Digital Modeling of 1930 Santos Hernandez Classical Guitar Geometry

by

Andrew DeShields

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ABSTRACT

With advancement in computational power, it is possible today to create digital instruments with highly accurate geometry as well as material properties. Here, a Santos Hernandez classical guitar built in 1930, is digitally constructed in SolidWorks from plans of the actual instrument. The complete instrument consists of more than twenty parts, which were then meshed with appropriate finite elements in HyperMesh. This assembled finite element model can be analysed in any finite element solver such as Abaqus to understand the structural and acoustic wonders of such great instruments of the past, which would be very difficult to do otherwise.

Thesis Supervisor: Nicholas Makris
Tile: Director of the Laboratory for Undersea Remote Sensing

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1. Introduction

Many great instruments of the past have become non-functional today. These instruments may be costly to recreate, or be made out of materials that would not make them viable to recreate. Making the instrument digitally can help us understand how the instrument works and sounds without having to rebuild the instrument from scratch. This study seeks to create a digital Santos Hernandez classical guitar from 1930 in order to digitally create its sound based on the laws of physics, and further understand what physical attributes of the instrument are important to its sound.

2. Background

Several studies have been done prior to this one where digital instruments have been modeled using CAD software [2] [3]. There have also been a few studies in which finite element models have been made for a guitar [2] [4]. However these studies use either simplified geometric assumptions or incomplete structural-acoustic coupling capability [2] [4]. This thesis deals with the construction of the digital model of an existing guitar from its plans, with no simplifying assumptions. With recent publication of more accurate material properties of wood [7], this can help create a very accurate digital model for analysis and sound production.

2.1. Mechanisms of Acoustic Guitars

All guitars produce sound by transmitting vibrations from plucked strings to the nearby surrounding air. Electric guitars use electric induction to detect the vibration of the strings to convert the vibrations to sounds that are transmitted to speakers. Acoustic guitars however, rely on different mechanism of the guitar to amplify the vibrations from the strings and preserve the sound quality.

Guitars consist of two sections: the neck and the body. Strings run from the top neck to the middle of the body, ending at the bridge of the guitar. Strings are made of various thicknesses, lengths, masses, and strung with different tensions to create different frequencies when strummed. When a string is plucked its vibration is transmitted to the bridge, and causing the rest of the instrument to vibrate.

Another key aspect of the acoustic guitar is its soundboard. The soundboard of the guitar is the top plate of the guitar. The soundboard amplifies the sound of the guitar. The strings and the sound board are connected by the bridge. Although the string is much smaller than the sound board, the sound board is forced to vibrate due to the string being tied to the soundboard through the bridge. The sound boards of guitars are often made of thin wood to allow them to vibrate more, but are reinforced along the length of the soundboard to keep it from breaking.

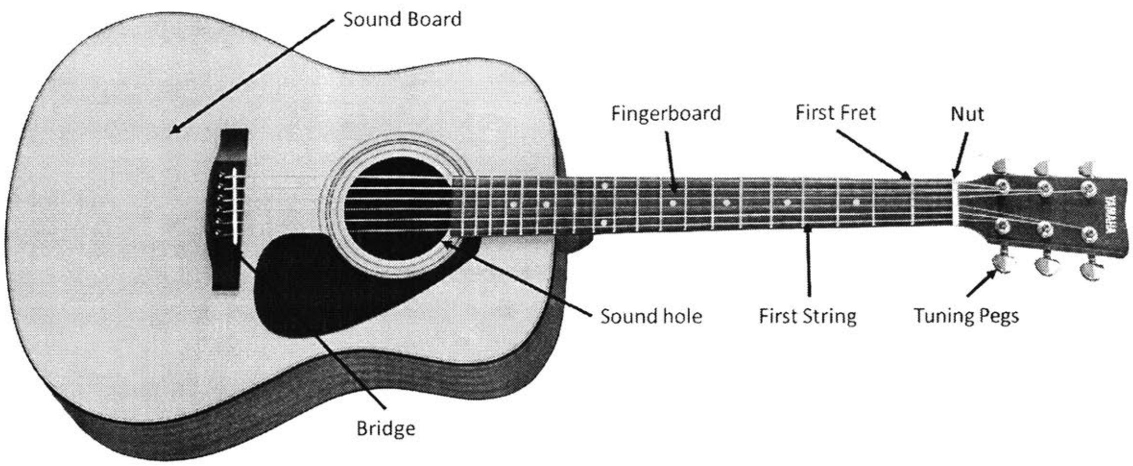

Figure 2-1. Different parts of an acoustic guitar. [1]

2.2. Previous Studies

The most similar study to this one that has been conducted was by Amit Zoran at the Massachusetts Institute of Technology [2]. The study, which was named "Chameleon Guitar: A Physical Heart in a Digital Instrument" a major part of the study was to find the optimal shape of a guitar body given restraints such as area of the top plate. Zoran used Finite Element Modeling software with forces similar to those encountered while playing the guitar to find how the top and bottom plates of the guitar was displaced with different modes. After finding an ideal shape, Zoran continued to physically create the guitar and give it to guitar players to find out how it compared to the guitars they play. Although the purpose was different, many of the methods that Zoran used to find the ideal plate shape set the groundwork for the methods that would be used in this research.

Another aspect of the project that has had prior research done is how the guitar interacts with its environment. In Zoran's paper, he finds the displacement of the guitar faces, and the displacement of the air directly next to it. He measures these interactions with various sensors on the guitar body. Similarly, Evangelista and Eckerholm modeled the interaction between the guitarist's fingers and the strings themselves in a study called "Player–Instrument Interaction Models for Digital Waveguide Synthesis of Guitar: Touch and Collisions." [3] This research seeks to take similar measurements of a digital guitar and remove the error present from the measuring equipment.

One study that does a great job of solving the time domain model of the vibration and acoustic radiation from a guitar is paper by Gregorire Derveaux et al. [4] called "Time-domain Simulation of a Guitar: Model and Method." This paper creates a 3D body to represent a digital guitar, with a top plate, air domains, soundboard, strings, etcetera. A specific spectral method is used to solve the dynamic top plate model for a damped heterogeneous orthotropic material. The air and plates of the guitar are solved with a fictitious domain method. From there, frequency analysis is performed to evaluate the transfer of energy through the various components, from the strings to the soundboard, and the soundboard into the air.

This research analysed the acoustic response of a guitar both through the body and into the surrounding air. An analysis is also carried out to obtain the energy transferred between different parts of the guitar to each other or into the air. However, a major place in which this research falls short is that the three-dimensional (3D) models of the guitar are extremely undetailed. The 3D models are just the basic shapes of the instrument, and thus the data that is acquired from this model may not be very accurate. The study of the Santos Hernandez guitar seeks to make a more accurate 3D representation of a guitar.

2.3. Details of 1930 Santos Hernandez Classical Guitar

1930 Santos Hernandez Classical Guitar was chosen for this project for several reasons. It was chosen both for its prestige in the community, and its physical properties. First and foremost, the guitar chosen for the project still had to physically exist, and it had to be an acoustic instrument that relied on the direct mechanical vibration of air to create the instrument sounds. Although the bulk of the study was reliant on only the plans of the guitar, it is important for future work of this study that the guitar be available to test against data that has been acquired.

Santos Hernandez was a very established maker of guitars. In the beginning of his career he designed and built the Manuel Ramirez guitar of 1912. [5] This guitar was owned and played by Andres Segovia – a well-known romantic classical and baroque guitarist. This guitar is currently in the Metropolitan Museum of Art in New York. This particular guitar, built in 1930, is a good example of Santos' work, with beautiful materials and great style and charm in design and execution. [6] While doing some repair work of the guitar, Jeffrey Elliot also made technical drawings and detailed measurements of the instrument which were used to create the digital guitar accurately.

As for physical qualities of the guitar, it is praised for its tones, and its sound over the entire range of the musical spectrum. Jeffery Elliot valued the instrument for its charming, introverted quality of tone and this instrument, and says it is a wonderful example of Santos at his best. The Santos Hernandez concert classical guitar has a lush earthy tone. [5] The basses are firm, the mid-range is flat, and the trebles are sweet, lyrical and clear. The guitar sings even in the highest registers.

3. Design of the Digital Guitar

The guitar that is modeled is the 1930 Santos Hernandez Classical Guitar, using plans of the actual instrument. The guitar was created in SolidWorks, and was an assembly of over twenty parts of the guitar. The guitar could be thought of as modelled in two main parts; the body of the guitar and its neck. These parts were all combined with the strings and the bridge to create the entire guitar.

3.1. Details Regarding the Body

The body of the guitar consists of a top plate, bottom plate, a side face to connect the two, and top and bottom supports. The body could be thought of as constructed from the top plate and its supports, and the bottom plate and its supports with the middle connecting the two. There was also an end block at the base of the guitar connect the top and the bottom plates of the guitar.

The bottom plate was made using many point and curvature measurements from the plans. After extruding it to make it make it a plate, 3 supports were added at the bottom. As seen in the picture, one support spanned the entirety of the bottom plate to reinforce the stiffness of the bottom plate. The second supports spanned the width of the guitar to give it more reinforcements and to help give it points of contact with the side of the guitar. The final support wrapped around the side of the guitar in order to provide support for the sides of the guitar.

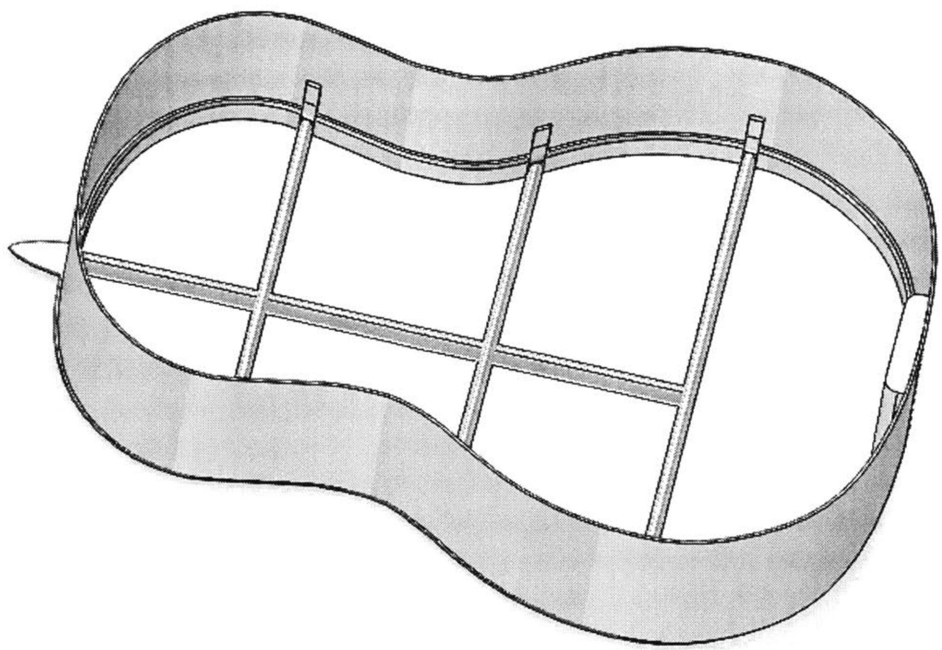

Figure 3-1. Inner side of the back plate. The back reinforcements span across the back. The side reinforcements connect the side and back, and the end block is the thick block of wood at the bottom.

The top half of the plate was more complex; it consists of more supports, has a sound hole as well as parts outside of the guitar. The top plate of the guitar had the same geometry as the bottom plate, so the geometry could be transferred. The side supports also had the same geometry. The reinforcements on across the top ran across the length of the guitar at the bottom. The lateral running supports at the top were similar in dimensions as those on the bottom, but in different locations. There was an additional support for the sound hole. The bridge was added on the top for the strings to attach to.

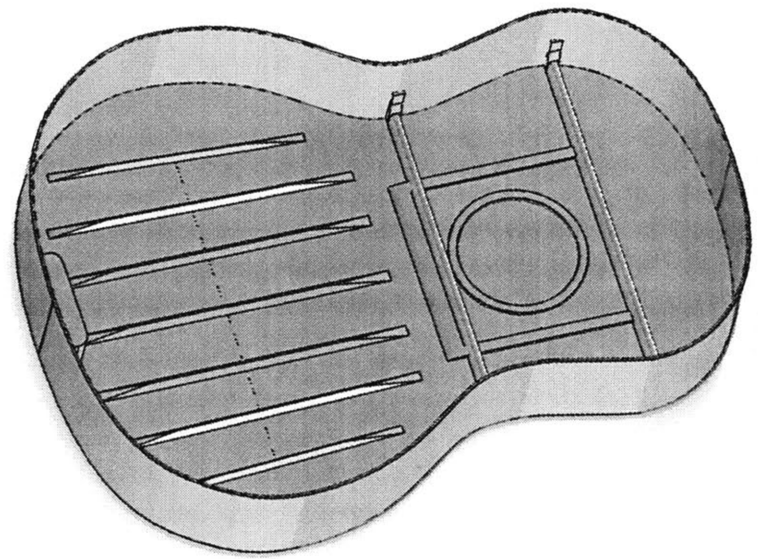

Figure 3-2. Inner side of the top plate. Has similar face supports and side supports, but has additional supports around the sound hole and longitudinal running face supports.

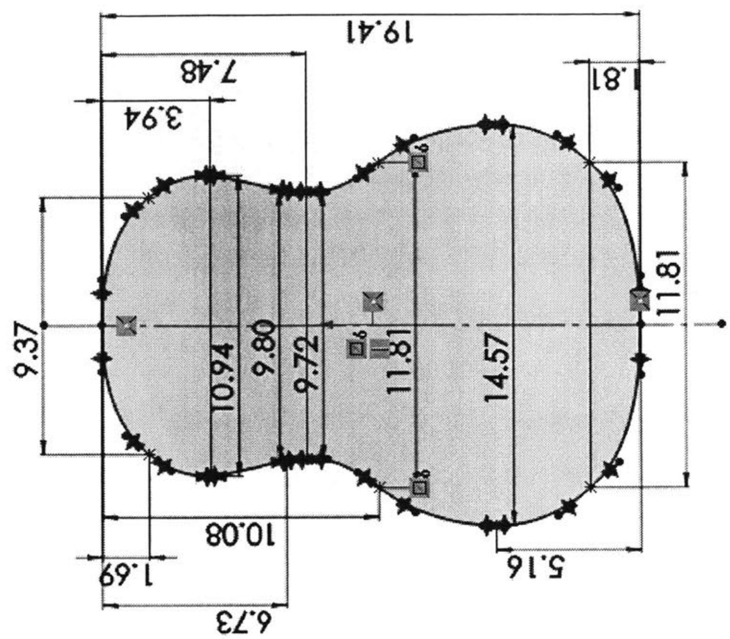

Figure 3-3. Outer side of the top of plate. The figure shows how the top and bottom plate were modeled from the measurements from the guitar plans

3.2. Details Regarding the Neck

The neck of the guitar was made after the body and fit to the sides of the guitar. The top half of the guitar was made of the fingerboard, nut, and neck. The neck had to be made by lofting the several cross sections of the base at various fret locations that were given in the plans. After lofting the base, the headstock of the guitar was added to the base with the given dimensions and hole locations to finish the neck of the guitar. The fingerboard and the nut were then added to the base.

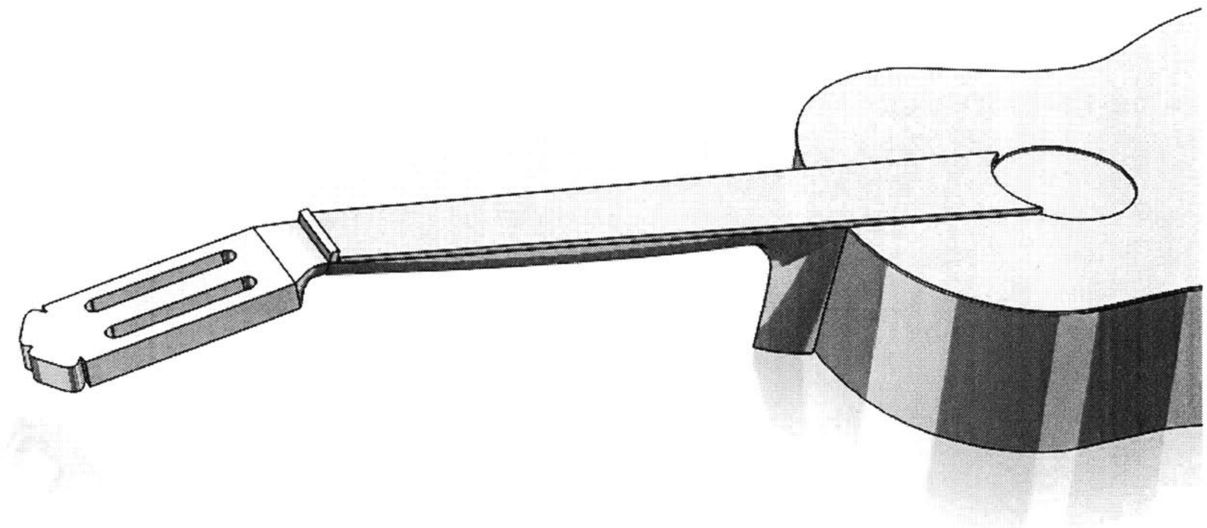

Figure 3-4. Upper section of the guitar. The main body was the neck, connected to the side of the drum, with the fingerboard and nut connected to the top of the neck

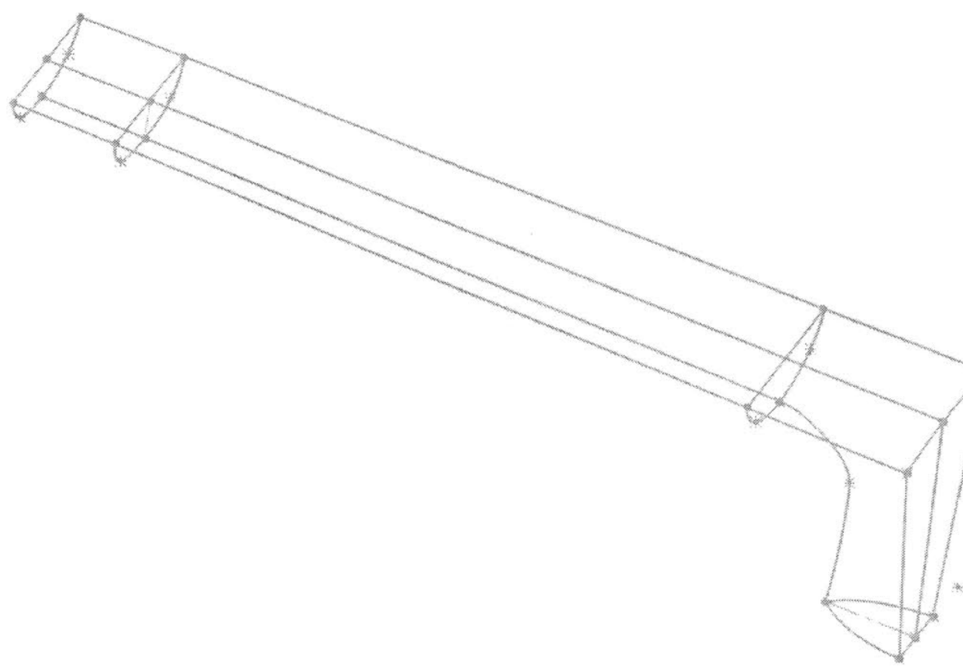

Figure 3-5. Sketches used to loft the neck of the guitar. The three cross-sections of the neck were given in the plans, and the bottom half was modeled to fit the body of the guitar.

3.3. Modeling for Abaqus

Several adjustments were made to the modeled guitar before export to Abaqus. The first change was that the top, bottom, and side plates of the guitar were converted to surfaces. In Abaqus, the surfaces can be meshed with shell element and given thicknesses, and in this way are much easier to manage when running simulations. In order to turn the bodies into surfaces, the inner most surface of the parts were used so that the parts still connected and laid flush with the air domain that would be placed inside.

However, one part was modeled as a solid. A circular region on the top plate around the sound hole was left as a solid body with its original thickness. If the circular region around the sound hole was converted into a surface as well, it would not be an accurate representation of how the sound waves go from the inner air domain into the outside.

Most notable of these changes was that air domains had to be created. The air domain was broken into two halves; the inside of the guitar and the outside of the guitar. The inner air domain was modelled by creating an intersection in SolidWorks from the top and bottom plates and the sides. The outer air domain was made by enclosing the entire guitar in the smallest possible sphere, and subtracting the inner solid parts (including the inner air domain). The reason for enclosing the body in the least amount of air possible is for computational efficiency.

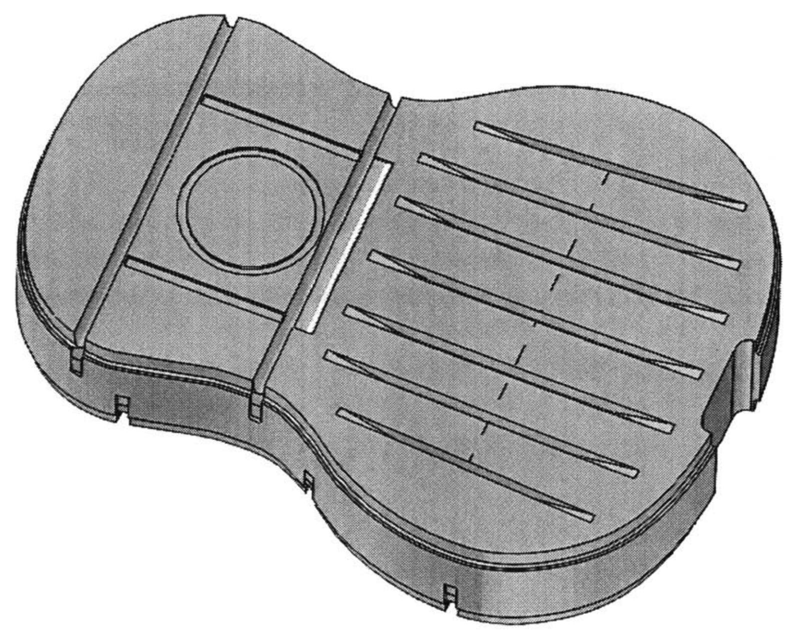

Figure 3-6. Inner air domain. The body was made by taking the inside of the top, bottom, and side surfaces and removing all of the internal body parts.

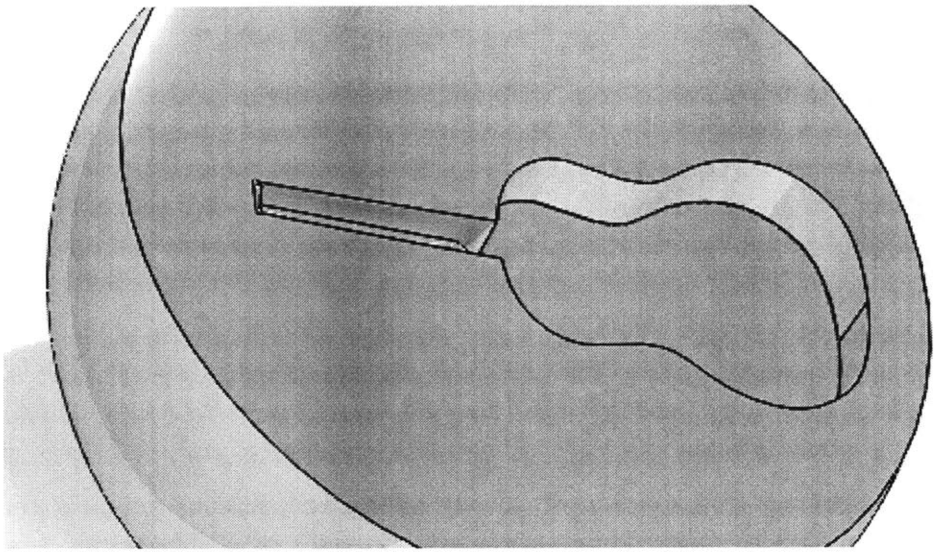

Figure 3-7. Outer air domain. The body was made by creating a solid sphere that completely covers all of the guitar, and making a mold using all of the guitar parts.

4. Testing and Results

For physical analysis of the digitally constructed model, the model that was modeled in Solidworks needs to be exported to a finite element software such as Abaqus, which is used here. HyperMesh was used to mesh the parts before export to Abaqus.

4.1. HyperMesh

HyperMesh is used to mesh the parts of the guitar, due to the meshing process in Abaqus not being user-friendly. HyperMesh is a dedicated pre-processor for meshing and has different methods to sequentially mesh the parts.

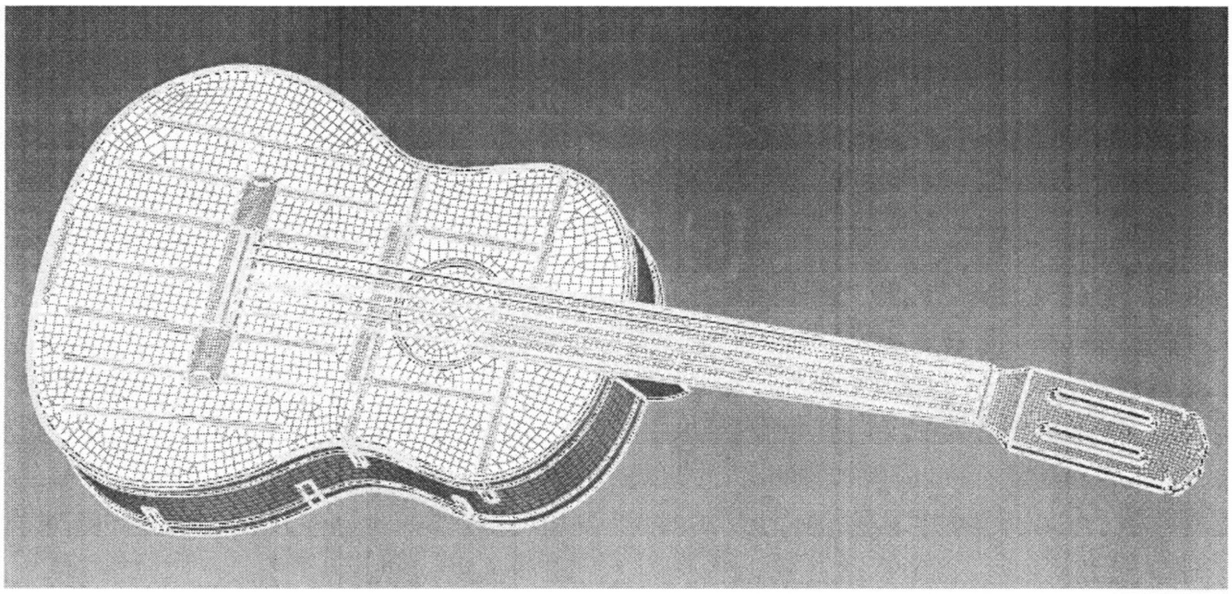

Figure 4-1. Complete mesh. The body was made by creating a solid sphere that completely covers all of the guitar, and making a mold using all of the guitar parts.

The air components need the least complexity of any of the parts. The air domain needs to transmit soundwaves from the bodies, and knowing the speed of sound and the maximum frequency that would be used for simulations, the following equation was used to figure out the necessary mesh density for the air:

$$\lambda = c/f$$

where λ is the wavelength, c is the speed of sound and f is frequency. 343 m/s was used as the speed of sound and 20,000 Hz as the maximum frequency because it is the highest frequency that humans are able to hear. Using these parameters, the smallest wavelength that will go through the air domains is found to be 0.01715 m long. In order to make sure the waves are fairly well defined, there should be about 8 data points per wavelength. This makes the mesh density for the air domain as one node every 2.4 mm.

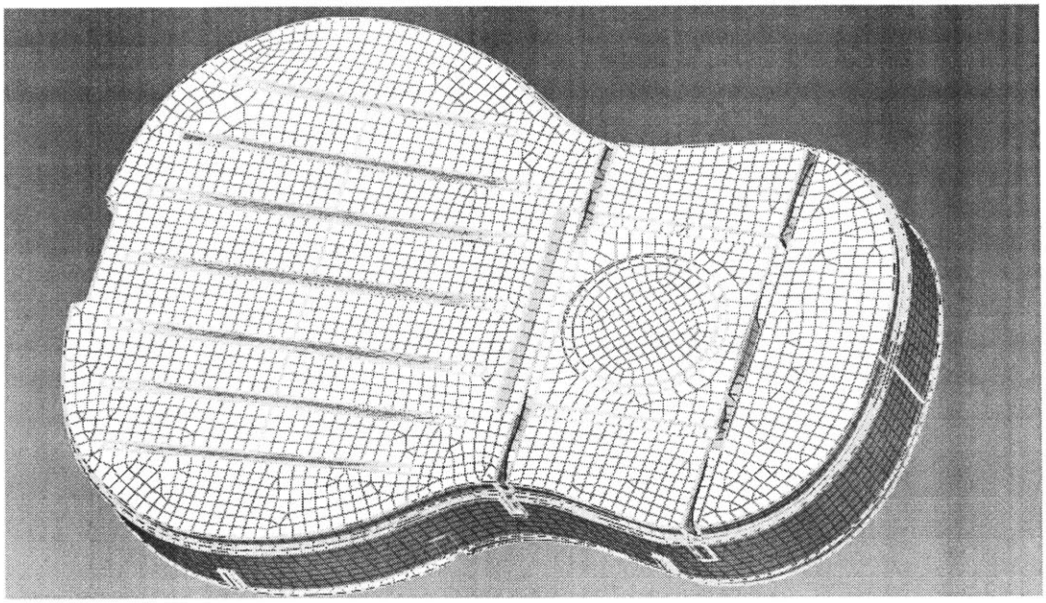

Figure 4-2. Mesh of inner air domain. The mesh thickness is set by the underlying smallest wavelength audible to the human ear.

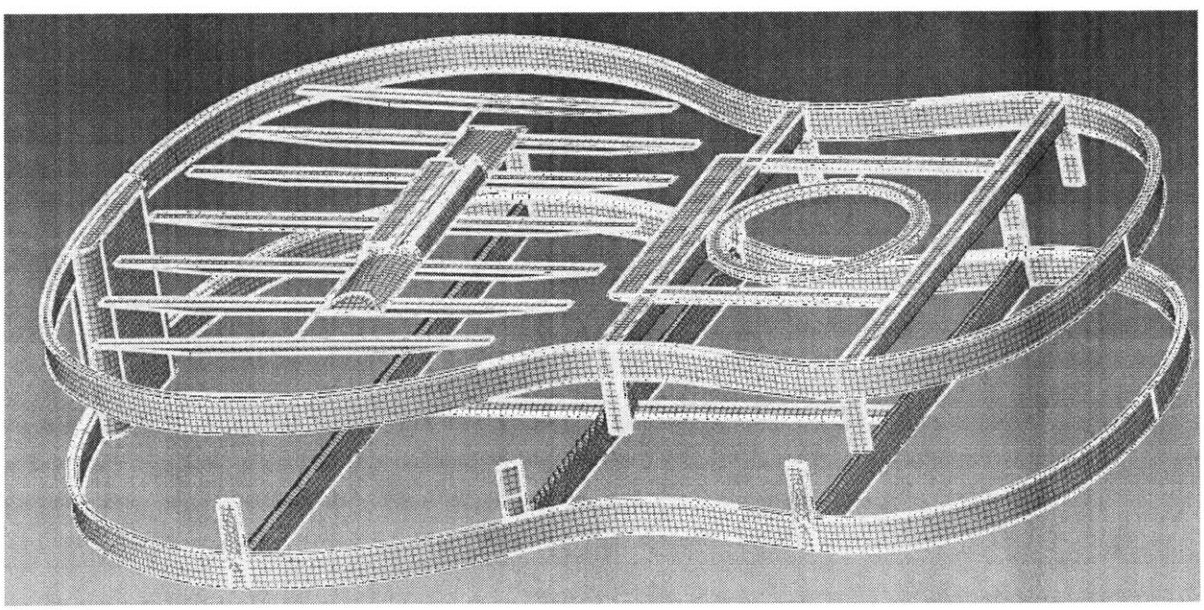

Figure 4-3. Mesh of support elements. The density of these meshes need to be much larger than the air domain, and even more so in complex geometries of parts.

In general, the solid bodies needed more definition than the air domain. This is because the deformations of the solid bodies' drive the deformations for the air domains, due to the complexity of the solid structure. More detailed parts, and more detailed areas of parts need a finer meshing then their less detailed counterparts. However, even with these finer meshed parts, with the control over the meshing of the parts that HyperMesh allowed the total number of nodes was ~72,163 nodes.

5. Conclusion

This project took a detailed plan for the 1930 Santos Hernandez Classical Guitar, and made an accurate 3D model of the guitar in SolidWorks. This is, to our knowledge, the most accurate digital model of a physical guitar that has been made. Different parts of the guitar were meshed with appropriate finite elements in the preprocessor software Hypermesh. The model and meshes that were created can further be used in a finite element modeling software like Abaqus to produce sound and carry out physical analysis that would be difficult and even impossible to do with an actual instrument.

5.1. Future Work

First, to finish the guitar model, the meshes that were created using HyperMesh need to be exported to Abaqus.In Abaqus, complete structural-acoustic coupling needs to be carried out. Accurate material properties need to be assigned to the sections before running simulations in the time or frequency domain for analysis. Material properties of parts of the Santos Hernandez Guitar are acquired from literature. [7]

The next step would be to compare the digitally constructed sounds with the actual instrument. If there are any major discrepancies, changes need to be made to the guitar model to more accurately represent the guitar in the finite element analysis simulations.

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