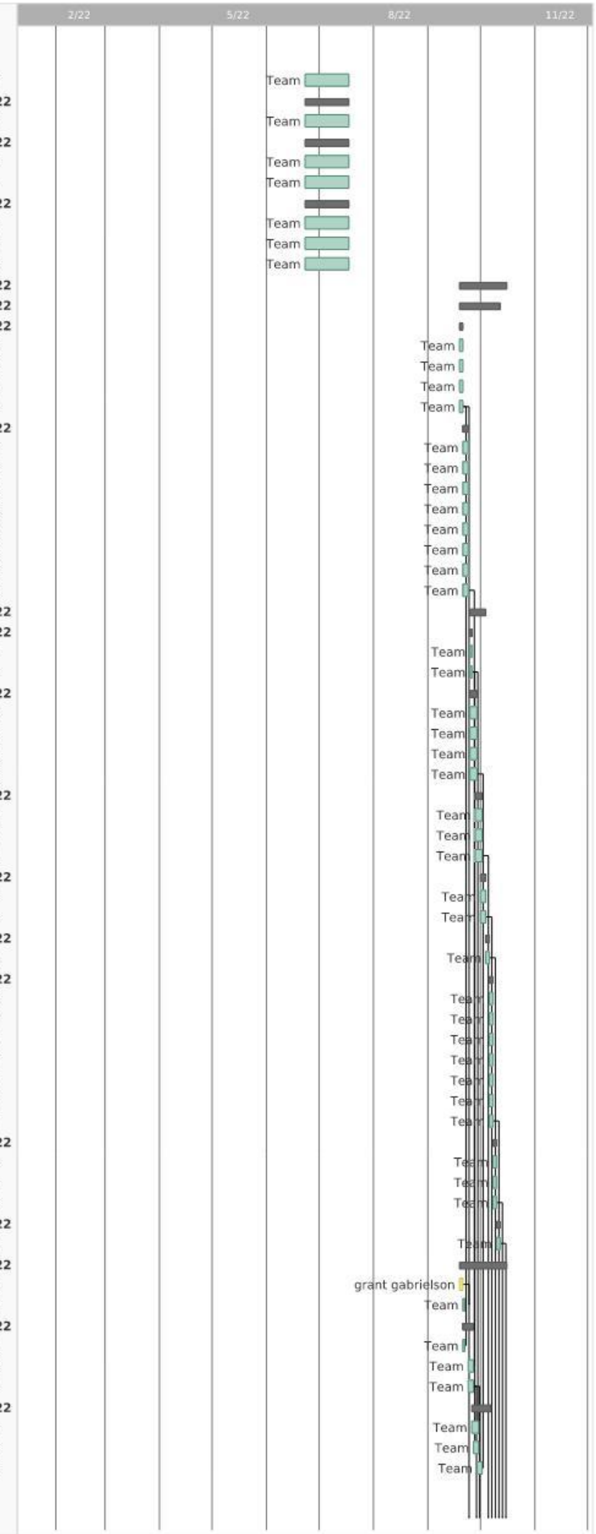
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
8	Total cost	Sum amount of money required to purchase the raw materials and manufacture.	Sum the costs.	$0 < Cost , $3000	Complete prototype.	Complete prototype.	Blake Sousa	5/29/2022			
9	Damage caused to club	During testing, take notes of scratching, scuffs, or residual damage caused from dropping the club.	Record damages to clubs.	none	Complete prototype.	Complete prototype.	Andre Fisher	5/29/2022			
10	Lifetime	Analyze the health of the machine after all other testing is complete, there should be zero wear or tear to the device at the end.	Record damages to measuring instrument.	5,000 measurements	Complete prototype.	Complete prototype.	Roman Hays	5/29/2022			

Appendix G: Gantt Chart

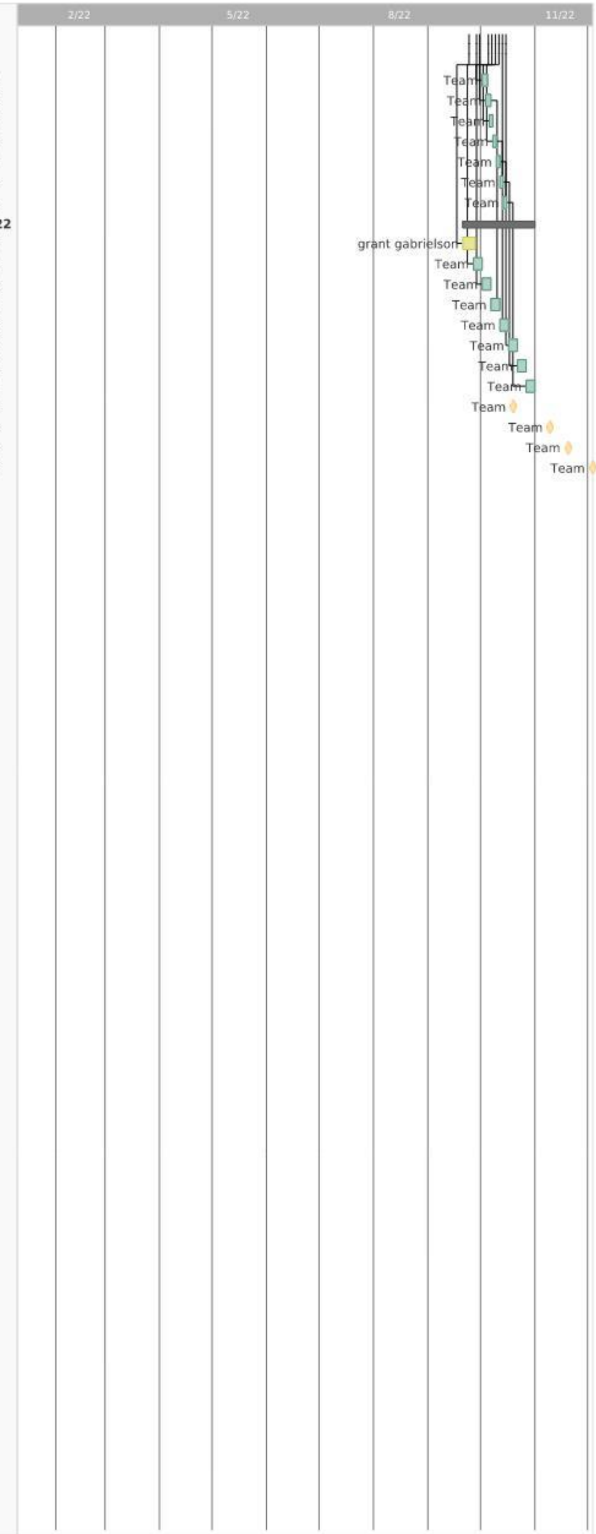
W22 Golf Club Measurement	start	end	
Scope of Work (SOW)	**01/11/22**	**02/03/22**	
Preliminary Design Review (PDR) Report	**02/10/22**	**03/11/22**	
Critical Design Review (CDR) Report	**03/15/22**	**06/08/22**	
FMEA	03/15	03/17	andre fisher
Peer Review: Manufacturing Plan Summary	03/28	04/01	andre fisher, blake sousa, grant gabrielson, roman hays
PDR updates	03/30	04/04	grant gabrielson
Interim Design Review Presentation	**04/01/22**	**04/06/22**	
CAD: function and operations	04/01	04/06	blake sousa, roman hays
Status of Major Subsystems	**04/03/22**	**04/06/22**	
Changes since PDR	04/05	04/06	grant gabrielson
Anticipated Manufacturing Processes	04/03	04/06	blake sousa
Analysis/Tests Completed	04/03	04/06	andre fisher
Remaining Analysis/Tests	04/03	04/06	andre fisher
Plans for structural Prototype	04/01	04/06	andre fisher
Current Concerns	04/01	04/06	blake sousa
Structural Prototype Plans	04/02	04/06	grant gabrielson
Logbook Self Assessment	04/15	04/15	andre fisher, blake sousa, grant gabrielson, roman hays
iBOM	**04/15/22**	**04/22/22**	
Datum/Base	04/15	04/22	blake sousa
Lie Angle	04/15	04/22	andre fisher, grant gabrielson
Loft Angle	04/15	04/22	andre fisher, grant gabrielson
Face Angle	04/15	04/22	andre fisher, grant gabrielson
F1 Length	04/15	04/22	roman hays
Manufacturing Plan	**04/23/22**	**04/27/22**	
Table of Subassembly Demands	04/23	04/27	roman hays
Manufacturing Order of Operations	04/23	04/27	blake sousa
Assembly Order of Operations	04/23	04/27	roman hays
Assembly Drawings, Part Layout	04/23	04/27	roman hays
Design Verification Plan	04/27	04/29	andre fisher
CDR Rough Draft	**04/27/22**	**05/05/22**	
Title Page	04/27	05/05	grant gabrielson
Abstract	04/27	05/05	grant gabrielson
Table of Contents	04/27	05/05	andre fisher
Introduction	04/27	05/05	blake sousa
System Design	04/27	05/05	andre fisher
Design Justification	04/27	05/05	blake sousa
Manufacturing Plan	04/27	05/05	grant gabrielson
Design Verification Plan	04/27	05/05	roman hays
Conclusions	04/27	05/05	roman hays
References	04/27	05/05	grant gabrielson
Appendices	**04/27/22**	**05/05/22**	
Drawing & Spec Package	04/27	05/05	Team
iBOM	04/27	05/05	Team
Analyses, Simulations etc.	04/27	05/05	Team
FMEA	04/27	05/05	Team
Design Hazard Checklist	04/27	05/05	Team
Design Verification Plan	04/27	05/05	Team
Gantt Chart	04/27	05/05	Team
Flowcharts/Pseudocode	04/27	05/05	Team
Wiring Diargrams	04/27	05/05	Team
Structural Prototype	05/10	05/10	Team
CDR Presentation	05/10	05/10	Team
CDR Final	05/10	05/10	Team
Drawing and Spec Package	05/10	05/10	Team
Install DesignSafe Software	05/10	05/10	andre fisher
Safety Review	**05/11/22**	**05/11/22**	
Hazard Checklist	05/11	05/11	andre fisher
Risk Assessment	05/11	05/11	blake sousa
FMEA	05/11	05/11	grant gabrielson
System Assembly Drawings	05/11	05/11	roman hays
Wiring Diagrams	05/11	05/11	grant gabrielson
Experimental Design Planning Form	05/19	05/19	andre fisher
SOLO: Logbook Self-Assess	05/21	05/23	andre fisher, blake sousa, grant gabrielson, roman hays
SOLO: What If Scenario	05/23	05/23	andre fisher, blake sousa, grant gabrielson, roman hays
Preliminary Experiment Test Procedure	05/24	05/25	blake sousa
SOLO: Write a Test Procedure	05/30	05/30	andre fisher, blake sousa, grant gabrielson, roman hays
SOLO: Team Feedback	06/01	06/01	andre fisher, blake sousa, grant gabrielson, roman hays

Task	Start	End	Assigned
CDR Report Updates	05/21	06/08	grant gabrielson
Manufacturing and Test Update	05/29	06/08	roman hays
Ethical Debate Outline	05/27	05/27	andre fisher
Final Design Review (FDR) Report	**04/29/22**	**12/02/22**	
Purchasing and Acquiring Materials	**04/29/22**	**07/17/22**	
Base Subassembly	**06/23/22**	**07/17/22**	
Pre-Machined Base Plate	06/23	07/17	Team
Pre-Machined Slider Plate	06/23	07/17	Team
Lie Subassembly	**04/29/22**	**07/17/22**	
Lie Base Subassembly	**06/23/22**	**07/17/22**	
Pre-Machined Lie Base	06/23	07/17	Team
Lie base to Lie Stand Bolts	06/23	07/17	Team
Bolting end plate bolts	06/23	07/17	Team
Raw Material for Lie Stands	06/23	07/17	Team
Lie Arm Subassembly	**06/23/22**	**07/17/22**	
Pre-Machined Small Arm	06/23	07/17	Team
Raw Materials to be machined	06/23	07/17	Team
Shafts	06/23	07/17	Team
Spacers	06/23	07/17	Team
Ball bearings	06/23	07/17	Team
Plastic Washers	06/23	07/17	Team
Shaft Collars	06/23	07/17	Team
Ball Screw	04/29	05/01	Team
Bolts	06/23	07/17	Team
Shaft Clamping Subassembly	**06/23/22**	**07/17/22**	
Mounting Subassembly	**06/23/22**	**07/17/22**	
Shafts	06/23	07/17	Team
Bolts	06/23	07/17	Team
Linear Bearing Subassembly	**06/23/22**	**07/17/22**	
Raw Materials for Manufacturing	06/23	07/17	Team
Pre-Manufactured Bearing Housing bott...	06/23	07/17	Team
Pre-Manufactured bearing top	06/23	07/17	Team
Linear Bearings	06/23	07/17	Team
Retaining Rings	06/23	07/17	Team
Bolts	06/23	07/17	Team
Clamp Housing Subassembly	**06/23/22**	**07/17/22**	
C-Clamp Housing Subassembly	**06/23/22**	**07/17/22**	
Raw materials to be manufactured	06/23	07/17	Team
shaft	06/23	07/17	Team
bolts	06/23	07/17	Team
Symmetrical Separator Subassembly	**06/23/22**	**07/17/22**	
Raw materials to be manufactured	06/23	07/17	Team
All-Thread for symmetric screw	06/23	07/17	Team
Ball Bearing	06/23	07/17	Team
Retaining Ring	06/23	07/17	Team
Plastic Washer	06/23	07/17	Team
Knob	06/23	07/17	Team
C-Clamp Assembly	**06/23/22**	**07/17/22**	
Raw materials to be manufactured	06/23	07/17	Team
linear ball bearings	06/23	07/17	Team
Retaining Rings	06/23	07/17	Team
Bolts	06/23	07/17	Team
Zero Slider Subassembly	**06/23/22**	**07/17/22**	
Pre-Manufactured Slide Plate	06/23	07/17	Team
Raw materials to be machined	06/23	07/17	Team
bolts	06/23	07/17	Team
Loft & Face angle Assembly	**06/23/22**	**07/17/22**	
Pre-Manufactured loft/face slider	06/23	07/17	Team
Raw Materials to be manufactured	06/23	07/17	Team
Shafts	06/23	07/17	Team
Knob	06/23	07/17	Team
Bolts	-	-	
Encoder	06/23	07/17	Team
Encoder Housing	06/23	07/17	Team
Snaprings	06/23	07/17	Team
Washer	06/23	07/17	Team
Digital Subassembly	**06/23/22**	**07/17/22**	
Microcontroller Unit	06/23	07/17	Team
Encoder Connecting Cables	06/23	07/17	Team

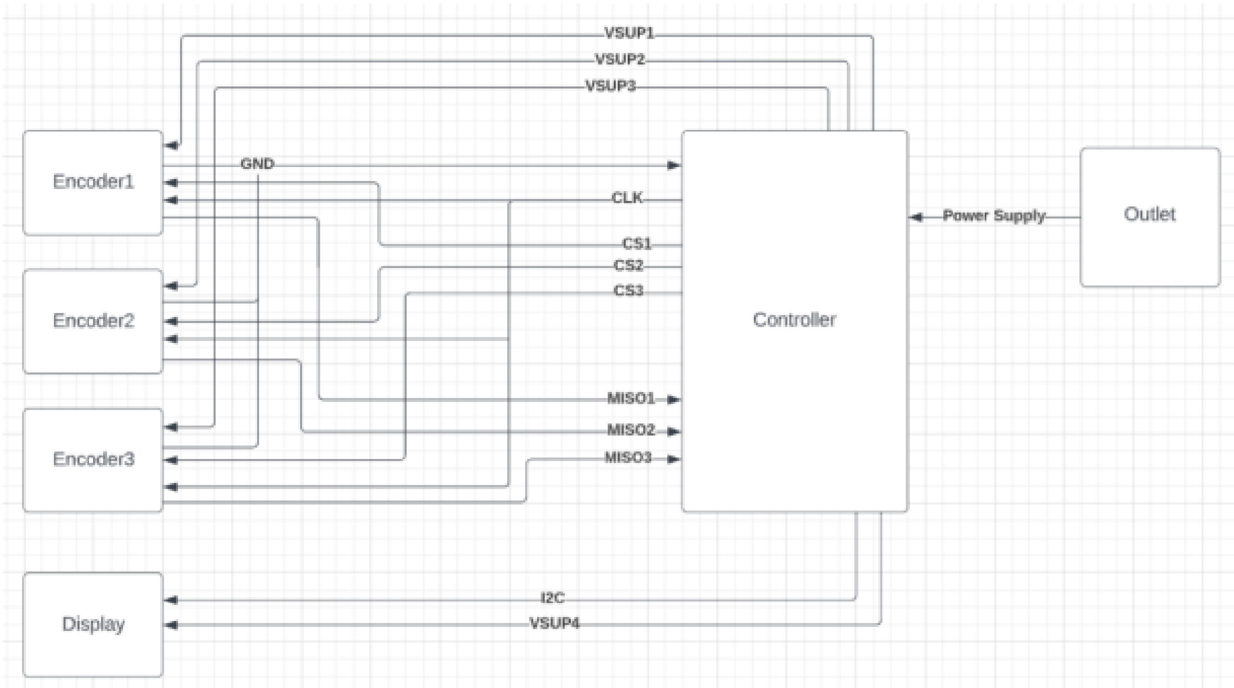
I2C Digital Interface	06/23	07/17
Keel Point "Zeroing" Subassembly	**06/23/22**	**07/17/22**
Raw Materials to be manufactured	06/23	07/17
F1 Subassembly	**06/23/22**	**07/17/22**
Raw materials to be manufactured	06/23	07/17
bolts	06/23	07/17
Laser Subassembly	**06/23/22**	**07/17/22**
Leveling Laser	06/23	07/17
Raw materials to be manufactured	06/23	07/17
Bolts	06/23	07/17
Manufacturing and Assembly	**09/19/22**	**10/15/22**
Manufacture the Following:	**09/19/22**	**10/11/22**
Lie Base Subassembly	**09/19/22**	**09/20/22**
Lie Stand 1	09/19	09/20
Lie Stand 2	09/19	09/20
Bolting End Plate 1	09/19	09/20
Bolting End Plate 2	09/19	09/20
Lie Arm Subassembly	**09/21/22**	**09/23/22**
Main Arm	09/21	09/23
Main Arm Shaft	09/21	09/23
Small to Main Shaft	09/21	09/23
Bearing Plate 1	09/21	09/23
Bearing Plate 2	09/21	09/23
Flange 1	09/21	09/23
Flange 2	09/21	09/23
Flange 3	09/21	09/23
Shaft Clamping Subassembly	**09/25/22**	**10/03/22**
Mounting Subassembly	**09/25/22**	**09/25/22**
2 Sliding shaft ends	09/25	09/25
2 sliding shafts	09/25	09/25
C-Clamp Housing Subassembly	**09/25/22**	**09/28/22**
Slider Base Plate	09/25	09/28
2 C-Clamp Shaft	09/25	09/28
Housing Slider Backing	09/25	09/28
2 Shaft Ends	09/25	09/28
Symmetrical Separator Subassembly	**09/28/22**	**10/01/22**
Symmetrical Separator	09/28	10/01
Symmetric Screw	09/28	10/01
2 Symmetric Screw Housing	09/28	10/01
C-Clamp Subassembly	**10/01/22**	**10/03/22**
C-Clamp Top	10/01	10/03
C-Clamp Bottom	10/01	10/03
Zero Slider Subassembly	**10/04/22**	**10/05/22**
Loft face zero plate	10/04	10/05
Loft and Face Angle Subassembly	**10/06/22**	**10/07/22**
Vertical Adjustment Base	10/06	10/07
2 slide shafts	10/06	10/07
Housing to encoder	10/06	10/07
Iron Contact	10/06	10/07
Loft encoder shaft	10/06	10/07
Face encoder arm	10/06	10/07
Face encoder Shaft	10/06	10/07
F1 Subassembly	**10/08/22**	**10/09/22**
Base Contact Slider	10/08	10/09
Mandrel Contact	10/08	10/09
Mounts	10/08	10/09
Laser Subassembly	**10/10/22**	**10/11/22**
Sliding Plate	10/10	10/11
Assemble the Following:	**09/19/22**	**10/15/22**
Digital Assembly	09/19	09/20
Base Subassembly	09/21	09/21
Lie Subassembly	**09/21/22**	**09/26/22**
Lie Base Subassembly	09/21	09/21
Lie Arm Subassembly	09/24	09/26
Ball Screw Part	09/24	09/26
Shaft Clamping Subassembly	**09/26/22**	**10/06/22**
Mounting Subassembly	09/26	09/29
Linear Bearing Assembly	09/27	09/29
C-Clamp Housing Subassembly	09/29	10/01



Symmetrical Separator Subassembly	10/02	10/04
C-Clamp Subassembly	10/04	10/06
Zero Slider Assembly	10/06	10/07
Loft and Face Angle Assembly	10/08	10/09
Keel Point Subassembly	10/10	10/11
F1 Subassembly	10/12	10/13
Laser Subassembly	10/14	10/15
Testing	**09/21/22**	**10/31/22**
Encoder and Digital Assembly	09/21	09/27
Ball Screw and Lie Assembly	09/27	10/01
Lie accuracy with encoder	10/02	10/06
Alignment Accuracy of Shaft Clamping	10/07	10/11
Loft and Face angle accuracy with encoder	10/12	10/16
Effectiveness of Keel Point Subassembly	10/17	10/21
F1 Accuracy	10/22	10/26
Effectiveness of Laser Subassembly	10/27	10/31
VP Sign-Off	10/18	10/18
DVPR Sign-Off	11/08	11/08
Expo	11/18	11/18
FDR Final	12/02	12/02



Appendix H: Wiring Diagrams



FDR APPENDICIES

A. Commented Code
B. Final Wiring Diagram
C. Final Project Budget
D. User Manual
E. DVP&R
F. Test Procedures
G. Prototype Drawing Package

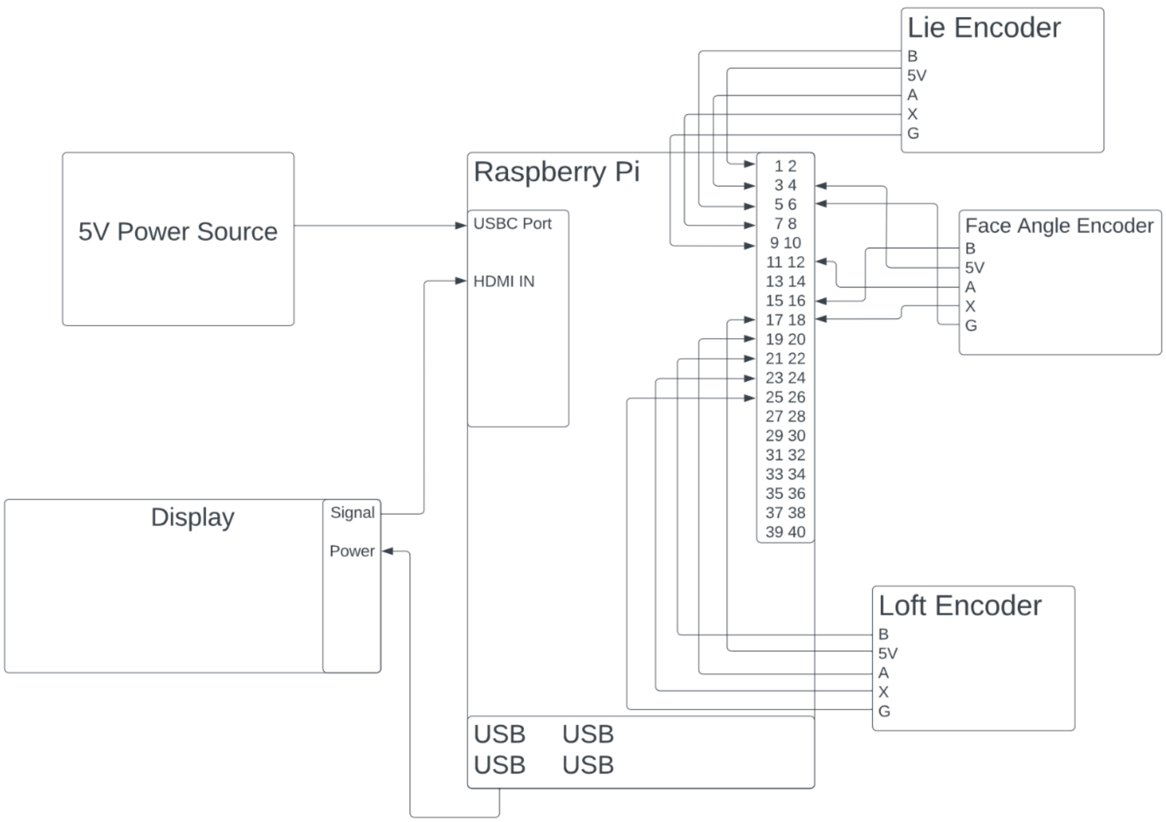
Appendix A: Commented Code

```
"""

@author: grantgabrielson
"""

#importing relevant libraries
import time
import numpy as np
from gpiozero import RotaryEncoder

#ppr value from encoder datasheet
ppr = 5120
#stop time, in seconds
tstop = 600
#sample time, in seconds
tsample = 0.0001
#display time, in seconds (for printing values)
tdisp = 0.5

#pin configurations
#Lie pins
pinA_li = "BOARD3"
pinB_li = "BOARD5"
#Face angle pins
pinA_fa = "BOARD19"
pinB_fa = "BOARD21"
#Loft pins
pinA_lo = "BOARD12"
pinB_lo = "BOARD16"

#create encoder objects for each encoder
#RotaryEncoder class is imported from gpiozero library
#native to Raspberry Pi
#lie
encoder_li = RotaryEncoder(pinA_li, pinB_li, max_steps = 0)
#loft
encoder_lo = RotaryEncoder(pinA_lo, pinB_lo, max_steps = 0)
#face angle
```

```
encoder_fa = RotaryEncoder(pinA_fa, pinB_fa, max_steps = 0)

#introduces variables for encoder readings
#lie
anglecurr_li = 0
#loft
anglecurr_lo = 0
#face angle
anglecurr_fa = 0

#introduces time variables
#previous time
tprev = 0
#current time
tcurr = 0
#start time
tstart = 0
#sets start time to current counter value
tstart = time.perf_counter()

#tells user is is now measuring
print('Starting now')

#runs this loop until the counter hits the stop time
while tcurr <= tstop:
    #waits for the selected sample time between readings
    time.sleep(tsample)

    #sets current time with respect to start time
    tcurr = time.perf_counter() - tstart
    #sets current lie angle (zeros at 89.5 deg)
    anglecurr_li = -360 / ppr * encoder_li.steps + 89.5
    #sets current loft angle (zeros at 0 deg)
    anglecurr_lo = abs(360 / ppr * encoder_lo.steps)
    #sets current face angle (zeros at 0 deg)
    anglecurr_fa = abs(360 / ppr * encoder_fa.steps)

    #checks if the current time has passed the next
    #display time but the previous time has not, to
    #make sure each reading is displayed at the
```

```
    #proper interval
    if (np.floor(tcurr/tdisp) - np.floor(tprev/tdisp)) == 1:
        #prints blank space between readings so UI only
        #shows most recent readings
        print("   ")
        print("   ")
        print("   ")
        print("   ")
        print("   ")
        print("   ")
        #prints all three angle values continuously
        print("+----------------+")
        print("|Lie Angle: " f'{anglecurr_li:.2f}'"|")
        print("|Loft Angle: " f'{anglecurr_lo:.2f}'"|")
        print("|Face Angle: " f'{anglecurr_fa:.2f}'"|")
        print("+----------------+")

    #sets the time for the start of next computation as
    #the end time for this computation
    tprev = tcurr

#tells the user it is done reading
print('done')
#closes all three encoder objects
encoder_li.close()
encoder_lo.close()
encoder_fa.close()
```

Appendix B: Final Wiring Diagram



Appendix C: Final Project Budget

Callaway Golf Head Measuring Device - Prototype												
Indented Bill of Material & Manufacturing												
Assy Level	Part Number	Descriptive Part Name				Qty	Part Cost	Tax Cost	Total Cost	Source	More Info	Additional Notes
		Lvl0	Lvl1	Lvl2	Lvl3							
0	1000	Prototype Main Assembly				-				------		
1	1100		Base SubAssembly			-				------		
2	1110			Base Plate		1	$ -	$ -	$ -		Cut and Bolt Together	Completed
3	1111				T-Slotted Framing	1	$ 37.58	$ 3.38	$ 40.96	mcmaster.com	47065T101	6 Feet
3	1112				Diagnol Brace	1	$ 27.63	$ 2.49	$ 30.12	mcmaster.com	47065T188	12 inches
3	1113				Silver Corner Bracket	10	$ 7.92	$ 0.71	$ 86.33	mcmaster.com	47065T236	
3	1114				Silver Corner Surface Bracket	2	$ 11.60	$ 1.04	$ 25.29	mcmaster.com	47065T267	
3	1115				End-Feed Nut 1/4"-20	1	$ 3.30	$ 0.30	$ 3.60	mcmaster.com	47065T142	Pack of 4
2	1120			Slider Plate		1	$ -	$ -	$ -	Mustang 60	3D Print	Completed
1	1200		Lie SubAssembly			1		$ -	$ -			
2	1210			Lie Base Subassembly		1		$ -	$ -			Completed
3	1211				Bolting End Plate 1	1	$ -	$ -	$ -	Mustang 60	3D Print	Completed
3	1211-2				Bolting End Plate 2	1	$ -	$ -	$ -	Mustang 60	3D Print	Completed
2	1220			Lie Arm SubAssembly		1	$ -	$ -	$ -			Completed
3	1221				Small Arm	1	$ -	$ -	$ -	Mustang 60	3D Print	Completed
3	1222				Main Arm Shaft	1	$ 9.00	$ 0.81	$ 9.81	mcmaster.com	6750K13	1 Foot - Cut to Size
3	1223				Small to Main Shaft	1	$ -	$ -	$ -	mcmaster.com	6750K13	Cut from Main Arm Shaft
3	1224				Small Arm Shaft	1	$ -	$ -	$ -	mcmaster.com	6750K13	Cut from Main Arm Shaft
3	1225				Bearing Plate 1	1	$ -	$ -	$ -	Mustang 60	3D Print - Tap M6 x 1.00 mm holes	Completed
3	1226				Bearing Plate 2	1	$ -	$ -	$ -	Mustang 60	3D Print - Tap M6 x 1.00 mm holes	Completed
3	1227				Lie Arm Ball Bearing	3	$ 13.09	$ 1.18	$ 42.80	mcmaster.com	2342K164	Purchased
3	1228				M6 x 1.00 x 20mm	1	$ 10.89	$ 0.98	$ 11.87	mcmaster.com	93395A360	Pack of 25 - Purchsed
3	1229				Lie Shaft Collar	8	$ 1.45	$ 0.13	$ 12.64	mcmaster.com	9414T6	Purchased
2	1230			Ball Screw Part		1	$ 36.99	$ 3.33	$ 40.32	amazon.com	SFU1204	Purchased
2	1240			Lie Bolts A		2	$ 2.85	$ 0.26	$ 6.21	mcmaster.com	97050A116	
2	1250			Lie Bolts B		4	$ 1.85	$ 0.17	$ 8.07	mcmaster.com	97050A119	
2	1260			Lie Bolts C		1	$ 12.48	$ 1.12	$ 13.60	mcmaster.com	91290A336	
2	1270			Lie Bolts D		1	$ 11.38	$ 1.02	$ 12.40	mcmaster.com	91290A334	
	1280			Ball Screw Rail		1	$ -	$ -	$ -	Mustang 60	3D Print	
1	1300		Shaft Clamping Subassembly			1		$ -	$ -			
2	1310			Main Arm		1	$ -	$ -	$ -	Mustang 60	3D Print	Completed
2	1320			Housing Slider		1	$ -	$ -	$ -	Mustang 60	3D Print - Tap M6 x 1.00 mm holes	Completed
2	1330			C Clamp		2	$ -	$ -	$ -	Mustang 60	3D Print - Tap M6 x 1.00 mm holes	Completed
2	1340			1/2 Aluminum Rod		1	$ -	$ -	$ -	mcmaster.com	6750K16	Cut to Size - Predrill - Tap for 6 x 1.00mm thread
2	1350			Connecting Bolts M6 x 1mm x 10mm		1	$ 14.57	$ 1.31	$ 15.88	mcmaster.com	91290A316	Purchased - Pack of 100
1	1400		Zero Slider Subassembly			0		$ -	$ -			Completed
2	1410			Slide Plate		1	$ -	$ -	$ -	Mustang 60	3D Print	Completed
1	1500		Loft & Face Angle Assembly			0	$ -	$ -	$ -			
2	1510			Loft/Face Slider		1	$ -	$ -	$ -	Mustang 60	3D Print - Tap 3/8-16 Hole	Completed
2	1520			Vetrical Adjustment Base		1	$ -	$ -	$ -	Mustang 60	3D Print	Completed
2	1530			Slide shafts		1	$ 20.75	$ 1.87	$ 22.62	mcmaster.com	6750K16	Cut to Size - Predrill - Tap for 6 x 1.00mm thread
2	1540			Slide Shaft to slider plate bolts		2	$ -	$ -	$ -	mcmaster.com	93395A360	same bolts from zero slider assembly
2	#REF!			Height Cap		1	$ -	$ -	$ -	Mustang 60	3D Print	Completed
2	#REF!			Height Knob		1	$ 22.10	$ 1.99	$ 24.09	mcmaster.com	7762K103	Purchased
2	#REF!			Flat, Iron Contact		1	$ 12.09	$ 1.09	$ 13.18	mcmaster.com	8975K421	Water Jet - Purchased but not Complete
2	#REF!			Wood Contact Piece		1	$ -	$ -	$ -	Callaway		
2	15-10-0			Driver Contact Piece		1	$ -	$ -	$ -	Callaway		
2	15-11-0			Loft Encoder Shaft		1	$ -	$ -	$ -	mcmaster.com	6750K13	1/4" Shaft From Lie Assembly
2	15-12-0			Loft Arm to Cylinder Bolts		1	$ 12.00	$ 1.08	$ 13.08	mcmaster.com	91502A143	M5x.088 PKQ 25
2	15-15-0			Face Angle Arm		1	$ -	$ -	$ -	mcmaster.com	8975K421	Water Jet - Purchased but not Complete
2	15-16-0			Face Encoder Shaft		0	$ -	$ -	$ -	mcmaster.com	6750K13	1/4" Shaft From Lie Assembly
1	1600		Digital SubAssembly					$ -	$ -			
2	1610			Encoders		3	$ 22.50	$ 2.03	$ 73.58	cuidevices.com	AMT10E2-0120-I2000-S	Purchased
2	1620			Encoder Mounting Bolts		1	$ 10.78	$ 0.97	$ 11.75	mcmaster.com	92832A178	Pack of 50
2	1630			Raspbeery PI Sub Assembly								
3	1631				Raspbeery Pi 4 Model B	1	$ 164.99	$ 14.85	$ 179.84	amazon.com	Broadcam BCM2711, quad-core Cortex A72	Purchased
3	1632				Rasphberry PI Housing	1	$ -	$ -	$ -	Mustang 60	3D Print	
3	1633				Rasphberry PI Cover	1	$ -	$ -	$ -	Mustang 60	3D Print	
2	1640			Display Sub Assembly								
3	1641				User Interface Housing	1	$ -	$ -	$ -	Mustang 60	3D Print	
3	1642				User Interface Cover	1	$ -	$ -	$ -	Mustang 60	3D Print	
3	1643				Digital Display	1	$ 56.99	$ 8.99	$ 65.98	amazon.com		Purchased
	Total Parts					81		**Total:**	**$ 764.02**			

Component Description	QTY	Vendor	Buyer	Cost	Reimbursed?
Springs for clamping system	1	mcmaster	Andre	$22.97	No
Mcmaster - Materials, Shafts, and Bollts	1	mcmaster	Blake	$445.92	Yes
Raspberry Pi	1	Amazon	Grant	$170.74	No
Final Digital Display	1	Amazon	Grant	$65.98	No
Laser + Bracket	1	Amazon	Grant	$62.13	No
Arduinos + I2C Disp.	1	Amazon	Grant	$58.45	No
Final encoder (1st)	1	Digikey	Grant	$32.94	No
Final encoder (2nd and 3rd)	1	Digikey	Grant	$58.89	No
3 Test encoders	3	P3 America	Grant	$189.75	No
Total				$1,107.77	

Appendix D: User Manual

	User Manual			
Callaway GOLF	**Department**	**Documentation**	**Revision**	**Date**
			00	11/3/22

Clubometer – Loft, Lie, and Face Angle Measurement for Golf Clubs

Section A	**PURPOSE AND SCOPE**

The purpose of this document is to detail how to measure the loft, lie, and face angle as they apply to irons, woods, and drivers' heads.

This applies to the Incoming Quality Control process.

Section B	**SAFETY**

1. Be cautious of moving parts and pinching points.
2. Be cautious with electrical components and any liquids.
3. Ensure object is securely placed on a stable surface to avoid falling.

Section C	**EQUIPMENT SET-UP**

1. Place device on flat table with enough room to operate.
2. Plug in the device.
3. Plug in the laser.
4. Inspect device for any wear that may affect measurement.
5. Inspect wires for any misconnections.

Section D	**INSTRUCTIONS**

1.0 Mark Face Center

1.1. Use centering cup or face template to mark face center (Fig. 1).

1.2. Verify the correct mandrel is used for face cups and club heads (Fig. 2).

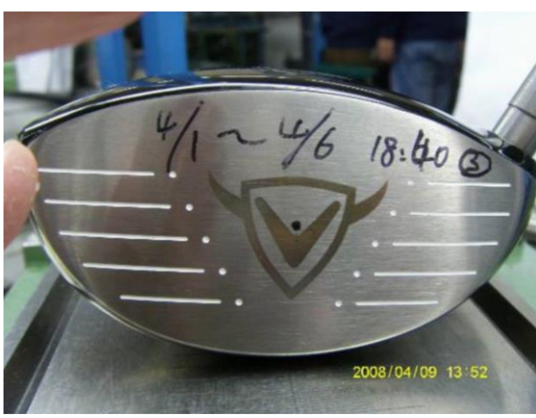


Fig. 1

Fig. 2

.0 Loft/Face Angle Measurement

2.1. Measure and mark the keel point for the face cup or club head on the Clubometer base plate.

2.1.1. Obtain keel point reading from the inspection plan or product specification.

2.1.2. Measure keel point distance from the Clubometer base plate center line using a digital caliper.

NOTE: The center line is the longest line etched into the Clubometer base plate.

2.2 Zero encoders for measurement.

2.2.1. Use the zero plate to adjust the loft and face angle measurement arms to their zero position (Fig. 3).

2.2.2. Use the crank to adjust the lie angle to its upright (90 degree) position (Fig. 4).

2.2.3. Run the measurement script to set this as the zero point for the encoders.

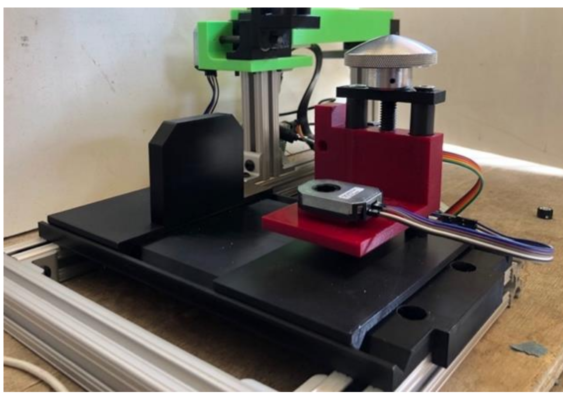


Fig. 3

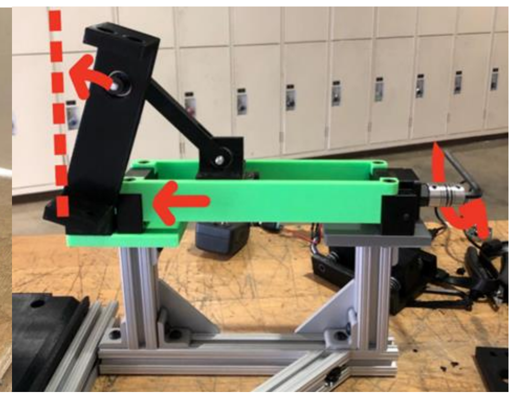


Fig. 4

2.3. Set the Design Lie Angle of the face cup or club head being measured.

2.3.1. Obtain the Design Lie Angle from the inspection plan or product specification.

2.3.2. Turn the crank on the Lie Angle Measurement scale until the digital lie angle reading matches the Design Lie Angle (Fig. 3).

2.4. Place the club or club head with mandrel into the Clubometer by separating the clamp and adjust the club head so that its sole is just touching the Clubometer base plate.

2.5. Adjust the position of the club head so that the sole lines up with the keel point marked on the Clubometer base plate (Fig. 5).

2.6. Release the sides of the clamp so that it secures the club in place (Fig. 6).

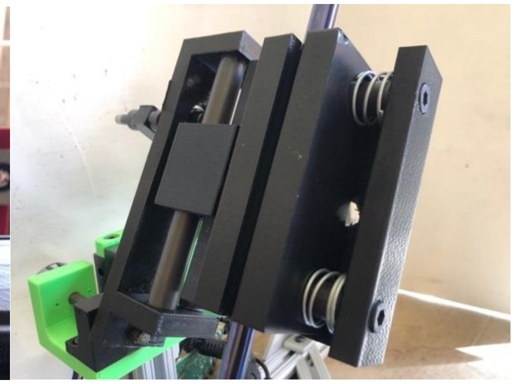


Fig. 5 Fig. 6

2.7. Center the face of the club head.

2.7.1. Place crosshair laser attachment on base plate to get the center mark of Clubometer base plate.

2.7.2. Adjust the Clubometer base plate (forward or backward) so that center of the face cup or club head aligns to the center line on the Clubometer base plate.

2.7. Verify the keel point on the face cup or club head has not moved from the keel point marked on the Clubometer base plate.

2.8. Measure Face/Loft Angle.

2.8.1. Place Face/Loft Angle Gauge on the Clubometer base plate (Fig. 7).

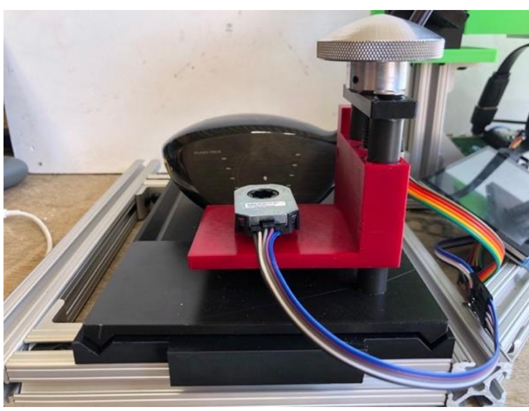



Fig. 7 Fig. 8

2.8.2. Adjust the Face/Loft Angle Gauge height using the knob to line up the Face/Loft Angle Gauge with the marked center on the face cup or club head (Fig. 7).

2.8.3. Slide the Face/Loft Angle Gauge slowly up to the face cup or club head until the two points on the Face Angle Gauge contact the face evenly (Fig. 8).

2.8.4. Record the Face Angle as displayed on digital readout.

2.8.5. Verify Face Angle reading with the Face Angle in the inspection plan or product specification.

2.8.6. If measuring a Driver or Wood connect the proper loft angle measurement attachment.

2.8.7 Lower Loft angle arm and slide the Face/Loft Angle Gauge slowly up to the face cup or club head until the piece hits the club face.

2.8.8. Record the Loft Angle as displayed on digital readout.

2.8.9. Verify Loft Angle reading with the Loft Angle in the inspection plan or product specification.

2.8.10. Remove Face/Loft Slider Attachment.

3.0 Lie Angle Measurement

3.1. Ensure encoders are properly zeroed (refer to Section 2.2) and club is properly clamped (Section 2.4-2.6).

3.2. Place Laser Slider onto Clubometer Baseplate (Fig. 9).

3.3. Measure Lie Angle.

3.3.1 With the zeroing laser directed at the club face, decrease the lie angle by turning the hex key until the zeroing laser is horizontal with the grooves of the club face (Fig. 10).

3.3.2. Record the Lie Angle as displayed on digital readout.

3.3.3. Verify Lie Angle reading with the Loft Angle in the inspection plan or product specification.

Fig. 9

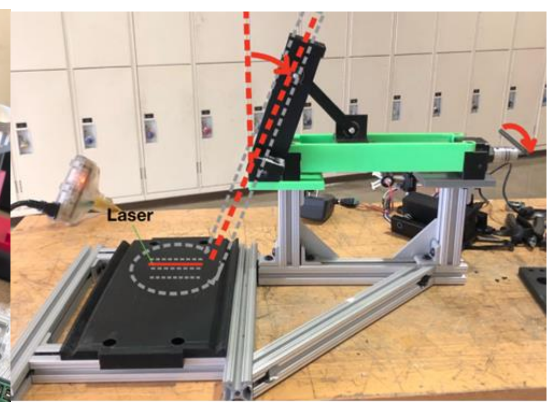


Fig. 10

Appendix E: DVP&R

DVP&R - Design Verification Plan (& Report)

Project:	W22 Golf Measuring Device Assembly		Sponsor:	Callaway Golf					Edit Date:		10/17/2022
TEST PLAN									TEST RESULTS		
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
1	Time to measure a club	Analyze the amount of time required to measure an club head once the club head is set up in position.	Time it takes to measure each club.	"+"8 minutes	Prototype and timer.	Functioning prototype and timer.	Roman Hays, Grant Gabrielson	5/29/2022	11/13/2022	Max: 3:15 Min: 1:24	Were able to test irons only. Keel point information required for woods and drivers, but have not been provided. Measurements for woods and drivers expected to take longer, but will be less than 8 minutes.
2	Amount of measurement types	Analyze number of measurements needed to measure the desired aspects of the clubhead once the prototype design is assembled.	Sum the number of measurement types per process.	"+" 3	Finalized design.	Finalized design.	Andre Fisher	5/16/2022	10/2/2022	3	Three measurements are the lie, loft, and face angle. Extra measurements would have been the F1 and keel point measurement.
3	Intuitiveness	Individually, teach random people to use our prototype to measure a golf club and see how many attempts it would take for them to do measure a club unaided.	Measure the attempts it takes for a new person to operate the device.	≤ 5	Complete prototype.	Complete prototype.	Roman Hays, Grant Gabrielson	5/29/2022	11/13/2022	3.4	Everyone was able to operate the machine on their own after a maximum of 4 attempts.
4	Set up time	Measure the amount of time it takes to set up a club and zero the device.	Measure the time it takes to set up a new golf club in the measuring instrument.	"+" 3 minutes	Lie angle subassembly, datum, club clamping mechanism, keel point measurement.	Lie angle subassembly, datum, club clamping mechanism, keel point measurement.	Roman Hays, Grant Gabrielson	5/29/2022	11/13/2022	Max: 2:51 Min: 0:49	Did not have the proper tools to open and close the clamp. Operating the device with proper tools, as designed, it will take significantly less time.
5	Number of components	Counting the datum and lie angle/clamping mechanism as one (because they are connected), analyze the number of additional subassemblies required to measure the golf club.	Count the number of subassemblies.	"+4" subaseemblies	Finalized design.	Finalized design.	Blake Sousa	5/16/2022	11/13/2022	7	

DVP&R - Design Verification Plan (& Report)

Project:	W22 Golf Measuring Device Assembly		Sponsor:	Callaway Golf					Edit Date:		10/17/2022
TEST PLAN									TEST RESULTS		
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
6	Batter/plug-in required?	Will the measurement device have any sort of electricity necessary, or is it all mechanical?	Note if there are electronics.	1 battery/plug in	Finalized design.	Finalized design.	Roman Hays	5/29/2022	11/13/2022	yes	The device will incorporate digital components for ease of use and accuracy, which require an electrical power source.
7	Accuracy of lie measurement	Using a Callaway golf club, with a known lie angle, determine how close the prototype can get to the target angle.	Lie angle.	Up to +/- 0.5 degrees of 61°	Finalized design.	Finalized design.	Andre Fisher	11/13/2022	11/16/2022	62.73°	The 3D printers at school cannot hold the tight tolerances and the material is succeptable to bending. This makes it unsurprising that we were unable to hit the measurement we desired.
8	Precision of lie measurement	Using a Callaway golf club, determine how close the measured angles are to each other.	Lie angle.	Standard deviation up to +/- 0.3°	Finalized design.	Finalized design.	Andre Fisher	11/13/2022	11/16/2022	0.3°	The standard deviation is within the acceptable bounds.
9	Accuracy of loft measurement	Using a Callaway golf club, with a known loft angle, determine how close the prototype can get to the target angle.	Loft angle.	Up to +/- 0.5 degrees of 23.5°	Finalized design.	Finalized design.	Andre Fisher	11/13/2022	11/16/2022	26.75°	The 3D printers at school cannot hold the tight tolerances and the material is succeptable to bending. This makes it unsurprising that we were unable to hit the measurement we desired.
10	Precision of loft measurement	Using a Callaway golf club, determine how close the measured angles are to each other.	Loft angle.	Standard deviation up to +/- 0.3°	Finalized design.	Finalized design.	Andre Fisher	11/13/2022	11/16/2022	0.84°	The variation of the measurements is caused by the bending in the lie stand through to the shaft clamping system. Therefore there is more than expected variation in the measurement.
11	Calculation of Loft Angle Deviation	The loft angle has a signigicantly higher standard deviation than other measurements. This test is designed to calculate the prototype's low quality manufacturing effects on the loft angle.	Loft angle.	< 0.7° error due to manufacturing defects.	Finalized design.	Finalized design.	Andre Fisher	11/13/2022	11/16/2022	6.13°	The mean value is about 6°, but the measurement varied between 1.99° and 7.31°. Using high quality manufacturing will get rid of this error because GD&T such as flatness, perpendicularity, and parallelism may be controlled.
12	Accuracy of face measurement	Using a plate at a known angle, determine how close the prototype can get to the target angle.	Angle of a known face.	Up to +/- 0.5 degrees of 5°	Finalized design.	Finalized design.	Andre Fisher	11/13/2022	11/16/2022	4.75°	The face angle is constrained more, allowing it to be more specific.

DVP&R - Design Verification Plan (& Report)

Project:	W22 Golf Measuring Device Assembly		Sponsor:	Callaway Golf							Edit Date:	10/17/2022
TEST PLAN											**TEST RESULTS**	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING			Numerical Results	Notes on Testing
								Start date	Finish date			
13	Precision of face measurement	Using a plate at a known angle, determine how close the measured angles are to each other.	Angle of a known face.	Standard deviation up to +/- 0.3º	Finalized design.	Finalized design.	Andre Fisher	11/13/2022	11/16/2022		0.43º	The standard deviation is within the acceptable bounds, but has a standard deviation close to 0.5 degrees the referenced surface is not extremely flat and a small amount of weight may disrubt the reading.
14	Total cost	Sum amount of money required to purchase the raw materials and manufacture.	Sum the costs.	$0 < Cost , $3000	Complete prototype.	Complete prototype.	Blake Sousa	5/29/2022	11/13/2022		$1,300	We went over budget by approxiamately $300.
15	Damage caused to club	During testing, take notes of scratching, scuffs, or residual damage caused from dropping the club.	Record damages to clubs.	none	Complete prototype.	Complete prototype.	Andre Fisher	5/29/2022	11/16/2022		None	No damages to club.
16	Lifetime	Analyze the health of the machine after all other testing is complete, there should be zero wear or tear to the device at the end.	Record damages to measuring instrument.	3 broken components	Complete prototype.	Complete prototype.	Blake Sousa	5/29/2022	11/16/2022		None	No damages to machine.
17	Rotational precision of ball screw	Analyze the number degrees changed per one revolution of the ball screw	Degree variation of the lie angle per revolution of the ball screw.	<,= 2 degrees/revolution	Complete prototype.	Complete prototype.	Blake Sousa, Grant Gabrielson	5/30/2022	11/13/2022		1.82º	The ball screw connected to the digital output makes it very easy to adjust the lie angle to the correct measurement.

Appendix F: Test Procedures

Time to measure a club

Purpose: Calculate how long it takes to measure a golf club once the club is set up.

Scope: Measurement time.

Equipment:

- Timer
- Golf clubs
  - Iron
  - Wood
  - Driver
- The measurement device

Hazards: None

PPE Requirements: None

Facility: Cal Poly, Building 197: Engineering Projects Center

Pass criteria: Average measurement time < 8 minutes

Procedures:

1. Set up golf club in fixture.
2. Start time.
3. Follow measurement procedures, measuring lie, loft, and face angles when appropriate.
4. Stop time.
5. Record time.
6. Repeat 3 times per club.

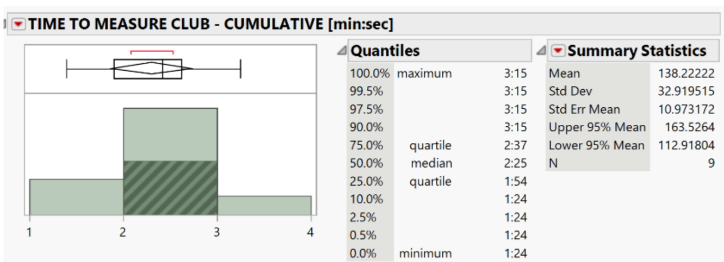
Results:

Pass Criteria	Fail Criteria	Number of Samples to Test
< 8 minutes	> 8 minutes	3

Test Dates:

- November 13, 2022
- November 17, 2022

Test Results:



Quantiles

100.0%	maximum	3:15
99.5%		3:15
97.5%		3:15
90.0%		3:15
75.0%	quartile	2:37
50.0%	median	2:25
25.0%	quartile	1:54
10.0%		1:24
2.5%		1:24
0.5%		1:24
0.0%	minimum	1:24

Summary Statistics

Mean	138.22222
Std Dev	32.919515
Std Err Mean	10.973172
Upper 95% Mean	163.5264
Lower 95% Mean	112.91804
N	9

Maximum time = 3:15
Minimum time = 1:24

Performed By: Roman Hays

Time to set up a club

Purpose: Determine the amount of time it takes to set up a golf club.

Scope: Set up time.

Equipment:

- Timer
- Golf clubs
  - Iron
  - Wood
  - Driver
- The measurement device

Location: Cal Poly, Building 197: Engineering Projects Center

Hazards: None

PPE Requirements: None

Procedures:

1. Select golf club to test.
2. Start time.
3. Follow set up procedures defined in the User Manual.
4. Set up golf club in fixture.
5. Stop time.
6. Record time.
7. Repeat 3 times per club.

Results:

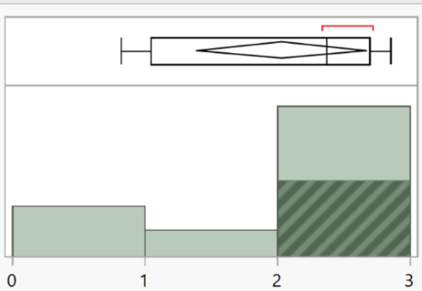
Pass Criteria	Fail Criteria	Number of Samples to Test
< 3 minutes	< 3 minutes	3

Test Dates:

- November 13, 2022
- November 17, 2022

Test Results:

SETUP TIME - CUMULATIVE [min:sec]



Quantiles

100.0%	maximum	2:51
99.5%		2:51
97.5%		2:51
90.0%		2:51
75.0%	quartile	2:42
50.0%	median	2:22
25.0%	quartile	1:03
10.0%		0:49
2.5%		0:49
0.5%		0:49
0.0%	minimum	0:49

Summary Statistics

Mean	121.77778
Std Dev	49.030036
Std Err Mean	16.343345
Upper 95% Mean	159.4656
Lower 95% Mean	84.089956
N	9

Maximum time = 2:51
Minimum time = 0:49

Performed By: Roman Hays

Intuitiveness of Device

Purpose: Evaluate the intuitiveness of the measuring device.

Scope: Ease of use.

Equipment:

- 5 test subjects
- Golf clubs
  - Iron
  - Wood
  - Driver
- The measurement device

Hazards: None

PPE Requirements: None

Facility: Cal Poly, Building 197: Engineering Projects Center

Procedure:

1. Randomly select subject for test.
2. Pick club type from trial using random number generator.
3. Set up club in device.
4. Demonstrate measurement procedure to subject.
5. Reset device.
6. Subject attempts to measure club without assistance.
7. If a subject requires assistance, repeat steps 4-6.
8. Allow 5 attempts per subject.
9. After successful measurement or 5 attempts, choose a new subject for the test and repeat steps 1-8.

Results:

Pass Criteria	Fail Criteria	Number of Samples to Test
< 5 Addition Demonstrations	> 5 Addition Demonstrations	5

Test Dates: November 13, 2022

Test Results:

Subject	# Times Additional Help is Required	Pass/Fail?
1	4	Pass
2	4	Pass
3	3	Pass
4	2	Pass
5	4	Pass

Performed By: Roman Hays, Grant Gabrielson

Lie Angle Metrology

Purpose: Measure the accuracy of the lie angle measurement about a club with a known lie angle.

Scope: Accuracy of lie angle.

Equipment:

- Golf club with known lie angle value.
- The measurement device

Hazards: None

PPE Requirements: None

Facility: Cal Poly, Building 197: Engineering Projects Center

Procedure:

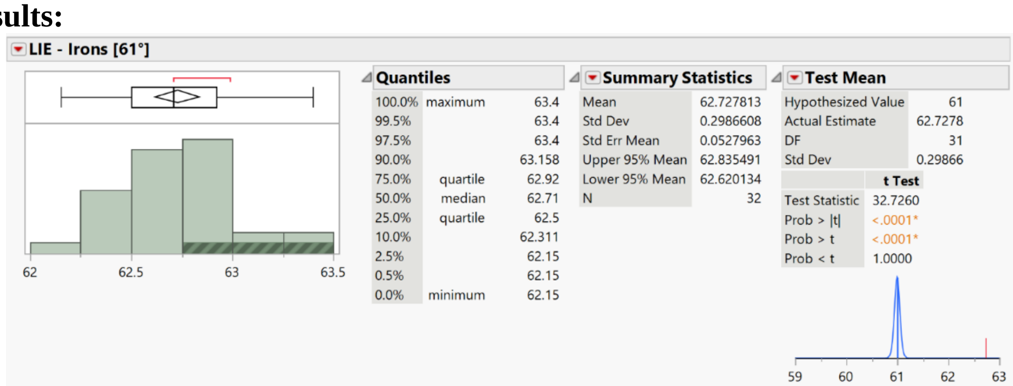
1. Set up golf club in fixture.
2. Zero the lie angle encoder.
3. Measure the lie angle of the club in accordance with measurement User Manual instructions.
4. Record measurement.

Results:

Accuracy		
Pass Criteria	**Fail Criteria**	**Number of Samples to Test**
Mean value within $61^\circ \pm 0.5^\circ$	Mean value outside $61^\circ \pm 0.5^\circ$	32
Precision		
Pass Criteria	**Fail Criteria**	**Number of Samples to Test**
Standard deviation < 0.6°	Standard deviation > 0.6°	32

Test Dates: November 14, 2022

Test Results:



Mean	62.73°
Standard Deviation	0.30°
95% Confidence Interval	(62.62°, 62.84°)

Performed By: Andre Fisher

Face Angle Metrology

Purpose: Measure the accuracy of the face angle measurement about a club with a known face angle.

Scope: Face angle effectiveness

Equipment:

- Surface set to a known 5° angle
- Measurement device

Hazards: None

PPE Requirements: None

Facility: Cal Poly, Building 197: Engineering Projects Center

Procedure:

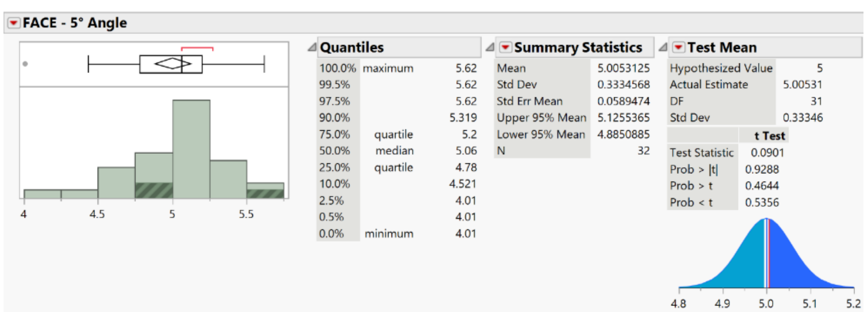
1. Set up golf club in fixture.
2. Zero the face angle encoder.
3. Measure the face angle of the club.
4. Record measurement.

Results:

Accuracy		
Pass Criteria	**Fail Criteria**	**Number of Samples to Test**
Mean value within 5º ± 0.5	Mean value outside 5º ± 0.5	32
Precision		
Pass Criteria	**Fail Criteria**	**Number of Samples to Test**
Standard deviation < 0.6º	Standard deviation > 0.6º	32

Test Dates: November 14, 2022

Test Results:



Mean	5.01°
Standard Deviation	0.33°
95% Confidence Interval	(4.89°, 5.13°)

Performed By: Andre Fisher

Loft Angle Metrology

Purpose: Measure the accuracy of the loft angle measurement about a club with a known loft angle.

Scope: Loft angle effectiveness.

Equipment:

- Golf club with known loft angle value.
- The measurement device

Hazards: None

PPE Requirements: None

Facility: Cal Poly, Building 197: Engineering Projects Center

Procedure:

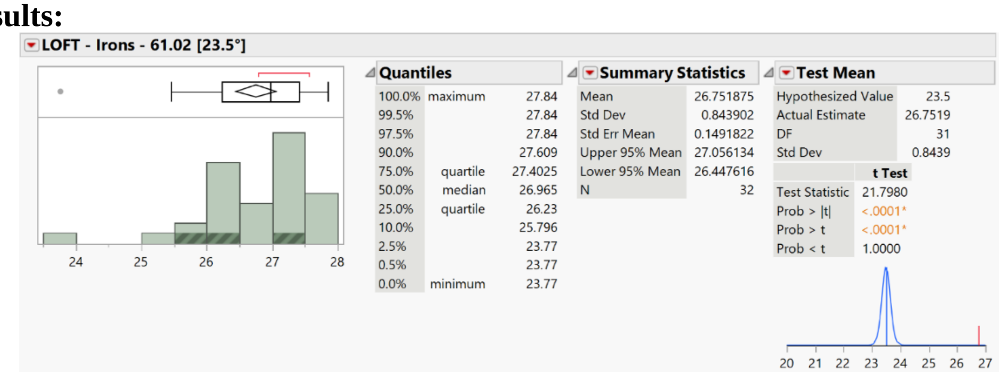
1. Set up golf club in fixture.
2. Zero the loft angle encoder.
3. Measure the loft angle of the club.
4. Record measurement.

Results:

Accuracy		
Pass Criteria	**Fail Criteria**	**Number of Samples to Test**
Mean value within 23.5º ± 0.5	Mean value within 23.5º ± 0.5	32
Precision		
Pass Criteria	**Fail Criteria**	**Number of Samples to Test**
Standard deviation < 0.6º	Standard deviation < 0.6º	32

Test Dates: November 14, 2022

Test Results:



Mean	26.75°
Standard Deviation	0.84°
95% Confidence Interval	(26.45°, 27.06°)

Performed By: Andre Fisher

Loft Angle Deviation

Purpose: Determine the cause of a large standard deviation.

Scope: Loft angle effectiveness.

Equipment:

- Golf club
- Clamp
- The measurement device

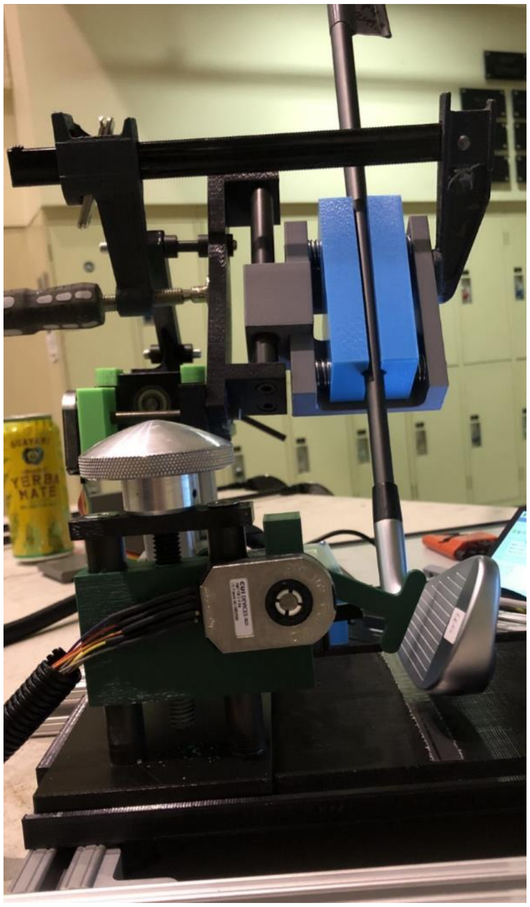
Hazards: None

PPE Requirements: None

Facility: Cal Poly, Building 197: Engineering Projects Center

Procedure:

1. Set up golf club in fixture.
2. Set the club with known dimensions to its designed lie angle.
3. Make sure the club is horizontal with 3D printed datum set.
4. Measure the loft angle.
5. Apply torque to clamping fixture in one direction, make sure lie angle stays the same.



6. Measure new loft angle.
7. Record measurement.

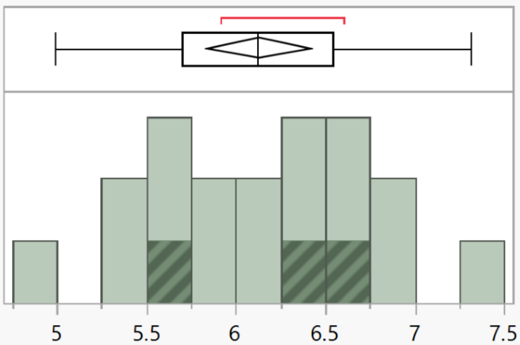
Results:

Pass Criteria	Fail Criteria	Number of Samples to Test
Mean < 0.7°	Mean > 0.7°	19

Test Dates: November 14, 2022

Test Results:

LOFT - Deviation - Lock Clamped System



Quantiles

100.0%	maximum	7.31
99.5%		7.31
97.5%		7.31
90.0%		6.82
75.0%	quartile	6.54
50.0%	median	6.12
25.0%	quartile	5.7
10.0%		5.27
2.5%		4.99
0.5%		4.99
0.0%	minimum	4.99

Summary Statistics

Mean	6.1326316
Std Dev	0.6005538
Std Err Mean	0.1377765
Upper 95% Mean	6.4220893
Lower 95% Mean	5.8431739
N	19

Mean	6.13°
Standard Deviation	0.60°
95% Confidence Interval	(5.84°, 6.42°)

Performed By: Andre Fisher

Ball Screw Range of Motion

Purpose: Determine the maximum and minimum lie angles achieved due to ball screw.

Scope: Total range of motion of the lie angle.

Equipment:

- The measurement device

Hazards: None

PPE Requirements: None

Facility: Cal Poly, Building 197: Engineering Projects Center

Procedure:

1. Zero the lie angle encoder.
2. Rotate ball screw to maximum lie angle.
3. Record the maximum lie angle measurement.
4. Rotate ball screw to minimum lie angle.
5. Record the minimum lie angle measurement.

Results:

Pass Criteria	Fail Criteria	Number of Samples to Test
Maximum angle ≥ 85°	Maximum angle ≤ 85°	2
Minimum angle ≤ 50°	Minimum angle ≥ 50°	

Test Dates: November 12, 2022

Test Results:

Minimum Angle	30.23°
Maximum Angle	89.5°

Performed By: Roman Hays & Grant Gabrielson

Ball Screw Angular Displacement

Purpose: Quantitively determine the number of lie angle degrees changed per rotation of the ball screw.

Scope: Determine how easy it will be to get specific lie angles by hand.

Equipment:

- The measurement device

Hazards: None

PPE Requirements: None

Facility: Cal Poly, Building 197: Engineering Projects Center

Procedure:

1. Zero the lie angle encoder.
2. Record initial angle.
3. Rotate ball screw 1 revolution
4. Record final angle.
5. Repeat steps 2-4 for 5, 10, 15 revolutions

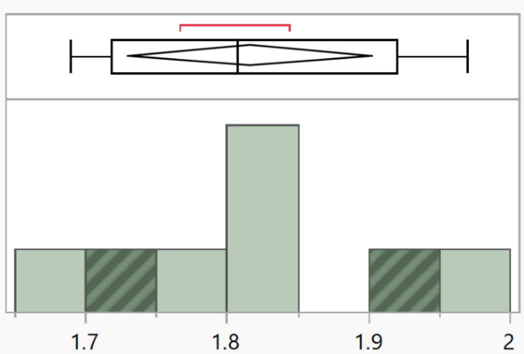
Results:

Pass Criteria	Fail Criteria	Number of Samples to Test
$\Delta(°)$/rotation $\leq$ 5°/rotation	$\Delta(°)$/rotation > 5°/rotation	2

Test Dates: November 12, 2022

Test Results:

BALL SCREW



Quantiles

100.0%	maximum	1.97
99.5%		1.97
97.5%		1.97
90.0%		1.97
75.0%	quartile	1.91975
50.0%	median	1.807
25.0%	quartile	1.71825
10.0%		1.69
2.5%		1.69
0.5%		1.69
0.0%	minimum	1.69

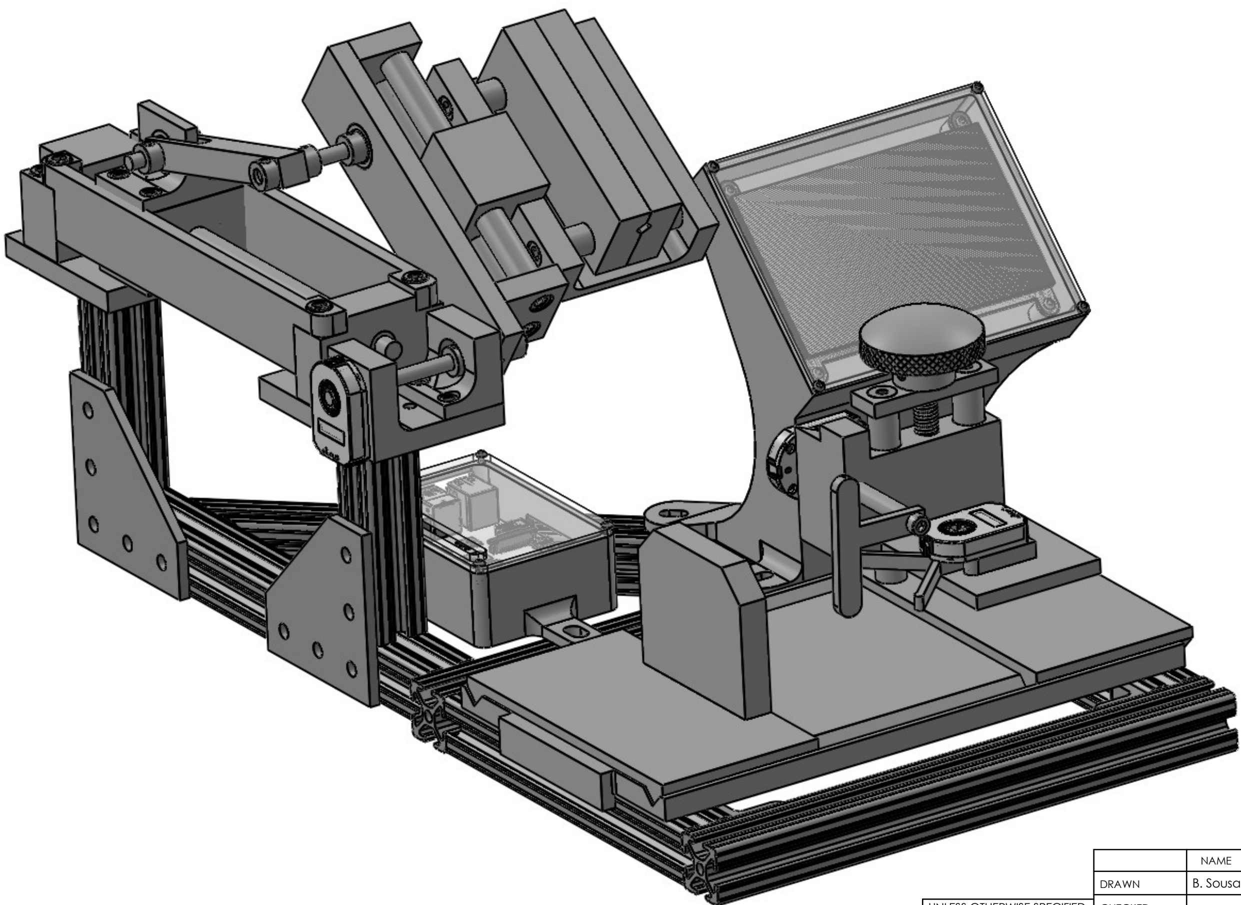
Summary Statistics

Mean	1.8165
Std Dev	0.101822
Std Err Mean	0.0359995
Upper 95% Mean	1.9016253
Lower 95% Mean	1.7313747
N	8

Mean	1.82°
Standard Deviation	0.10°
95% Confidence Interval	(1.73°, 1.90°)

Performed By: Roman Hays & Grant Gabrielson

Appendix G: Drawing Package



	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: These components were designed to build a concept prototype that was made mainly through 3D Prints

TOP GOLF CALLAWAY BRANDS

TITLE:

PROTOTYPE MAIN ASSEMBLY

SIZE B | DWG. NO. 1000 | REV 1

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 22

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

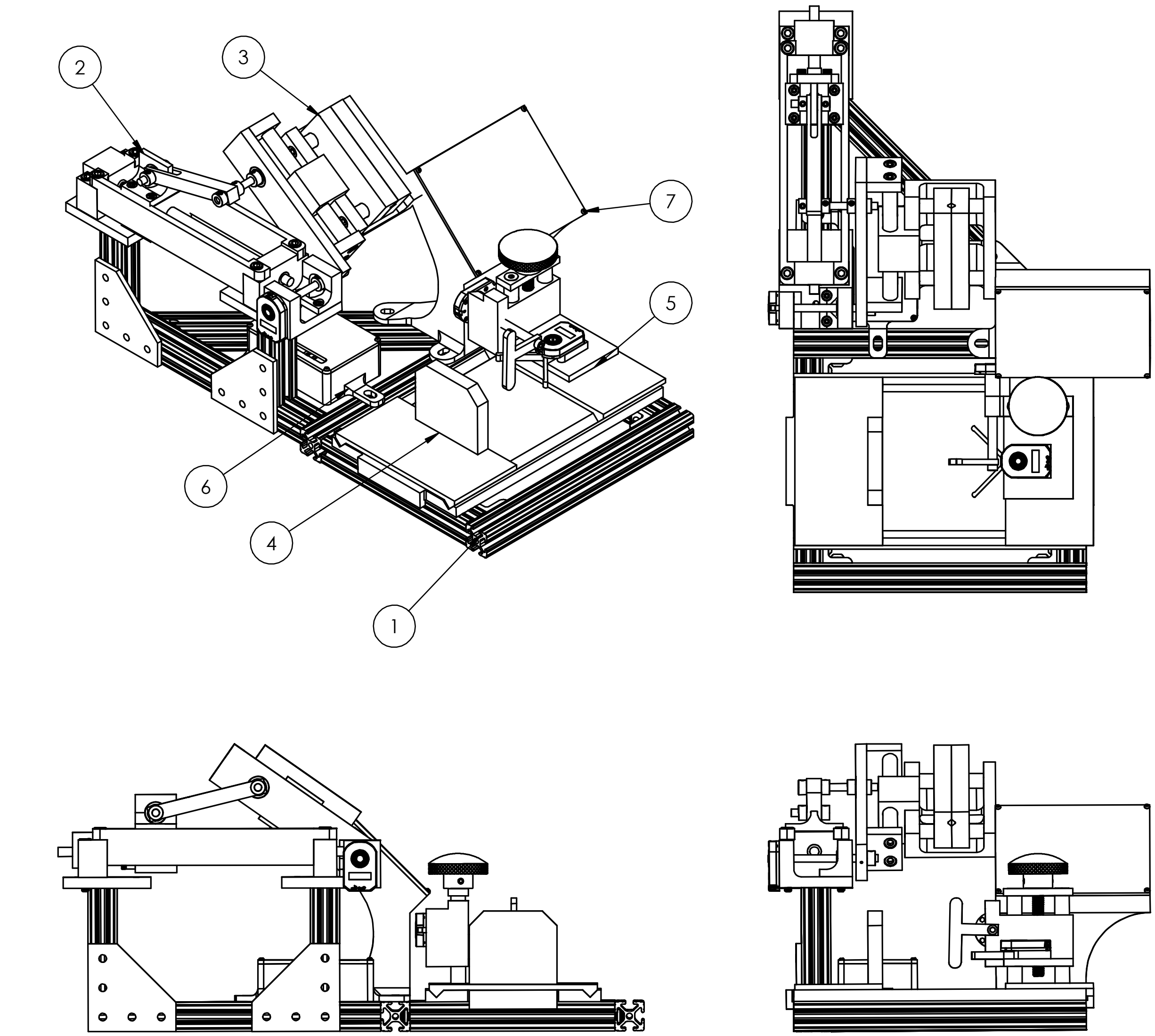
MATERIAL

FINISH

DO NOT SCALE DRAWING

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF TOP GOLF CALLAWAY BRANDS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF TOP GOLF CALLAWAY BRANDS IS PROHIBITED.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1100	Base Subassembly	1
2	1200	Lie Subassembly	1
3	1300	Shaft Clamping Subassembly	1
4	1400	Zero Slider Subassembly	1
5	1500	Loft & Face Angle Subassembly	1
6	1630	Rasphberry PI SubAssembly	1
7	1640	Display Sub Assembly	1

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

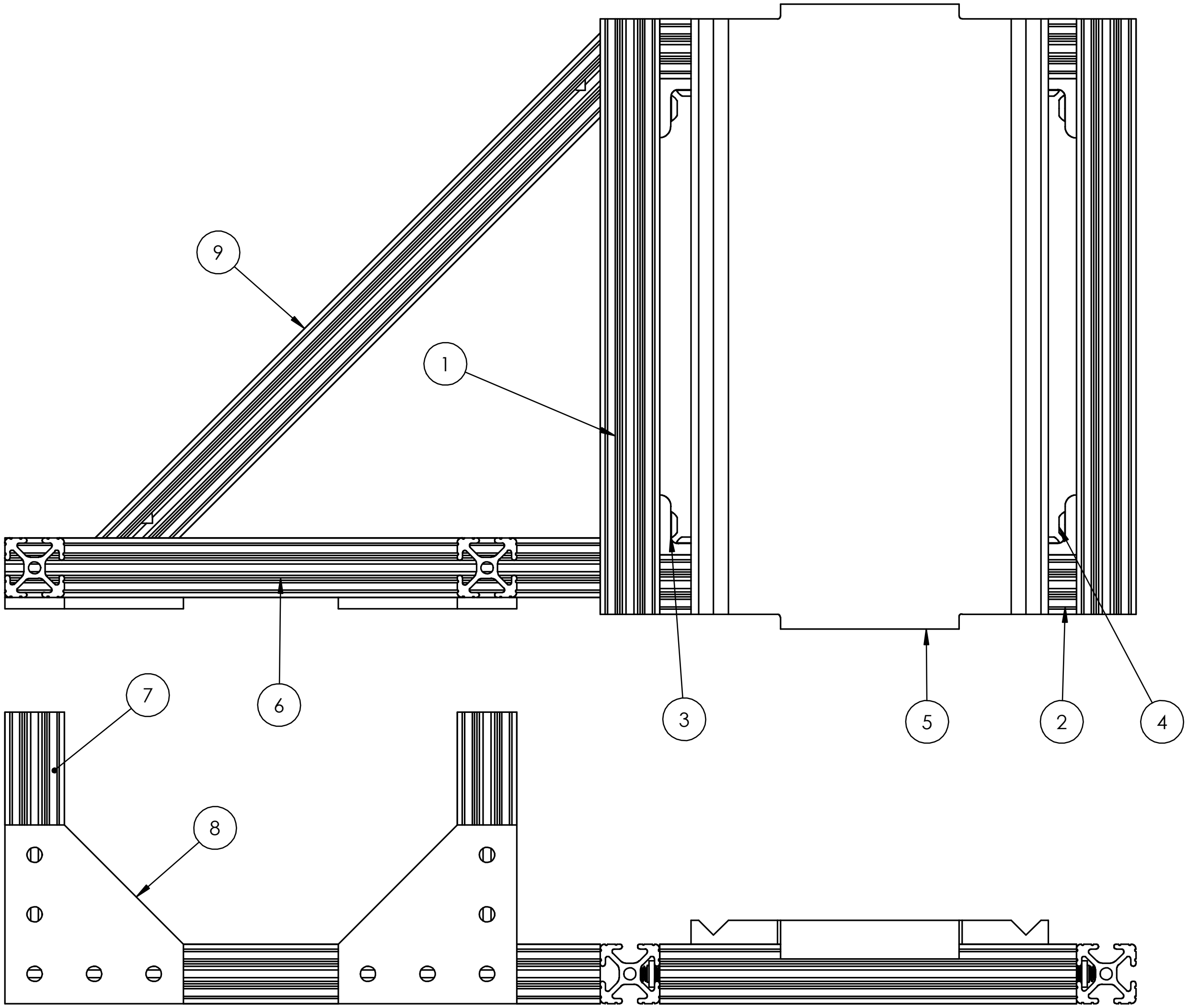
COMMENTS:

TOP GOLF CALLAWAY BRANDS

TITLE: SUBASSEMBLY CALLOUT

SIZE **B** DWG. NO. 1000 REV 1

SCALE: 1:4 WEIGHT: SHEET 2 OF 22



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1111	T-Slotted Framing - 47065T411	2
2	1111	T-Slotted Framing - 47065T411	2
3	1113	Silver Corner Bracket	4
4	1113	T-Slotted Framing	8
5	1120	Slider Plate	1
6	1111	T-Slotted Framing-47065T411	1
7	1111	T-Slotted Framing 47065T411	2
8	1114	T-Slotted Framing 47065T267	2
9	1112	Daignol Brace - 47065T188	1

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

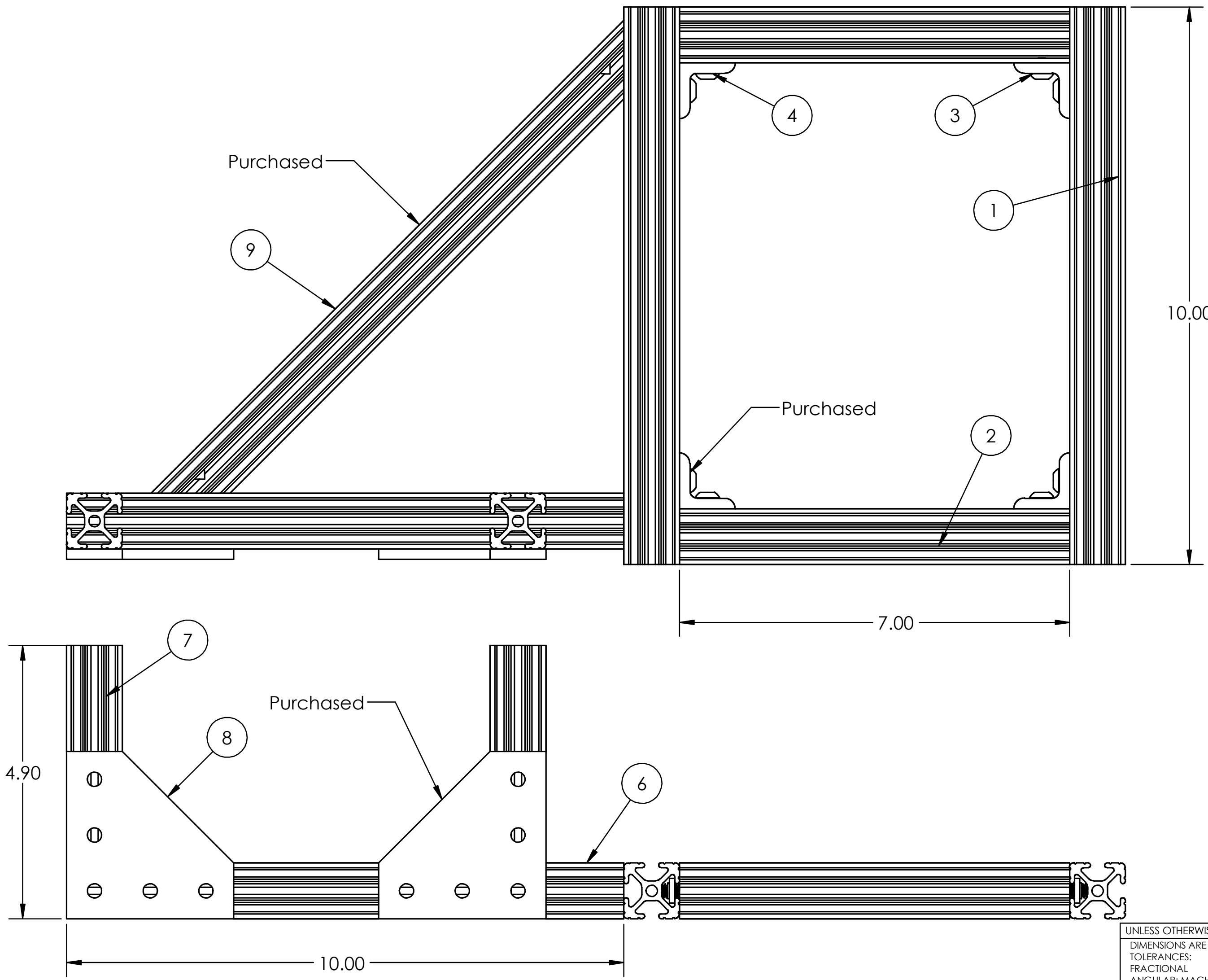
TOP GOLF CALLAWAY BRANDS

TITLE:

BASE SUB ASSEMBLY

SIZE **B** DWG. NO. 1100 REV 1

SCALE: 1:4 WEIGHT: SHEET 3 OF 22



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1111	T-Slotted Framing - 47065T411	2
2	1111	T-Slotted Framing - 47065T411	2
3	1113	Silver Corner Bracket	4
4	1113	Silver Corner Bracket Bolts	8
6	1111	T-Slotted Framing- 47065T411	1
7	1111	T-Slotted Framing 47065T411	2
8	1114	Surface Brackets 47065T267	2
9	1112	Daignol Brace - 47065T188	1

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: EXTRUDED ALUMINUM IS CONNECTED USING CORNER AND SURFACE BRACKETS PURCHASED ONMCMASTER. THESE BRACKETS COME WITH THE NECESSARY BOLTS FOR ASSEMBLY.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

TOP GOLF CALLAWAY BRANDS

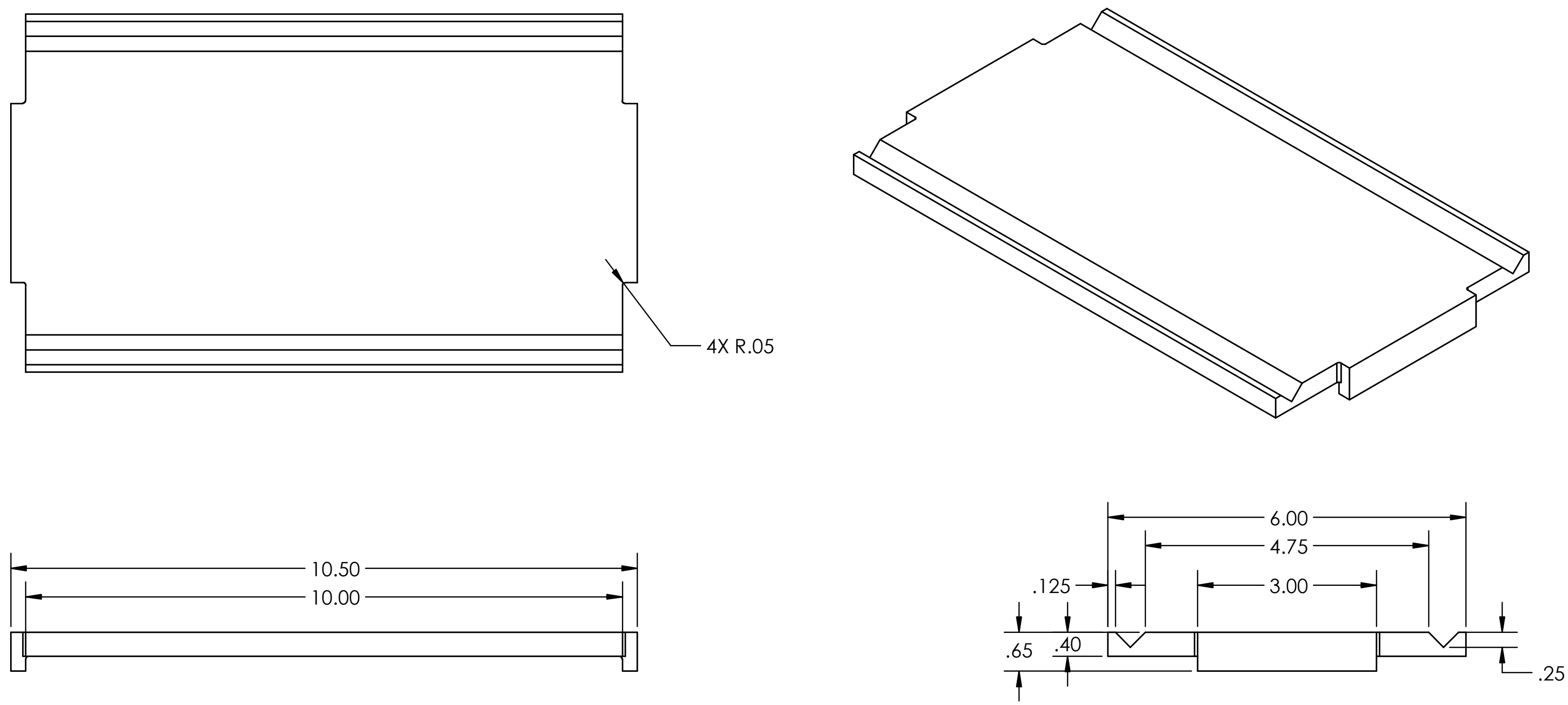
TITLE:

BASE PLATE

SIZE **B** | DWG. NO. 1110 | REV 1

SCALE: 1:2 | WEIGHT: | SHEET 4 OF 22

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	1120	Slider Plate	1



	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: EXPORT TO STL AND PART CAN BE 3D PRINTED

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL
3D PRINT

FINISH

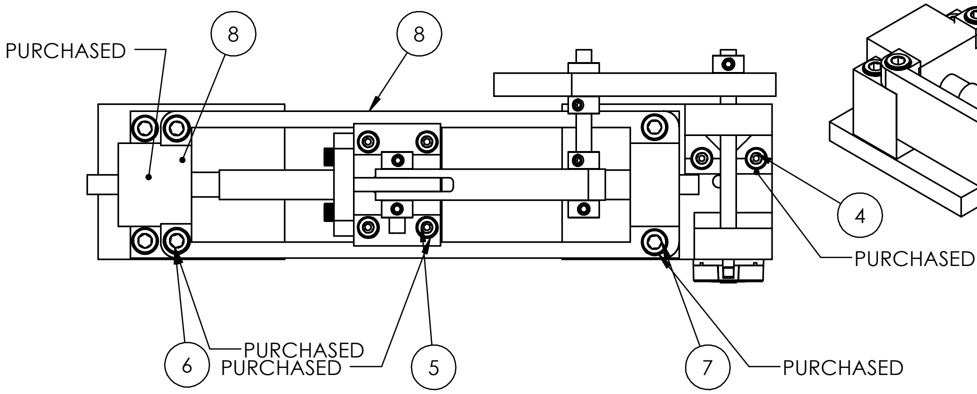
DO NOT SCALE DRAWING

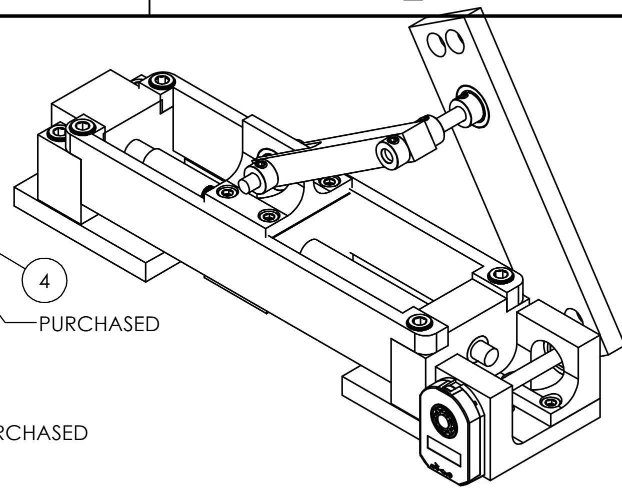
TOP GOLF CALLAWAY BRANDS

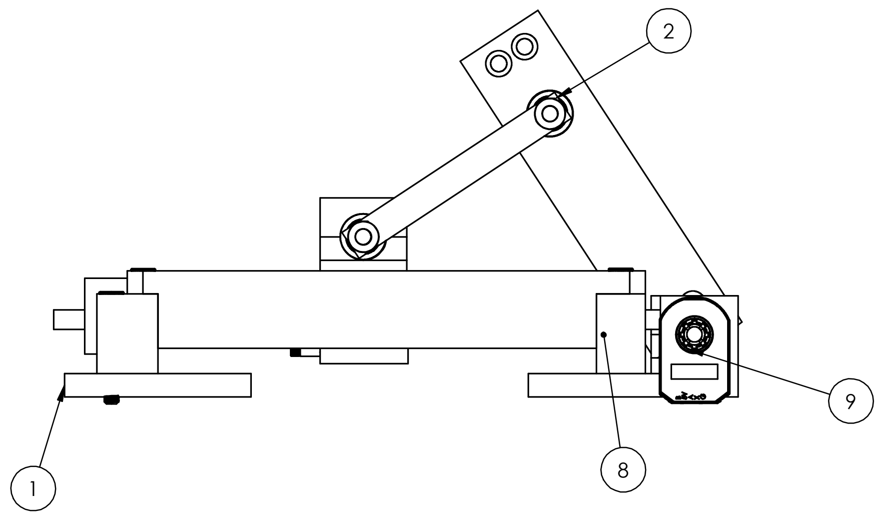
TITLE:
SLIDER PLATE

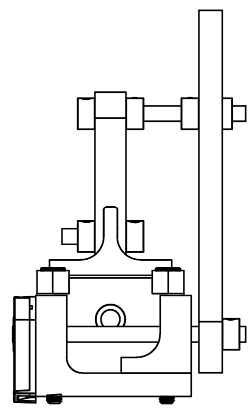
SIZE B | DWG. NO. 1120 | REV 1

SCALE: 1:2 | WEIGHT: | SHEET 5 OF 22









ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1210	Lie Base Subassembly	1
2	1220	Lie Arm Subassembly	1
8	1230	Lie Ball Screw Part	1
4	1240	Lie Bolts A	2
5	1250	Lie Bolts B	4
6	1260	Lie Bolts C	4
7	1270	Lie Bolts D	2
8	1280	Ball Screw Rail	1
9	1610	Encoder	1

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TOP GOLF CALLAWAY BRANDS

TITLE:

LIE SUBASSEMBLY

SIZE **B** DWG. NO. 1200 REV 1

SCALE: 1:2 WEIGHT: SHEET 6 OF 22

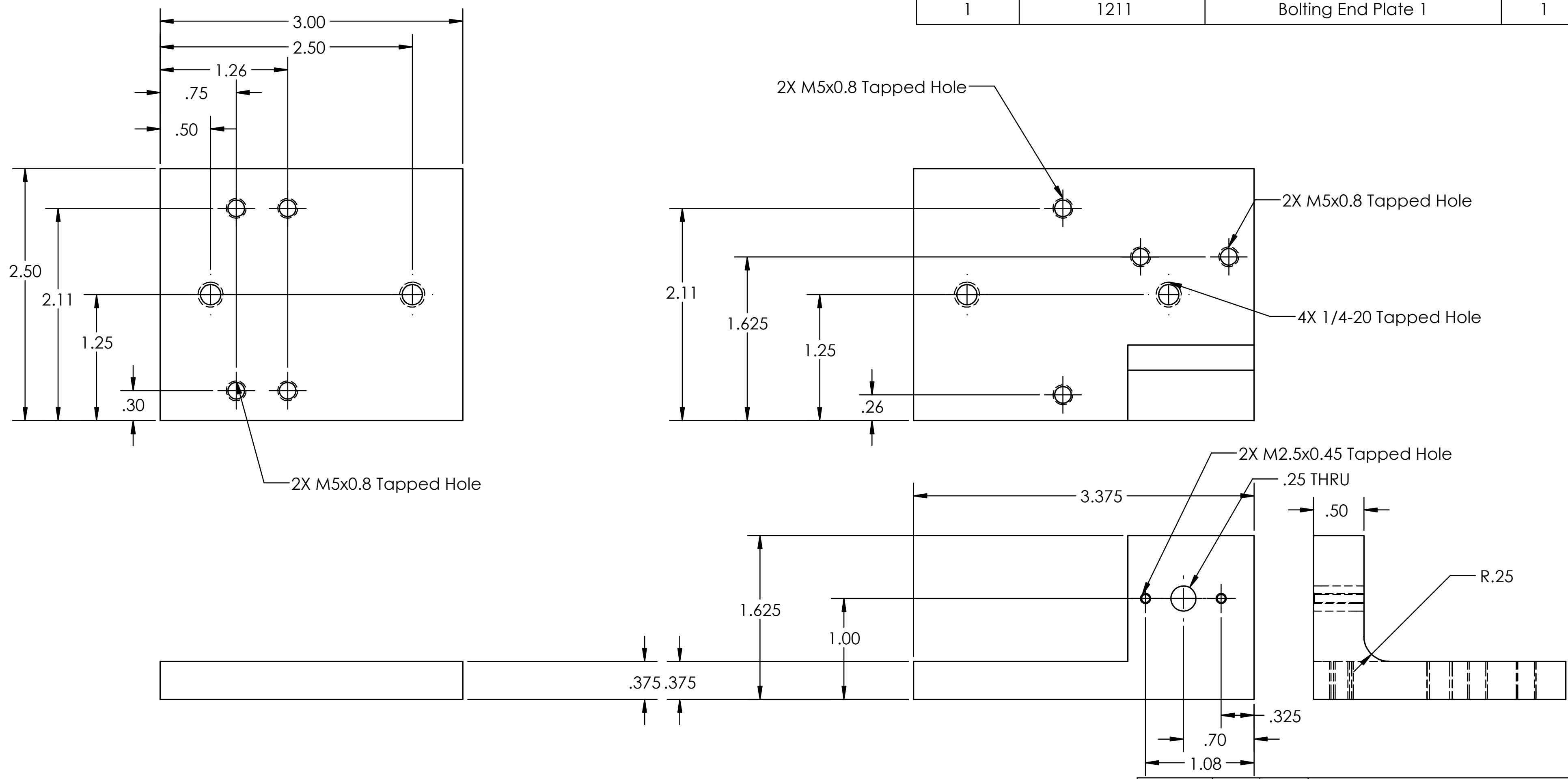
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1211	Bolting End Plate 1	1



	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:BOLTING END PLATE 1 & 2 BUT IS MODELED AS ONE COMPLETE PLATE.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

TOP GOLF CALLAWAY BRANDS

TITLE:

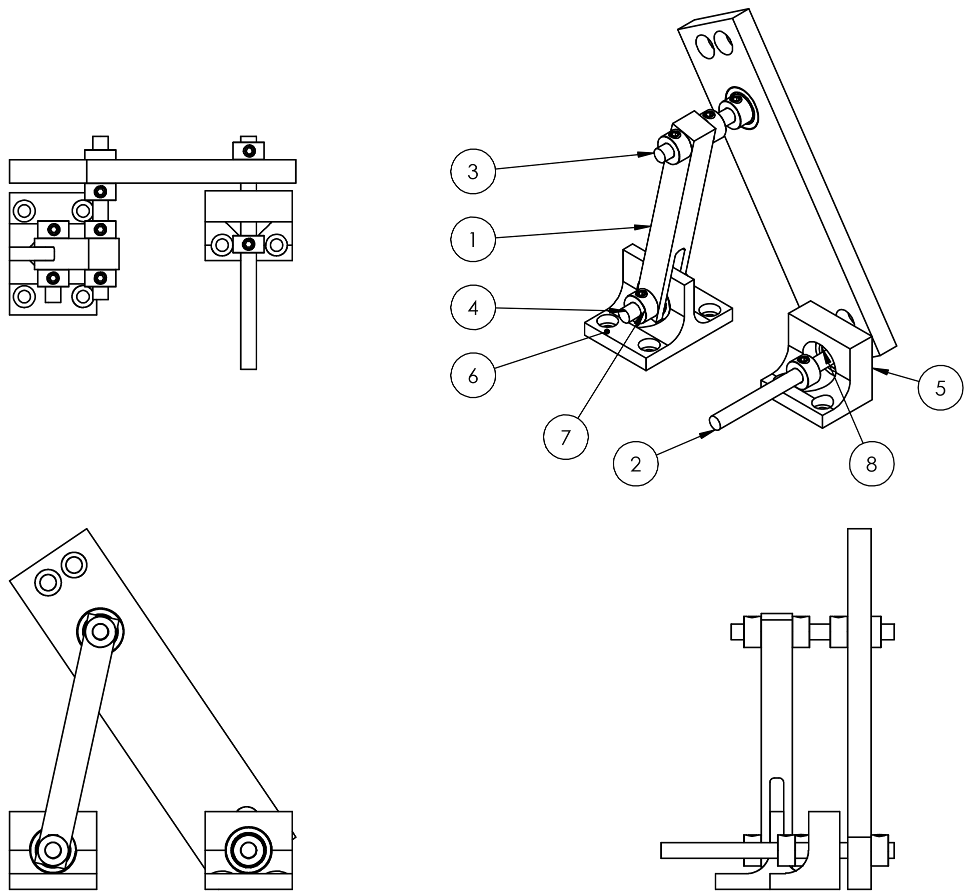
LIE BASE SUBASSEMBLY

SIZE **B** DWG. NO. 1210 REV 1

SCALE: 1:2 WEIGHT:

4 3 2 1

B



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1221	Small Arm	1
2	1222	Main Arm Shaft	1
3	1223	Small To Main Arm Shaft	1
4	1224	Small Arm Shaft	1
5	1225	Bearing Plate 1	1
6	1226	Bearing Plate 2	1
7	1229	Lie Shaft Collar- 9414T6	8
8	1227	Lie Arm Ball Bearing- 2342K164	3

B

A

A

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TOP GOLF CALLAWAY BRANDS

TITLE:

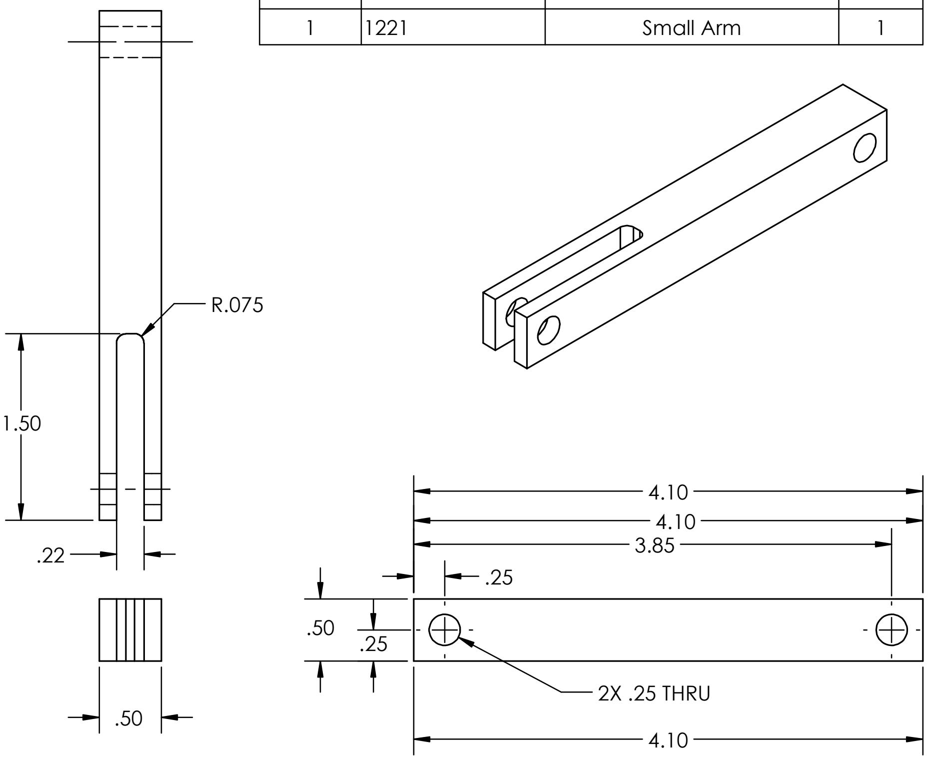
LIE ARM SUBASSEMBLY

SIZE **B** DWG. NO. 1220 REV 1

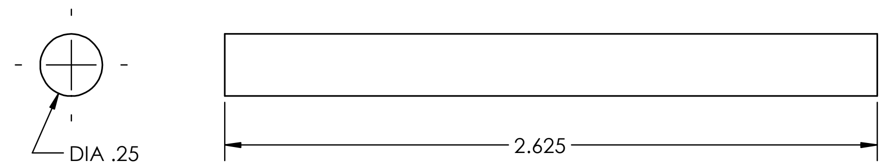
SCALE: 1:2 WEIGHT: SHEET 8 OF 22

4 3 2 1

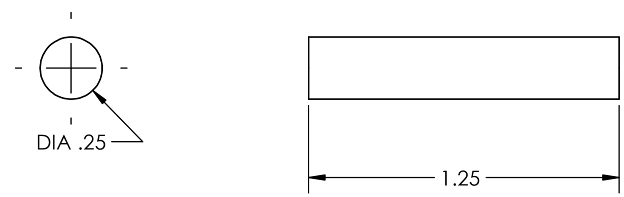
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1221	Small Arm	1



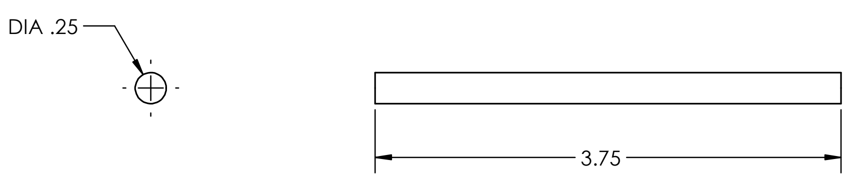
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
3	1223	Small To Main Arm Shaft	1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
4	1224	Small Arm Shaft	1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
2	1222	Main Arm Shaft	1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TOP GOLF CALLAWAY BRANDS

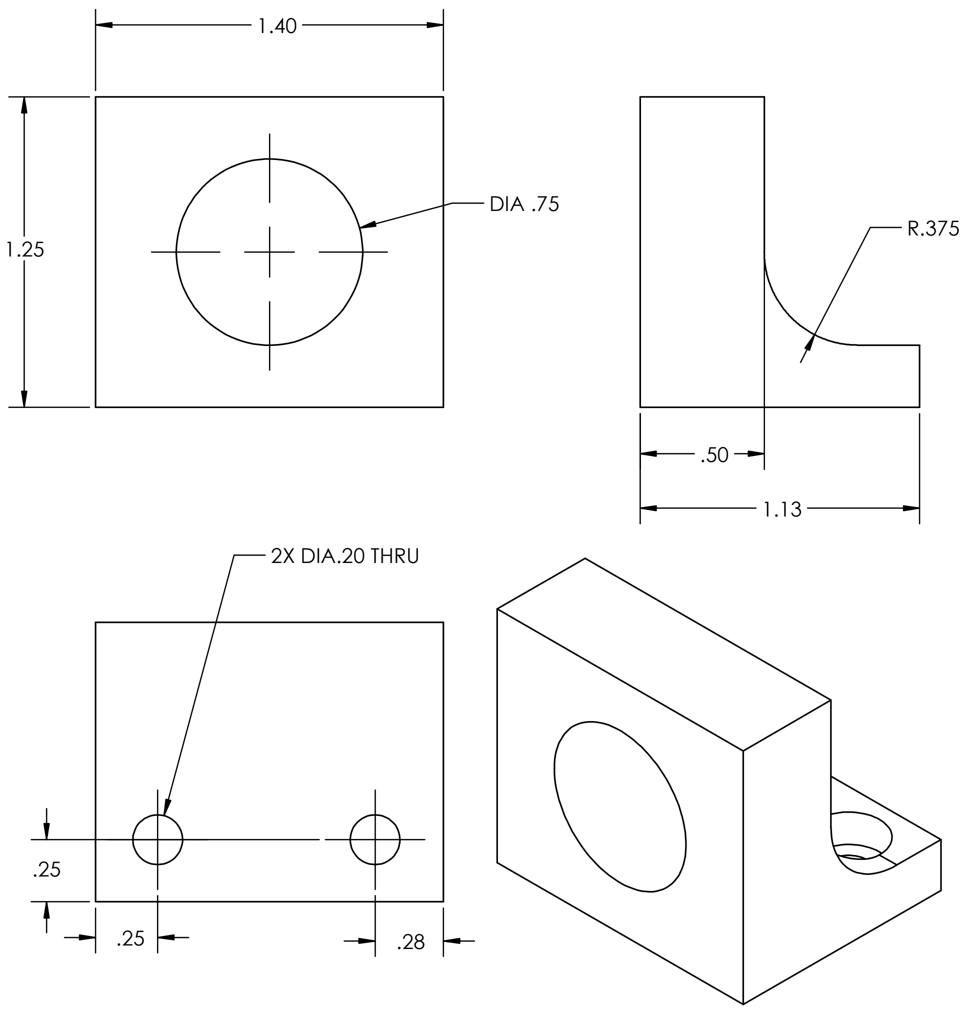
TITLE:

LIE ARM COMPONENTS

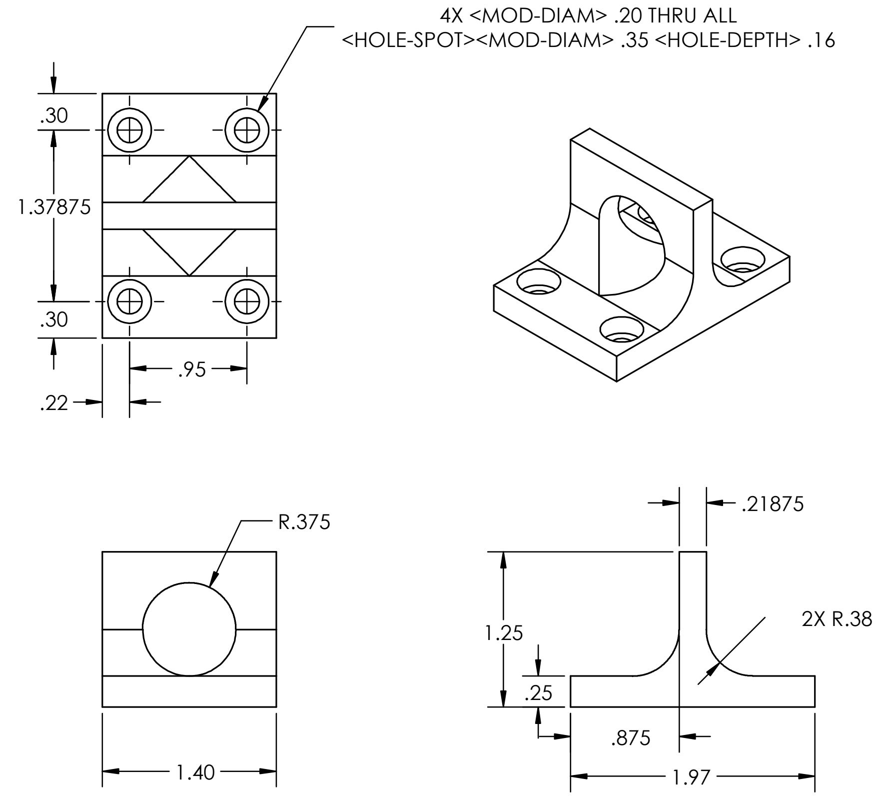
SIZE **B** DWG. NO. 1220 REV 1

SCALE: 1:1 WEIGHT: SHEET 9 OF 22

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	1225	Bearing Plate 1	1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
6	1226	Bearing Plate 2	1



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TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TOP GOLF CALLAWAY BRANDS

TITLE:

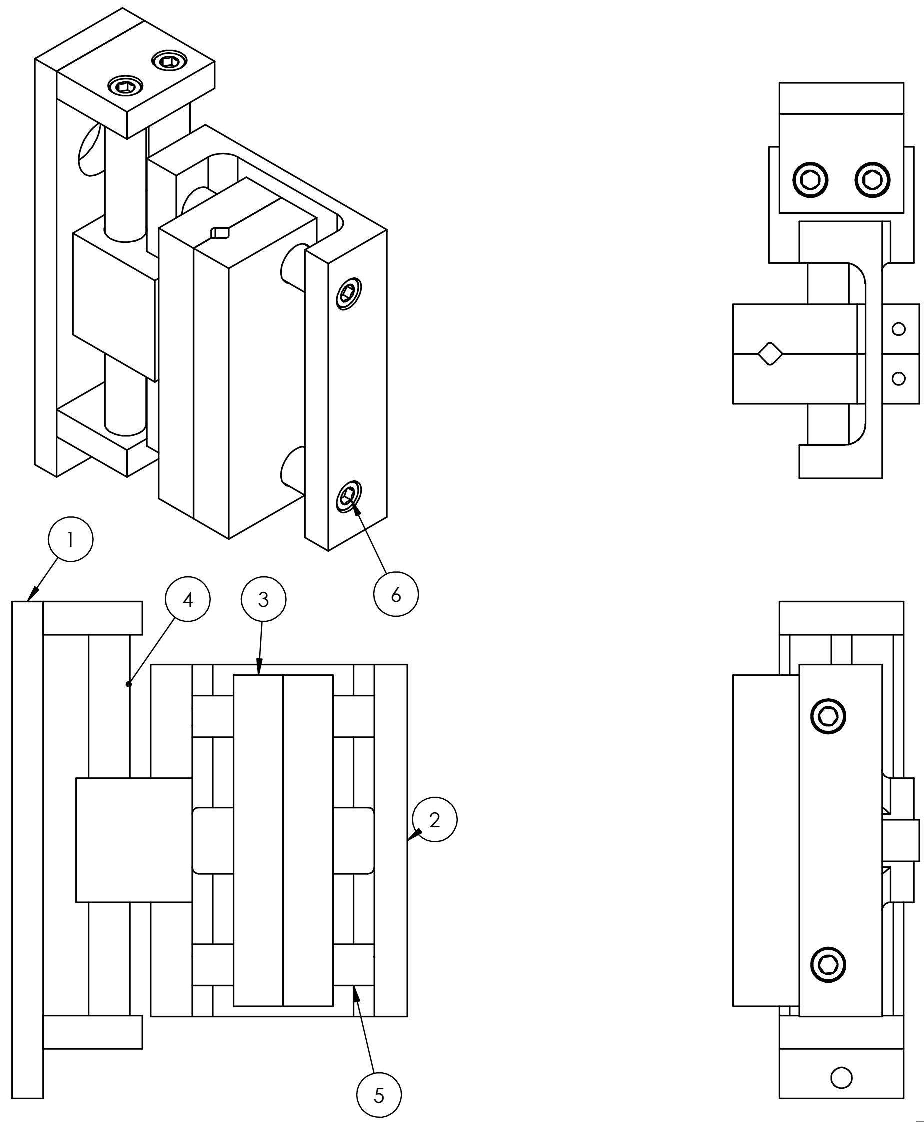
LIE ARM SUBASSEMBLY

SIZE **B** DWG. NO. 1220 REV 1

SCALE: 2:1 WEIGHT: SHEET 10 OF 22

4 3 2 1

B



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1310	Main Arm	1
2	1320	Housing Slider	1
3	1330	C Clamp	2
4	1340	Sliding Shaft -1/2" Rod	2
5	1340	C Clamp Shaft - 1/2' Rod	2
6	1350	Alloy Steel Socket Head Screw 91290A316	8

A

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

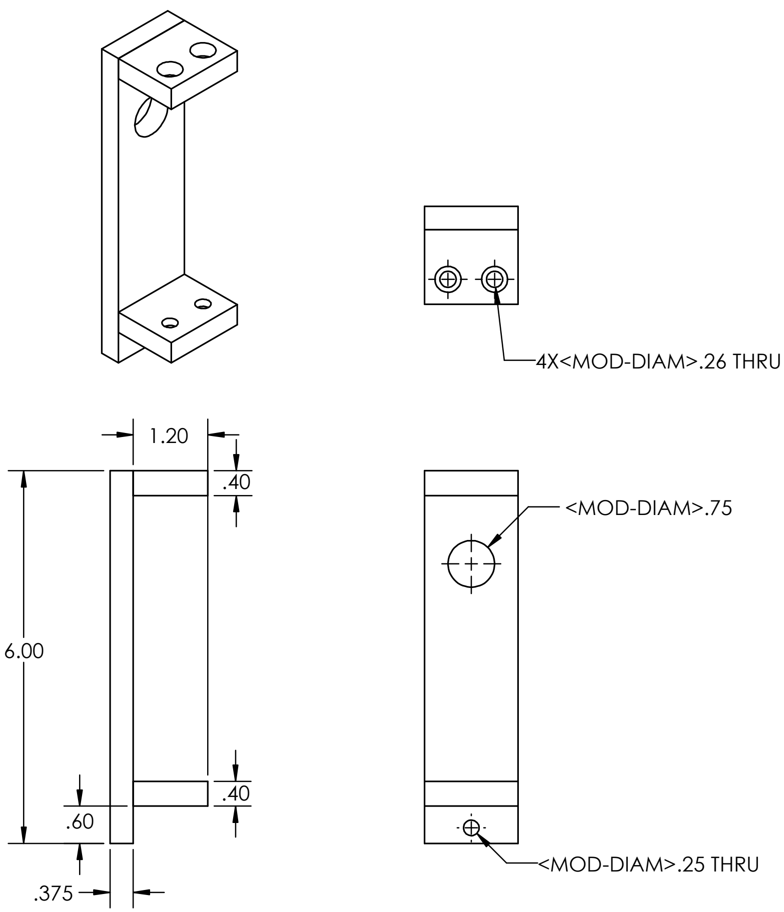
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL
MATERIAL
FINISH
DO NOT SCALE DRAWING

TOP GOLF CALLAWAY BRANDS
TITLE:
SHAFT CLAMPING SUBASSEMBLY

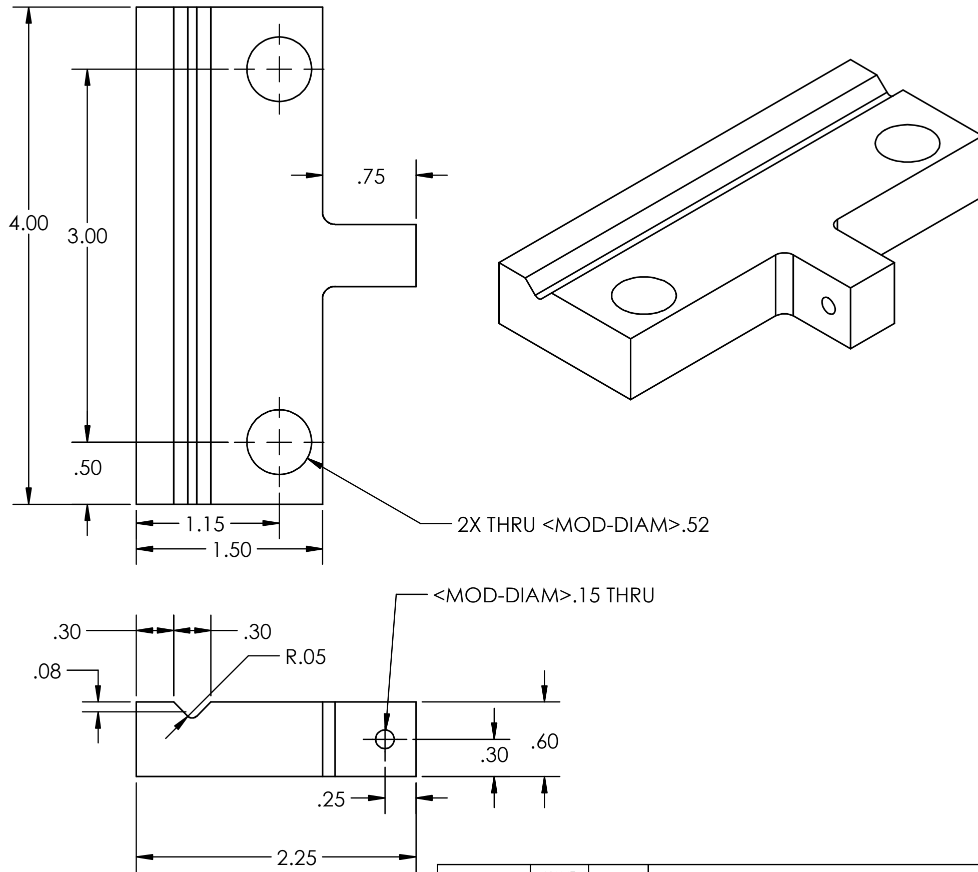
SIZE **B** DWG. NO. 1300 REV 1
SCALE: 1:2 WEIGHT: SHEET 11 OF 22

4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1310	Main Arm	1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1330	C Clamp	2



PROPRIETARY AND CONFIDENTIAL

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

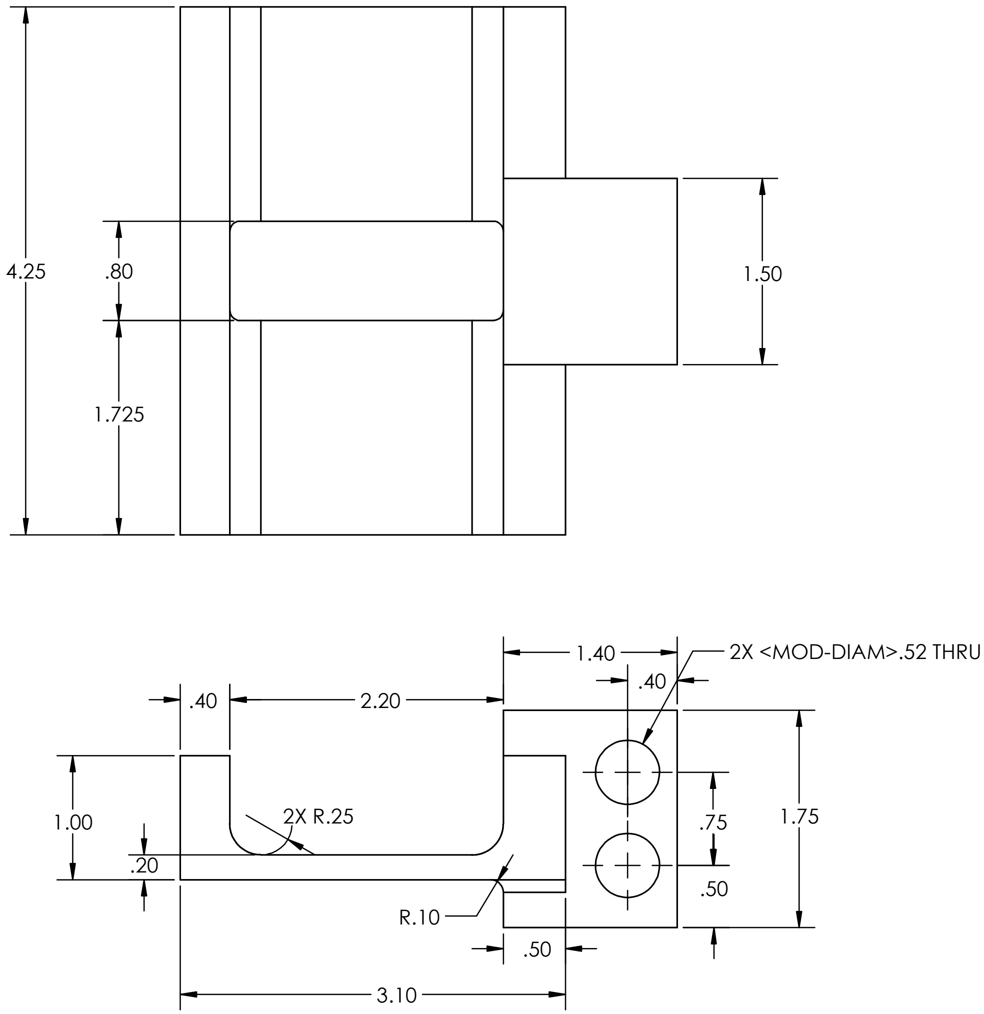
TOP GOLF CALLAWAY BRANDS

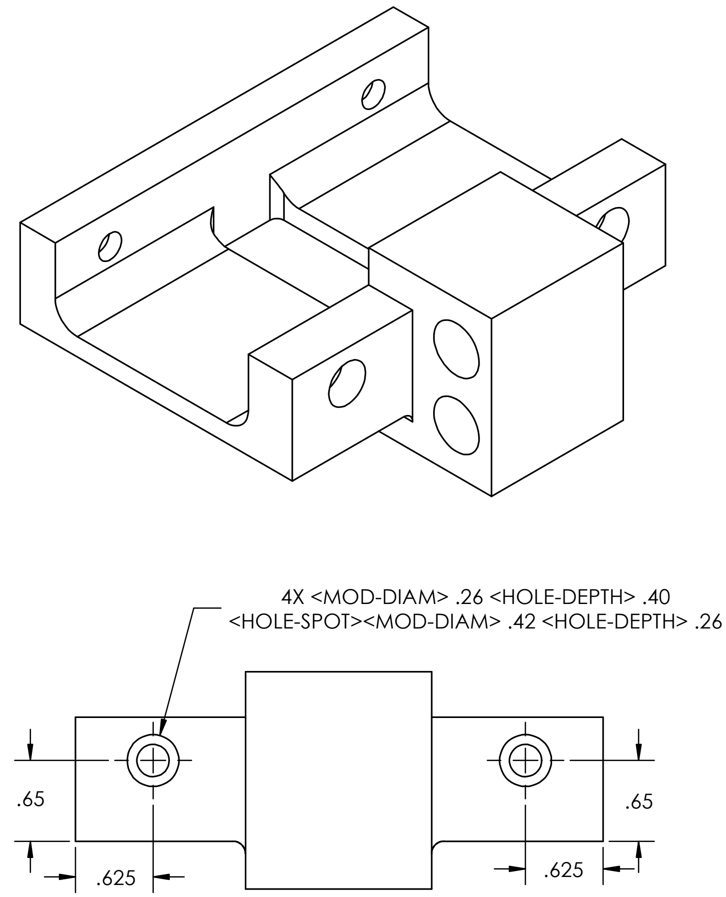
TITLE:

SHAFT CLAMPING PARTS

SIZE **B** DWG. NO. 1300 REV 1

SCALE: 1:2 WEIGHT: SHEET 12 OF 22





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
3	1320	Housing Slider	1

PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TOP GOLF CALLAWAY BRANDS

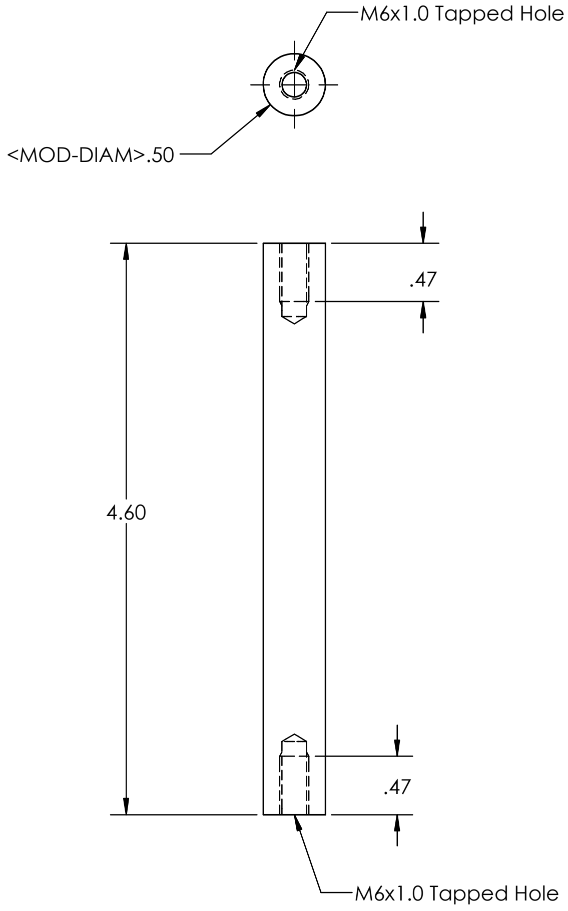
TITLE:
SHAFT CLAMPING PARTS

SIZE **B** DWG. NO. 1300 REV 1

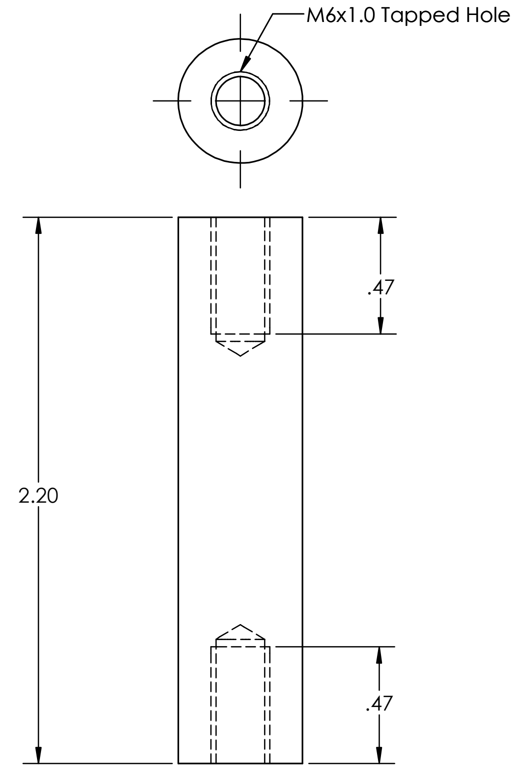
SCALE: 1:1 WEIGHT: SHEET 13 OF 22

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
4	1340	Sliding Shaft 1/2" Rod	2



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	1340	C Clamp Shaft - 1/2" Rod	2



	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

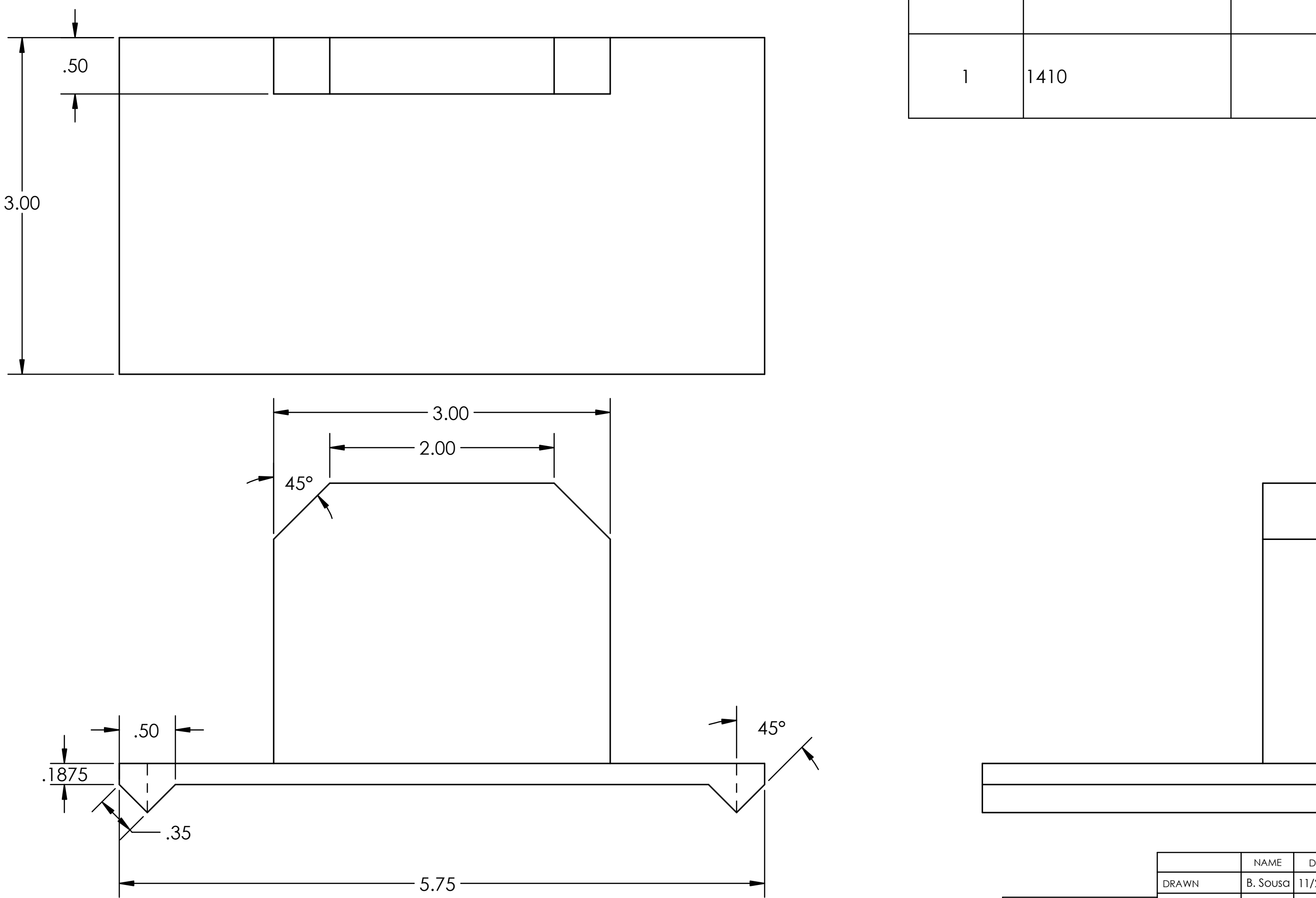
PROPRIETARY AND CONFIDENTIAL

TOP GOLF CALLAWAY BRANDS

TITLE:
SHAFT CLAMPING PARTS

SIZE **B** DWG. NO. 1300 REV 1

SCALE: 1:1 WEIGHT: SHEET 14 OF 22



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1410	Zero Slide Plate	1

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: EXPORT TO DXF AND 3D PRINT

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

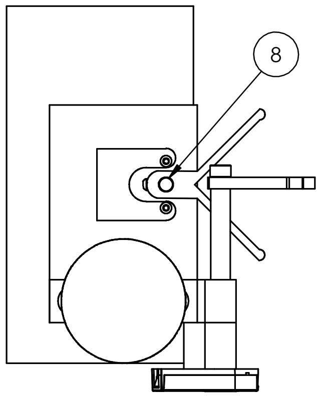
TOP GOLF CALLAWAY BRANDS

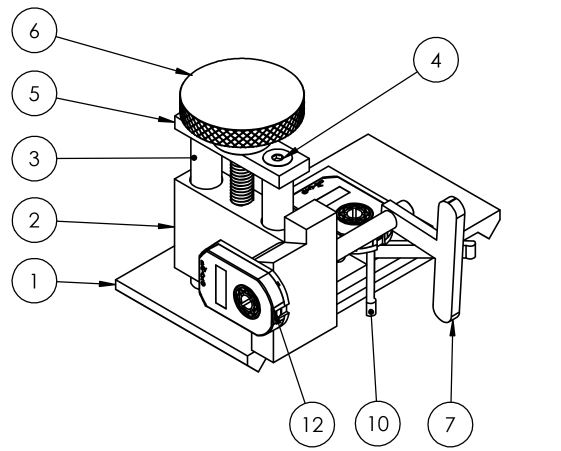
TITLE:

ZERO SLIDER SUBASSEMBLY

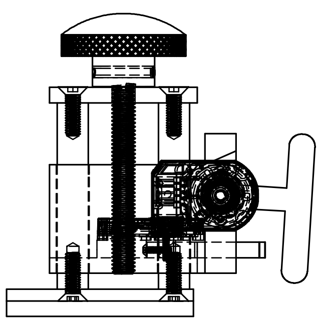
SIZE **B** DWG. NO. 1400 REV 1

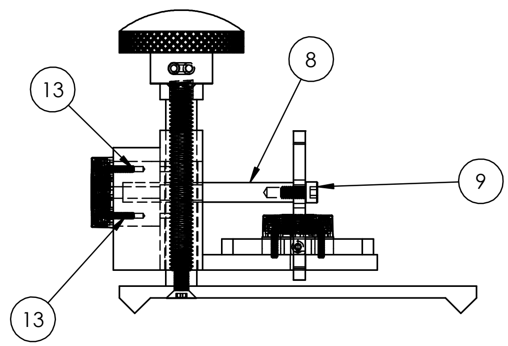
SCALE: 1:1 WEIGHT: SHEET 15 OF 22





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1510	Loft/Face Slider	1
2	1520	Vertical Adjustment Base	1
3	1530	Slide Shafts	2
4	1540	316 Stainless Steel Hex Drive Flat Head Screw 93395A360	4
5	1550	Height Cap	1
6	1560	Aluminum Knurled Palm-Grip Knob 7762K103	1
7	1570	Loft Flat Iron Contact	1
8	15-10-0	Loft Encoder Shaft	1
9	15-11-0	Blue-Dyed Zinc-Plated Alloy Steel Socket Head Screw 91502A143	1
10	15-12-0	Face Angle Arm	1
11	15-13-0	316 Stainless Steel Dowel Pin 93600A618	1
12	1610	Encoders	2
13	1620	Zinc-Plated Alloy Steel Button Head Torx Screws 92832A178	5





PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TOP GOLF CALLAWAY BRANDS

TITLE:
LOFT/FACE ANGLE SUBASSEMBLY

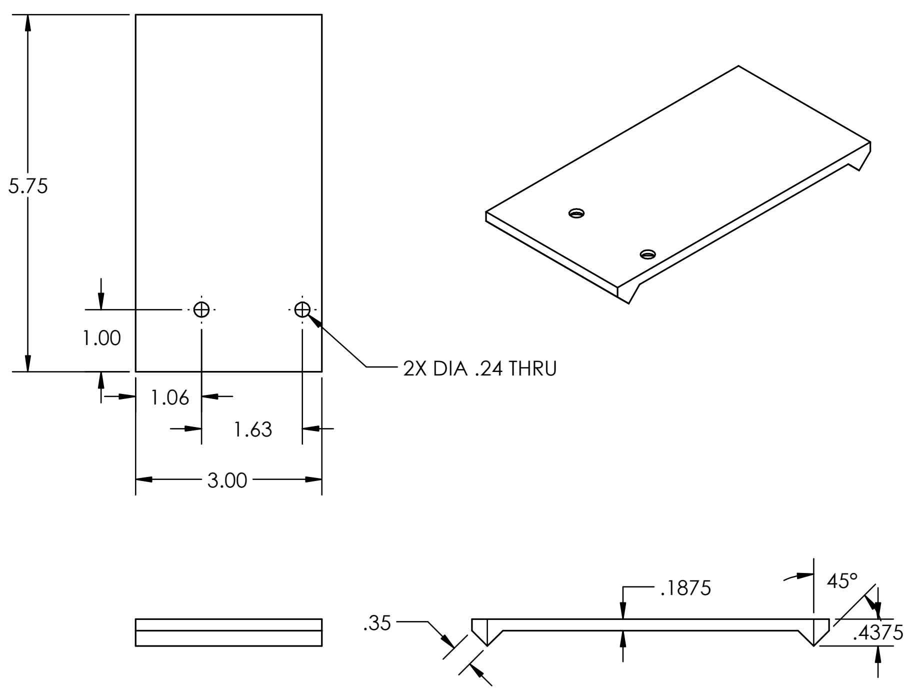
SIZE B DWG. NO. 1500 REV 1

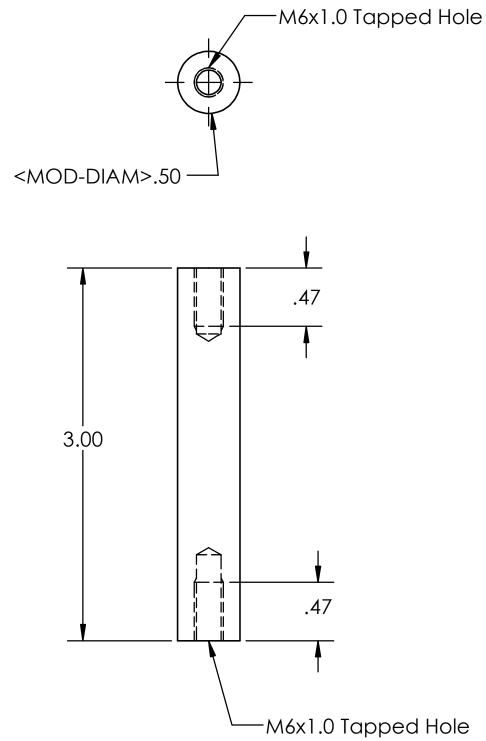
SCALE: 1:2 WEIGHT: SHEET 16 OF 22

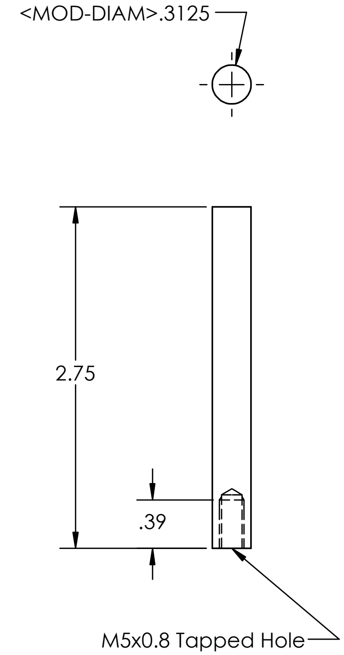
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1510	Loft/Face Slider	1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
3	1530	Slide Shafts	2

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
8	15-10-0	Loft Encoder Shaft	1







PROPRIETARY AND CONFIDENTIAL

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TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TOP GOLF CALLAWAY BRANDS

TITLE:
LOFT/FACE ANGLE SUBASSEMBLY

SIZE **B** DWG. NO. 1500 REV 1

SCALE: 1:2 WEIGHT: SHEET 17 OF 22

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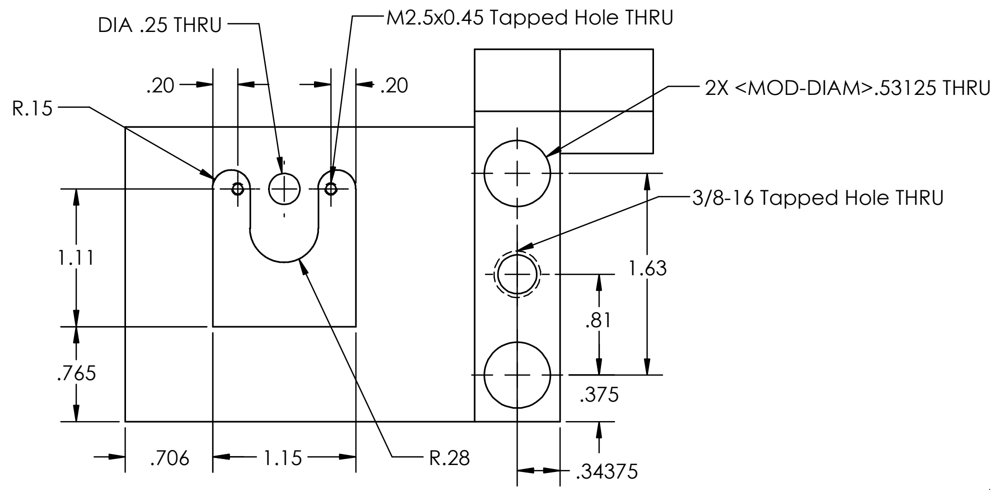
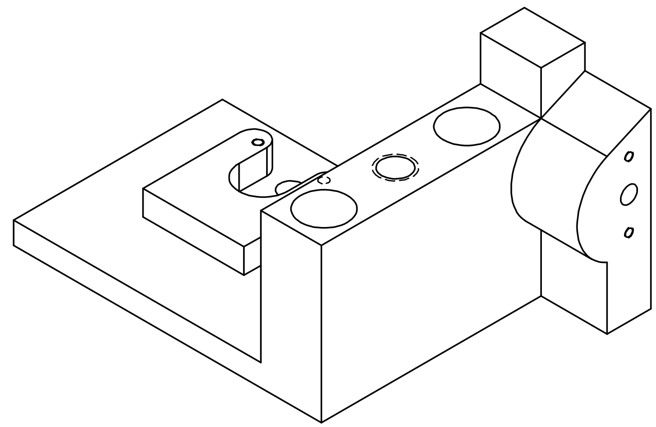
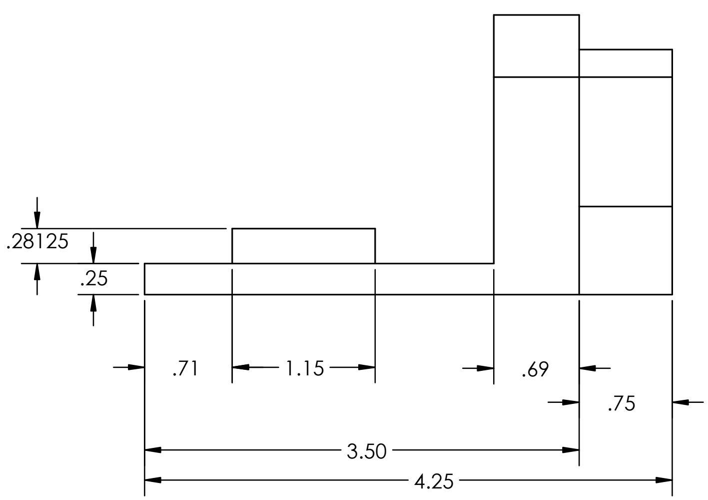
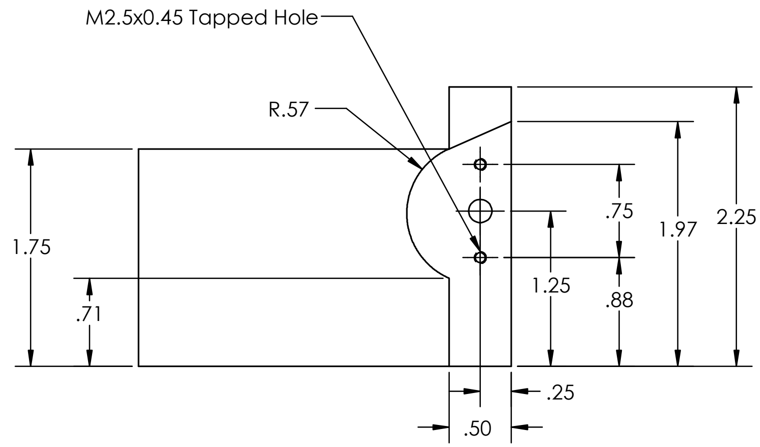








ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
2	1520	Vertical Adjustment Base	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

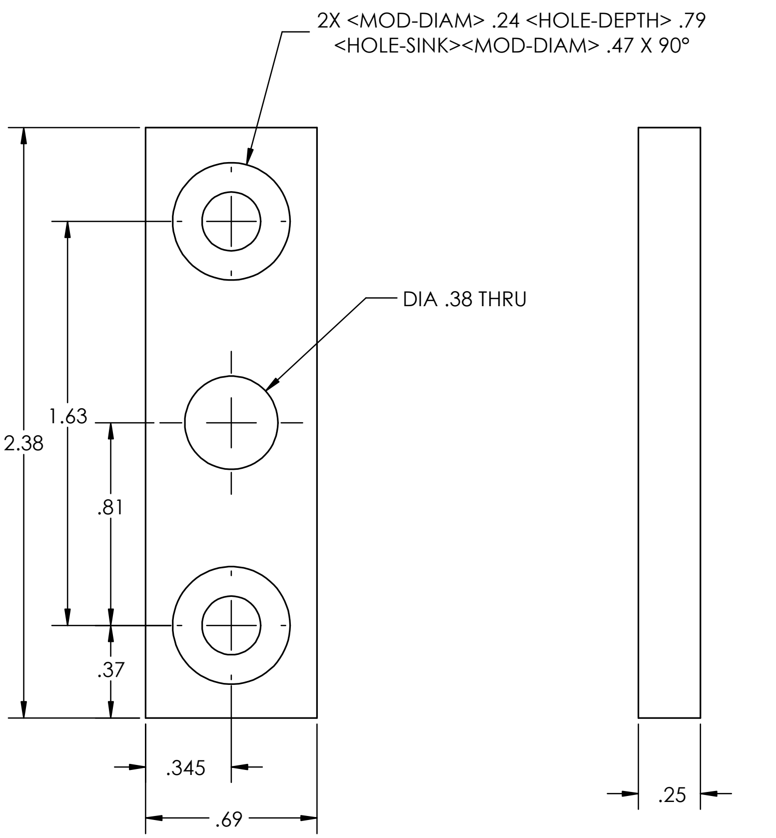
TOP GOLF CALLAWAY BRANDS

TITLE:
LOFT/FACE ANGLE SUBASSEMBLY

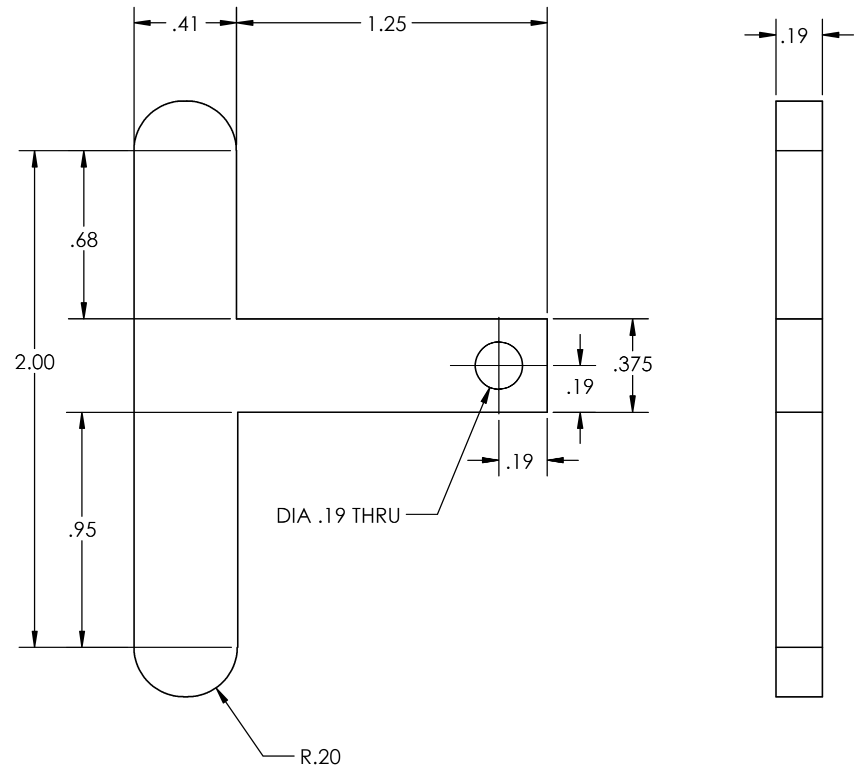
SIZE B | DWG. NO. 1500 | REV 1

SCALE: 1:1 | WEIGHT: | SHEET 18 OF 22

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	1550	Height Cap	1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
7	1570	Loft Flat Iron Contact	1



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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TOP GOLF CALLAWAY BRANDS

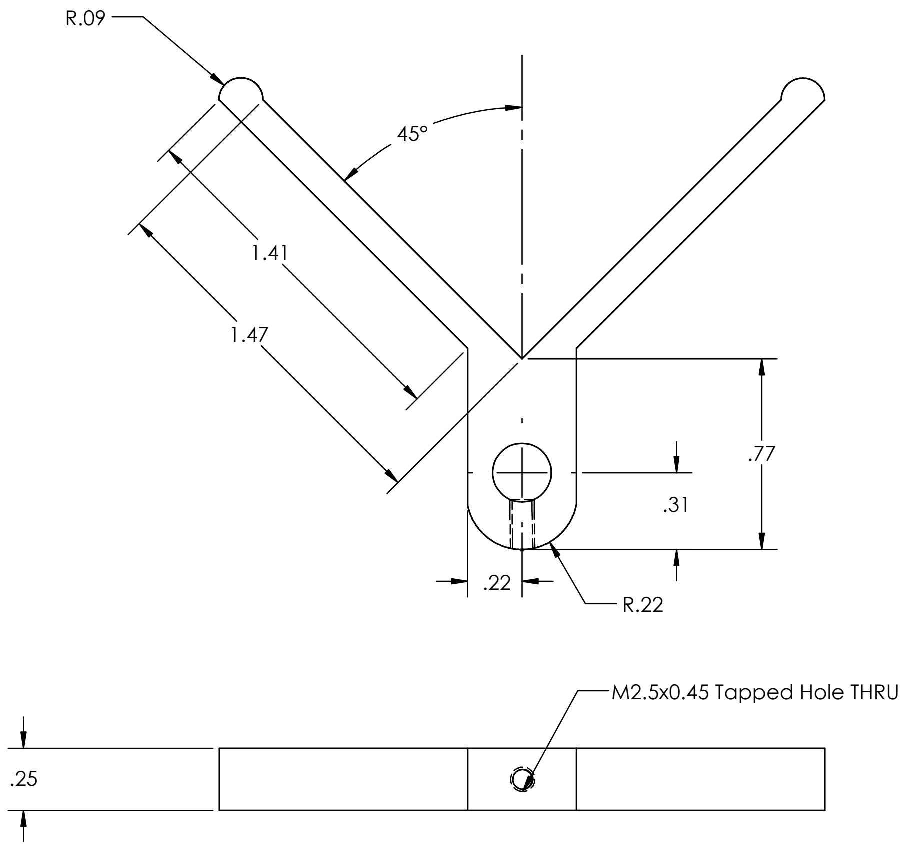
TITLE:
LOFT/FACE ANGLE SUBASSEMBLY

SIZE B | DWG. NO. 1500 | REV 1

SCALE: 2:1 | WEIGHT: | SHEET 19 OF 22

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
10	15-12-0	Face Angle Arm	1



	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

UNLESS OTHERWISE SPECIFIED:
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MATERIAL

FINISH

DO NOT SCALE DRAWING

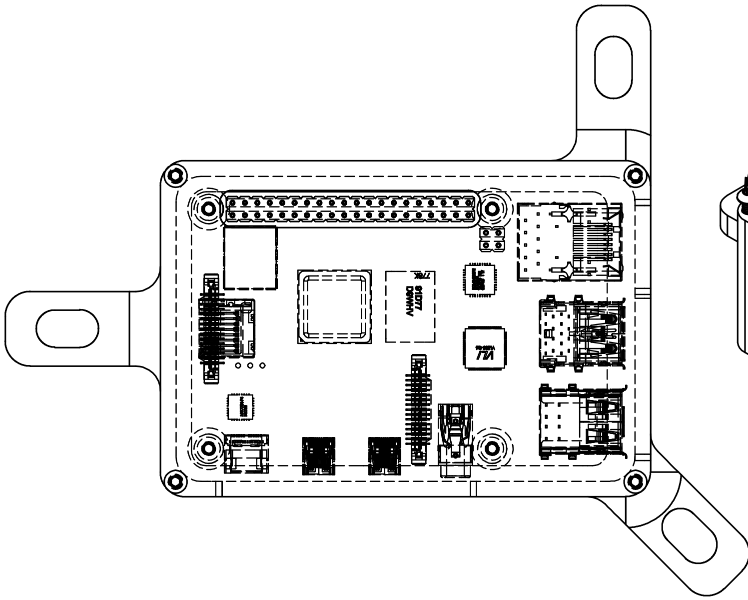
TOP GOLF CALLAWAY BRANDS

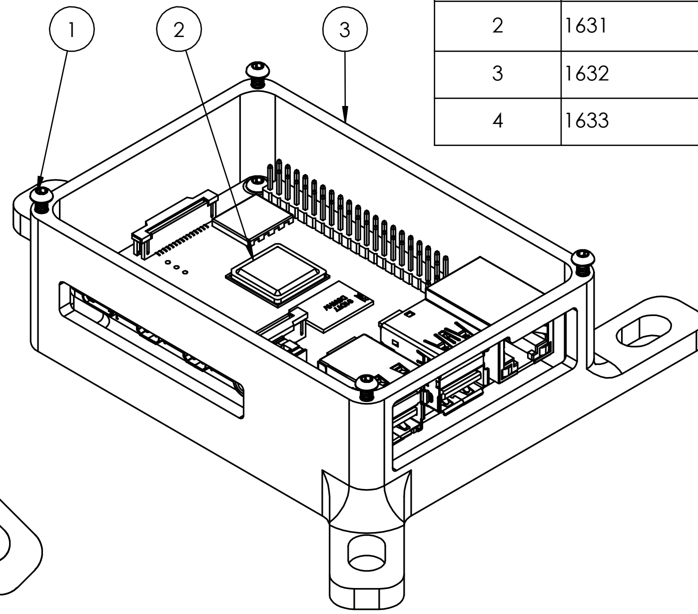
TITLE:
LOFT/FACE ANGLE SUBASSEMBLY

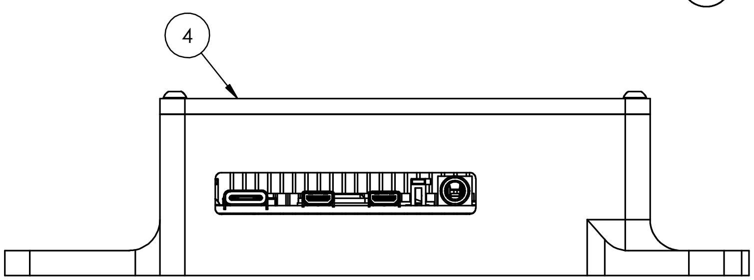
SIZE B | DWG. NO. 1500 | REV 1

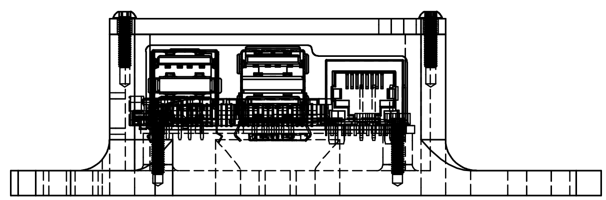
SCALE: 2:1 | WEIGHT: |

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1620	Zinc-Plated Alloy Steel Button Head Torx Screws 92832A178	8
2	1631	Rasphberry PI 4Model B	1
3	1632	Rasphberry PI Housing	1
4	1633	Rasphberry PI Cover	1









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TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: THE HOUSING SHOULD BE EXPORTED TO A STL AND 3D PRINTED. THE COVER SHOULD BE EXPORTED AS A DXF AND CUT OUT OF ACRYLIC ON A WATER JET.

TOP GOLF CALLAWAY BRANDS

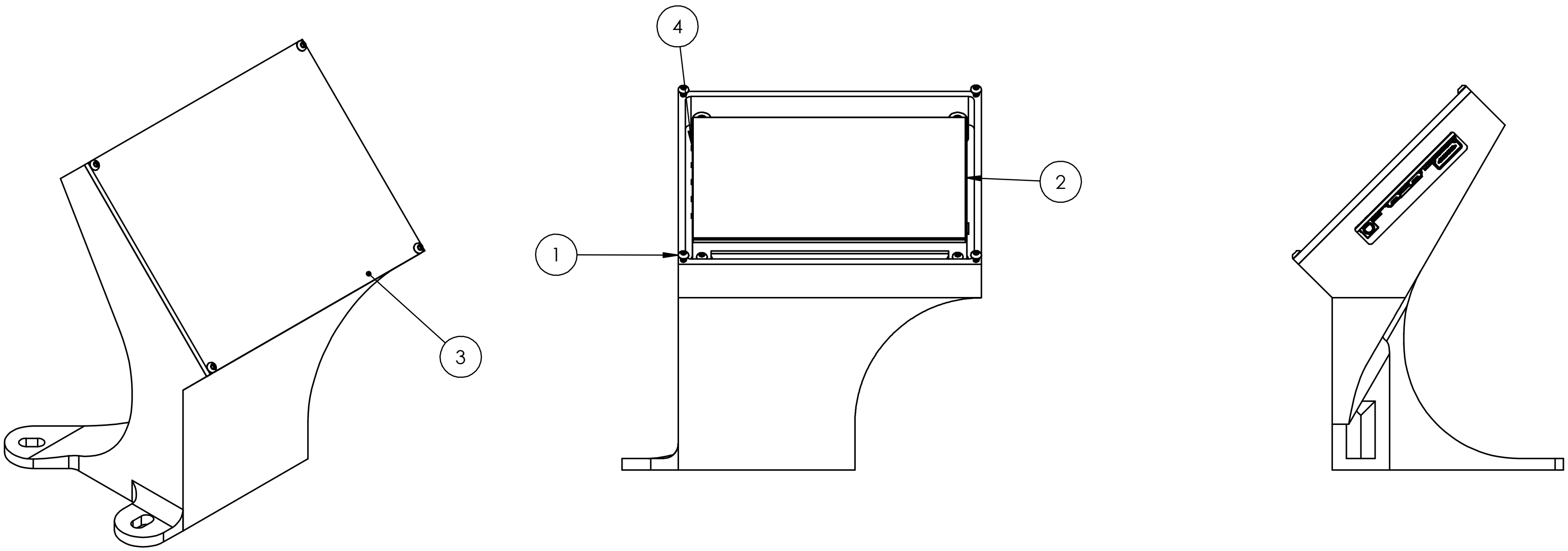
TITLE:

RASPHBERRY PI SUBASSEMBLY

SIZE **B** DWG. NO. 1630 REV 1

SCALE: 1:2 WEIGHT: SHEET 21 OF 22

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1620	Zinc-Plated Alloy Steel Button Head Torx Screws 92832A178	8
2	1641	User Interface Housing	1
3	1642	Display Cover	1
4	1643	Digital Display- REFER to IBOM	1



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TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Sousa	11/28/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: THE HOUSING SHOULD BE EXPORTED AS A STL AND 3D PRINTED. THE COVER SHOULD BE CONVERTED TO A DXF AND CUT OUT ON THE WATER JET.

TOP GOLF CALLAWAY BRANDS

TITLE:

DISPLAY SUBASSEMBLY

SIZE **B** DWG. NO. 1640 REV 1

SCALE: 1:4 WEIGHT: SHEET 22 OF 22