# Adapted Musical Instrument

An Interactive Qualifying Project Report

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Submitted to

Worcester Polytechnic Institute:

Professor VJ Manzo, Advisor

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## Introduction:

This project studies the bracing and its function on acoustic guitars. All acoustic guitars have supports built on the upper side of the body to enhance the strength of the guitar. These supports, known as bracing, not only enhances the strength but also allows the sound to vibrate.

One of the problems that acoustic guitars tend to have is over bracing. Guitars are sometimes over braced and because of this, the guitar will not produce a warm and rich tone as expected. Guitars that have bracing that are too thick are labeled as “over braced”. These guitars are structurally strong, but due to excessive thickness in the brace, the top of the guitar will not vibrate freely which puts a constraint on the sound of the guitar. Along with understanding the function of the bracing, the team's goal is to build a prototype that will allow guitar builders to shave off any additional amount of material in order to achieve a resonant tone. To do this, the team will be studying different types of bracing on existing guitars.

This project primarily seeks to answer the questions on the development and modification of the bracing. Some of the topics that will be discussed in this project are:

1) What is an ideal shape of the bracing that can be implemented on most acoustic guitars?

2) How would the builders know the strength and the sound it would produce without assembling the guitar completely?

3) Is it possible to make modification to the bracing (such as shaving) on guitars that has been completely built?

4) What tools/software can be used to analyze the strength and sound of the guitar?

## Background:

Before designing a device to shave the bracing, it is important to study about the bracing and existing braces on guitars. This section explains the importance of bracing on an acoustic guitar, traditional methods builders use to modify the braces and finally the different types of braces structure and the variation of bracings.

Bracing on acoustic guitars has mainly two functions. It provides structural integrity and allows the sound to vibrate and produce a resonant tone. For this reason, the bracing is labeled as mechanical-structural and mechanical-sonic support [1]. Without the bracing the top side of the guitar will eventually break due to the vibration of strings. If the top of the guitar is made thick without the bracing, it might be able to withstand the stresses, but it will not be able to produce desirable sound.

Bracing is done to other instruments such as violin, ukulele, cello and double bass as well. In contrast to acoustic guitars, these instruments use a fixed pattern in most of them, whereas guitars have wide variety of patterns. Along with the patterns, the number of bars, thickness and the positioning of the brace are important parameters. All these parameters can have an impact on the dynamic of the sound.

Acoustic guitar bodies are made from extremely thin wood, usually between .080″ and .125″ thick [3]. This thin wood has nowhere near the amount of strength required to hold up against the constant string tension and pressure. Therefore, the inside of an acoustic guitar has braces running across the top and back. Some acoustic guitars even have small braces on the sides of the body [3]. These braces help reinforce the guitar body as well as transfer the tone.

Acoustic guitar bracing is traditionally made of lighter weight woods like Sitka Spruce. Light woods are usually desirable because they don’t dampen the vibrations of the guitar body. When the strings are played, they vibrate the bridge, which transfers energy to the top of the guitar [3]. Anything that is glued to the top of the guitar will deaden the vibrations. To put it in perspective, the heavier the braces are, the more difficult it is for the strings to vibrate the top of the guitar.

Bracing are installed at key spots to add stiffness, and later they are usually scalloped to achieve a resonant tone [5]. Many builders glue the brace on to the soundboard first and then shape them as necessary. This method isn't necessarily wrong and still can give a good sound from the guitar, but some builders find it efficient to shave the bracing first and then glue it to the soundboard.

Scalloping the bracing has an important role in the sound a guitar produces. Scalloping is way to control the pitch of the guitar. The length of the brace is reduced by scalloping which increases the pitch and by shaving and reducing the height of the brace, the pitch is lowered [5]. Scalloping at different section can produce different pitch. For instance, the farther scalloping is done from the edge the higher pitch sound it will produce [5].

In order to design a prototype, several existing tools were studied along with the approach builders have been using up until now. Builders tend to use traditional tools such as chisel and sandpapers to shave off the wood. This is usually done before the instrument has been completely assembled. Builders build the flat top of a guitar with the bracings on it and shave it off as needed.

Since the braces help support the guitar body, a loose or broken brace can cause damage to the body. Many times, the body will develop a bump or dip in the top or sides because the brace isn't glued on properly to support it [5]. A common place for bumps is right behind the bridge. Cracks can also develop in the finish or even in the wood itself [5]. It is important to catch brace problems early, so it doesn't result in major damage to your guitar. first, using a mirror with an adjustable length handle, the adjustable length handle will allow you to stick the mirror into the body to examine the braces. Loose braces can be difficult to spot because the gap between the brace and the guitar top might be extremely small. In this case to run a thin feeler gauge against the bottom of the braces. If there is a gap, the feeler gauge should be able to fit in between the brace and the guitar body [2]. After, found the cracked or loose brace, it is time to fix it. Working through the sound hole of your guitar is difficult and requires a special set of clamps [2]. A deep c-clamp is used to glue loose braces on the top of the guitar. These clamps look exactly like a traditional c-clamp but with an extremely deep throat.

Feeler gauges are a common machinists tool used to measure small distances between objects. A traditional set of feeler gauges consists of 12 to 36 different strips of sheet metal that vary in thickness from .002" to .040" thick [6]. Guitar repair feeler gauges are no different than regular machinist feeler gauges. Guitar gauges just have specific uses that are unique to the guitar. Feeler gauges can be used to measure many differ parts on your guitar. One use for a feeler gauge is when to fix loose and cracked braces. Another useful tool is a deep c-clamp is used to glue loose braces on the top of the guitar. These clamps look exactly like a traditional c-clamp but with an extremely deep throat. Since it is almost impossible to use a traditional clamp on the braces on the back of the guitar, you can use a jack. These jacks are very similar to car jacks. These usually consist of two pieces of wood separated by a screw. When the screw is turned, the two pieces of wood get farther apart. As we can see in the figure.

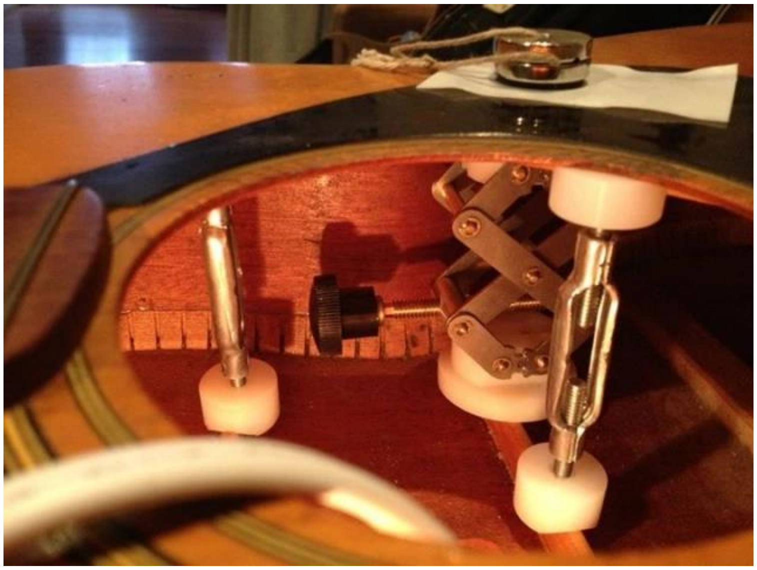

***Fig (1) Brace Repair Jack***

To shave off the brace on an instrument that has been completely built can be very tricky. A completely built guitar has strings attached and a sound hole of about 4 inches in diameter. In order to shave off the wood, one must remove the strings and work through the sound hole. The size of hole doesn't give us the freedom to move around efficiently. This can create problems like over trimming or even shaving off the wrong brace accidentally. Therefore, a tool/technology which can fit through the sound hole and shave off the material to a right amount would be an ideal tool.

Unlike modifying the braces on an open flat top, the only way to modify an assembled over braced guitar is by reducing the thickness of the brace as advised by Ken Parker. On the open flat top, the bracing can be trimmed off in almost any direction. Trimming such as tapering and scalloping is also doable with less chance of error in an open flat top. For an assembled guitar, the advance trimmings can be challenging and there would be a higher chance of error. Therefore, our group decided to focus on a tool that will shave the material off the brace from sideways.

## Types of Bracing:

Ladder bracing:

Ladder Bracing is the oldest design in guitars. 200 years ago, most guitars had a simple design called ladder bracing. It's basically a guitar with struts glued in perpendicular to the soundboard. It's a system where braces are distributed parallel to each other. Even though there are a variety of modern designs, ladder bracing continues to be relevant in guitar design. It's considered more suitable for parlor guitars, romantic guitars and lightly strung instruments. Most of the flattop acoustic guitars being produced during this period featured ladder bracing. Companies such as Oscar Schmidt, Kay, Regal and others opted for this style of top brace as a means of keeping production costs at a minimum.

***Fig (2) Ladder Bracing***

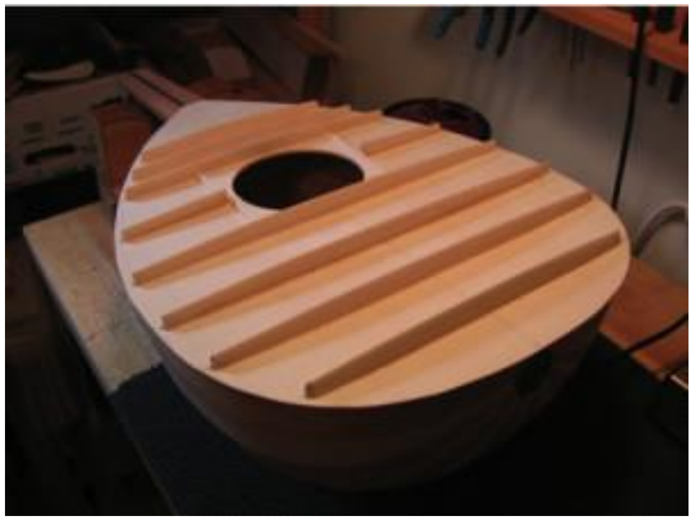

***Fig (3) Ladder Bracing on Arabic Lute***

Fan bracing:

Fan Bracing is used in classical guitars but was found to not be sturdy enough for steel strings. It designed to transfer tone and as much volume as possible for a classical guitar. A fan pattern resembles the shape of fan. These braces usually fan outward from the bridge plate pointing at the bout of the guitar. In 1884, Antonio de Torres made the first guitar with fan bracing. Guitar maker is regarded as the father of the modern Spanish guitar. He managed to break the inherited traditional standards of guitar making, in order to experiment as well as develop his own methods for guitar making.

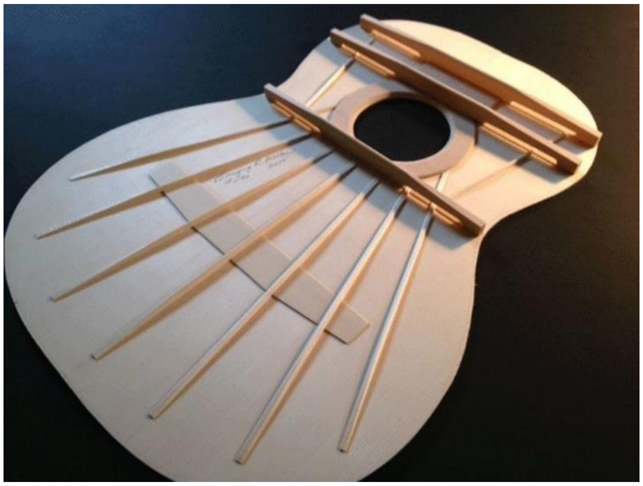

***Fig (4) Fan Bracing***

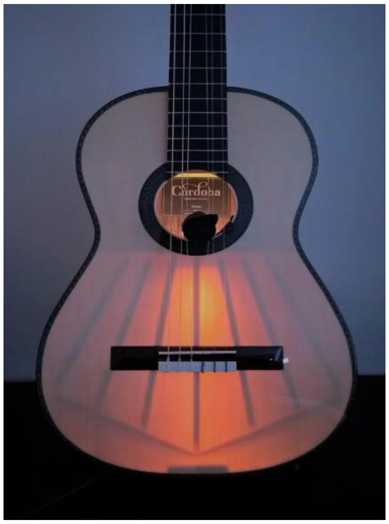


***Fig (5) Torres Replica***

## Radial Bracing:

Radial designs appeared during the 1970s. There are lots and lots of variations of this design and each one sounds different. The radial bracing is very similar with the fan bracing. There are a small group of Australian Luthiers who are focusing in the development of radial bracing guitars like Simon Marty, Roning Moyes and Jesse Moore but this system has not been adopted by other manufacturers in a majority way.

***Fig (5) Radial Bracing***

## Lattice Bracing:

Lattice braced designs appeared at the end of the 1970s. The way these guitars work is simple: a lattice structure is rigid, which means that soundboards can be way thinner than usual and keep up with the string tension. That way these designs can reduce the total weight of the guitar. Guitars with this design are still popular today and many players still use them. Lattice bracing able to gives you more volume and faster string response. One of the instruments has lattice bracing is Smallman guitar by Greg Smallman.

***Fig (6) Lattice Bracing***

***Fig (7) Smallman guitar***

## X bracing:

The X bracing, originally developed by C.F. Martin in the 1850's. This pattern features the two main braces running in an "X" from the upper bouts to the lower bouts. The "X" crosses usually 1-1.5 inch away from the sound hole. There are several auxiliary braces other than the main X-braces. This pattern provides the strength and well-balanced tonal palette that most builders find attractive.

The other alteration of the X bracing would be a double X bracing. This design includes additional X brace which is usually built below the X brace. Guitars that include the double X brace has sometimes been labeled as "overbuilt" due to the additional bracing. We can find the X brace on an archtop guitar like Koentopp Chicagoan.

***Fig (8) X Bracing***

***Fig (9) Koentopp Chicagoan X Bracing***

## Variation of bracings:

All these different types of bracing can vary in design. For instance, two guitars having the X bracing may differ from one another. One might have a different cut out than the other one which will have less material and evidently will sound different as well.

There are mainly three variation of bracing:

1) Standard or Straight bracing

2) Scalloped bracing

3) Tapered Bracing

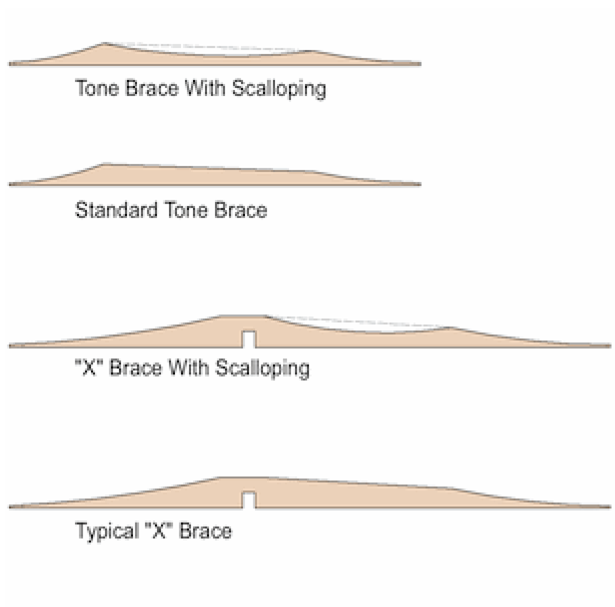


***Fig (10) Variations of Bracing***

## Standard bracing:

Standard bracings are traditional type of bracing used on many acoustic guitars. This type of brace is a straight rectangular wood without any material cut off. These bracing provide strong structural support but makes the guitar less flexible. This is a good choice on guitars that require more structural integrity rather than the sound.

***Fig (11) Martin 1840 Spanish Style 28***

## Scalloped bracing:

Scalloped bracing is also used widely on guitars. The shape is mostly rectangular, but towards the end the wood is scalloped to achieve flexibility. Designing proper scallop can have a significant difference in the sound of the instrument. A scallop that is too steep will have little or no effect and too long of a scallop can weaken the brace significantly. Due to the flexibility, the guitar will sound more clearer and louder compared to a standard bracing.

***Fig (12) 1942 Gibson Opaque Blonde Jumbo 35 Guitar***

Tapered Bracing:

Tapered bracing has a similar function as the scalloped bracing. It has less material at the end similar to the scalloped bracing which allows the top of the guitar to vibrate more freely. The only difference is the shape at the end which is tapered rather than scalloped.

***Fig (13) Martin 1945 D-18 with Tapered Bracing***

## Methodology:

This section describes three major areas which the team followed in order to meet the design requirement. The interview with the expert, the prototype, and the data and analysis section where we describe about the interview takeaways, construction and assessment of the device.

### Interview I:

Our methodological approach was to conduct a focus group interview with an expert in luthier in order to ask open-ended questions about a tool that would potentially be able to trim the bracing from a guitar without removing the top. An interview was conducted by the team to learn more about how the builders have been modifying the bracing and what can be a good tool to solve the problem of over bracing. The interview was done with American luthier, Ken Parker. Ken Parker is the founder of Parker guitars and has experience working with the guitar for over 40 years. He is known for making distinctive arch top guitars and Parker fly electric guitars. The team had prepared questions related to the subject and the information received from Mr. Parker were used to design the tool. The questions were more focused on ways to solve the over bracing problem and a design of a potential tool. The team had studied how builders trim the bracing on an open flat top guitar as mentioned above. However, the team was not sure on the feasibility of the methods on an assembled guitar. For instance, the bracings are easily scalloped on an open flat top guitar, so questions like whether scalloping could or couldn't be done on an assembled guitar were asked. Other questions about the potential concept of the tool were asked in the interview. In particular, how the device would hold onto the brace and be able to trim off material were important questions highlighted in the interview. The whole idea of designing this particular tool was to be able to modify the brace inside the guitar post assembly. Therefore, some of the existing methods were explained to us and how each of them had their limitations to a completely assembled guitar. From the interview, the team noted down some of the tools that could be used for trimming the brace. The team also showed and explained the method using a software that analyzed the frequency of the modeled guitar. The response from Mr. Parker on using the software method seemed to be impractical in the real world. For this reason, the software method was dropped by the team.

## Prototype:

In the interview, we were introduced with tools that could help with our goal of designing the device. Different types of trimmers such as bagel shaped cutter, high speed steel and carbide bits, and circular saw blades were introduced. The team went thoroughly through the cutting tools to see which tool would be ideal for our project. The bagel shaped cutter was ideal for shaving materials of the wood as it was festooned with sharp spikes as shown in fig (5). The problem with this cutter was the size of it. It had a bigger diameter which would have been a problem to insert it through the sound hole of the guitar even if it was oriented at 90 degrees as advised by Mr. Parker.

***Fig (5) Bagel Shaped Cutter.***

The high-speed bits were ideal in terms of the size as well as it was a great cutter to shave woods like spruce. The bits were cylindrical in shape as shown in fig (6). Due to it being a tall and cylindrical in shape, we were unable to fit in the motor with the design we came up with.

***Fig (6) Cylindrical Bit.***

The final option was the circular saw blades as shown in fig (7). These blades could be custom made, which means we could make a blank disc of steel or carbide of any size we want and suppliers like Tunco Manufacturing Inc could install the grits on the plates for us. The team decided to go with the circular saw blades because of its customable size and also because of its ability to shave the wood efficiently.


***Fig (7) Circular Saw Blades.***

After the selection of the cutter, we were informed about the required motor's speed in RPM. The RPM is based on the diameter of the disc. The RPM should be around 13000 for a disc of diameter of 1.5 inches. Using this ratio, the team could come up with required RPM since the team decided to have a custom sized disc.

## Data and Analysis:

### Interview Takeaways:

There were important aspects the team were informed in order to design the device. There were three challenges imposed for the construction of the device. The first challenge was that the device should be able to trim away minimum level of material from the brace. The idea behind this was so that the brace wouldn't be over trimmed and the guitar wouldn't be ruined structurally and musically. As informed by Mr. Parker, the sound of the guitar changes with the function of a cube when reducing the thickness of the brace. This meant, the blades and motor needed to operate in optimal level throughout the trimming process. The other challenge was the path the device would follow. As mention before, guitars have different bracing structure on them. The device would need to follow the path of the brace no matter what shape and size the bracing is being dealt with. The final challenge was to control the device by the users remotely. Since the guitars have bracing on top plate, the device needed to somehow hold onto the brace and move simultaneously.

## Construction:

This device has components that needs to be ordered as well as parts that needs to be designed and created. Components such as motors, sensors, breadboards, circuits, LED lights, receiver and fasteners can be bought through different suppliers. The device includes five motors in total, two dc motors to spin the cutting blades, and two servo motors to control the movable arms on the device and one motor to move the wheels. The motors for cutting blades require to be around 10000 RPM as we designed the blades to be of 1-inch diameter. The motors can be ordered through eBay, where they have motors of various RPMs as well as of considerably small sizes. An ideal size motor would be of around 5 mm diameter and of 10 mm in total length. Electronics such as sensors, breadboards, circuits, receivers, and LED lights can be ordered through electronics distributor such as Spark Fun electronics. The device includes two sensors, the first one being an ultrasonic sensor to sense the walls as the device approaches the end of the guitar. The other sensor to measure the thickness of the brace before and after the trim. These sensors will be connected to the breadboards along with other electronics. The ultrasonic sensor will be mounted on top of the device along with the LED light and the camera and be connected to the breadboard as shown in fig (9). The thickness sensor will be mounted on the custom hole made in the cart as shown in fig (9).

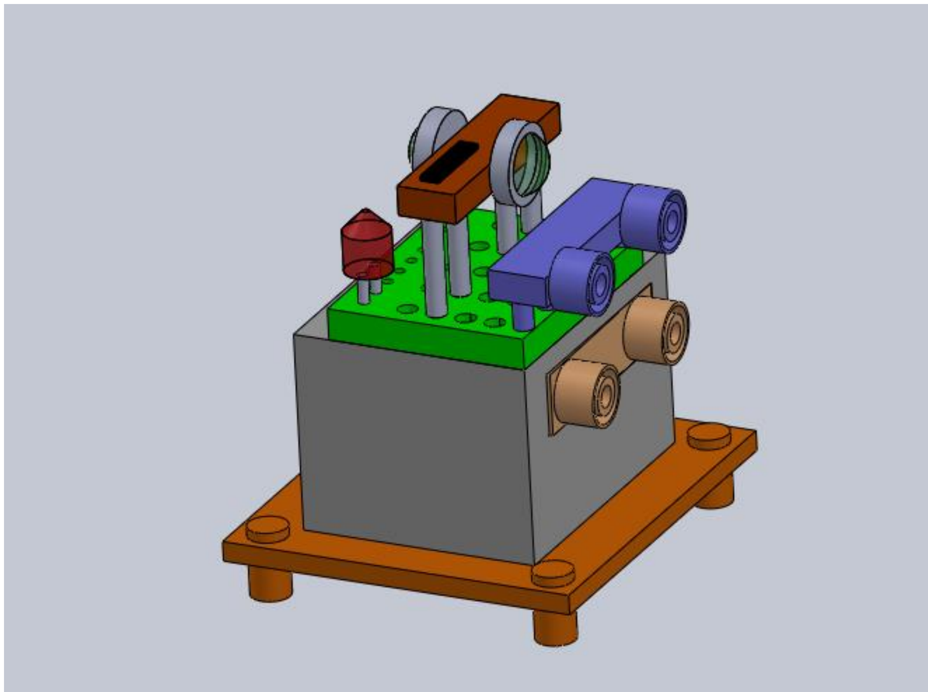

***Fig (9) Electronics setup.***

The receiver will be placed at the back of the cart as shown in fig (10). This receiver will include various channels and the channels will allow the user to independently control the motors for blades, servo motor for the arms and the motor for the wheels. In another words, this design will require a receiver with at least three channels. The receiver will be preprogrammed and the user can control the necessary motors through a remote control. The wheels can be custom made or be bought online. The second breadboard located inside the cart will have the motor and battery for these wheels. The motor will be connected to one of the channels in the receiver.

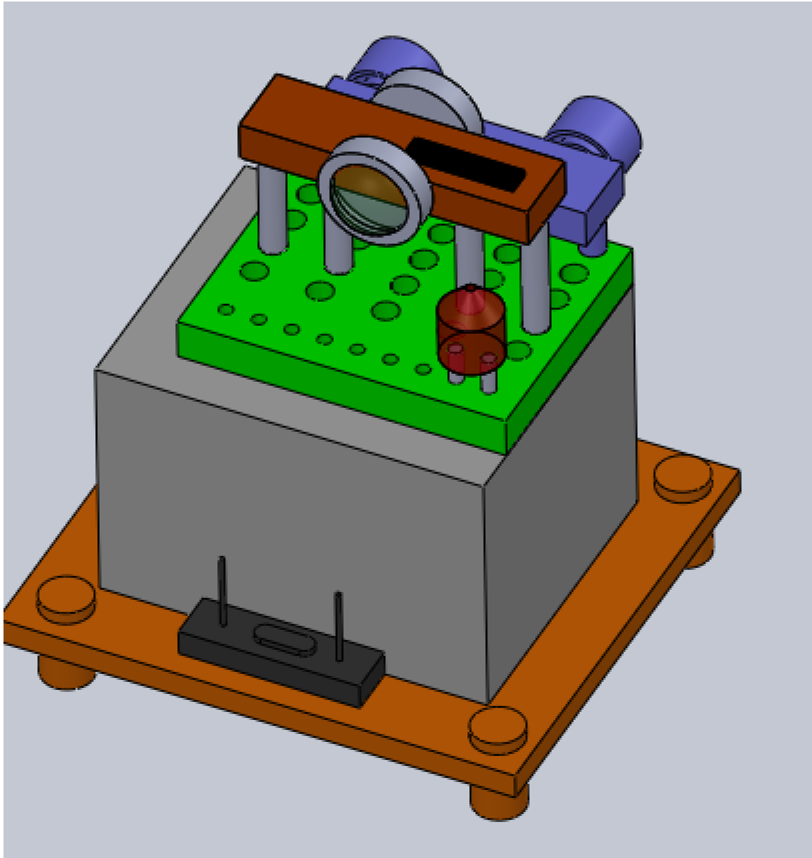

***Fig (10) Receiver location.***

The components that need to be designed and created are the cart with its base, arms for the device, linkage from servo to the arm, and the shafts for the wheels and arms as shown in fig (11). These parts need to be custom made with reasonable dimensions. These components can be designed in SolidWorks and 3D printed in the lab.

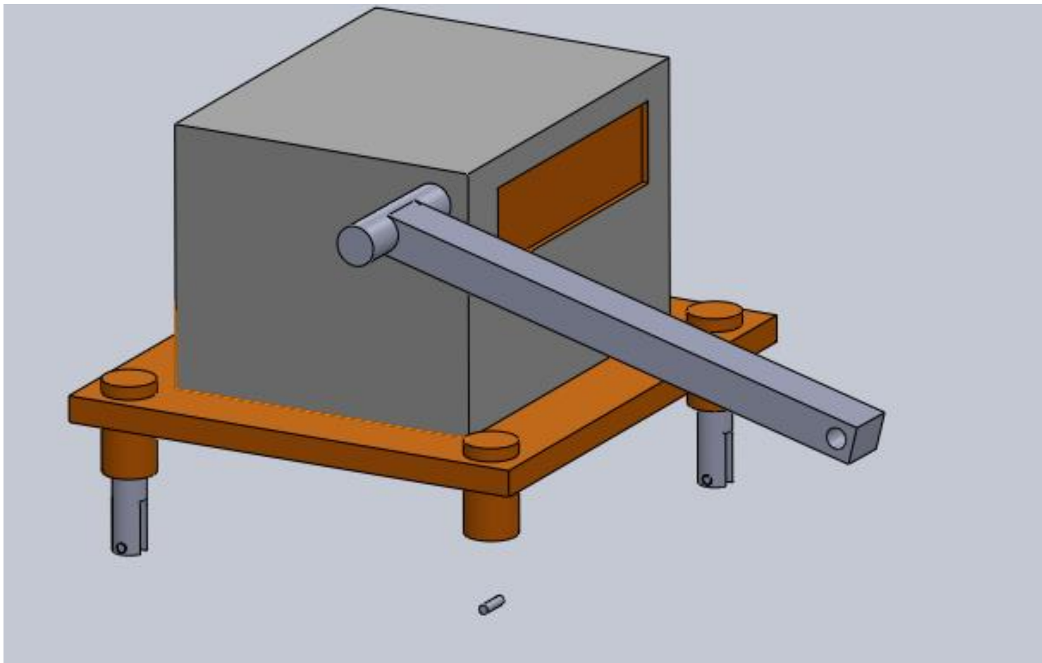

***Fig (11) Parts to be created.***

Appendix B includes a Bill of Materials table where all the necessary parts are listed out with the price of the parts. The parts that require 3D printing are an estimated price as the team had no access to the 3D printing lab and determining the exact amount is implausible.

## Assessment:

In theory, the device will be inserted through the sound hole and the device will be kept on top and parallel to the brace that needs to be trimmed. For this, all of the strings on the guitar needs to be removed and the guitar needs to be turned upside down (top plate facing the floor). This device isn't designed to work against the gravity, since it has no means of holding on to the brace and moving simultaneously. Once it's in "place", the bottom sensor will measure the thickness of the brace and show the output. Then the arms of the device will be moved close to the brace, making sure it has a bare connection. Once it is connected, the motor will be started, which spins the blades and the device will be moved forward and backward the brace by the operator. Since the height on this device is adjustable, it can also move up and down the tapered and scalloped slopes. As the device is moved forward and backward by the operator the spinning discs on both sides slowly takes off the material. Once the device does one trip, the second sensor will measure the thickness of the brace. The first sensor is active throughout the whole process, and if it senses the wall the bright LED will light up. This will alert the user to stop the movement of the device and move it in opposite direction. Once the user decides that the trimming is enough on one brace, the device will be moved to another brace and the process will be repeated.

Initially, the device can be tested on an open flat top guitar before trimming an actual guitar. This way there is less risk of ruining the guitar and its sound. The test will let us know how the tool will behave under the selected RPM and show us the characteristics of the movement and of the device as a whole. If the tool works as intended on the open flat top, we can step up and do an experiment on an old impaired assembled guitar. Again, keeping track of how the tool behaves and making changes to unstable parts, we can build an ideal device that can be used in an actual over braced acoustic guitar.

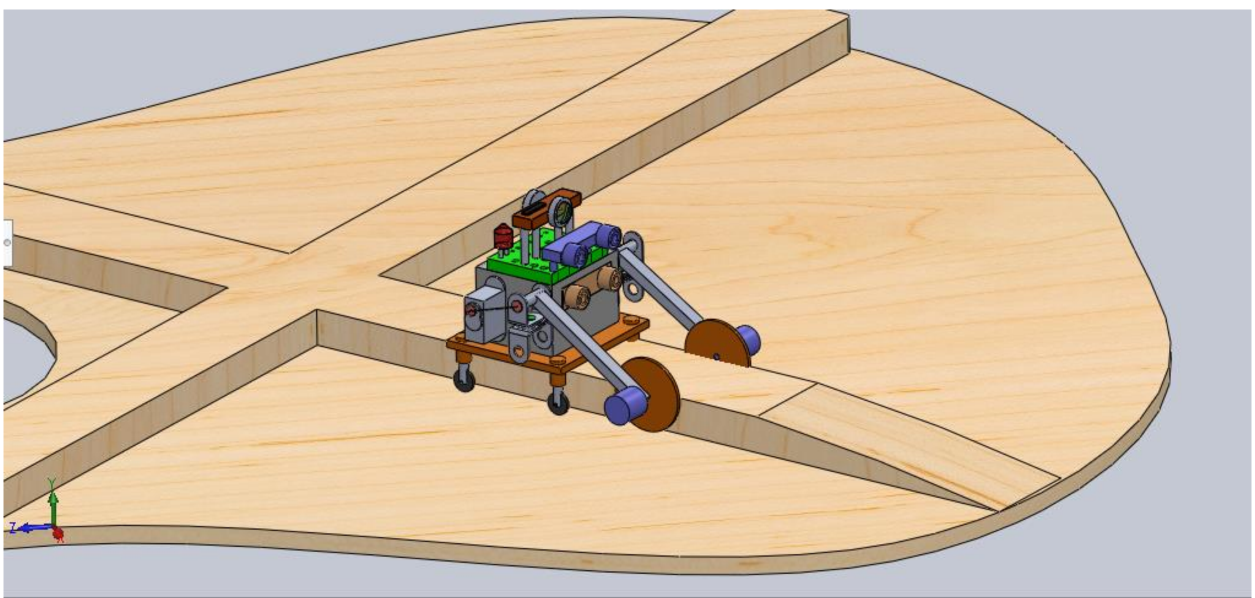

***Fig (12) Final Assembly.***

## Conclusion:

The team focused on designing a prototype device to aid in the process of shaving an over braced guitar. Along with researching about the implementation of bracing in guitars, the team studied existing problems related to bracing and about the existing tools used by the builders. The team came up with a device to work with a completely assembled over braced guitar. The device was designed, but due to not having a complete access to labs and tools, the team was not able to build the design. The next step for the team would be to take this design and build the device and use it in the real world. In order for the designed device to work, it needs to be tested on an open flat top and also on a completely assembled guitar. Once the device is tested in a flat top guitar and the results are what we expected, the team would like to explore more ways to make this device smaller in terms of size. The idea for having a smaller size device is to make it work on a f hole guitar as well. Also, for future studies a traditional video or a manual tutorial can be created on how to use the tool and its assembly. These experiments can be carried out by other teams to see if the tool is feasible or not.

Although there are more scopes in this area such as fixing a loose bracing and installing a new set of braces in an assembled guitar, the team focused only on shaving an over braced guitar due to limited time. If given another opportunity, the team would like to build more efficient tools that would aid in fixing various bracing problems in an acoustic guitar. This device the team designed is specifically designed to be used in a round hole guitars. A new tool needs to be designed for a guitar with a f-hole. The applications of such a design are endless and expand beyond music. Overall, in all forms of art, technology can be used to help broaden the scope of users. The improvement of the tools is only the beginning, this teaching method can be used on further projects.

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http://www.vintagemartin.com/

**Appendix A:**

Kutzall Extreme ( Bagel Shaped Cutter)
https://www.rockler.com/kutzall-extreme-4-1-2-shaping-disc?sid=V91040&promo=shopping&utm_source=google&utm_medium=cpc&utm_term=&utm_content=&utm_campaign=PL&tid=pla&gclid=Cj0KCQjw3Nv3BRC8ARIsAPh8hgLqDkd4VgkkiU8f-1xelG0MVa2fhHjHV7abpB0TbStaJaFZwaK2NBcaApK3EALw_wcB

Tunco Manufacturing Inc.
http://www.tuncomfg.com/

Steel and Carbide Bits
http://www.severancetools.com/

Guitar Top Tuning
https://www.youtube.com/watch?v=Ei5-DkVTrEE

Parker Guitars
KenParkerArchtops.com

## Appendix B: Bill of Materials

| ITEM NO. | PART NAME | Price (Unit Price) | QTY. |
|---|---|---|---|
| 1 | Cart | ~ $ 3.00 | 1 |
| 2 | Breadboard | $1.00 | 1 |
| 3 | Wheels | $7.00 | 4 |
| 4 | Wheel Motor | $3.20 | 1 |
| 5 | Hinges | $1.00 | 2 |
| 6 | Servo Motors | $4.00 | 2 |
| 7 | Arm shafts | ~ $0.25 | 2 |
| 8 | Arms | ~ $2.00 | 2 |
| 9 | LED red | $0.50 | 1 |
| 10 | Ultrasonic sensor | $4.25 | 1 |
| 11 | Thickness sensor | $5.00 | 1 |
| 12 | Blades Motors | $0.99 | 2 |
| 13 | Blades | $6.99 | 2 |
| 14 | Receiver and Controller | $60.00 | 1 |
| 16 | Servo Linkage and pins | $3.70 | 1 |
| 17 | Battery | $10.00 | 1 |
| 16 | Breadboard | $1.00 | 1 |
| 19 | Camera | $5.50 | 2 |
| 20 | TOTAL | $140.13 | 28 |