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4D TIME DOMAIN BEAMFORMING ON WAVEFORM TIMESLICES IDENTIFIES SEPARATE SOURCES OF AEROACOUSTIC NOISE ON A HOVERCRAFT

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ABSTRACT

Earlier studies have shown that hovercraft noise is dominated by 2 tonal noises – the engine firing frequency and the blade passing frequency. 3D narrowband beamforming analysis of the latter on a particular test craft shows there are at least 2 major sources apparent within each bladepass period. But standard time domain beamforming using the whole bladepass Fourier waveform gives a noisepicture which is an average of the two sources. By gating in timeslot slices of the total bladepass Fourier waveform and time domain beamforming only on that slice it's possible to see clearly how each source develops and decays during the bladepass period. By splitting the total bandpass waveform into 32 such time slices a short 'movie' is produced. A downside of this partial waveform technique is that the sound sources appear to move over time towards the centre of the microphone array, due largely to the way the beamformer works. However the volume peaks within this movie do indicate accurately the position of the sources of noise and their phase relationship with the position of the fan blades. In the case of our test craft this partial waveform technique showed 2 noise sources within the lift air distribution ducting behind the fan, where the air is poorly ducted and thus air turbulence is likely to occur. One particular source correlated well with a regular dirty patch deposited in the same position on a similar craft, which was cured by improving the ducting.

1 INTRODUCTION

Hovercraft noise is mostly tonal and related to the engine firing frequency, from sources such as the exhaust and air intake; and the fan blade passing frequency, mostly from turbulence noise associated with airflow obstructions. Noisecam, a 2D homebrew beamforming system with a 16 microphone semicircular array, has been used to quickly characterise over 100 craft. [1] This was further developed as part of a comprehensive measuring system with 6 farfield dba meters and extended into a 3D system with 24 microphones which has been used for more detailed analysis of a test craft. [2].

The 3D system has now been further developed to include a 'partial waveform' technique which offers clearer source location where 2 or more sources may exist at the same frequency. The technique provides a 'slow motion' replay of an event, for example a single bladepass, showing individual sources occurring as the blade rotates. The resulting 4D noisepics have been used to explore 2 suspected aeroacoustic noise sources which are believed to be within the lift air ducting of the test craft. – marked A and B in fig 2 below.

Fig. 1. Test craft with 2D mic array

Fig2 Test craft with 3D/4D mic array

2 PARTIAL WAVEFORM TECHNIQUE

The Noisecam system uses Fourier analysis to extract the waveforms at the target frequency (eg the bladepass frequency) at each microphone which are then used for narrowband, delay and multiply, time domain beamforming. In some cases it became apparent that there were 2 or more peaks visible in the waveform which may have come from 2 or more locations, and vary in phase relationship. The standard approach of beamforming on the whole waveform blurs these multiple sources into a single noisepic. At best the noisepic will show both sources in their correct locations, at worst it will merge the sources into a single, inaccurate, location, particularly where the sources are physically close. In both cases however valuable diagnostic information on the phase relationship between the sources and between the sources and, for example, the fan blade position is lost.

The technique of slicing the complete waveform into a number of timeslices and then beamforming individually on each timeslice has been shown to be able to separate the noise from individual cylinder heads on a car engine. [3] This partial waveform technique has been

applied to split the per microphone waveforms produced by Noisecam into 32 timeslices then beamforming has been used to produce a noisepic for each slice. The 32 noisepics form a movie. The noisepics are then normalised so that the magenta point of the loudest noisepic is used as the colour scale reference for each noisepic. The 32 are then displayed in a software viewer which allows the operator to see the individual noise sources grow then fade - and usually move. The relative noise volume of each noisepic is graphed enabling the operator to freeze frame to analyse the volume peaks and any sub peaks.
Noisecam has an opto sensor pointing at the fan blade which is normally used to identify the bladepassing frequency in order to target the initial fourier analysis. The opto sensor is sampled onto an extra channel alongside the 24 microphones and thus provides valuable information on the physical position of the fan during the bladepass. This is used to synchronise a graphic of the fan which is included in the noisepic. The position of the fan blades when a particular source is at its peak is a useful aid to analysis.

3 3D RESULTS

3D analysis of 40 noise samples at the blade passing frequency showed that the noise sources grouped into 2 areas, marked A and B in fig 2 above and fig 3 below. The relative volume, and exact position, of the two sources vary between samples, but fig 3 is typical.

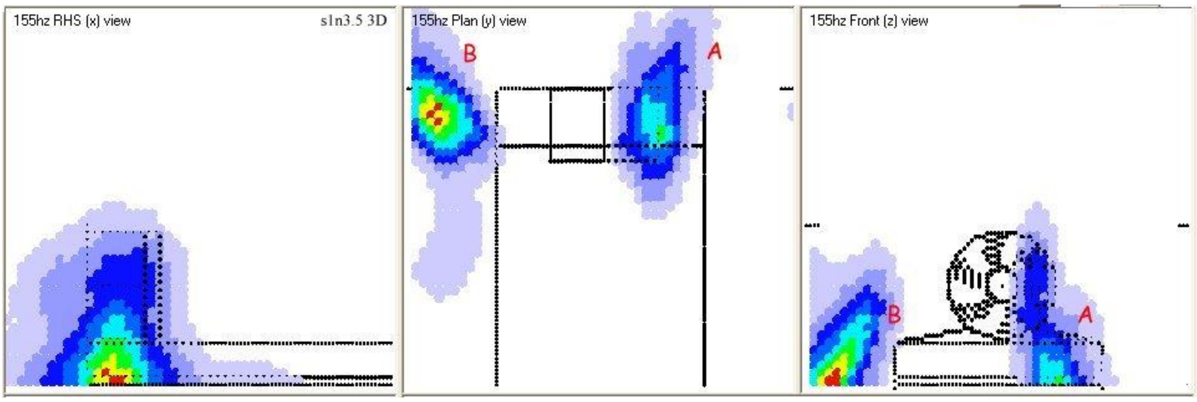

Fig. 3. A typical 3D noisepic at the blade passing frequency 155hz shows 2 sources

4 4D RESULTS

4D analysis using partial wavelength techniques of the sample shown in fig 3 has been used to produce a noisepic for each source. Fig 4 shows source B as a smaller spot on the ground just outside the skirt, presumably where turbulent air is passing under the skirt. Fig 5 shows source A which is apparently in the air distribution duct within the hull at a known air turbulence site where the lift airflow is poorly ducted behind the fan. Both figs include a graph of the sound volume of the overall waveform with a vertical dotted line indicating where in the sample this particular timeslice occurs.

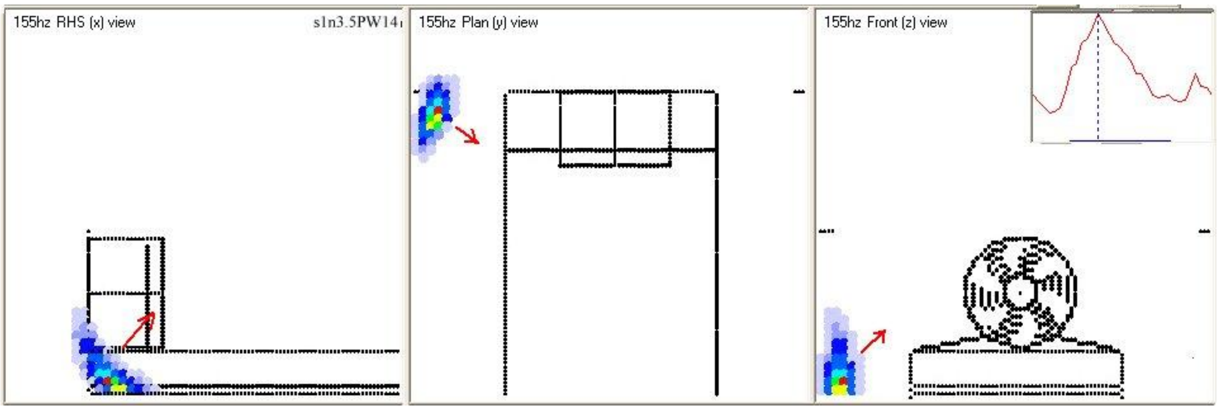

Fig. 4. 4D analysis at timeslice 14 shows location of peak B. Arrows indicate movement after peak

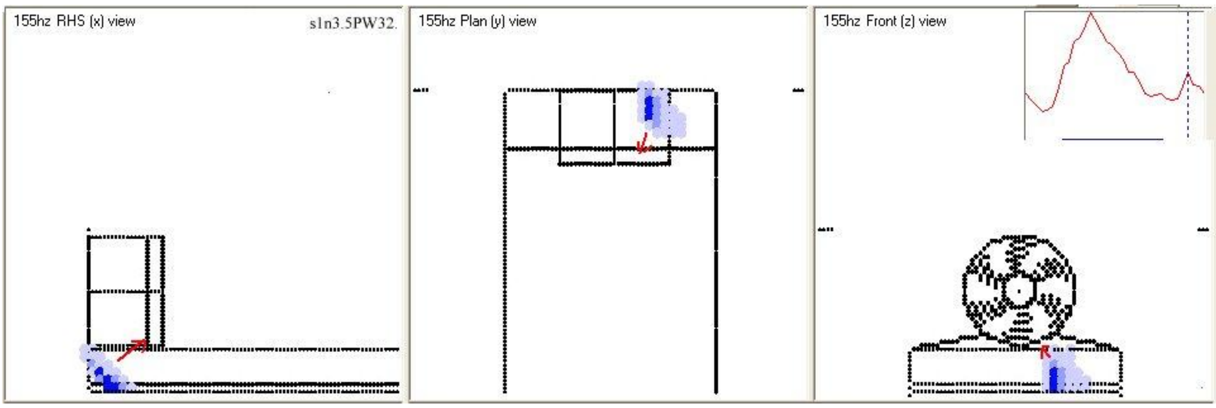

Fig 5 4D analysis at timeslice 32 shows location of sub peak A. Arrows indicate movement after peak

5 DISCUSSION

5.1 Sources appear to move in the movies.

In the 4D movies the noise sources detected by the partial waveform technique appear to move at around the speed of sound towards the centre of the microphone array both before and after their peak. The arrows in figs 4 & 5 indicate the direction. 4D movies using software simulated fixed point noise sources show the same effect. It's an intrinsic disadvantage of the partial waveform approach. The simulations however have a smooth rise and fall to the peak - as illustrated in fig 6 which is a 4D noisepic using a simulated spike noise at 150.4hz without any reflections or airflow effects. Where sub peaks occur on the rise and fall these may well be due to noise reflections off hard surfaces. In some cases the sub peaks can be correlated to specific surfaces such as the hull, duct, splitter plates etc. Sometimes the sub peak may be at an entirely different source. Fig 7 shows noise from the fan tip at the exact time a fan blade is passing, probably caused by turbulence from a strut at that point.

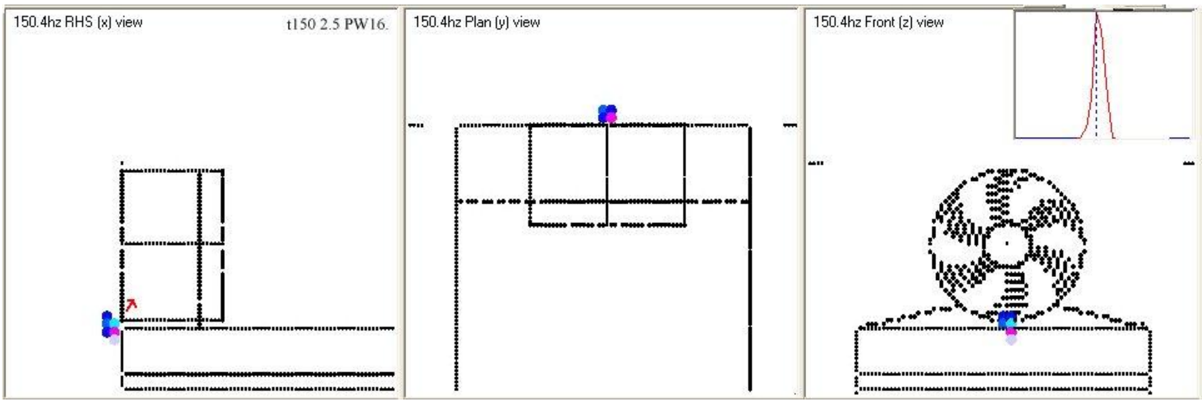

Fig 6 Software simulated noises show the same movement but volume has smooth rise & fall

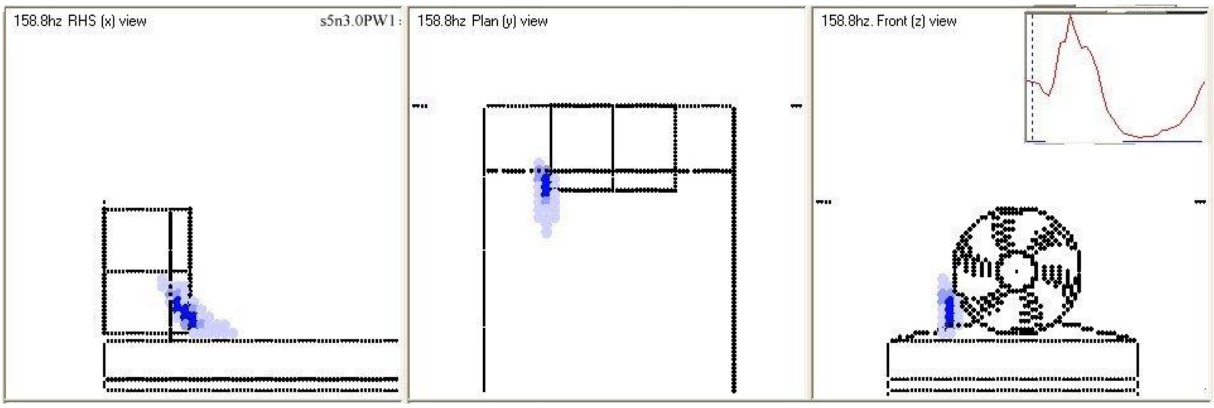

Fig 7 A noise sub peak locates to a blade tip as the blade is passing

5.2 Source position varies between samples.

Although the analysis shows that the sources can be grouped into 2 areas the relative volume, and exact position, of the two sources does vary between samples. Some of this could be attributed to different airflow patterns caused by varying engine speeds and positions of the splitter plate which alters the proportion of fan air which is ducted down for lift. Some could be due to natural fluctuations in the airflow turbulence patterns. Some may be due to the problem of beamforming through a moving mass of air which will cause doppler shift effects. This is most significant when the source is directly behind the fan and thus more of the audio path to the microphones is in the moving air.

If as suspected turbulence is causing noise to be generated in the lift duct behind the fan (position A) this is occurring within an enclosed space where none of the array microphones have the direct line of sight needed for beamforming. The microphones will only see the noise as it emerges from an orifice such as back out through the fan duct, which could be the picture seen in fig 5 above; or out under the skirt at the rear corner, which could be the picture seen in fig 8 below. The sample used in fig 8 also has 2 sub peaks. The first is under the skirt at the rear of the craft whilst the second sub peak is from the floor under the fan seen via the fan duct as shown in fig 9.

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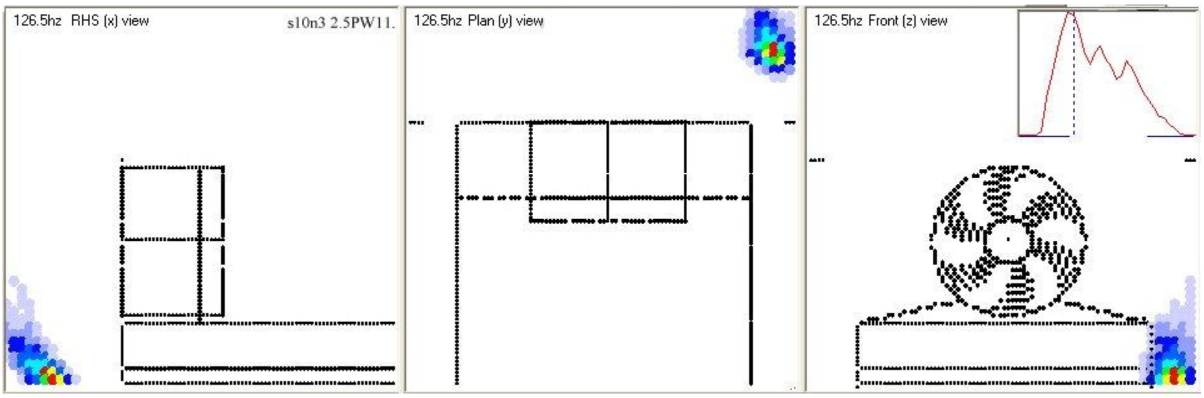

Fig 8 Peak noise is emitted under skirt at the rear corner

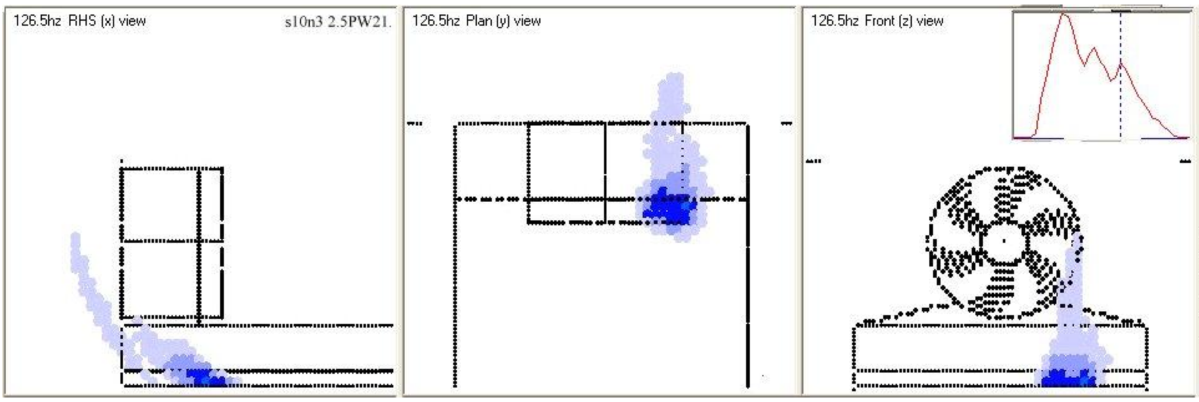

Fig9 A sub peak is emitted from the floor under the fan 2.65ms later

6 CONCLUSIONS

The partial wavelength approach may be a useful technique to refine the position of 2 or more sources at the same frequency within a sample and to establish the phase relationship between them and a generator - eg a fan. The intrinsic apparent movement of sources within a movie is a disadvantage; however by focussing on peaks and sub peaks the technique is still useful. However in the case studied the varying source position between samples means that the attribution of those perceived sources to particular causes is difficult and requires more work. It might be beneficial to try the technique on other case studies – for example engine noise where the sources are not hidden within the hull nor subject to airflow effects.

REFERENCES

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

[2] K. Oakley, *Noisecam –using 3D beamforming to better localise noise sources on hovercraft.* BeBeC2010, 2010.

[3] S. Guidati, *Advanced beamforming techniques in vehicle acoustics.* BeBeC2010, 2010.