The effects of different stiffnesses and coefficient of drag on the performance of a Padel racket

By

Francisco David Mora Armendariz

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ABSTRACT

The sport of padel is the fastest growing sport in the world. As the sport has evolved there have been more and more innovations in the equipment of Padel. One of the most important was moving from wooden paddles to ones made of fiber glass and carbon fiber. As such a prototype racket was designed and manufactured for this study through experiments to obtain data on existing commercially available rackets, a specific design was proposed and created. The prototype created is then compared to the other rackets in the same way that the original properties were measured. Although this racket needs to continue to be iterated on, the potential of a viable competitive racket is promising.

Thesis supervisor: Anette Hosoi
Title: Professor of Mechanical Engineering

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I would like to acknowledge Professor Anette “Peko” Hosoi for her invaluable help in the creation of this thesis. With her help I was able to develop this thesis and the work behind it.

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I would also like to acknowledge Henry Smith and Megan Gupta-She for helping me build the racket. As well as MIT Motorsports for allowing me to use their composite room for the creation of the racket.

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Contents

List of Figures

List of Tables

Chapter 1: Introduction

The sport of padel began in Acapulco, Mexico with a man named Enrique Corcuera in 1969 [1]. He created a court within his property that was 10m x 20m, with walls around it to prevent vegetation from taking over the court and a net in the middle like a normal tennis court would use [1].

Corcuera created the court because he did not have enough space in his land to make a full tennis court, but still wanted to enjoy the game [2]. The first padel regulations were invented by Corcuera's wife, and thus sparking the beginning of a new sport.

In the 1970s this sport expanded into other Spanish speaking countries like Spain and Argentina [2]. Fast forwarding to 2025, Padel is now played in over 140 different countries with almost 30 million amateur players worldwide [2]. It is now the fastest growing sport in the world [3].

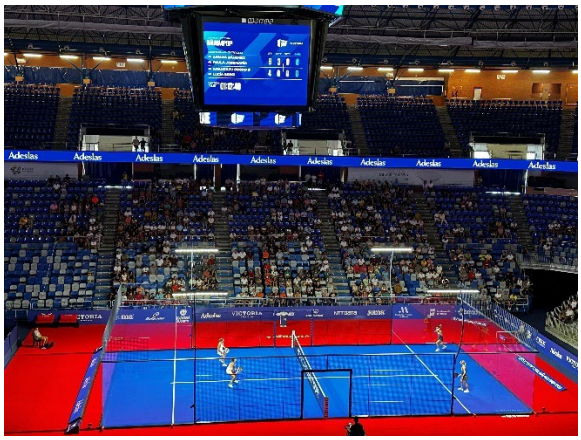

Figure 1: A padel court in Palacio de Deportes Jose Maria Martin Carpena in Malaga Spain.

Padel has had a lot of different types of equipment that it used throughout its history. The sport began by playing with typical tennis balls. As the game got more sophisticated, the balls became more specialized [1]. Similarly the walls used to be concrete, until an Argentine coach named Jorge Galeotti created the glass walls that are used today [2].

However, the biggest inspiration for this thesis is the racket itself. Originally made from wood, rackets have now evolved to materials such as carbon fiber [2].

Modern rackets are made up of a fiber glass or carbon fiber frame with an EVA foam core [4]. Holes are then drilled into it based on the manufacturer's design.

Figure 2: The evolution of what a racket is shown above. One of the first rackets is shown on the left made of wood [5]. The modern racket is on the right made of foam and carbon fiber [6].

Figure 2 shows the evolution of the padel racket, from one of the original rackets to a more modern version. The biggest differences between these two are the materials. Although both have holes, the older rackets were made of wood while the newer rackets have a combination of EVA foam and carbon fiber.

Current Padel research focuses on performance and the competitive aspect of the players themselves including things such as game strategy.

Chapter 2: Background

The coefficient of restitution can be defined as the ratio of outbound speed to the inbound speed in the direction normal to the impact surface [7]. In short it is the bounciness of something. A perfectly elastic collision would have a coefficient of restitution of 1 and a perfectly inelastic collision will have a coefficient of restitution of 0 [7].

The coefficient of restitution can be calculated using equation 1, which shows a ratio between the square roots of the work done during the compression phase of the bounce [8].

$$d \triangleq \sqrt{\frac{W_{nR}}{-W_{nC}}}$$

Equation 1: The ration of the square roots between work during compression phase and the restitution phase.

Taking assumptions of a perfectly vertical bounce and parallel surface, we can simplify this equation to that of equation 2. This simplification can also be made because of the assumption that the mass of the ball stays the same throughout the bounce.

The coefficient of restitution is affected by many factors. This includes the material of the ball and the bouncing surface, but it also includes the temperature and humidity [7].

Typically a ball will bounce more if it is more stiff and if the bouncing surface also has a higher stiffness [9]. A good example of this is a ping pong ball. It is a hard plastic ball bouncing on a racket. Similarly brand new tennis balls tend to bounce more because they have a higher air pressure, reducing the amount of deformation within the wall of the ball [10].

Other factors involved are the coefficient of drag and the stiffness of the racket. The coefficient of drag is a number that aerodynamicists use to model all of the complex dependencies of drag on shape [11]. In the case of a padel racket the drag coefficient will help to quantify the ease that a person would have of swinging the racket head. Typically, the easier a racket is to move the more control a player has on what the ball will do.

Within padel the coefficient of drag is highly dependent on the racket head size, the speed at which the racket swings at, and the hole pattern. Manufacturers will adjust all of these parameters to get the type of racket that they are looking for. Often having to make tradeoffs between aerodynamics and stiffness or the racket. This comes from the fact that adding the holes will affect the stiffness of the racket. This comes from the total area of the racket being reduced but also decreases the weight and therefore increases swing velocity.

The stiffness is used to describe the force needed to achieve a certain deformation of a structure [12]. The stiffness of the racket affects the way that the ball bounces. Typically, the

higher the stiffness the higher the bounce. This comes from the fact that a bouncy ball, in this case a padel ball, will want to return all the energy into itself. Therefore the less the bouncing surface deforms the more of that energy is returned to the ball itself [9]. The stiffness of the racket also determines the shock and vibrations felt by a player [13]. The higher the stiffness the less shock and vibrations that are felt by the player.

Assuming that the padel racket would act similarly to a tennis racket, there is a balance that needs to be struck with stiffness. Dampening the shock of the ball, contacting the racket is important so as to not injure the athlete, but too little and the player does not have a good feel for the ball [13].

Overall, there is typically a balance that racket manufacturers must make between different characteristics of a racket. Whether they want to balance weight, drag, stiffness, and so many other aspects that can't be measured such as color and feel which affects the way the athletes interact with the rackets. Within this study the coefficient of drag, stiffness, and coefficient of restitution were considered. The shocks and vibrations of the racket were not considered but future work should investigate it further.

Chapter 3: Methods

In order to first design the racket a baseline of what a “typical” racket’s properties were needed to be determined. This was done by taking different rackets that are commercially available and testing them. Figure 3 shows the four different types of rackets that were used.

Figure 3: From left to right this is the adidas racket, siux racket, mack racket, and head racket. Their colors of red, orange, brown, and purple will be used to represent each racket respectively.

Each racket has it’s own unique structure and price point. The materials of them are also slightly different where the adidas and siux rackets are made from carbon fiber the mack and head rackets are made using fiber glass. Each racket has it’s own design. For the sake of simplicity and better organization each racket will be represented by their own colors within the data. From left to right it will be red, orange, brown, and purple. Aligning with the design of each racket.

The qualities of the racket that were needed for this study were coefficient of restitution, stiffness, and coefficient of drag. Other properties such as mass, surface area, etc. were intrinsic properties that were easily measurable. The first three needed to be experimentally determined.

In order to determine the coefficient of restitution a drop test was created. Figure 4 shows the set up that was used to create the experiment.

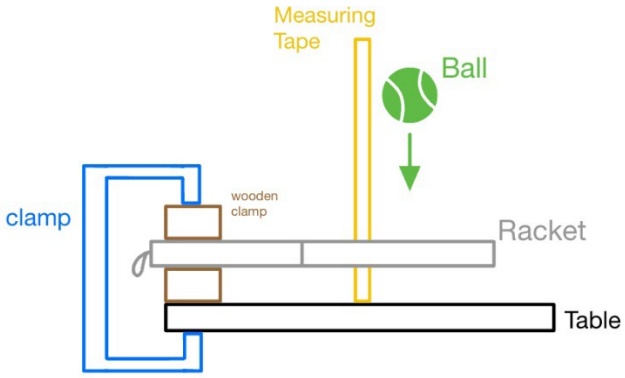

Figure 4: The set up for the drop test is shown. A ball is dropped somewhere near the center of the head of the racket. The racket is supported by a custom made wooden clamp that is secured to a table by another clamp. A measuring tape is placed in the background that is used in the video to determine the height of everything.

The clamp that was used was to wooden block that were bolted together. The clamp was then held on the table to prevent it from moving. This wooden clamp mimicked a person holding a racket in their hand. The ball was then dropped from approximately 1.7 m and filmed on a high speed camera at 240 fps. Using this video the height of the ball before and after bouncing was determined, as well as the change in velocity before and after impact on the racket. A measuring tape was also placed in the background to help determine the scale so that the heights and velocities could be easily evaluated.

Finding the coefficient of drag was the next step. Figure 5 shows the setup that was used to determine the drag on each racket.

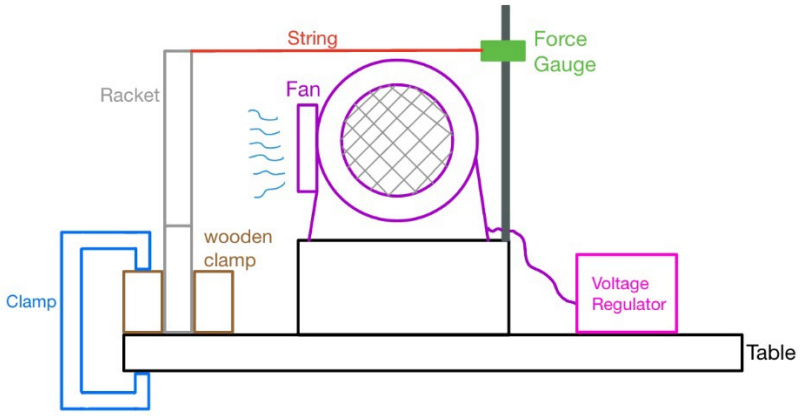

Figure 5: The set up for the drag coefficient is shown. The fan is pushing on the racket that is secured by a custom wooden clamp that is secured to the table via another clamp. The string attached to the force gauge measures the difference in tension before and after the fan is turned on. The voltage regulator helps to vary the speed of the fan.

A centrifugal fan was set up in front of a force gauge that was attached to the racket to determine the force that the wind pushed on the racket. 30 trials were run where an anemometer would measure wind speed and then force was determined. The strength of the fan was controlled via a voltage regulator.

The typical swing speed of a racket is an order of magnitude larger than what the fan could achieve. However, the small trend within the deviations of wind seemed promising. This should provide a reasonable estimate. Note that the voltage regulator was randomly set at different voltages to get a range of wind speed.

Finally testing the stiffness of the racket was performed using an Instron machine. Using a modified block, as seen in figure 6, that used a padel ball to push down on to the racket the stiffness was calculated based on similar characteristics that would be seen in a game.

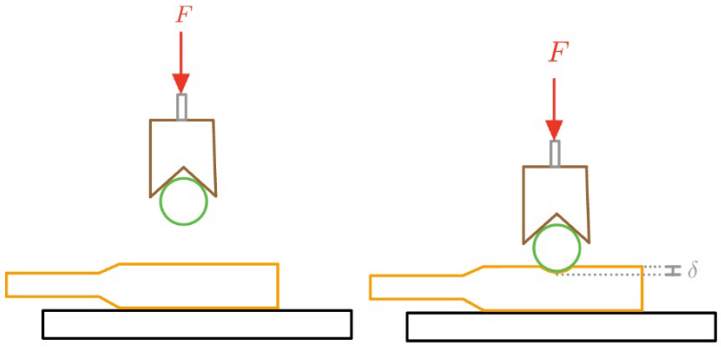

Figure 6: An Instron machine was used to push down on the racket. A custom block can be seen which was cut to fit a tennis ball within the two teeth. This ensures that the ball is always centered on the pressure block and allows for a repeatable experiment.

The Instron ran until it reached two newtons of force, and then plunged into the racket for 3 mm. This provided enough data points to determine stiffness without the possibility of breaking any of the rackets.

Other properties such as head surface area, hole area, and weight were determined with basic tools such as rulers and balances respectively. The manufacturers' details were also used when data was not complete.

Chapter 4: Results

From the first experiment, the coefficient of restitution can be determined. Since the ball begins at rest and frictional forces on the racket can be neglected, equation 2, provides the necessary calculations to determine the coefficient of restitution, e [14].

$$e = \frac{\sqrt{h_{bounce}}}{\sqrt{h_{initial}}}$$

Equation 2: h_{bounce} is the height of the bounce and $h_{initial}$ is the height of the ball at the starting point.

Here h_{bounce} is the height that the ball reaches after it collides with the racket. $h_{initial}$ is the starting height of the ball. The coefficient of restitution gives how "bouncy" something is. Figure 7 shows the coefficient of restitution for the four rackets.

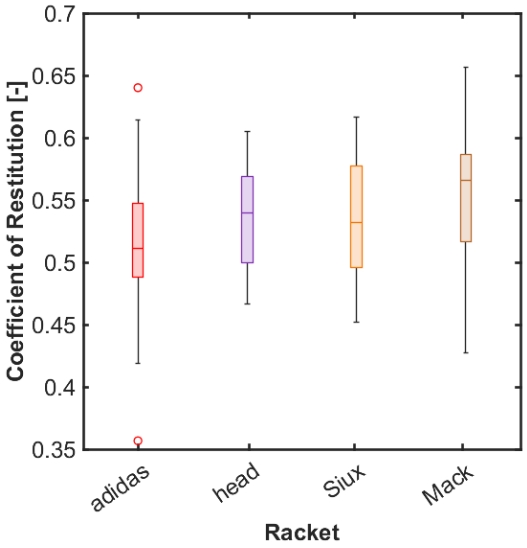

Figure 7: The coefficient of restitution is shown for the adidas, head, Siux, and Mack racket. Where the median values are 0.511, 0.539, 0.532, and 0.566 respectively.

It is clear that the coefficient of restitution for all of these rackets is relatively similar. Although the Mack racket has a slightly higher median. From the feel of the rackets the one that feels the bounciest is the Siux racket. The slight discrepancy between the feel and data are likely caused by minute changes in vibrations that are felt on the player's hand when the ball makes contact. It is also important to note that the Mack and the Siux rackets are made from fiber glass and carbon fiber respectively.

Next, in order to determine the coefficient of drag for each of the rackets the force that the wind applied to the racket was necessary. Using the set up from experiment two, figure 8, shows the force felt by each racket.

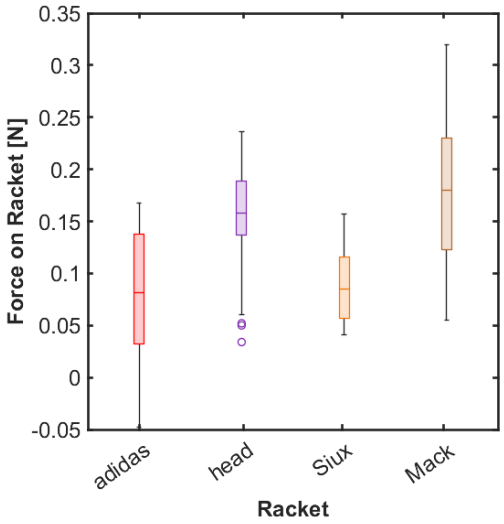

Figure 8: The force exerted by the wind on the racket is shown. The big whiskers are likely due to the variation of wind that came from the voltage regulator. The median from left to right is $0.082\ N$, $0.158\ N$, $0.085\ N$, *and* $0.180\ N$.

The coefficient of drag was determined using equation 3 [11]. For the area of the racket a total area of the face of the racket subtracted by the area of the holes was used.

$$C_D = \frac{2 \times F}{\rho \times A \times v^2}$$

Equation 3: F is the force that the racket feels. A is the surface area of the racket. ρ *is the density of air. And* v *is the velocity of the air.*

Table 1, shows the different drag coefficients for the different rackets.

Racket	Drag Coefficient
adidas	1.45 ± 0.405
Head	4.43 ± 0.488
Siux	2.35 ± 0.189
Mack	2.88 ± 0.161

Table 1: The respective drag coefficients for the rackets is displayed. The lowest coefficient of drag comes from the adidas racket and the highest from the head racket.

The racket with the smallest drag coefficient is the adidas racket. This means that it is theoretically the easiest to swing through the air. Qualitatively this is accurate, as this racket feels the best when moving. However, it is also important to note that the difference in feel is almost negligible when not in a competitive environment.

Finally, the stiffness was determined using the Instron, and the third test as described in the previous chapter. Figure 9, shows the results from the test.

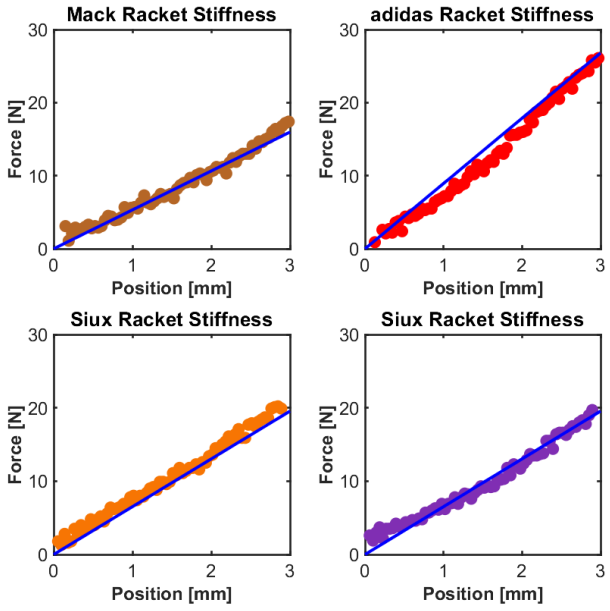

Figure 9: The position vs force is shown for each racket for a distance between 0-3mm. A fit line was then calculated. The slope of this line is the stiffness of each racket.

A first-order line, was used to determine the line of best fit. The slope of the line is the stiffness of each respective racket, as seen in Table 2.

Racket	Stiffness [N/mm]
adidas	8.94 ± 0.230
Head	6.52 ± 0.217
Siux	6.52 ± 0.174
Mack	5.32 ± 0.191

Table 2: The respective stiffness for each racket is shown. The highest stiffness being that of the adidas racket and the lowest stiffness being the Mack racket.

This shows the adidas racket to be the stiffest racket while the Mack racket is the least stiff. The determined values make sense as the adidas and the Siux rackets are made using carbon fiber while the head and Mack are made using fiber glass. This likely means that the foam of the Siux is less stiff than that of the head racket, for them to have similar values.

The data that was collected was used to influence the design of the racket. This is further explained in the next chapter.

Chapter 5: Design

Using the results of the previous data the stiffness, hole area, and ideal drag coefficient were determined somewhere in between all the other rackets. This was done based on qualitative data taken from many interviews, where the ideal racket is not too stiff so as there to be not much control, but stiff enough to hit hard. The ideal location is shown in figure 10.

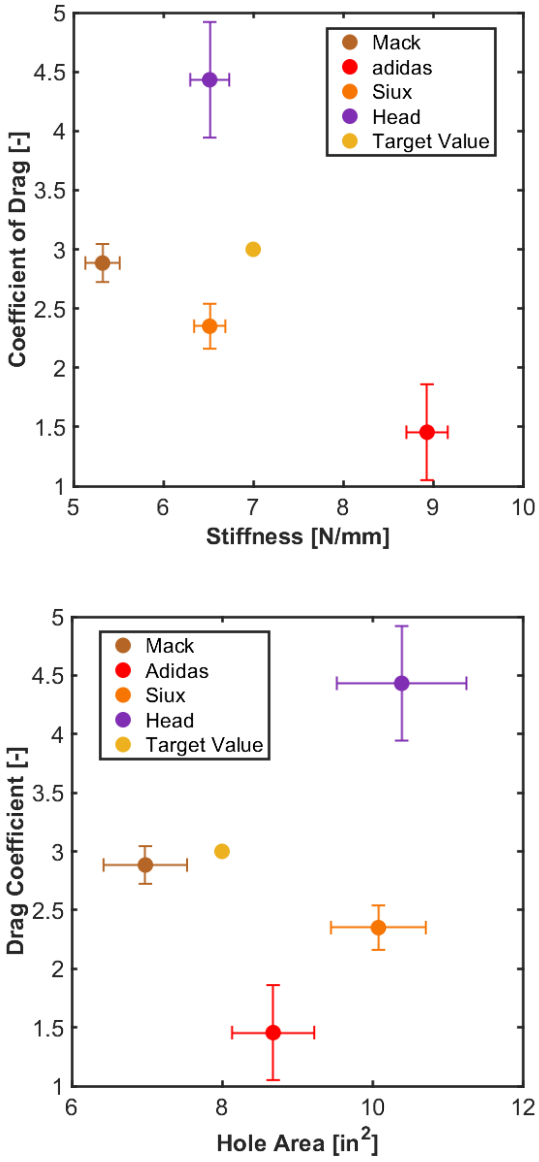

Figure 10: The location of the target value has a value of $7\ N/mm$ *with a coefficient of drag that is* 3*. These values are displayed with the other rackets measured around it. The desired hole area, which would theoretically give us the ideal coefficient of drag is* $8\ in^2$*.*

Using these values the material selection process was the next step. The main design constraint for selecting materials was the stiffness of the materials. Using a stiffness model of three springs in series, as seen in figure 11, the ideal stiffness of the carbon fiber and the foam were selected.

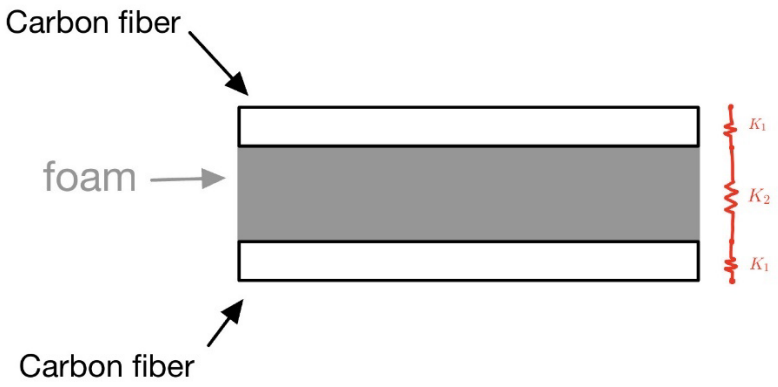

Figure 11: The basic model of the structure of a racket is shown. The stiffness of the entire racket would be the three stiffness in series, where both carbon fiber parts would share the same stiffness.

Equation 4, shows how the different stiffnesses were modeled and chosen for the ideal value of the total stiffness.

$$k_{tot} = \frac{1}{\frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_1}}$$

Equation 4: This is the model of adding springs in the series. Assuming each layer of the racket to be a spring it is possible to consider all of the stiffness to get the total stiffness k_{tot}

The foam that was selected has a density of 2 lbs/ft^3 and the carbon fiber that was selected is Carbon Fiber Fabric 2×2 Twill Intermediate Modulus 6k 205gsm/6oz 50" Hexcel IM7. Using their respective data sheets to find their stiffnesses it was determined these materials were the ones that would be satisfy the requirement. A lot of assumptions were made in this step due to the lack of data within each part. For example, for the carbon fiber only the compressive strength is provided, which we can equate to stiffness, however this does not take into account the epoxy that will be needed to use to cure the carbon fiber into the racket shape. The foam stiffness was also estimated using the Shore00 hardness scale, where the ideal hardness would be within the range of Shore00 90 ± 5.

With the materials chosen, a design was created. Utilizing SolidWorks as the main CAD software to draw upon the design, I was able to create a basic 2-Dimensional outline of the ideal racket that was extruded to the desired width (as shown in figure 12), that remained within the rules of the game.

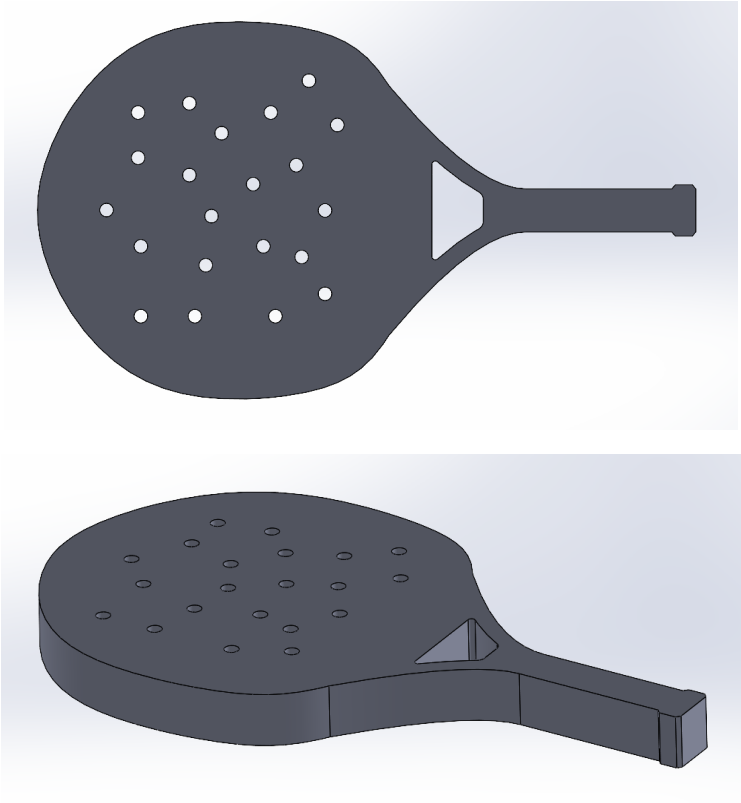

Figure 12: The racket design was based on the hole area that was needed for the target value of the coefficient of drag. The hole pattern was chosen at random.

The final design of the racket differs from this CAD model due to the more complex geometry that is required within the handle. There are chamfers along the corners of the handle that give a more ergonomic feel. These small details of the design will be further explained within the next chapter. However, the basic design of the racket was drawn upon this model.

Chapter 6: Manufacturing

Unlike professional rackets I needed to design this racket in a different manner due to the limitations of the equipment available to me. One of these items that is unavailable is a mold. Typically, rackets are made by placing the carbon fiber within a negative mold, that would form the racket. However, this process requires curing through an oven. Since I had no access to a mold nor an oven, I needed to mold the shape in a different manner.

A green molding foam was used to create the handle. As seen in figure 13 the handle was cut from a block of green foam and then slowly cut out pieces until the desired shape of the racket was achieved, based from the CAD model.

Figure 13: The handle was made from green molding foam. The outline was cut using a bandsaw and everything was then sanded down to desired dimensions.

I needed to separate the way that the head of the racket was made with the handle due to the different materials required for each part. The head needed to be the EVA foam that was determined from the design stage, while the handle needed to be made of something that was easily sculpted. The head of the racket was then cut from the EVA foam sheet and sanded down to the desired shape (as seen in figure 14). Using a CAD drawing, I was able to easily match the dimensions of the CAD with that of the real life foam, ensuring that both the handle and the fit together.

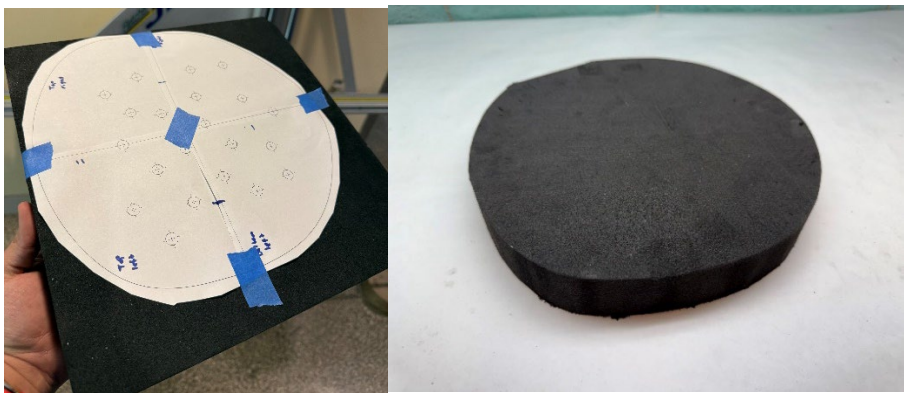

Figure 14: The EVA foam sheet had the outline of the racket head taped onto it, that then was used to follow the outline to form the shape into what would become the head.

The next step was to combine both foams together to form what would become the basic mold of the racket (figure 15). Using a spray foam adhesive, these two shapes were able to be strongly attached to each other. The EVA foams relatively low stiffness allowed it to bend into the shape of the handle allowing it to compensate for slight errors while manufacturing.

Figure 15: The EVA foam and the green molding foam are connected using a foam spray adhesive. This becomes the mold of the racket that will be wrapped in carbon fiber.

The next step is to wrap the racket in carbon fiber. This was accomplished within the MIT Motorsports “death room.” This is the only place on MIT’s campus where composite work could be accomplished. Once in place, the carbon fiber sheet was cut into two squares that would be able to cover up the entire racket. Then a mix of epoxy was created using Easy Composite Laminating Resin was used with a slow hardener (figure 16).

Figure 16: Epoxy is being mixed into the mixing cup using the manufacturers specifications. Within this step it was important to wear PPE to ensure that the process was as safe as possible.

This epoxy was ideal for this purpose because it would provide us enough time to fold the carbon fiber, without worrying about the curing time while we were working on it. Since this was a first time working with carbon fiber, it was ideal to take things slow.

The sheet of carbon fiber was then laid flat on the table on top of a vacuum bag. This vacuum bag was going to be used to help create an airtight seal that would be used to help mold the carbon fiber around the racket in a more uniform manner.

Then I applied the epoxy on to the carbon fiber using a disposable paint brush. (figure 17).

Figure 17: The epoxy that was mixed was then applied to the carbon fiber sheet using a disposable brush.

The mass of carbon fiber to epoxy was 1:1 according to the manufacturer, so it was important that this ratio be maintained. Once the carbon fiber was fully epoxied, the racket was placed on top and a second layer of carbon fiber was placed on. The epoxy was spread out through the second layer of carbon fiber and slowly pressed onto the mold. Once carefully molded over the entire racket, the racket was secured within the air tight sealed bag, and a vacuum was turned on (figure 18).

Figure 18: The vacuum bag was sealed tight using foam tape and the vacuum placed within the air pocket to suck out all the air.

After 24 hours, the carbon fiber was fully cured and ready to be cut into the proper shape. Using a Dremel, the basic outline of the racket was cut out, and everything was sanded down to ensure that the racket was as flat as possible. Holes were then drilled into racket following a similar pattern to the CAD model, but not maintained due to the lack of precise machinery available. One last hole was cut into the bottom of the handle where the safety strap would be attached. Figure 19 shows what the racket looked like after leaving the death room.

Figure 19: The racket was fully functional at this point. There were a few details that still needed to be completed before it was legal to play with.

The safety strap was needed to finalize the design of the racket. It was created using fabric from MIT's Metropolis Maker shop. By folding some of the fabric multiple times and sewing it together the strap was the completed (as seen in Figure 20).

Figure 20: The strap was made using dimensions from the other rackets. The color yellow was chosen due to the author's preference.

Once the strap and the racket were complete the last step was to place the strap within the racket itself. This was accomplished using a different form of epoxy. Using a silica based epoxy, the hole that was drilled within the base of the handle was filled. The strap was then inserted and then the rest of the handle was filled with remaining epoxy to ensure that the strap would remain in place (figure 21).

Figure 21: The epoxy that was used is slightly white in color. It was used since it will be strong enough to support the safety strap while having a relatively fast curing time.

Once the epoxy cured, the final step was to wrap the handle in an over grip. This is typical with other rackets as well. Figure 22 shows the final design of the racket. The name of the racket was then chosen from the color scheme of the racket, hence why it will now be known as the Wasp.

Figure 22: The final racket is now competition ready. The strap is attached, and the handle is ready and easy to grab. The yellow tape was used to ensure the over grip will not come off.

Certain issues arose while manufacturing. The biggest of them all came from laying out the carbon fiber. Due to the lack of experience and equipment, the hole that is typically within the handle, which can be seen in Figure 13, was covered up to ensure that the carbon fiber would not break before it was cured.

The vacuum bag also did not work. This created in a few uneven parts around the racket, but did not prevent the racket from having it's proper form.

Finally, the two layers of the carbon fiber did not bond together all that well, and so there are a few areas around the racket where the inside foam is exposed.

The holes created were also slightly different than the design because of the lack of drill bits available at the time of manufacturing. Since the holes were drilled using a hand drill, there is also a lot of tear within the foam. This likely creates a higher drag coefficient since there is not good airflow within like there are in other rackets.

Finally, the process had to be redone multiple times due to unforeseen trouble that was not considered at the time. This was not described in the procedure of how the racket was made.

All in all, this does not create major performance issues, besides the hole within the handle (see chapter 7).

Chapter 7: Comparison

Using the same test setups as was described before for the other rackets, the qualities of the Wasp were determined. The stiffness was once again determined using an Instron machine. Figure 23 shows the data.

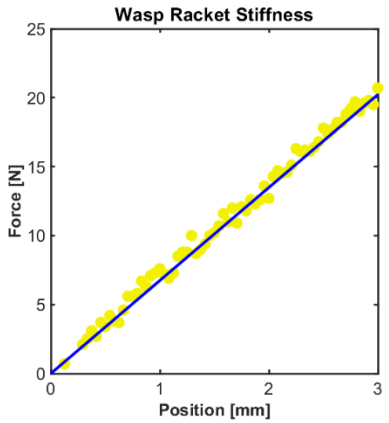

Figure 23: The Instron data is taken and used to determine the stiffness, which would be the slope of the fitted line. This gives a stiffness of 6.74 ± 0.14.

The coefficient of drag was found in the same way as described in chapter 3. Figure 24 shows the Hole Area vs Drag coefficient graph. Comparing the Wasp with the other rackets.

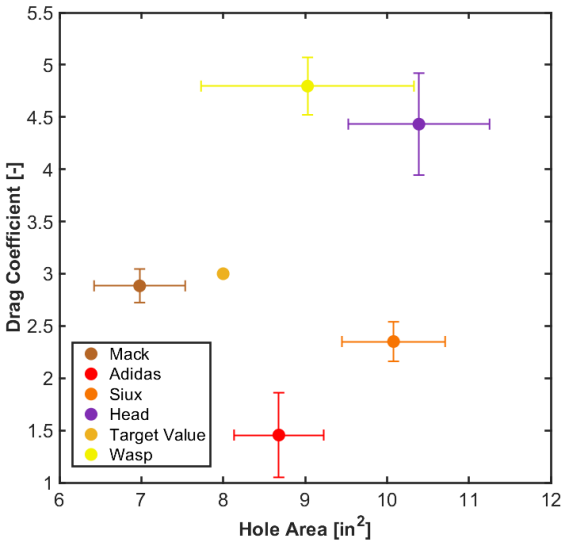

Figure 24: The error bars of the hole area are bigger for the Wasp because, besides the measurement errors, there are also manufacturing errors that do not exist with the professional rackets.

The area of the Wasp is seen as higher than the target value because there was some misalignment while drilling the holes and the drill bit that was used was the wrong size, but it was what was available at the time. The coefficient of drag can also be seen as much higher than the target value.

Figure 25 shows the force that the racket felt during the wind resistance testing.

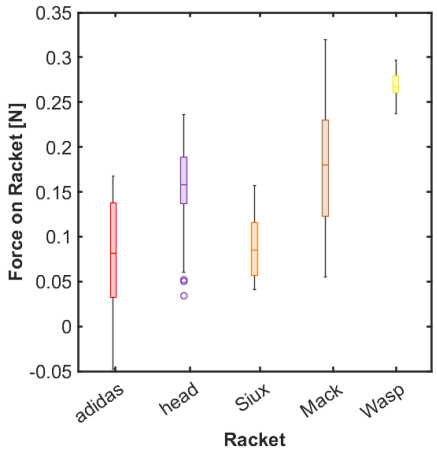

Figure 25: The mean force felt by the wasp racket is higher than that of the other rackets. This is likely due to the manufacturing error as described in chapter 6.

Figure 26 shows the same drag coefficient but plotted against the stiffness of the rackets. Similarly, it is clear that the coefficient of drag is higher than expected. However, the ideal stiffness is almost within the error bars of the measured stiffness.

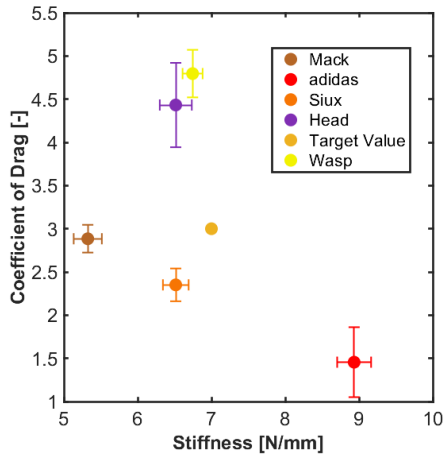

Figure 26: The stiffness of the wasp racket is 6.74 ± 0.14. This gives a nominal difference of 0.26 from the ideal stiffness. This gives good proof that the initial model was relatively accurate.

The fact that the measured stiffness is almost within the target value likely means that the initial assumptions made about foam and carbon fiber, were not that far off. The error likely comes more from the manufacturing of the racket rather than the materials themselves.

The error for the coefficient of drag is likely caused by this as well. Considering that the hole within the handle is covered, this increases the total area of the head of the racket. This drives up the area that must pass through the air, making it less aerodynamic.

Finally, it is important to look at the coefficient of restitution of the racket. Although the other results are not within the ideal range, they are somewhat expected due to the manufacturing errors. However, as seen in Figure 27, the Coefficient of Restitution for the racket is much lower than all the professional rackets.

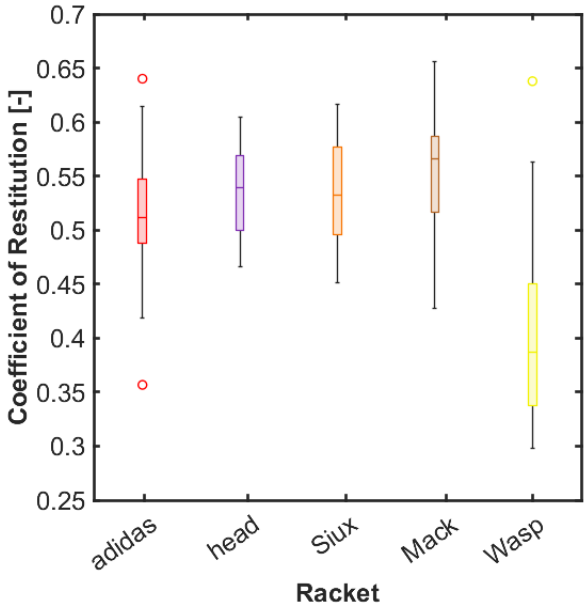

Figure 27: The coefficient of restitution for each racket is shown. The wasp has a much lower mean than all the other rackets.

The coefficient of restitution is also evident when playing with the wasp racket. Qualitatively, it feels a lot slower than the other rackets. There is also a lot less weight at the head of the racket than the other rackets have.

There are a few possibilities for this. One possibility is that the “sweet spot” is not at the head of the racket as with the other rackets. Another possibility is that there are vibrations within the racket that dampen the bounce a lot more in the Wasp than in the other rackets.

Understanding the errors within the racket are out of the scope of this thesis.

Chapter 8: Summary

Future iterations of the wasp racket would be needed to dial in the ideal stiffness, coefficient of drag, and coefficient of restitution. Due to the short timeframe of this study, only one prototype was manufactured. Future iterations should look into ensuring that the materials chosen will satisfy all of the target values. Other characteristics of the racket such as shock and vibrations should also be taken into consideration. Future iterations would also be designed for a different manufacturing process that includes a curing oven and more practice on tougher geometry when working with carbon fiber.

Due to the short timeframe of this study, a flow simulation of the racket aerodynamics was not completed. Future iterations should complete this to ensure that the hole pattern that is made can be optimized. A CNC machine with the proper tooling and speed should also be used to make the holes within the racket so as to prevent all the tearing within the foam. This would drastically improve the airflow within the holes.

The wasp racket that was designed to fill a gap that other professional rackets do not fill was made. The stiffness of the racket drove the design of the racket, along with the coefficient of drag.

Both specifications were not met, although this is likely due to manufacturing errors rather than the design itself.

Overall, though, the racket is viable for play and is within 2.5% of the regulations. These are due to the few manufacturing errors that occurred. Although this means that the racket would not be allowed in official competition, the Wasp can still be used to play Padel casually.

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