Acoustic Drum Exploration – Basis for Investigation

Theodore Argo IV Department of Physics, University of Illinois at Urbana-Champaign 1110 West Green Street, Urbana, Il 61801-3080, USA

ABSTRACT

A percussionist can alter the harmonic content of a tunable acoustic drum to provide a desired sound. By analysis of different aspects in construction of a drum the specific sound can be implemented. Through a Fast Fourier Transform of electronically acquired audio data an analysis of a drum can be performed at many stages of its construction. By dissecting the drum construction into various layers, a deviation from ideal membrane theory is observed. These deviations form the basis for further investigations into drum acoustics and non-ideal membranes.

I. INTRODUCTION

Throughout time man has created music. The earliest music was composed of percussive forces on solid objects. Thusly the percussion instruments are considered a simple means of creating musical sounds. The simplest design for a drum consists of a hide stretched over an opening. The tension in the stretched hide, or drum head, is what creates the sound when struck. In this way, the drum has evolved into the modern instrument appearing in the great concert halls and jazz clubs of the present day.

Modern drums have greatly evolved from their earliest predecessors. Many of the variables used to create different drum sounds are now controllable and tunable to the specific design of the percussionist or composer. These variables include, but are not limited to the material and construction of shell, sticks, and heads, as well as the adjustment of playing position and tuning of the heads. Each of these variables has a direct influence on the complexity of the sound the drum produces. From the ideal membrane model of a circular drum head each additional change of variable adds

yet another layer of complexity to the sound of the radiating head.

II. BACKGROUND

Past Research

Recently, in forums on the internet and conversations worldwide, there has been argument and criticism from many people regarding the way a drum should be built to enhance its tonal characteristics. Many people believe the player is the largest factor and the actual drum plays a relatively small role in the performance. Others claim that the drum has the most significant impact on the tone, reverberation, and other qualities desired by the musicians.

Some people have taken the question into their own heads. Thomas D. Rossing of Northern Illinois University has made important discoveries in the field of drum mechanics. He has used many methods to study different drum types and has tried to piece together exactly the way a drum vibrates so as to gain a larger picture of a drum's qualities. Through modal excitation he has observed the harmonic relationships of many of the vibrational modes of a drum head and has studied deviations from the model of an ideal circular membrane.

Others have taken a different approach. A study at Furman University of South Carolina has tested various heads for the snare drum in hopes of quantifying the different tonal properties of the heads being struck. The result of this study is a better understanding of the characteristics of the various heads and their effect on the sound of the drum.

In effect, scientists and musicians alike have decided that many characteristics of the drums have impact. The question that remains is to what extent each characteristic has an impact on an elementary drum head model.

Circular Membrane Model

The model in question is the mathematical representation of a drum head when vibrating. When struck in the center of the circular area, the ideal membrane exhibits vibrational modes consistent with mathematical Bessel functions. These modes are defined by a pattern of nodes and antinodes on the vibrating surface. As shown in figure 1, there exist many such vibrational modes, each with its own pattern.

The modes are labeled using a coordinate system of diameter by circular pairs. For example, the most fundamental mode, the (0,1) mode, consists of the membrane vibrating with a node at its boundary but nowhere else; zero diametric modes are present and one circular mode is present. The second most common mode is the (1,1) pair consisting of one diametric mode and one circular mode. The labeling system continues as more of either kind of mode are added.

Each mode also represents a certain frequency based on the amount of displacement of the membrane. For example, the (0,1) mode displaces the most and is, therefore, the fundamental. The (1,1) mode has less displacement due to the node running its diameter and, therefore, has a higher frequency as represented by 1.59 times the fundamental. Each mode is similarly labeled and quantified in figure 1 and is used as a basis for studying drums and other vibrating mediums.

The membrane theory has a requirement for its boundary conditions as well. The edge of the membrane must



Figure 1 – Ideal Circular Membrane Vibrational Modes

be fixed to a virtually infinite mass so as to force the antinode. If this does not occur, the wave is not as stable as it propagates since the edge of the membrane can deform.

The search for understanding these deviations was continued as development for the Physics of Electronic Musical Instruments and Physics of Music classes at the University of Illinois at Urbana-Champaign. Both classes study the characteristics of instruments and their sounds using only electronic instrumentation available to an average undergraduate physics lab. Due to these limitations, many advanced techniques can not be explored due to lack of instrumentation. Therefore, the goal of this exploration is the development of a setup by which the deviations from the standard membrane model can be observed without use of state of the art electronics and technology.

III. METHODS

Apparatus

To understand the effects of variables on a drum, a setup was created to analyze the sound spectrum of the struck drum. This included a constant force beater, a fixed stand, a drum, a microphone, and a computer system capable of taking the waveform data and performing the necessary calculations.

The general setup, as shown in figure 2, includes most of these elements. The consistent force machine was added at a later date and is discussed imminently.



Figure 2 – Drum Setup

The setup was designed to be used for any instrument desired. The microphone picks up the desired sound and sends the waveform data to the computer via a LabPC DAQ card which allows the raw voltage data from the microphone to be processed into a digital signal. The digital signal is then passed to a programmed LabVIEW interface which records, analyzes, and stores the desired data from an array of useful tools.

Use of drums with this setup is easily achieved if a few concerns are addressed. The drum must be sampled at a fast enough rate so that the impulse and reverberating sound can be captured efficiently. As well, the drum must be struck with constant force to assure results which are reproducible and comparable with other tests.

To solve the first problem, sampling speed, the LabVIEW interface was designed in such a way as to allow for monitoring of the time decay of the wave form and manual adjustment of sampling time and frequency. The exact settings are discussed as a part of the computer interface.

The second problem is that of a consistent impulse force with which the drum is struck. This is solved using a freely rotating device as shown in figure 3. The device is composed of a protractor for measuring the exact displacement of

the stick, a pivot formed of a bar and tube, and a rubber band with which to hold the stick.



Figure 3 – Consistent Force Machine

The pivot is simply used as a mechanism for the delivery of the blow. As shown in figure 4, the rubber band was affixed to a small copper tube which was, in turn, slid over a stationary metal bar. The copper tube was then allowed to freely rotate about this pivot with little friction.



Figure 4 – Stick Pivot

The rubber band was chosen as the device to hold the stick because of its pliability. A drummer's hand is not made of metal and, thusly gives slightly at each stroke. The rubber band was doubled over many times to provide a similar give. As well, the placement of the stick in the rubber band being off center of the pivot was designed to emulate a drummer's wrist. The stick's center of mass does not pivot around a single point, but instead rotates about the pivot of the wrist of the drummer.

For the tests utilized in this study, the stick was raised to a 45 degree angle above parallel and let fall to 45 degrees below parallel as measured on the protractor.

One cautionary note: when the stick strikes the drum head the stick will rebound. If the stick strikes the head again, the pure sound of the strike will be tainted. Therefore, a small wire was looped about the head of the stick in such a way that the rebound could be prevented. Once the stick had impacted, the wire was held by the tester until the data was collected to prevent the second strike from occurring.

Computer Interface

The interface for analysis of the data was programmed in National Instruments' LabVIEW. The interface was constructed to sample the sound, perform a Fast Fourier Transform (FFT) on the waveform, find the peaks in that transform, and output the findings for later analysis. Refer to the attached diagram and front panel for the specific layout.

The program receives the input signal via the DAQ card. The voltage data is then windowed and normalized to create a more standardized waveform. The data is then sent through a Fast Fourier Transform function which analyses a waveform its harmonic components for frequency and relative amplitude. These components are output to a graph for visual confirmation of proper data. The transform is then sent through a subroutine which takes the peaks above a threshold amplitude and bundles the specific frequency-amplitude pairs into a file for further analysis.

The data was sampled at an array for frequencies to determine the optimal value at which all relevant data could be picked up and a large enough sample taken. Firstly the FFT had its waveform windowed to a Hanning window to assist in containment of numerical leakage of the FFT spectrum. From analysis of preliminary results it was found that peaks in the FFT fell into a frequency range of 50 hz to 1600 hz. It was decided that the range 0-2000 hz was important for this data. The sampling frequency was finally set at 4400 hz which is slightly more than double the Nyquist Frequency for the sample. The Nyquist Frequency is the highest important signal frequency.

A large enough sample of the wave had to be obtained to gain an overall picture of the wave. Therefore, 4096 data points were sampled from the wave at 4400 hz giving a sample time of nearly one second. In this time the wave decays from the initial strike, but the harmonic content does not change in this decay. Ten samples were taken at each point to assure that the data was consistent and reproducible. These are the values that contribute to the overall averages as seen in sample data.

When observing the peaks from the FFT, a judgment had to be made concerning how large a peak had to be to be considered important. The value was initially suggested at 10 percent of the largest peak, but was quickly reduced to 5 percent as there were many harmonics in this 5 to 10 percent range.

In addition to this interface for data collection, Microsoft Excel and

another LabVIEW interface were used for analysis. The data was imported into Excel an analyzed using basic averaging and statistical (standard deviation) formulae to form a single, cohesive set of data. Excel then could produce a report containing average amplitudes and frequencies, error based on the standard deviation of the sample, the percent error compared with the amplitude, the normalized amplitude. and the normalized error. This set of data was then fed into a LabVIEW interface designed to give three-dimensional plots based on that information. Again, the layout of data is attached as figures 14 and 15 while the graphs are figures 11, 12, and 13.

Materials

For this phase of the project the equipment used was minimal. A Gretsch 13" X 9" Tom drum was the test drum. The drum was mounted on a standard Pearl snare stand. The microphone was a Peavey PVM 45i microphone with wind guard and patch cable. The sticks used were Vic Firth 5B, 5BN, and Gregg Bissonette models. The heads on the drum were Evans Genera G1 and G2 models.

IV. RESULTS AND DISCUSSION

Gretsch Drum Shell

The shell is the most fundamental piece of the drum. The materials for drum shells range widely from metal to various types of wood. The maple Gretsch Tom shell provided a stable base for the tests on the other parts of the drum setup. The shell was not varied in any way during this process.

Single Heads

The Evans Genera G1 drum head is essentially a sheet of manufactured plastic mounted to a metal rim. This head produced the results that were closest to the ideal membrane model.

Waveforms analyzed from the Genera G1 drum head closely resemble the ideal membrane model by following the modal patterns discussed earlier. The drum frequencies radiated from the drum head fall nearly into the frequency distribution of the model as shown in sample data as figure 5. Not all of the modes were present in sufficient amounts to appear in the final data, but the peaks that are present represent formal modes.

Genera G1 beater, No resonant, VF5B									
Mode	(0,1)	(2,1)	(0,2)	(4,1)					
Mode Ratio	1.00	211	2.23	3.07					
Average Frequencies	170.96	360.76	381.14	524.58					
Average Amplitudes	0.004	0.004	0.004	0.006					

Figure 5 – G1 Ideal Model Comparison

The other head examined was an Evans Genera G2. This head has a different construction than that of the G1. This head has two plastic membranes set into the wire rim with a thin film of oil between them. This dual layer system

Genera G2 Batter, no resonant, VF5B									
Mode Ratio 1.92									
Average Frequencies	90.50	173.67	181.17						
Average Amplitudes	0.08	0.04	0.01						

Figure 6 – G2 Ideal Model Comparison

causes very different results than those predicted by the ideal membrane as shown in figure 6.

Sticks

When looking at sticks there are many options to consider. The shaft of the stick can be made of various types of wood, most notably hickory and maple. The head of a standard snare or tom stick is made of either the same type of wood as the shaft or of nylon. Both types of sticks are in wide use.

The effect of the nylon versus wood head is the notable difference. The Vic Firth 5B stick is a single piece of hickory whereas the Vic Firth 5BN is a hickory shaft with a nylon tip. Overall, there was little difference between the two head types when their sounds are produced. The only notable difference is with the presence of the (1,1) mode. With the nylon sticks, the (1,1) mode was not favored as heavily. Instead, the nylon head tended to induce slightly more prominent high tones rather than this mode closer to the fundamental.

Tension

To properly play a drum head on a tom drum, the tension across the head in all directions must be approximately the same. By varying this tension, the drum's apparent pitch also changes. To tune a drum properly, an approximate star pattern must be used as demonstrated in figure 7. If this is method is not used, the head may seat improperly causing the head to rest unevenly on the drum.



Figure 7 – Drum Tuning Pattern

In most cases four or more tensions were studied for each set of tests. The tensions were decreased incrementally by quarter turns of the tuning rods.

The effect of tuning the drum to different pitches caused different modes to be expressed. For example, when at a high tension, the Genera G1 head exhibited only a single mode, its fundamental. As the tuning was decreased incrementally, as many as six modes were observed at the same striking position.

The effect of tuning the drum is consistent throughout the total data. As the tension on the head was lessened more modes became apparent.

Distance

Many drummers do not strike their drum heads in the center. Most opt to strike them slightly off center, usually by an inch or two. This is another deviation from ideal membranes since the ideal membrane model is excited from the center for clear modal representation.

Each tuning of the drum was tested at three different positions: the center, two inch offset, and four inch offset. As well, each head was probed at a single tuning across a narrower range of distances, each inch from center to edge.

The distance analysis for the two test heads produced similar results. As the distance from the center of the head increased. more harmonics became pronounced. The evident second harmonic was shown to be most prominent in the middle third of the distance tests, from 2 to 4 inches off center. As well, there was little else than the fundamental when struck in the middle. Higher frequencies became very apparent at larger distances creating a sharper, tinnier sound. An example of a distance analysis is attached as figure 15.

This leads to the conclusion that a strong fundamental and first strong harmonic are desirable choices in a drum sound, while higher harmonics are less desirable. A drummer's choice to strike a drum slightly off center is then a reflection of these desired characteristics.

Bottom Head

Tom drums are usually found with either one or two heads. The second head causes very large deviations from the basic membrane model. Difficulty arises when the second head is attached due to the individual resonances of that head. Each head on the drum will vibrate at different frequencies causing a very complex sound to emerge.

When a second head was added to the tom, the sound became very convoluted. The second head has multiple ways in which it can change the sound. If the two heads are tuned to the same fundamental pitch, that pitch will have a large presence, but the lesser harmonics will not be exactly the same and interfere, destroying them. As well, if the drums are slightly out of tune, as is popular with some drummers, many harmonics will sound creating a very rich tone, but he sound will need to be struck harder to gain the same volume.

Tuning can be achieved different ways with two heads. If both are the same, a harmonically consistent sound is created no matter the tension. If the bottom head is tuned lower or higher than the top head, the sound has many more harmonics available. The harmonics from the upper head are more apparent, so the tuning of the lower head can either add lower or higher harmonics to the mix.

Other Considerations

There are other considerations not taken into account in this study. Many variables exist with the shell itself. A single hollow cylinder will have inherent resonances much like any other open pipe. Once the hardware is added to the shell, there will be interruptions in the walls of the shell, and, thusly, the sounds it produces will differ.

The drum head sits on what is known as the bearing edge of the shell. This edge is the rim of the drum which is in contact with the actual head. Many different designs for this edge are in wide use. These include an equilateral triangle, a rounded edge, and 30-60-90 triangle to name a few. Each of these changes how the drum's tension is utilized. On a rounded edge much more of the head is in contact with the drum causing stronger coupling and more shell vibration. A strong point for the head to rest on causes less coupling and a more resonant head. The strong point enforces the required boundary conditions, where the rounded edge does not hold to them as rigidly.

Application

The results from this study can assist in the construction and restoration of drum sounds. Creation of desired drum sound can be affected by any of the variables expressed here. As well, people who are not mathematically or physically inclined can use the data here as a guideline for understanding and tuning of drums.

V. CONCLUSIONS

This study has explored the setup and implementation of a drum analysis system. The purpose of this study has two important future applications. The first is to create a working data acquisition system for use in the electronic musical instruments lab. Through this system many other devices and instruments can be analyzed for their content and properties. Secondly, the purpose of this exploration is to determine the difficulty of a real drum system when compared to an ideal membrane. This comparison shows the difficulty of modeling realworld simulations and works to spark ideas for doing so.

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Figure 8 – LabVIEW DAQ Interface Front Panel







Figure 11 – Distance analysis



Figure 12 – Distance Analysis



Figure 13 – Distance Analysis

Test: Distance Summary: Distance	Distance Genera G1 batter, Genera	a G2 resonan	t, Vic Firth	5BN Sticks,	Gretsch 1	3"X9" tom						
	Mode Multiple		1.63	1.71	2.97	3.31						
Center	Average Frequencies	133.15	216.70	228.11	395.01	440.32						
	Average Amplitudes	0.07	0.01	0.01	0.01	0.01						
	Average Error	0.00	0.00	0.00	0.00	0.00						
	Percent Error	3.98	0.00	6.25	5.02	5.73						
	Normalized Amplitudes	1.00	0.10	0.08	0.12	0.10						
	Normalized Error	0.04	0.00	0.00	0.01	0.01						
	Mode Multiple		1.63	1.71	1.78	2.37	3.31	4.37				
1 in off center	Average Frequencies	133.20	216.88	228.23	237.30	315.10	440.29	582.41				
	Average Amplitudes	0.07	0.01	0.01	0.01	0.01	0.01	0.01				
	Average Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	Percent Error	0.54	3.23	3.63	3.85	5.97	1.98	0.00				
	Normalized Amplitudes	1.00	0.07	0.08	0.08	0.13	0.11	0.07				
	Normalized Error	0.01	0.00	0.00	0.00	0.01	0.00	0.00				
	Mode Multiple		1.78	2.37	2.51	3.31	4.33					
2 in off center	Average Frequencies	133.22	237.39	315.20	334.32	440.59	576.52					
	Average Amplitudes	0.07	0.01	0.02	0.01	0.01	0.01					
	Average Error	0.00	0.00	0.00	0.00	0.00	0.00					
	Percent Error	0.25	2.30	4.33	6.39	2.92	0.00					
	Normalized Amplitudes	1.00	0.08	0.26	0.10	0.10	0.07					
	Normalized Error	0.00	0.00	0.01	0.01	0.00	0.00					
	Mode Multiple		1 62	1 71	2 37	2 5 1	2 97	3 31	3 76	4 58		
3 in off center	Average Frequencies	133 18	215 29	228.28	315 10	334.09	394.99	440.28	501 22	610 14		
	Average Amplitudes	0.08	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01		
	Average Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
	Percent Error	0.58	2.94	9.38	0.79	1.56	4.76	2.08	5.88	0.00		
	Normalized Amplitudes	1.00	0.15	0.08	0.43	0.09	0.07	0.09	0.07	0.07		
	Normalized Error	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00		
	Mode Multiple		1.62	1.71	1.78	2.37	2.51	2.97	3.76			
4 in off center	Average Frequencies	133.20	215.27	228.28	237.31	315.13	334.19	395.02	501.20			
	Average Amplitudes	0.07	0.02	0.01	0.01	0.03	0.01	0.01	0.01			
	Average Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
	Percent Error	0.64	2.56	4.38	5.47	0.95	1.48	5.92	2.97			
	Normalized Amplitudes	1.00	0.28	0.17	0.10	0.41	0.15	0.15	0.14			
	Normalized Error	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00			
	Mode Multiple		1.71	1.78	2.36	2.51	2.96	3.21	3.76	4.22	4.55	4.58
5 in off center	Average Frequencies	133.31	228.42	237.37	315.18	334.32	395.02	427.79	501.32	562.46	606.05	610.17
	Average Amplitudes	0.06	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01
	Average Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Percent Error	4.31	6.77	9.82	13.69	9.51	4.55	4.00	3.35	4.76	6.45	2.86
	Normalized Amplitudes	1.00	0.34	0.27	0.28	0.17	0.30	0.11	0.16	0.09	0.10	0.15
	Normalized Error	0.04	0.02	0.03	0.04	0.02	0.01	0.00	0.01	0.00	0.01	0.00

Figure 14 – Sample Distance Data Analysis

Tuning Summary:	Genera G2 beater, Gene	era G1 resonant, Vic Firth 5B Sticks				Zeroed				
	Playing position	Center				2 inch offset				
Tuning										
Down a quarter turn	Average Frequencies	95.76378	149.2724	191.4651		95.9742	149.8306	189.6426	193.0921	
-	Average Amplitudes	0.096	0.007444	0.005667		0.0918	0.0236	0.005	0.0063	
	Average Error	0.001054	0.00109	0.000756		0.000611	0.001507	0.000615	0.00026	
	Percent Error	1.098013	14.64421	13.33992		0.665588	6.385681	12.29273	4.132407	
	Normalized Amplitude	1	0.077546	0.059028		1	0.257081	0.054466	0.068627	
	Normalized Error	0.01098	0.011356	0.007874		0.006656	0.016416	0.006695	0.002836	
Medium	Average Frequencies	124.8958	201.9539	343.601		124.9182	186.8431	201.9301	343.3439	
	Average Amplitudes	0.07025	0.02025	0.005125		0.0876	0.0132	0.0279	0.0064	
	Average Error	0.00025	0.000526	0.000743		0.0004	0.000133	0.001016	0.000562	
	Percent Error	0.355872	2.598046	14.48824		0.456621	1.010101	3.641517	8.777239	
	Normalized Amplitude	1	0.288256	0.072954		1	0.150685	0.318493	0.073059	
	Normalized Error	0.003559	0.007489	0.01057		0.004566	0.001522	0.011598	0.006413	
Up a quarter turn	Average Frequencies	151.4416	255.1966	495.1353		151.6529	255.2924	576.074		
	Average Amplitudes	0.0998	0.0134	0.0041		0.1142	0.0146	0.0012		
	Average Error	0.000389	0.000562	0.00069		0.001031	0.000163	0.000814		
	Percent Error	0.389509	4.192114	16.83928		0.902488	1.118488	67.8142		
	Normalized Amplitude	1	0.134269	0.041082		1	0.127846	0.010508		
	Normalized Error	0.003895	0.005629	0.006918		0.009025	0.00143	0.007126		
Up a half turn	Average Frequencies	170.1746	288.198			170.1063	287.9856			
	Average Amplitudes	0.0262	0.0017			0.0241	0.0068			
	Average Error	0.002091	0.00087			0.0001	0.000133			
	Percent Error	7.981876	51.16858			0.414938	1.960784			
	Normalized Amplitude	1	0.064885			1	0.282158			
	Normalized Error	0.079819	0.033201			0.004149	0.005533			
Tuning	Playing position	Center				2 inch offse	et			

Figure 15 – Sample Tuning Data Analysis