

A Closer Look at Line Array Systems & How they Work

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Purpose:

The past half a decade has seen major manufactures replace their giant stacks of speakers and replace them with line arrays for large concert venues. Even smaller venues like local churches have started to install Line Array systems if for no other reason, than they are “cooler.” Sad part is that if you ask most people, even Sound Engineers, they do not know how they work differently, just that they do. This has caused a problem in that people are now using line arrays when they may not be the correct choice in all situations. Also, as people using this equipment, we found ourselves wanting to know what is going on inside of them to make an informed choice about selection in equipment. It is similar to that of a Race Car driver, though he may not be able to build the car, he or she should still know what kind of engine and wheels they are currently using.

The History/ Current Research:

1930: Wolf and Malter publish article in Soc. America.

1940: Olsen Publishes “Elements of Acoustical Engineering” 1st edition.

1957 : Harry Olson publishes his findings on the line array effect of a more narrow beam with increased frequency in his text Acoustical Engineering.

1960's : Column arrays started to take over as PA systems.

1979 : NEXO was founded by Eric Vincenot and Michael Johnson

1984 : Physicist Dr. Heil founds L-ACOUSTICS®

1992: (L'Acoustics) V-DOSC modular line source created by Christian Heil

1995 : (L'Acoustics) ARCS® Constant Curvature Array

2000, May : NEXO created their GEO line array series.

2001: EAW introduces the KF760 Line Array in Florida.

2001: Meyer creates M3D : their first line-array system

2002: Meyer creates M2D & M1D systems: More compact arrays

2003: Meyer creates the MILO Curvilinear array loudspeaker

“A line array is a loudspeaker system that is made up of a number of loudspeaker elements coupled together in a line segment to create a near-line source of sound. The distance between adjacent drivers is close enough that they constructively interfere with each other to send sound waves farther than traditional horn-loaded loudspeakers, and with a more evenly distributed sound output pattern” ~Wikipedia

The theory behind line array systems has been around and tested since the 1930's. The question that has always been out there is if this is the case, why did it take more than fifty years before they were developed for use in the public stage. Although there were some experiments with them in the 1960's, mostly taking four cabinets on their side to make a “line array” L Acoustics was one of the first major manufactures of the technology for the professional arena. They are still seen as the pioneer for

the technology and are sought after by high-end bands for concerts. Meier systems are the second in the running for development of Line array Systems, and since then, they have exploded onto the marketplace. We wondered if this was due to modern technology allowing for development of more accurate line arrays, is there something to the line arrays themselves that the new driver technology has made better. In either case, once touring shows realized the benefits of the Line Array in SPL output for long distances, Gain before Feedback, and allowed for a lighter trailer in the end. Honestly, the cost savings of cutting three trucks to one is enough to get most companies to hop on the band wagon.

Looking into the research from the companies that produce the speakers, their claim is that a normal speaker will not work as line array system. Their claim, especially from L' Acoustics, is that it takes a special speaker that works similar to a line array to combine together to make a line array. The claim is that frequencies above 8k will start to interfere with each other due to this. On the other hand, if you read the "white paper" by James R. Griffin he would argue otherwise. Though I haven't found why it's called the "white paper" it's is nicked named as such on most of the websites that reference it. It is referenced a deal due to the simplification of the theories that have to do with Line arrays. Although he agreed that there is some merit to using a speaker incased in a horn that allowed for more of a square wave, he stated that the distance between the speakers are more important.

Touring Systems without Line Array Technology:



With Line Arrays:



The crowd at Madison Square Garden, Rolling Stones concert, November 27, 1969.

Original Experiment:

In the thought process we commonly use for Theatre Design work, we “thought big” on what we wanted to accomplish for this semester and testing. The original idea was to test the amplitude and frequency response of three sets of speakers in the Festival Theatre at Krannert. One set would be a line-array system with the other two sets being a traditional horn and woofer speaker system. In all testing areas, the speakers would be at the center of the stage facing the audience.

First, we were going to take the Nexo Line array system with twelve boxes and use our genie lift to hang them off of the ground. From there, we would test their frequency response and SPL levels in several spots around the theatre to see how they act. We would then remove the Nexo system, and stack a set of three JF 560 speakers on top of a Bag-end Sub. The sub would not be wired, but be used purely as a way to lift the speaker to the “typical” height. We would then again test the frequency response and SPL levels of the Speakers in the same spots as we tested with the Nexo Line Array. In the third testing scenario, we would flip the middle 560 upside down so that the bottom two speakers would be Woofer-Horn Horn-Woofer and repeat the testing sequence.

The purpose of using these three different methods of stacking speakers is that it has been proposed by our current boss that the line array should have a better frequency response and have a more even SPL loss as distance away from the speakers increase. Also, stacking the 560’s with the middle set upside down would cause a decrease in destructive interference while increasing constructive interference. Now, although it would be agreed that for rock concerts where a “wall of sound” is preferred the line array does perform better, they have not been proven to perform that much better in re-enforcement and CD-playback type of shows. Furthermore, even though stacking the middle set of 560’s is supposedly “better” doing shoot-outs (testing speakers next to each other) even those who preach the difference can’t always tell the difference. Similar to that of those who say the hate Pepsi and love coke, and yet chose the glass of

Pepsi 25% of the time in a blind taste test. Although everyone is open to their opinion upon what is better, it would be nice to have known scientifically how much of a difference the line array makes vs. the traditional horn and woofer system in the Tyron Festival Theatre and if the flipped speaker concept has any merit.

As a second portion to this experiment, we were going to use eight similar microphones and test each of these speaker configurations by stationing the speakers in a coordinate position around the speakers. If looking down, they would be :00, :07:30, :15.00, :22.30, :30.00, 37:30, :45, and 52:30 around the speakers at different frequencies. This should allow us to create our own graph of frequency response of these speakers.

New Experiment:

After pushing those in scheduling at Krannert for a few months, we realized that finding time and space to set up these systems and do all the testing was not realistic. Unfortunately, even though we work in the space a good portion of our days, we were not allowed the time to reserve the rooms. So, we needed a new plan.

Robert re-read the white papers one day (see history) and realized that it said to create a line array one simply needs to put a number of drivers as close to each other as possible. The amount of control one receives is proportional to the distance between the driver to the next driver for high end and the distance of the speaker column as a whole for the low end.

We then decided to create a small line array to test if this theory was true. At first the thought was to buy some decent drivers, make custom cabinets, etc. but the first looks into price of decent woofers of three inch size proved more expensive than we could afford. When a seller had some generic amp powered computer speakers on sale for a buck a pair, we had a winner. Though we knew that the frequency response of these speakers would be less than ideal for reference listening. Our thought was that since the principal of the line array system is that the constructive interference should work with low quality speakers, we should see the effects during testing. It was decided upon arrival of the speakers that it would save a lot of wasted effort to use the cabinets the drivers were already incased rather than building new cabinets.

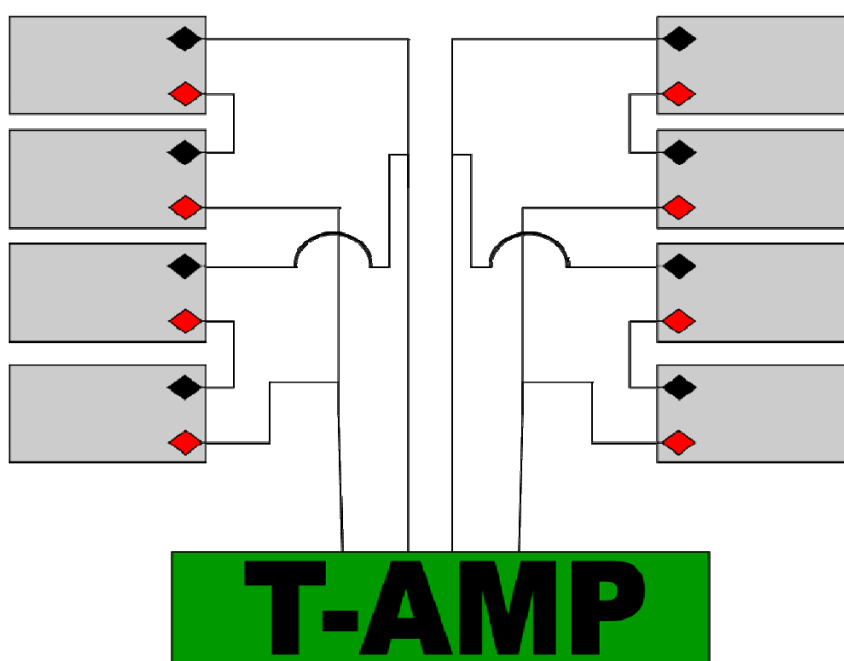
Steps to creating and testing the speaker array:

1) Buy Speakers and T-amp.

1. We acquired fourteen knowing we would need eight for the project, a few spares in case one of us soldered something wrong, and Robert wanted to make a mini-Leslie with one set of them as a side-project for later.

2) Rewire Speakers.

1. The T-Amp bought for the speakers was rated at fifteen Amps per channel without listing an Ohm Minimum or Maximum. Due to this, we decided to re-wire the speakers in the group of four so that the overall resistance would still equal four ohms. In addition, each speaker was rated for five amps of power. In this arrangement, each speaker could get a maximum of three and three quarters Amps, thereby limiting our ability to accidentally blow up a speaker.



3) Build A Support system for the speakers:

There was some debate at first upon how to hold-up the speakers. Traditionally, line-arrays are held up by hanging them from the ceiling, but we decided that for the sake of testing, that this could prove problematic. As a proof of concept, we first attached the speakers using gaffers tape. Though this was not the prettiest option, we could listen to the group and hear that the principal of the system was working before we started drilling holes.

We were allowed access to the machine shop, and found some copper L-Brackets of the correct size and some screws and a couple old pieces of wood as a base. To connect the speakers to the L-Bracket we:

1. Lined Up the Array and made markings
 2. Drilled holes into the sides for the screws
 3. Check alignment on each speaker in respect to each other.
 4. If needed, re-drill holes in speakers to realign.
 5. Recheck alignment
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After building the two line array systems, we took them to Steve Errede to start testing. In all situations, we used both a particle and pressure microphone to capture data with a Lock-in amplifier and will just refer to them as the microphones.

Testing:

Test phase 1 – (On the ground)

We started by setting a line array on a stool facing the two microphones on a stand. We then manually raised and lowered the microphones on the rod and hand-recorded the results. We then took the results and entered them into one of Steve's custom spreadsheets. The data that we captured at first looked a lot like garbage. We attempted to do the same experiment set up again using a program to capture the data, thinking that we may have had some bias with our capturing abilities, but the results were similar. We later realized that the reason for this was that the room reverberation was causing major issues at even distances as close as one meter. As a note, from this point on we used the data capturing software that Steve has developed in the lab.

Test phase 2 – (Far Field Up – Microphones on motor)

Our First attempt on testing with the step motor, we decided to have the microphones stationary on the table approximately 40cm from the table. With this set-up, the speakers were directly facing the wall. The results gave us some weird peaks where we knew we shouldn't have gotten. Our thoughts were that the step motor was causing some of the data irregularities along with the reflections on the wall just behind the microphones even though we had covered the motor and the wall behind the motor with as much foam as we could find.

Test Phase 3 – (Far Field Up – Microphones Stationary)

The next major attempt the speaker array attached to the motorized rig thinking that the movement of the microphones and the speakers facing the wall might be causing the problem. We placed the microphones at the end of the table approximately 79 cm from the center of the speaker array. After capturing the data and placing it in the spreadsheet program, we noticed a similar bias towards one of the sides of the graph. We decided to

run the test again to see if we had somehow not lined up things correctly, and the results were the same.

At this point we were unsure what was causing the lean to one side of the speaker array. Our first guess was that we may have wired one speaker in the line array out of phase. We took a 9v battery to check the polarity, and discovered nothing. We then decided to just flip the speaker system upside down and see if the results changed any.

Test phase 4 – (Far Field Upside-down)

The only difference between Test phase 4 and 5 is simply that we took the line and flipped it upside down. If the speakers were causing the irregularity in response, then the graphs should show it. After testing, the graphs were not identical, but they were very similar. From this, we concluded that it was not the speakers causing the variation on one side, but something due to the room noise. We looked at the graphs and realized that we were close to one window on the same side that there was a considerable dip in pressure. We decided that it was likely that the window was absorbing some of the sound, thereby causing the errors.

Test phase 5 – (Far Field Moved)

Though it was a pain to do, we moved the whole set-up over around four feet so that it was equal distant from the two closest windows. This proved to give us better results, but in the end, we still had some inconsistencies that seemed to be caused by room noise. It was then decided that we would decrease the distance of the microphones and thereby concentrating on the near-field.

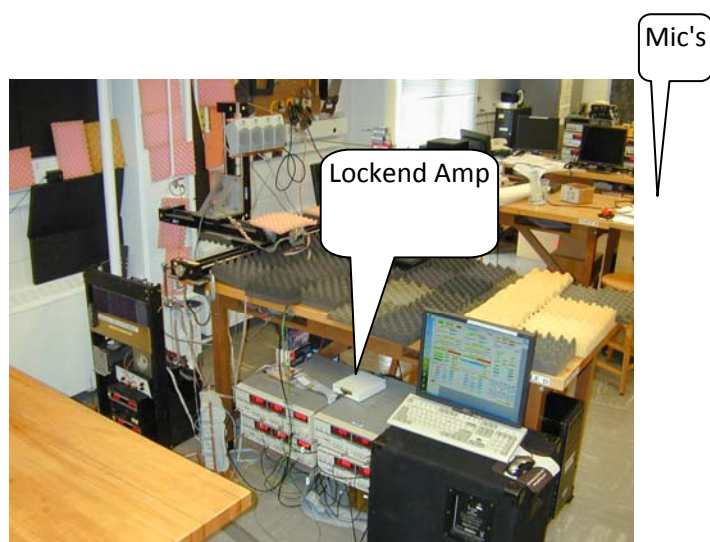
Test phase 6 – (Near Field)

In the last test phase, there was a pressure and a frequency microphone stationed 34.5 cm from the center line of the array. For no apparent reason, we had left the microphone array “upside down” from when we flipped it in test phase 4. We ran the test once at 10k, and after receiving some results closer to “white tower” we decided the next move

would be to one more run at 10k, and then test at 5k, 2k, and 1k as well. The results of these tests are in the section bellow.

Test Phase 6.5 – (one speaker)

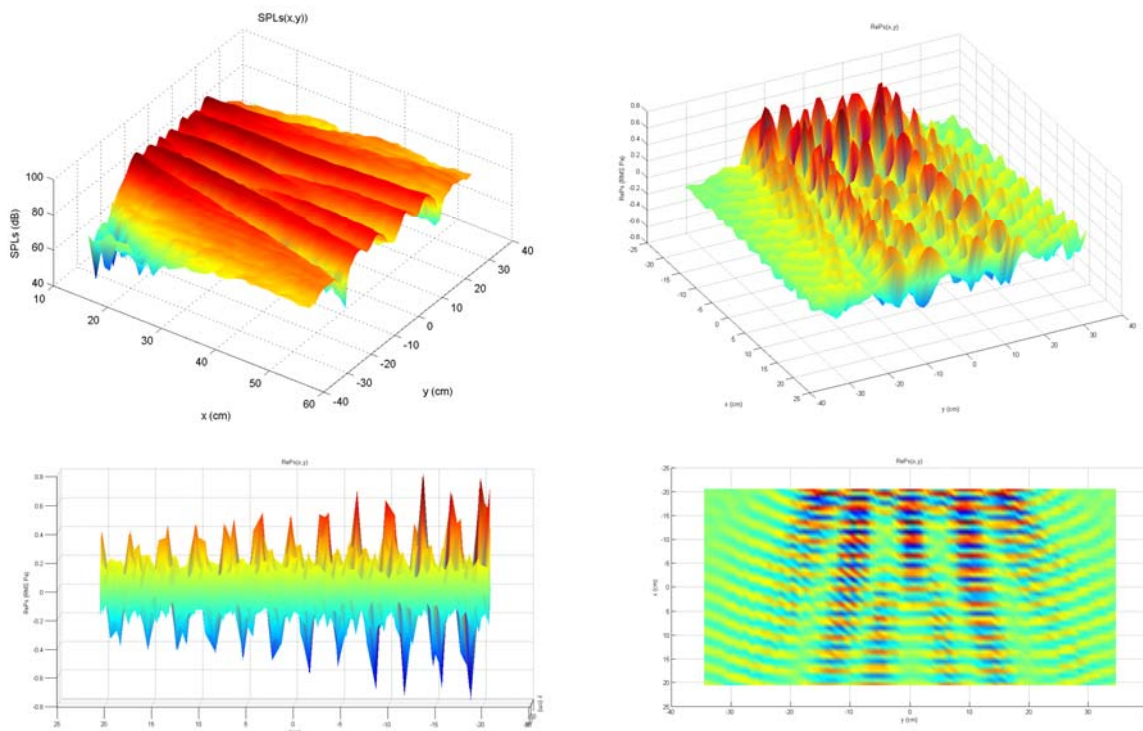
As of the time of writing this paper, we have not done this, but we plan to test one single speaker in the same manner as we tested the line array and compare the two with each other. We know we won't get the complicated interference patterns, but we're hoping to see a well curved signal with an increased rate of SPL loss as compared to distance.



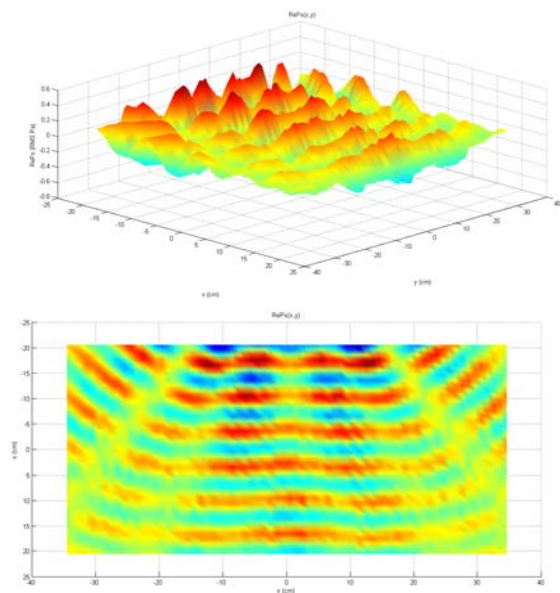
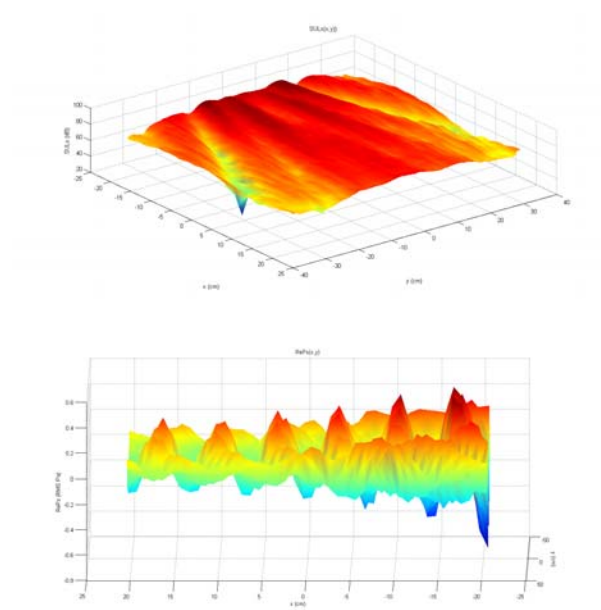
Results:

The pictures below help show pressure and phase responses as the distance changes between the microphones and the line array. There are results below to compare reactions. Feel free to continue to look at different results on the server.

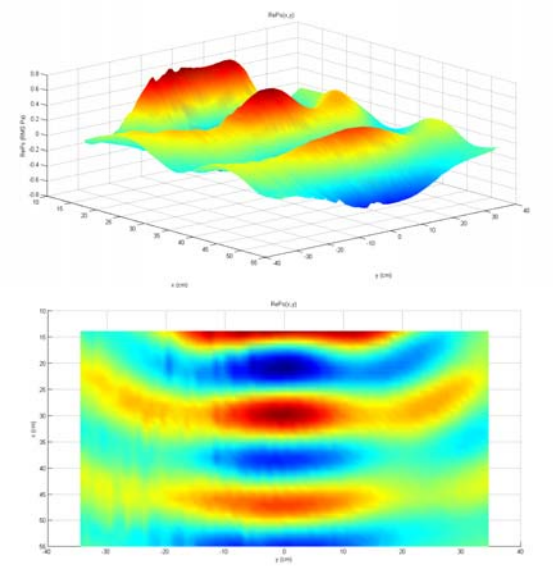
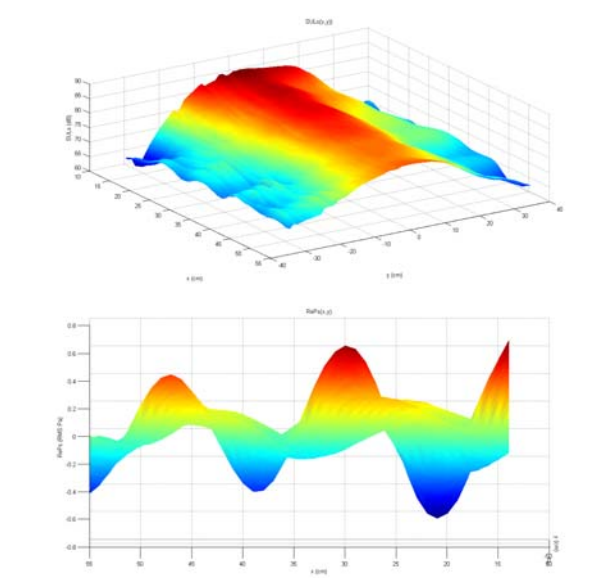
10K:



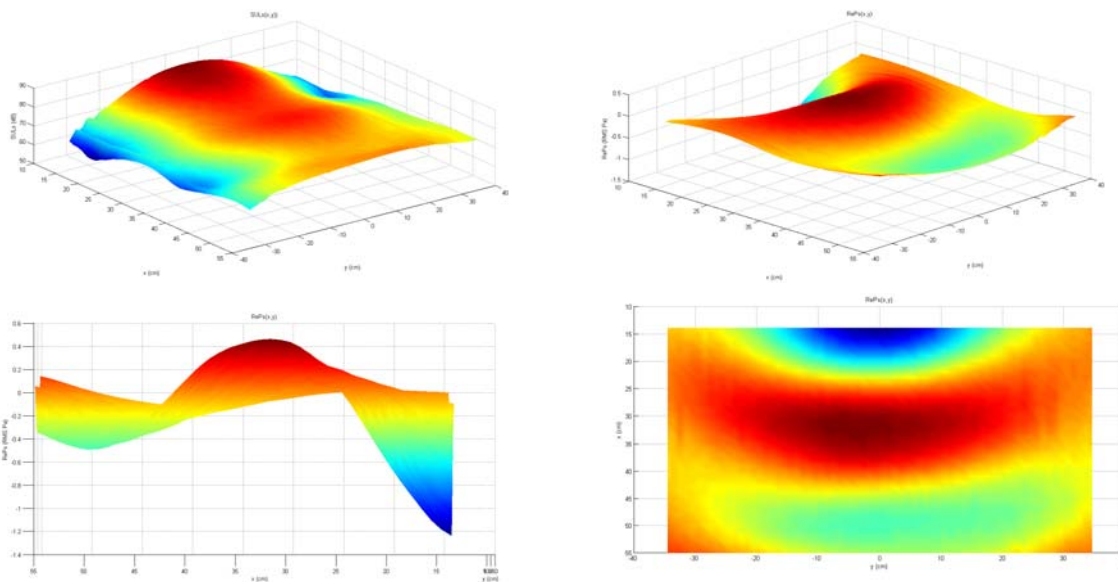
5K:



2K:



1K:



Thanks to the work of Steve Errede, we have several hundred megabytes worth of data of which we could sift through and show. All have merit, but for the purposes of the original point of this experiment, the thought that the line array is working “correctly” as a line array can be seen in these four graphs of each of the different frequencies. According to the calculations given by the “white pages,” we should have “control” with our speakers between 466.7Hz and 13760Hz. Although the testing at 10Khz and even at 5Khz are still very directional do to the nature of those frequencies, there is still a distinct pattern in which the waves are working together to make one single wave pattern. It is curious why at 10k the line of waves are not as straight as the lesser frequencies, but as this is close to the limit of control as proposed by the white papers (13k), it may be that if we tested 15K we would see total degradation of this line.

In addition, the resulting data showed distinct lobes projecting from the array and it also showed interesting curves radiating away from the direct pattern. In looking at the 10k and 5k patterns you can see the phase changing, and the alternating propagation of sound vs. the sloshing.

Reflections:

Looking back, there are several things that seem like common sense issues but were really helpful in the experiment process.

The first testing series was good because it helped us to check that everything worked, but it was easy to see that there would be reverberation issues. At first, it was hazy as to why do it when you know it might not work, but over time it became apparent that the test we ran that day helped show us our inevitable goal.

It would have been nice to continue recording more data.

After the whole testing process, it appears that we discovered as much about the nature of the room as our self-built line array. A large portion of our testing process was dedicated to getting over the acoustics of the room. If we had an infinite amount of time, with an anechoic chamber it would have been nice to have doubled or tripled the space between the microphone and the array so as to test the lower frequencies in the far field. This would have allowed us to discover if the interference above 8k was as much of a problem as the high-end systems claim. Though we believe it may have been heard in some of the 10k runs we had, it's a wonder how much this affects systems that are not large scale. In addition, it would have been helpful to have a few full wavelengths of which to look at with the lower frequencies. Along those lines, a test at 750 or 500Hz would have been interesting to see.

In the end, we think that the process was successful. Throughout the class, most of the math was quite simply over our heads. That being said, it was still a worthwhile for us to “see” what the math is and to grasp the concepts of these complicated formulas, even at a fundamental level.