NOISECAM - USING 3D BEAMFORMING TO BETTER LOCALISE NOISE SOURCES ON HOVERCRAFT

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ABSTRACT

Light Hovercraft are fun but with high revving engines and fans they can be noisy. NoiseCam, a homebrew 2D beamforming system, has been used on over 130 amateur craft worldwide to identify the loudest noise sources, resulting in several craft being reduced by up to 10dba. It localises and quantifies individual tonal sources such as engine exhausts, air intakes and fan turbulence in the range 40hz to 800hz, typically within about 100mm and about 5hz.

A number of improvements have been made to the system. It now incorporates a ring of far-field dba meters to provide direct traceability from regulatory dba measurements, through frequency analysis and then beamforming to locate the key sources. The problem of large spot size and positional displacement of low frequency sources has been addressed by a technique for adding spikes to the beamformer waveforms. A 3D microphone array with 24 mics is being developed to reduce astigmatism and better identify fan turbulence sources. Turbulent areas identified by the system have been confirmed by probing with pressure sensors. An air horn audio marker beacon now provides better alignment between the noisepics and conventional pictures.

1 INTRODUCTION

NoiseCam, a homebrew beamforming system, has been used to identify noise sources on over 130 light hovercraft worldwide over the past 3 years. [1] The noise sources are mostly tonal noise from engine air intakes and exhausts together with fan turbulence noise associated with airflow obstructions. The 2D semicircular 16 mic array is coupled to 12bit A-D converters sampling at 20khz. The waveforms from the top 6 loudest frequencies are analysed using a delay and multiply beamformer scanning 50*50 points, usually in a 2m square area.

The 2D system now forms part of a comprehensive measuring system that aims to measure the statutory dba overall noise and provide an analysis path to break that noise into its component frequencies, find their source and in the case of turbulence confirm it with other techniques.

A number of craft have had noise levels reduced by up to 10dba following remedial work. Recent work has focussed on improving the accuracy of noise location, particularly at low frequencies, including the development of a 3D upgrade.

2 COMPREHENSIVE MEASURING SYSTEM

The 2D system is now augmented with a ring of 6 farfield dba meters providing statutory dba measurements and farfield frequency analysis directly into the same Noisecam a-d units. The beamforming analysis can then be focussed on those frequencies that have most impact on the dba results. Optical sensors simultaneously measure fan and engine rpm providing confirmation to the frequency analysis. A car air horn operating at 833hz has been used as a point source marker to aid alignment between noisepics and conventional pictures. An array of 12 electronic pressure sensors has been used to map air turbulence behind the fan to confirm turbulence generated noise shown by Noisecam, although old fashioned tufts of string still provide very useful confirmation.

Fig 1 A cruising craft under the 2D array with 2 dba meters visible

The noise level on the craft above was reduced from 84 to 75dba as the result of a year long series of tests that progressively reduced turbulence and exhaust noise; enabling it to meet EU standards for jetskis.

3 LOCATING AIR TURBULENCE NOISE

Fig 2 Griffon TD2000 -prop noise source?

Fig3 3F - generated by pylon turbulence

The largest craft tested is the 20 seat diesel powered Griffon TD2000 with it's 2m dia prop. The loudest noise was at 204hz, the third harmonic of the prop blade passing frequency. Beamforming showed the source was behind the pylon where the vortex from the back of the circular pylon met the prop. Typically the source is slanted to the left by the clockwise swirl of air going into the prop. An aluminium airfoil at the back of the pylon but slanted to the left is planned. Hopefully that will reduce the vortex and the noise. This problem has been found on many light hovercraft. Most struts etc in front of the fan are round tube for structural reasons and even where airfoil cross section struts are used they are placed at right angles to the fan plane and are thus large 'stalled wings' to the air coming in at an angle due to the swirl. The turbulence is easily crosschecked using tufts of string.

4 2D ARRAY LOW FREQUENCY DISPLACEMENT PROBLEMS

The 2D semicircular array has always produced output spots that are larger with low frequencies and are oval in shape. Software simulations confirm that the latter is due to the semicircular shape of the array, thus sensitivety is about twice in the horizontal axis compared to the vertical. Simulations of a fully circular array confirm this. However experience has shown there is often a problem correctly locating low frequency noise, typically under 300hz, when the source is low to the ground. Sometimes sources are even reported as below ground. Much of this is due to reflections off the floor of the craft, or the ground. A higher frequency noise, say 500hz, is often shown as 2 sources, one typically the engine air intake and the other a reflection off the floor. But a low frequency often merges the source and the reflection into a single apparent location midway between the two. The harmonic content of the source also influences whether two sources or a single merged source is displayed.

Tests with software generated noise sources without reflections show that there is a further problem however due to the unbalanced geometry of the 2D array. The magenta points of low frequency sources are shown as displaced further away from the origin of the array (the top) than they actually are.

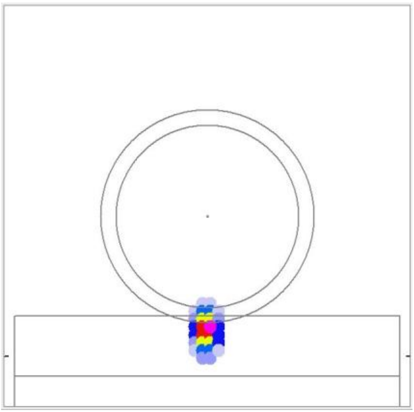

Fig. 4. At 500hz the location is correct

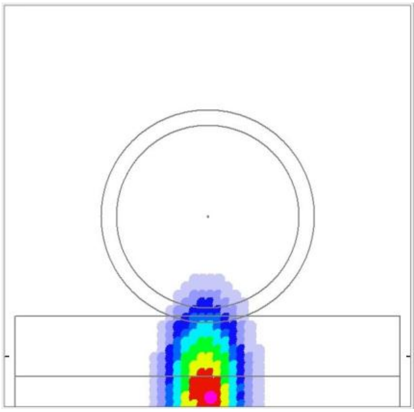

Fig. 5. At 150hz the location is displaced

Software simulations show the displacement of a pure sinewave is predictable by the formula:

$$d = \lambda^3 \times D_o^3 \times C$$

Where:

d = displacement

λ = wavelength

D_o = distance of source from array origin

C = derived constant eg .0063

All measurements in metres

Although this formula could be used to predict the displacement, in practise the effects of ground reflections and random harmonic content in the beamformer waveforms make this correction method impracticable. Tests show the problem does not arise with a fully circular array.

5 THE ‘SPIKE’ SOLUTION

Both the large spot size and the displacement at low frequencies are due to the slow alignment of long wavelengths in the beamformer. By placing a spike on the peak of each sinewave the beamformer has a better key resulting in a smaller spot and a much more accurate location. The height of the peak is a multiple ‘m’ of the original waveform peak. By steadily increasing m more harmonics are added to the waveform and the spot gradually gets smaller until ultimately only the magenta point remains.

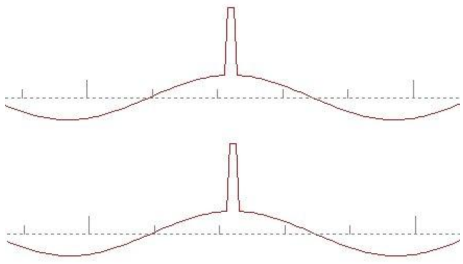

Fig 6 Marking waveform peaks with a spike

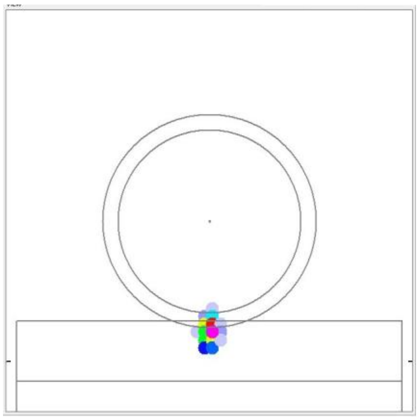

Fig7 150hz now correct and smaller spot

In cases where more than one source exists at that frequency the beamformer waveforms can be low pass filtered prior to adding spikes, which results in a single spot on the loudest source. Having identified the loudest source potentially other sources can be located by inverse techniques. The spike method might also offer a faster processing method. Instead of scanning 125k points in full the magenta point might be calculable using the time delays to the spikes in each waveform.

6 3D NOISEPICS

The 2D array is very insensitive in the z axis. This can be useful for a quick 'catch all' test but sometimes the results leave unanswered questions. For example is that large noise source on the exhaust silencer the output of the exhaust, therefore a better silencer is needed, or a leaking joint on the input pipe which just needs attention from a spanner?

Fig8 Front view shows exhaust problem

Fig10 Side view shows it's the exhaust output

Initial 3D tests have been made using the 2D semicircular array mounted horizontally augmented with 2 linear arrays each of 4 mics at right angles to the plane of the 2D array. The Noisecam software has been upgraded to scan 50*50*50 points, normally in a 2m cube. Several output techniques have been tried but the conventional side, plan and front views seem to offer the clearest picture. A graphic of the stylised hull and duct is saved into the scan array to aid analysis.

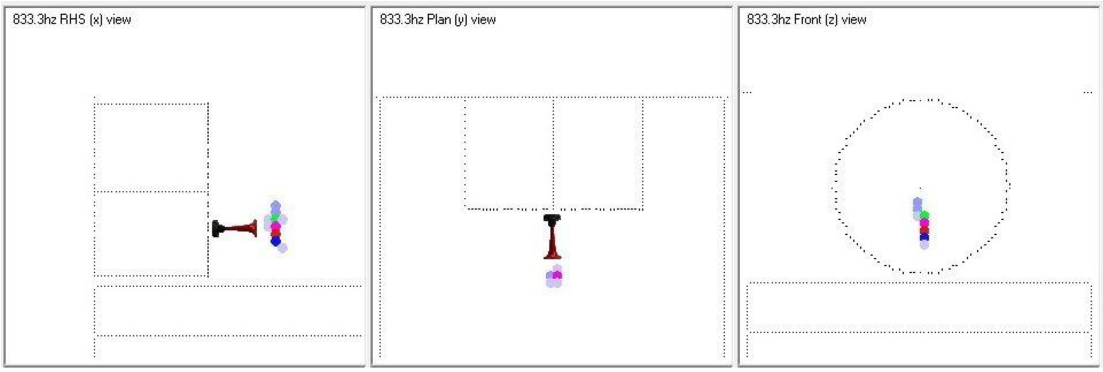

Fig 11 3D view of the 833hz air horn test source, using 'spike' at m=4

Fig 11 shows the astigmatism problems of the test 3D array. The spot is very oval in the vertical axis because of the poor sensitivety of the 2 linear side arrays, with just 8mics over a 1.6m length compared to 16 mics over 3.8m in the side to side axis and 16 mics over 1.9m in the fore and aft axis.

A better array is being developed with elliptic curves in both planes to get the sensitivety better balanced between the 3 axes. The advent of the spike method to improve low frequency performance may allow a closer mic spacing which will hopefully enhance performance in the 800-1200hz range, which suffers from aliasing problems at present. It's important that the array has a good view into the duct as several of the turbulent sources are there. These sources often appear to be directional, ie they are loudest to the front and rear of the craft rather than the sides. It's also important to retain a drive through design so that the array can be pre setup then a no of craft driven and tested in quick succession. Typically 30 seconds is needed to align the craft, anchor it, rev up to full power then take 3 test samples.

7 CONCLUSIONS

The 2D Noisecam system has proved a useful tool to identify noise sources on light hovercraft resulting in several craft being reduced by about 10dba. Recent work has quantified a problem that the 2D array reports low frequency sources with a large spot size and often displaced apparently below ground. A potential solution involving marking waveform peaks with a spike has shown potential for correcting both problems. Tests with an initial 3D array have produced encouraging results but a new array is required to overcome a problem with astigmatism caused by the distribution of mics being uneven over the 3 axes.

REFERENCES

[1] K Oakley , "Noisecam – using beamforming to identify noise sources on hovercraft", *BeBeC2008,* 2008