Analysis of Factors Affecting the Sound Generated by Airboats

Aquiles Perez, MS
Research Asistant, Florida Atlantic University, Boca Raton, Florida, USA, aperezm@fau.edu

Oren Masory PhD.
Professor, Florida Atlantic University, Boca Raton, Florida, USA, aperezm@fau.edu

Steward Glegg, PhD.
Professor, Florida Atlantic University, Boca Raton, Florida, USA, aperezm@fau.edu

Abstract

This study presents graphical and numerical comparisons of the factors affecting the sound generated by airboats; an airboat travels on water and wet land by means of an air pusher propeller attached to an internal combustion engine.

These analysis shows the engine and propeller RPM as the main contributors of sound. The contribution of the engine is a tonal sound can be reduced by using a muffler. The sound generated by the propeller is a flapping sound clearly identified at high revolutions (over 1800 RPM). Above mid-range speeds, the propeller sound takes over, and any reduction of sound on the muffler does not play any role. The only method to control the sound of an airboat without any design modifications is to maintain the operational RPM at mid-range when the mufflers devices contribute to the sound reduction.

1. Introduction

To understand the different elements of an airboat affecting the sound level, comparisons on sound spectral have been performed.

Data collected at Ocala location (December 2004) has been used for the analysis [1]. The effects considered on the analysis are the blade passing frequencies (BPF), firing frequencies (FF), and their harmonics at several RPM.

To present the results in a concise manner, the sound spectrum has been divided into nine subplots (Fig 3-a). The rows represent the measurements from 3 different microphones: Mic. 1, Mic. 2 and Mic. 3 where their locations are shown in Fig. 1 for static test (boat sitting on the trailer) and in Fig. 2. for drive by test (boat moving on water). The microphones are located at distances of 50 ft. from the propeller. The columns indicate the ranges of frequencies considered for the analysis, first column, low-frequency form 20 to 200 Hz, mid-frequencies from 200 to 700 Hz and high-frequencies form 700 to 2000 Hz.

Table 1 presents the frequencies affecting the sound spectrum (firing frequencies (FF) and blde passing frequencies (BPF)). FF are produce by the engine (engine sound) and blade passing frquencies are produced by the rotation of the propeller. This table also includes the elements, which contribute on the sound generation at the mentioned frequencies. These elements are the number of cylinders (NC), number of blades (NB), gear ratio (GR) and RPM of the engine (in percentage). The relation between BPF, RPM, and number of blades is presented on Eq. 1

$$\text{Blade Passing Frequency} = \frac{NB * RPM_{engine}}{60 * GR} \tag{1}$$

The relationship between the RPM of the engine and the frequencies at which the sound is generated (Firing Frequencies) for V-engines are as follow (Eq. 2):

$$\text{Firing Frequency} = \frac{\text{RPM} * \text{\# of cylinders}}{120} \tag{2}$$

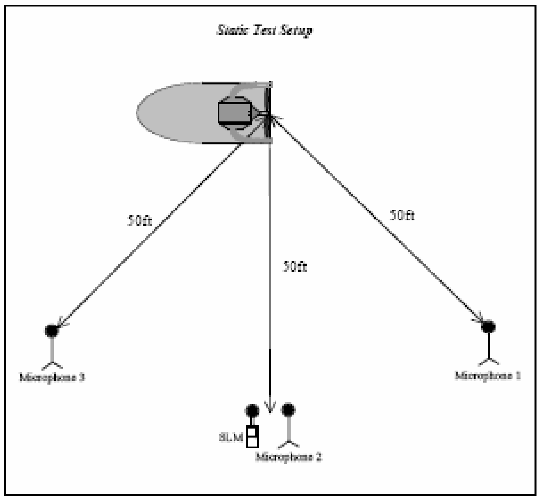

Fig. 1 Microphone Position Static Tests

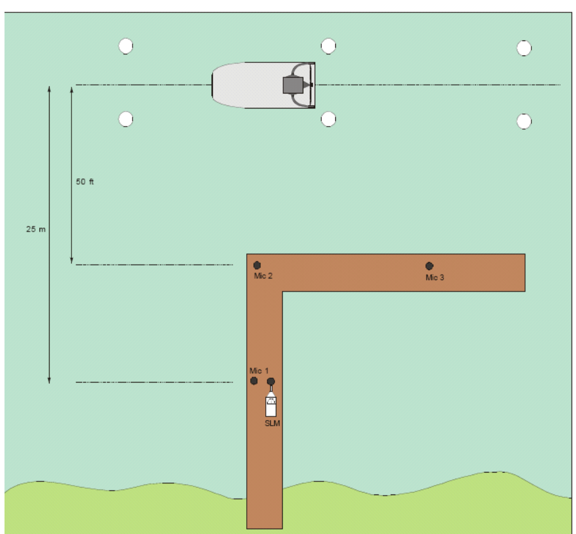

Fig. 2 Drive By Test Configurations[1]

Table 1 FF and BPF of the Different Experiments

	Configuration				Static Test			Drive-by Test		
Boat #	**Speed**	**NC**	**NB**	**GR**	**RPM Eng.**	**FF**	**BPF**	**RPM**	**FF**	**BPF**
3	**Idle**	**8**	**2**	**1.73**	**550**	**36.7**	**10.6**	**NR**	**NR**	**NR**
	50%				**1800**	**120.0**	**34.7**	**NR**	**NR**	**NR**
	100%				**4400**	**293.3**	**84.8**	**NR**	**NR**	**NR**
5	**Idle**	**8**	**4**	**1**	**700**	**46.7**	**46.7**	**550**	**36.7**	**36.7**
	50%				**1800**	**120.0**	**120.0**	**2100**	**140.0**	**140.0**
	100%				**2600**	**173.3**	**173.3**	**3000**	**200.0**	**200.0**

*** FF= Firing Frequency, BPF= Blade Passing Frequency, NC= Number of Cylinders, NB= Number of Blades, GR= Gear Ratio, RPM Eng= Revolutions per minute of the engine.**

In addition to BPF, FF and their harmonics, there are sounds generated by the vibrating of the parts of the boat. This excitation is directly related with the acting parts of the engine and propeller. The vibartions of ths parts generate sound throughout the whole body structure.

2. Propeller Comparison

2.2 Boat # 3 Propeller Comparison

2.2.1 Boat# 3 propeller comparison without muffler

At idle speed without muffler, Fig. 4-a shows that the engine plays the biggest role in sound generation. In this case, the reduction in frequencies is observed at mid-frequencies (between 200 and 600 Hz of up to 15 dB (A)). At 50% speed without muffler (Fig. 4-b), boat # 3 presents sound difference with and without propeller (at 100 Hz the sound difference is equal to 20 dB(A)). At full speed (Fig. 4-c), the effect on the reduction of the blade passing frequency (Boat#3 BPF=84.8 Hz) of 15 dB(A) . Also, it is clear that from 300 Hz to 2000 Hz there s a reduction of 20 dB(A) without a propeller.

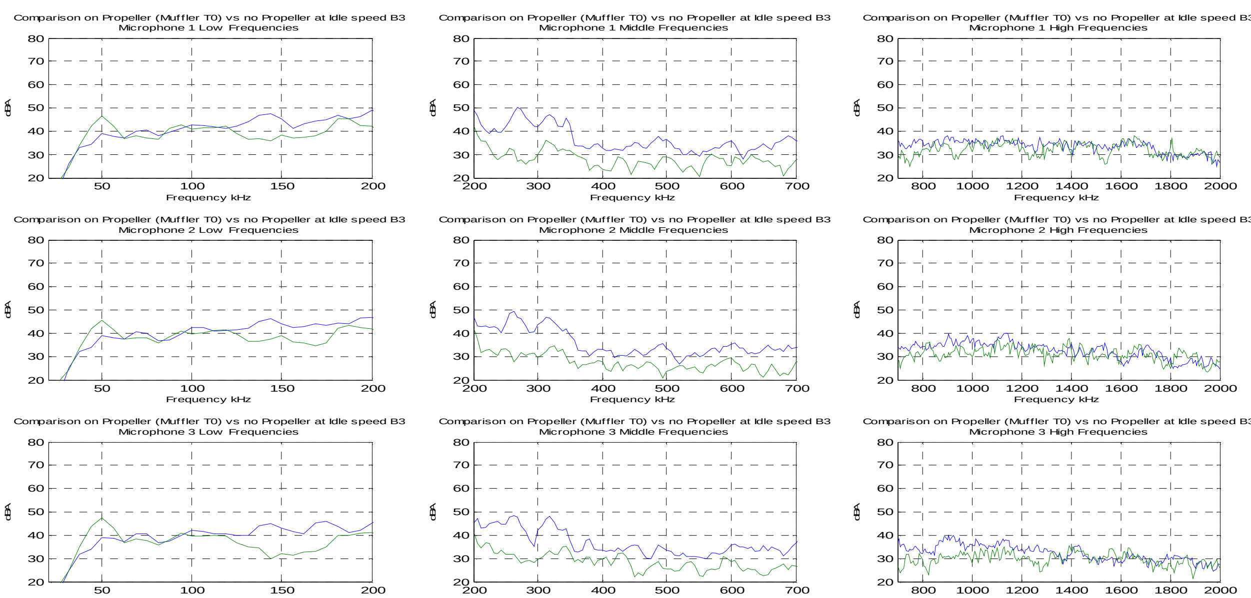

Fig. 3-a Spectra for Boat #3 at Idle Speed with Propeller (__) and without propeller (__)

From the previous graphs, it has been determined that there is not difference between the sound recorded from three microphones (at 50 ft. the sound generated is multidirectional); therefore, it has been decided to present only the sound spectrum from microphone 1 in the following graphs.

2.2.2 Boat# 3 propeller comparison with muffler T11

At idle speed using muffler T11 (IMCO CM119 + flex pipes) (Fig. 5-a), the difference in the sound level between 100 Hz and 350 Hz is 20 dB (A). At 50 % speed with muffler T11 (Fig. 5-b), the difference is observed over the whole frequency spectrum and rise up to 25 dB (A). This difference is greater than in Fig. 4-b without muffler. Comparing figures 4-b and 5-b indirectly show the reduction of sound due to the muffler at 50% speed. Similar differences to the ones presented at 50% speed have occurred at 100% speed for this boat (Fig. 5-c). There is a difference on sound due to the propeller effect that goes up to 20 dB(A). This sound reduction is greater than Fig. 4-c. Fig. 5-c shows clearly the effect of the BPF and their harmonics (also this effect is observed on table 2).

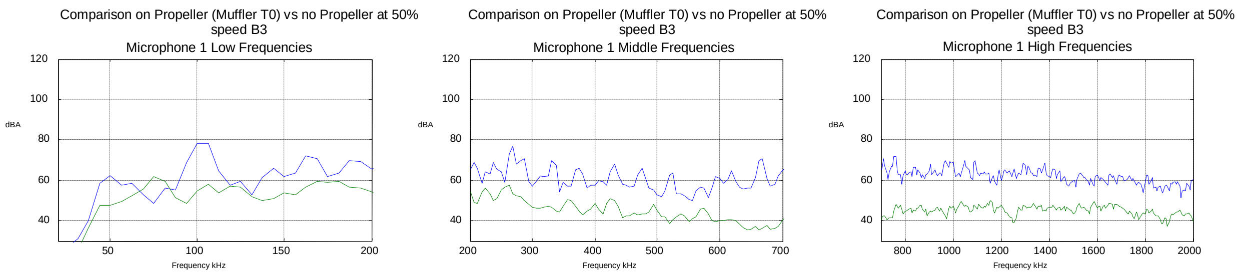

Fig. 3-b Spectra for Boat #3 at 50% Speed with Propeller (__) and without propeller (__)

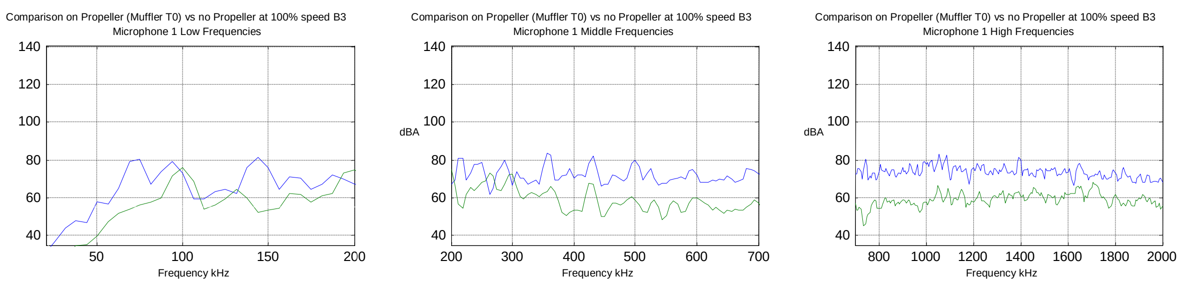

Fig. 3-c Spectra for Boat #3 at 100% Speed with Propeller (__) and without propeller (__)

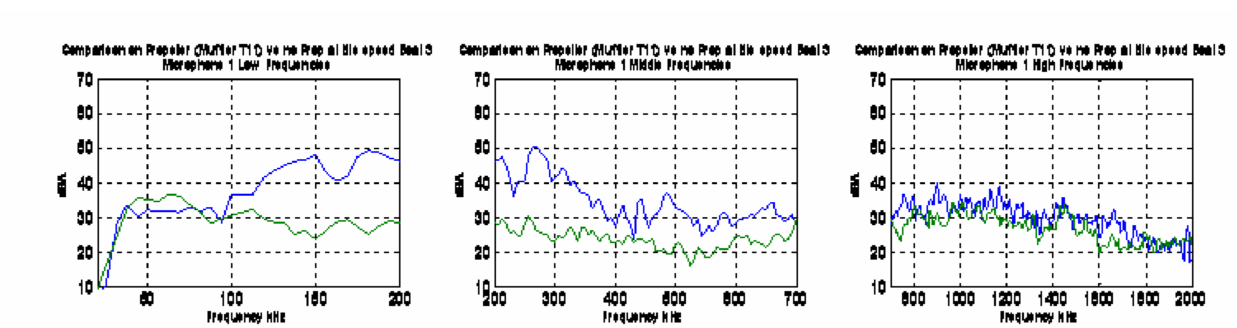

Fig. 4-a Spectra for Boat #3 at Idle Speed with propeller (__) and without propeller (__), with Muffler T11

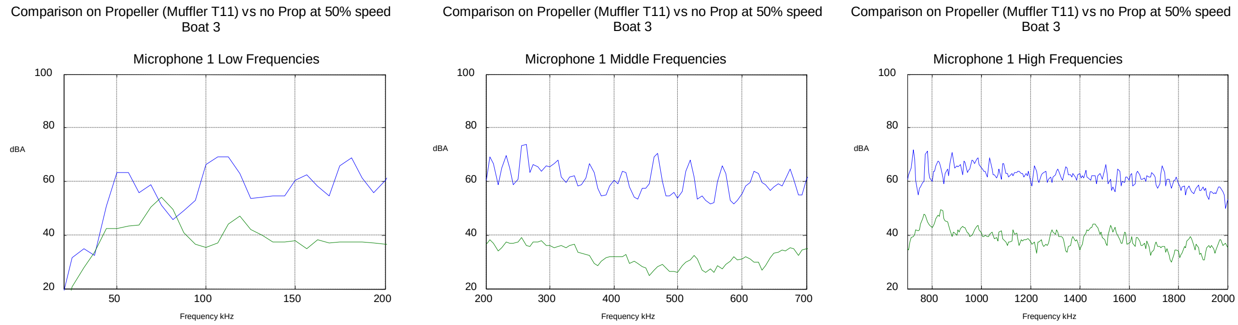

Fig. 4-b Spectra for Boat #3 at 50% Speed with propeller (__) and without propeller (__) with Muffler T11

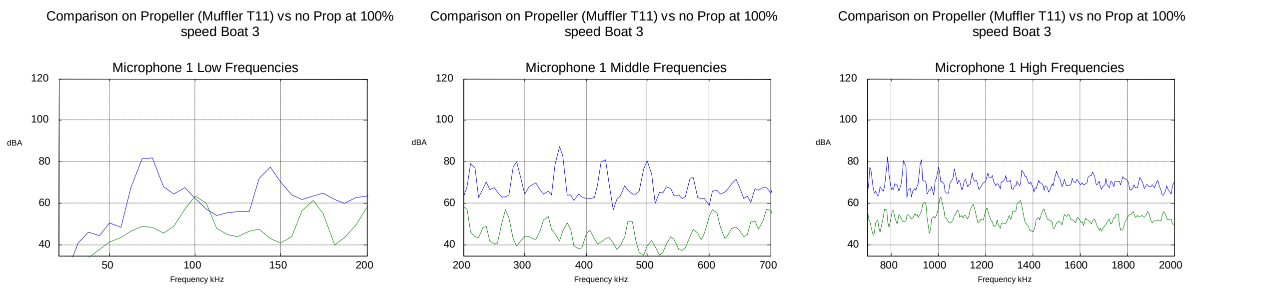

Fig. 4-c Spectra for Boat #3 at 100% Speed with propeller (__) and without propeller (__), with Muffler T11

2.2.3 Boats #3 numerical propeller comparison

Table 2 presents numerical comparisons for boat #3 with and without propeller. These comparisons are based on integrations obtained using the trapezoidal method in Matlab. These numerical comparisons represent the area of the sound spectrum for each of the three frequency scales. These values have been collected for reference comparisons and show that for all the cases the sound generated with propeller is greater than without propeller.

Table 2 Numerical Propeller Comparison for Boat# 3

RPM	Channel	Without Muffler					
		With Prop	Without Prop	With Prop	Without Prop	With Prop	Without Prop
		Low Freq		Mid Freq		High Freq	
Idle	1	7210.46	6891.29	18000.39	13700.47	43400.26	41542.97
	2	6992.94	6523.10	18043.23	14028.63	41863.37	38536.71
	3	6992.94	6523.10	18043.23	14028.63	41863.37	38536.71
50%	1	10687.64	9200.29	29872.06	22084.16	80260.30	58513.15
	2	10406.95	8874.76	30458.90	22031.57	79332.95	55928.14
	3	10406.95	8874.76	30458.90	22031.57	79332.95	55928.14
100%	1	11735.32	9844.26	35568.03	28968.94	95173.58	76511.93
	2	11259.42	9726.94	35022.49	28836.44	93730.98	75049.16
	3	11259.42	9726.94	35022.49	28836.44	93730.98	75049.16
		With Muffler T11					
Idle	1	6774.10	5271.13	17003.96	11637.55	38536.14	34889.86
	2	6607.85	5250.07	16702.33	11438.95	37670.37	33742.40
	3	6509.26	5088.82	16821.69	11583.69	40471.67	34277.70
50%	1	10004.23	7025.24	29811.33	15779.59	79883.59	50167.84
	2	9823.88	7033.29	28239.84	15584.08	76086.80	49760.22
	3	9770.80	6883.23	29823.55	15511.24	78312.18	51031.94
100%	1	10858.52	8297.25	33377.20	22281.96	90344.14	68406.10
	2	11008.60	8376.68	32996.07	21203.11	86584.24	67641.61
	3	10799.69	7930.85	32927.09	21981.96	89293.58	70839.94

3. Muffler Comparisons

The following analysis presents comparisons between mufflers. Similarly to the propeller effect, these comparisons have been made at Idle, 50% and 100% speed.

3.1 Boat# 5 Muffler Comparison on Drive-By Test

The effects of sound reduction due to muffler T6 (IMCO CM119 + solid pipes) on boat 5 on drive-by tests can be observed on figures 6.

3.1.1 Boat# 5 graphical muffler comparison on drive-by test

Fig. 6-a shows a slight reduction at idle speed on low frequencies (around 60 Hz of 10 dB(A)). In addition, a high sound reduction on peaks is occurring at mid-range and high-range frequencies (starting at 280 Hz every 100 Hz with a high 15 dB(A) for each peak. At 50% speed, Fig.6-b shows sound reduction at low level frequencies around 100 Hz and from 150 Hz to 180 Hz, Fig. 6-c shows a comparison on sound spectra levels for boat#5 at 100% speed. At low frequencies, there is a clear sound reduction with muffler T6 (at 100 Hz there is a difference of 20dB(A)).

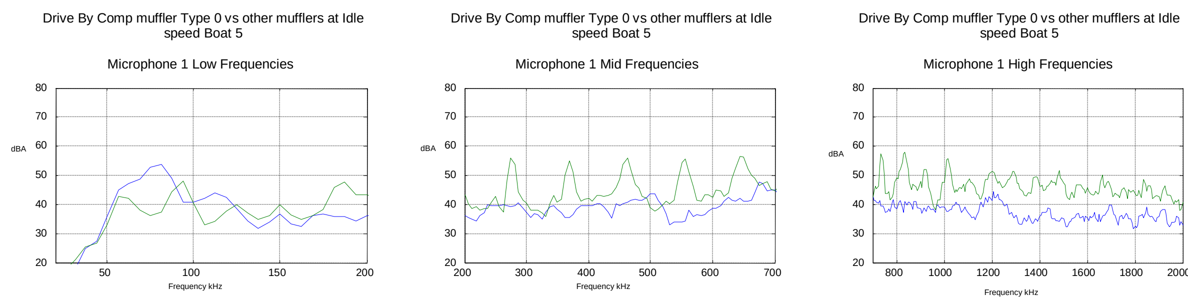

Fig. 5-a Spectra for Boat #5 at Idle Speed with Muffler T6 (__) and without Muffler (__) Drive By Test

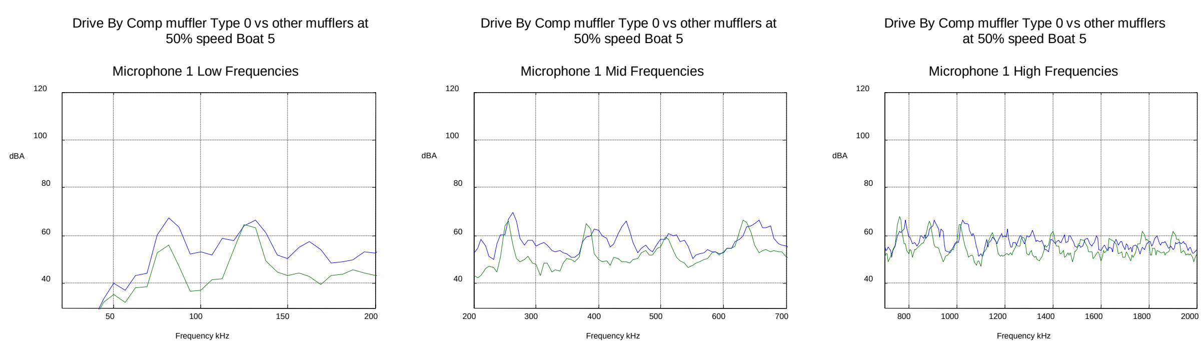

Fig. 5-b Spectra for Boat #5 at 50% Speed with Muffler T6 (__) and without Muffler (__)Drive By Test

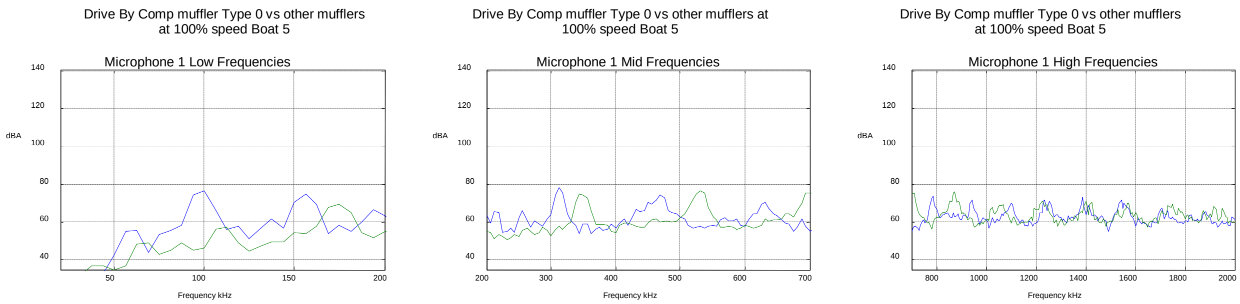

Fig. 5-c Spectra for Boat #5 at 100% Speed with Muffler T6 (__) and without Muffler (__) Drive By Test

3.1.2 Boat #5 numerical muffler comparison

Table 3 shows the numerical comparison of the muffler effect for the three ranges of frequencies on boat# 5. These values show that without muffler the sound generate is higher for most of the cases.

Table 3 Numerical Muffler Comparison for Boat# 5

RPM	Channel	Static Test					
		Muffler T6	Without Muffler	Muffler T6	Without Muffler	Muffler T6	Without Muffler
		Low Freq		Mid Freq		High Freq	
		Drive By Test					
Idle	1	6680.93	6598.84	19323.33	22031.40	50702.48	62407.57
	2	7535.75	7225.74	21898.16	24166.60	54905.11	67307.36
	3	7391.22	6560.65	22214.80	23244.97	57542.97	64073.54
50%	1	8788.77	7471.75	28435.47	25721.04	74413.78	70815.24
	2	9366.47	8067.17	29429.59	27137.30	77874.03	76039.36
	3	8484.44	7251.75	28966.81	26779.89	75157.79	72525.46
100%	1	9877.99	8681.78	30463.02	29866.70	81071.19	82154.53
	2	10693.38	8953.03	32812.74	30779.43	86776.26	85227.78
	3	10087.19	8412.99	32513.86	29398.95	85278.10	79743.10

4. Conclusions

The analysis performed for sound spectra has concluded the following:

- It has been found that with and without propeller at lower speeds, the sound is similar. This means that at lower speeds, the engine generates the sound. At mid-range speeds, the different between with and without propeller becomes clear, and the contribution of sound by the propeller is significant.

- At high RPM, the sound of an airboat with propeller is much higher than without propeller, but still at some frequencies, the sound of an airboat with and without propeller is similar.

- In general, not all the mufflers have the same sound reduction, in some cases the muffler do not provide a sound reduction while in some others the effect is clearly noticeable.

- Graphical and numerical sound spectral comparisons have been made with and without propellers for boats # 2, 3 and 5 and with different types of mufflers for boats 5 and 6. Sound spectral analysis of the engine sound without a muffler at high RPM show that the firing frequency and their harmonics manifest as peaks. With a muffler, these peaks are reduced and the engine sound becomes a broadband noise.

- When comparing the muffler with propellers over mid-range speeds, it was found that the propeller sound is dominant, and any reduction of sound due to the muffler cannot be accomplished.

- While comparing the propeller effect with and without muffler, it has been further found that especially at low (from 20 to 200 Hz) and mid-range (from 200 to 700 Hz) frequencies; the use of muffler reduces the engine noise.

- The only method to control the sound of an airboat without any design modifications is to maintain the operational RPM at mid-range when the mufflers devices contribute to the sound reduction.

5 Future Works

In order to reduce propeller noise it is necessary to reduce the tip Mach number. The Tip Mach number is a function of the length of the blade and the RPM (Eq. 4.4). If the lengths of the blade or the RPM are reduced, the thrust force required to move the airboat will be reduced. Therefore, it is necessary to come up with new blade designs, which with a smaller blade length at lower RPM, generate enough thrust to drive the airboat. Engine sound can possibly be reduced using engine enclosures [2]. Enclosures are proven to provide sound reduction. However, it is necessary to measure the effect of these enclosures on the sound level.

Finally, the development of mufflers, to reduce sound level over broader frequencies range, will also help reduce the engine sound effect further.

REFERENCES

1. Glegg, Stewart; Masory, Oren and Coulson, Robert "Analysis of Sound Generated by Airboats", Florida Atlantic University, Boca Raton June 2005

2. General Motor Research Laboratory, Engine Noise, Plenum Press New York 1982