NOISECAM – USING BEAMFORMING TO IDENTIFY NOISE SOURCES ON HOVERCRAFT

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ABSTRACT

Racing single seat hovercraft may be a fun thing to drive but with a 2 stroke engine and a high revving industrial cooling fan they can be noisy. Identifying the loudest sources on each craft quickly and easily is challenging because of the variety of noise sources, and because each craft is different and mostly homemade.

A low cost, homebrew, beamforming system has been built and successfully used to identify around 95% of sources on 100 hovercraft from across Europe during the 2007 season. The system uses a highly portable 2 metre radius semicircular array of 16 microphones with comb filter software to focus on tonal noise, a delay and multiply algorithm to improve 'noise picture' definition and a simple inverse technique to estimate the db elimination value of individual frequencies. It pinpoints sources in the range 30hz to 800hz, typically within about 100mm and about 5hz, even though several similarly loud sources are present within the space of about a 1.5 metre cube. The common sources are engine air intakes, exhaust silencers, and various fan obstructions such as pulleys, radiators, stators, engine covers etc causing airflow turbulence and thus noise. It has also provided early warnings of bearing and crankshaft failure.

1 INTRODUCTION

Past measurements have shown that the noise of amateur light hovercraft is predominantly tonal and related to the fan blade passing frequency and the engine firing frequency. Allowing for the more significant harmonics this represents a range from 30hz to 800hz. With most craft being home made, with a variety of designs, engines and fans, the club needed a simple technique to quickly test an individual craft and advise the owner what steps he needed to make to reduce noise, in some cases to bring the craft below the sports self imposed limits of 96dba at 25metres.

Beam forming systems offered a solution but the proprietary systems available were too expensive, generally didn't cover the frequency range and seemed to offer poor definition of the sources. Using a number of ideas from Bebec2006 a system was built tailored to our needs. This has been taken to 12 racing and cruising events across Europe and over 100 craft have been tested. It has given a good overview of noise sources with the opportunity to compare and contrast. ie why is source X strong on one craft but not on another.

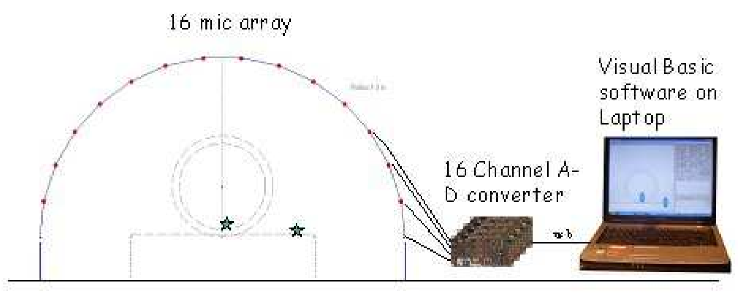
2 SYSTEM DESIGN

2.1 Microphone Array

The target frequency range suggested that microphones needed to be spaced about 40cm apart. Existing array designs suggested a large structure that would be difficult to carry around in a small suitcase. The solution was an adaptation of the vertical line array design previously used to measure high speed trains [1]. Wrapping the array in a 2 metre radius semicircle over the craft takes advantage of the fact the craft can be revved to full power whilst anchored to the ground, and the curved shape gives a range of microphone separations thus widening the effective frequency range. Software simulations showed that adequate resolution could be gained with 16 microphones.

Rather than use expensive precision microphones electret mic inserts were used. These cost around 2 euros each but have a frequency response from 20hz to 16khz. The low target frequency range allows a reasonable tolerance on microphone positioning so the framework was constructed of thin aluminium tubing and rope stayed. Each piece was under 40 cm in length to fit in that small suitcase, assembly at the test site usually taking 30 minutes.

Fig. 1. The basic noisecam system in use.



2.2 A-D Converter

To keep costs down a custom designed 16 channel 12 bit A-D converter was developed with a 20 khz sampling rate. To allow for the 25db range between the quietest cruising craft and the loudest F1 racer each channel has a digitally controlled 8 bit adjustable gain analogue pre amp. The system comprises four 4 channel modules multiplexed together sharing a USB2 interface to the controlling laptop. Each module has 32 mbit of on board flash memory allowing 32 0.4sec samples to be stored before tests need to be halted for the data to be uploaded to the pc. Firmware for the 8bit AVR processors in each module was written in assembler whilst the analysis software in the laptop was written in Visual Basic 6.

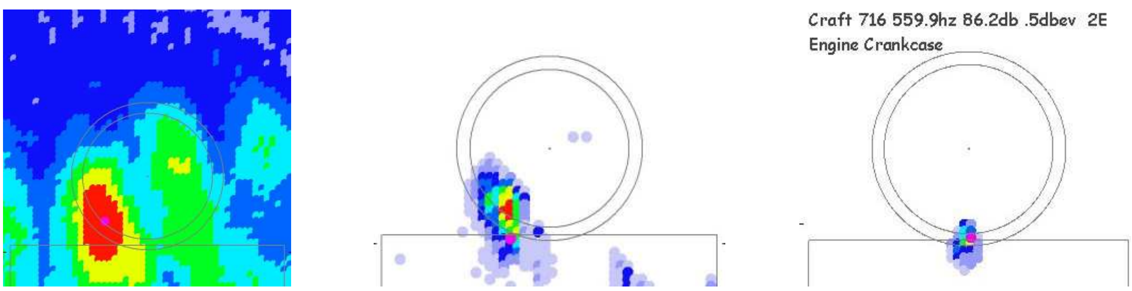
2.3 Analysis Software

The first step is a frequency analysis to establish the loudest 6 frequencies averaged across all 16 microphones. These are matched as likely engine or fan frequencies or their harmonics by referring to a database of craft data with such information as no of cylinders, 2 or 4 stroke, no of fan blades, gear ratios and expected rpms. A comb filter is then used to extract the waveform at each microphone for each of the top 6 frequencies. This complex waveform includes the overharmonics.

A scan then maps the noise amplitude at a matrix of 50*50 points across a 2 metres by 2 metres target area to establish a ‘noise picture’ for that frequency. At each point the waveform is multiplied by a gain factor which reflects the distance between that point and the individual microphone. Each waveform is then shifted by a number of timeslots to reflect the time delay involved in that distance. The time shifted waveforms are then multiplied together to get a value for the noise amplitude at that point. This differs from classical beamforming where the waveforms are added together. It follows on from techniques used in the natural world by bats as reported by Bannasch [2]. It greatly enhances the definition of the noisepic making it much easier to define the source but means the noisepic cannot be colour coded in decibels. Simulations showed that a colour scale from magenta for the highest amplitude point on that noisepic down to pale blue for an amplitude 20% of the highest, gave a useful practical level of definition.

Fig.2. A comparison between different algorithms applied to the same input data shows the increased definition achieved by the narrowband delay and multiply.

Broadband Delay & Sum | *Broadband Delay & Multiply* | *Narrowband Delay & Multiply*



A simple inverse technique is used to estimate the ‘db elimination value’ (dbev) of each of the top 6 frequencies. ie if that frequency was completely eliminated what would be the reduction in the overall noise level. The waveform calculated by the comb filter is subtracted from the original at each microphone and the dbev is the reduction in overall amplitude. The dbev is a statement of the overall elimination value of a particular frequency total noisepic, not necessarily the value of a particular noise source shown in the noisepic. There is a risk that some noise sources may be present at that frequency which do not show up on the noisepic. To guard against such ‘dark noise’ a check is made of the amplitude of the highest noise source on the noisepic with the overall frequency amplitude seen at the microphones, allowing for distance effects. The percentage dark noise results observed suggest the system is not missing significant tonal sources.

3 TYPICAL RESULTS

Fig. 3.On some craft the yellow splitter plate behind the fan, which separates lift from thrust air, is poorly shaped and causes turbulence and thus noise. This cruiser has a quiet 4 stroke engine with a good exhaust and could be up to 6db quieter if this turbulence was eliminated.

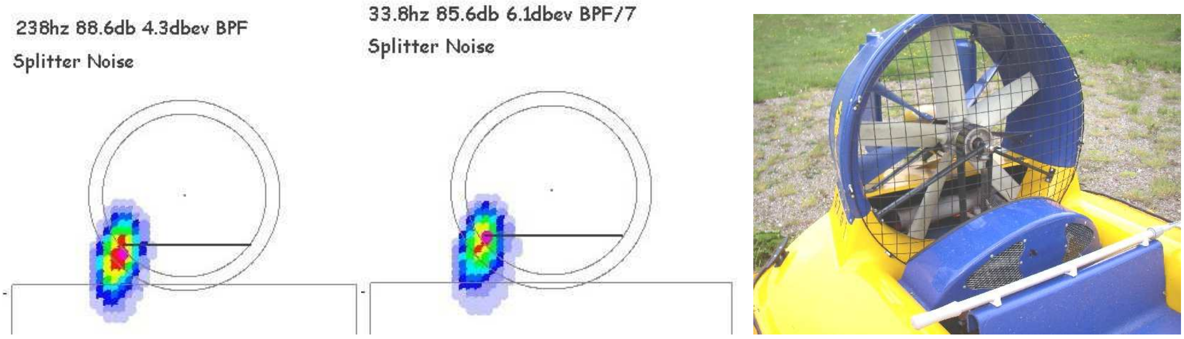


Fig. 4. Other obstructions close to the fan cause turbulence and thus noise eg an engine pulley 50mm from fan tip and a radiator 150mm away whose turbulence has been displaced by air swirl

Fig.5. On this craft with a separate lift fan the 4th harmonic of the lift engine firing frequency is loudest. The engine air intake is louder than the exhaust outlet.

Fig.6. This craft has an engine air intake about 5db louder than the exhaust. It has a good exhaust silencer but doesn't have the airbox intake silencer that is often fitted to snowmobile versions of this engine.

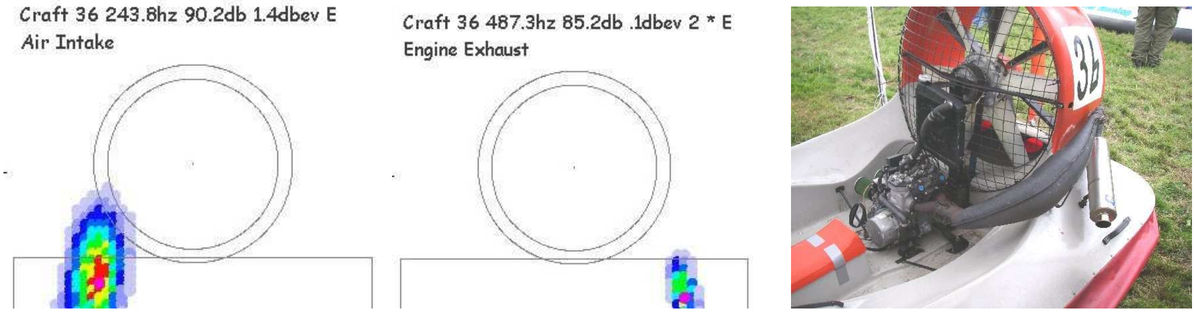
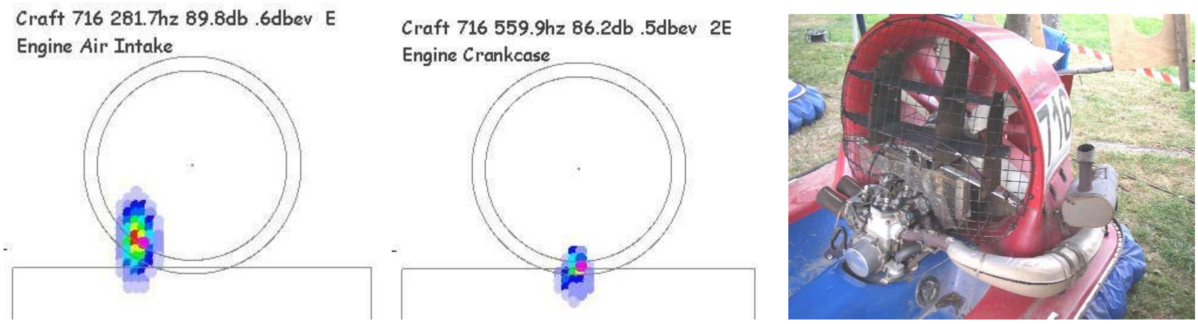


Fig.7. It was expected that the air intake on this craft would be loudest as it has a good exhaust silencer. The crankcase noise however was unusual and reported quickly to the driver. 3 races later it seized.



4 DISCUSSION

The 1000's of noisepics produced by the system in 2007 have proved a valuable insight into the noise problem and a series of noise reducing ideas are now being studied and tested.

Experience has also identified a number of issues with the noisecam system which will be addressed for the 2008 season. A single finite noise source is shown on the noisepic as an oval because the vertical sensitivety is half that of the horizontal due to the array not being a full circle. Once understood this is acceptable but the poor sensitivety of the array in the z (fore and aft) axis is an issue. On the one hand it's an advantage because a single planar noisepic will pick up noise sources both in front and behind the duct, reducing analysis computation time. However sometimes it is confusing because it doesn't differentiate between a leaky exhaust joint and the silencer outlet 800mm away, because they are both in the same position in 2D. A 3D array would be beneficial.

The system doesn't use a conventional camera and although the simple cartoon cross section of a craft on the noisepic has proved very effective there are registration issues if the craft is not precisely in the correct place during the test. It's proposed to fit a loudspeaker emitting a 500hz tone as a marker beacon on top of the fan duct as an aid to more accurate registration.

A ring of 8 microphones at the standard 25 metres around the craft will be added in 2008 to measure far field noise in accordance with club rules and to provide a reliable calibrated total power measurement between one test and another.

Although the actual craft test takes only a minute, typically at the end of a race, analysis has taken several hours with the consequence that drivers got results weeks later. The analysis is now being automated on an expert system basis so that analysis takes only a minute of computation time and results can be handed to drivers within minutes. This will improve the use of the system for non-destructive testing. Predicting crankshaft failure is of little use if the results reach the driver a month after it failed.

5 CONCLUSIONS

Noisecam is a simple low cost beamforming system, customised to the needs of sports hovercraft, which is already producing worthwhile results. It successfully identifies the locations of tonal noise at different frequencies and gives an indication of the reduction in overall db amplitude if that frequency could be eliminated.

REFERENCES

[1] U Michel , "History of Acoustic Beamforming", *BeBeC2006, 2006*

[2] R Bannasch, "Acoustic Underwater Communications, 3D-Positioning and Bionic Principles", *BeBeC2006*, 2006.