PIV STUDY OF RESONANT AIR COLUMNS

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1. INTRODUCTION

Particle Image Velocimetry (PIV) is a non-intrusive, whole-field technique used in fluid dynamics for flow visualisation. The method consists of capturing two images of an illuminated, seeded flow in rapid succession and analysing them to produce a velocity vector map. The analysis involves cross-correlating small regions, called *interrogation areas*, of the first image with corresponding regions of the second image. Each interrogation area correlation results in a displacement vector which can be converted to a velocity vector, assuming the time interval between images captures is known. Repeating for the whole image leads to a velocity vector map.

The tracer particles used to seed the flow under investigation must follow the flow faithfully. When applying PIV to the measurement of acoustic fields in air, particles with a size of the order of 1 μm or less must be used. The particles must also have good scattering characteristics to ensure maximum image contrast in the illuminated region. Smoke particles fulfil these required conditions and have proved to be acceptable for seeding sound fields.

One of the main problems when using PIV to measure acoustic phenomena is the need to capture images at high speed. For example, in a 1 kHz resonant sound field, to measure the particle velocity over 1/10th of a cycle requires an image capture rate of 10 kHz. That is, a time separation between images of 100 μs. Recent advances in high-speed imaging technology have now made it possible to use the technique to measure particle velocities in sound fields.

Acoustical PIV measurements have previously been carried out to investigate acoustic streaming in an air column [1, 2] and jet velocities in flute-like instruments [3]. In this paper, a PIV study of oscillatory particle motion in a resonating air column during one acoustic cycle is presented.

2. EXPERIMENTAL SET UP

Figure 1 shows a schematic diagram of the experimental set up. A 620 mm long, 34 mm wide square air column is seeded using smoke particles. The air column is rigidly terminated at one end, coupled to a loudspeaker at the other end, and has a first resonance frequency of 303 Hz. Light from a 532 nm Yag-Nd laser is expanded to a sheet by an optical set up consisting of three cylindrical lenses. The laser sheet is used to illuminate a region halfway along the air column's length. The square geometry of the air column reduces optical flare, which is a particular problem when illuminating a transparent curved flow passage. A high-speed digital camera is focussed on the region of interest.

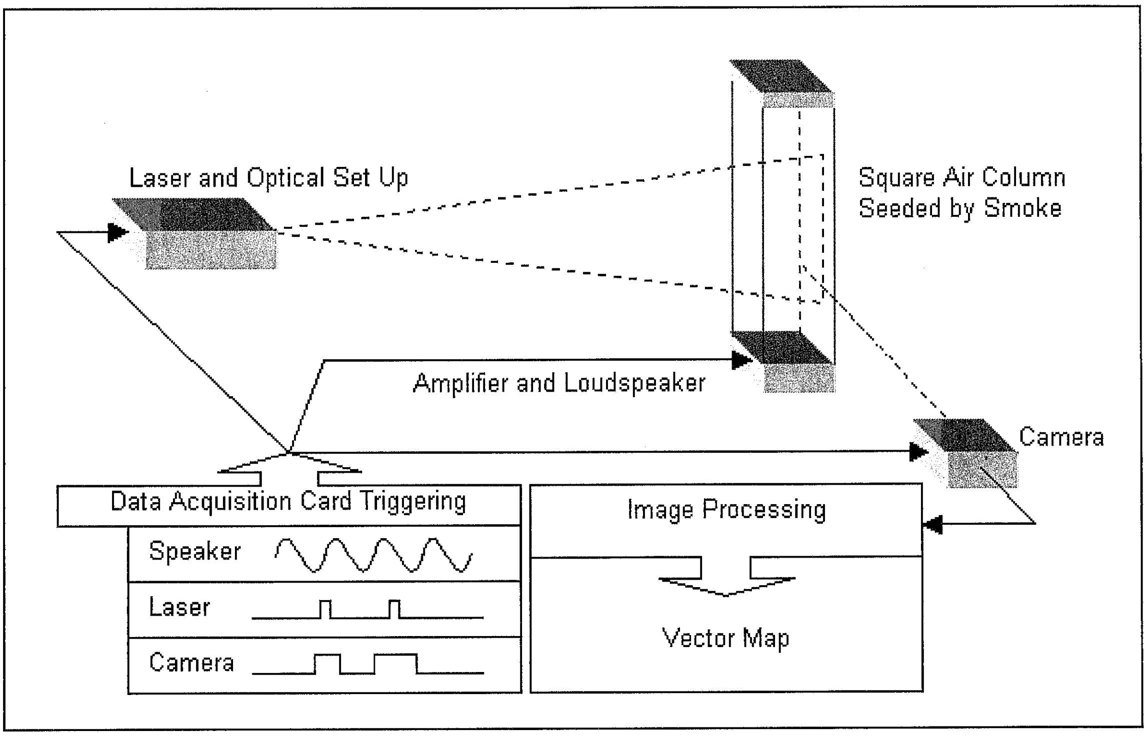


Figure 1. Schematic diagram of experimental set-up.

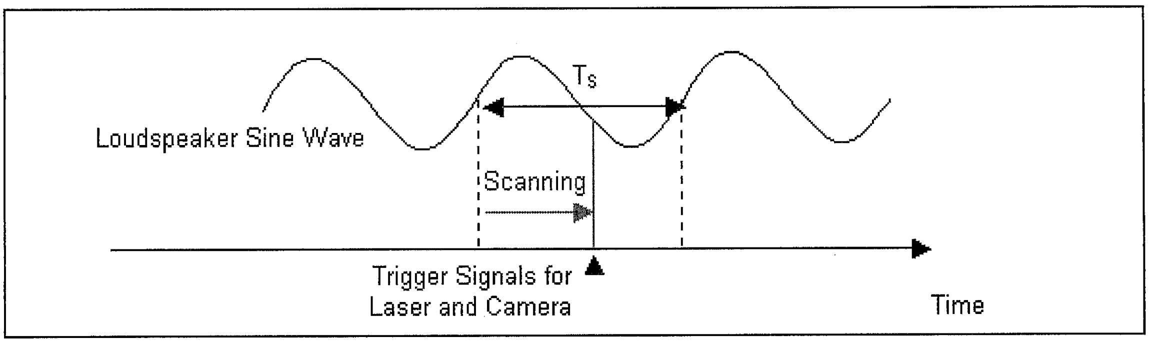
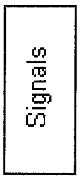


Figure 2. Advancement of the laser and camera trigger signals relative to the sinusoidal signal sent to the loudspeaker.



This hardware set up is controlled by self-written software using a data acquisition card as the interface. The card simultaneously sends the following signals to the loudspeaker, laser and camera:

a. A 303 Hz sinusoidal electrical signal is amplified and used to drive the loudspeaker. (The period of the sine wave is T_S = 1/303 = 33 ms). The air column is excited at the first resonance frequency to maximise the amplitude of oscillation of the smoke particles halfway along its length.

b. Two 100 μs duration voltage pulses separated by 200 μs are sent to the laser, causing it to flash twice.

c. The camera is triggered by a TTL signal resulting in the acquisition of two images. The TTL signal is synchronised with the voltage pulses sent to the laser, to ensure that the two laser flashes occur during the two exposures.

After triggering the hardware in the way described above, a pair of PIV images is stored digitally and cross-correlated to produce a vector map.

The above procedure is repeated 33 times. After each repetition, the signals sent to the camera and laser are advanced by 100 μs relative to the signal sent to the loudspeaker. This ensures that 33 image pairs are captured covering one complete 33 ms cycle of the smoke particles' sinusoidal motion (Figure 2).

3. RESULTS

Figure 3 shows a selection of velocity vector maps processed from images captured during one cycle of the particles' motion. The sinusoidal variation in velocity is clearly apparent. In Figure 3(a), the particles are moving with a large downward velocity. Moving through the figures, the downward velocity is reduced until, by Figure 3(d), the velocity of the particles is zero. The velocity of the particles then increases in the upward direction approaching a maximum in Figure 3(g). Between Figures 3(g) and 3(i), the upward velocity of the particles decreases reaching zero again. Finally, in Figure 3(j), the particles return to downward motion.

Inspection of the vector maps reveals that at large particle velocities the number of correctly calculated vectors is reduced. It is not entirely apparent why this should occur but an investigation is currently being carried out to see if the effect is related to interrogation area size.

Figure 3b.

4. CONCLUSION

The PIV measurement technique has been used to analyse the motion of seeding particles in an air column resonating at 303 Hz. Image pairs were captured at 100 μs intervals. Analysing the set of PIV image pairs verifies the sinusoidal behaviour of particles in the sound field. This experiment provides a good basis for future work using PIV to analyse sound fields in more sophisticated geometric flow passages, in particular ducts with discontinuities.

5. REFERENCE

[1] D Rockliff, D M Campbell, C A Greated, *PIV Experimental Study on Acoustic Streaming in Cylindrical Air-Filled Tubes using High Intensity Sound Field*, Proceedings of the 5th French Congress on Acoustics (CFA 2000), September 2000, pp 199-202

[2] D Rockliff, C A Greated, *Application of PIV to the Measurement of Acoustic Fields in Woodwind Instruments*, Proceedings of the International Syposium on Musical Acoustics (ISMA 2001), Prugia, Italy, September 2001, pp 383-386

[3] A Bamberger, A Orth, *Fluid Dynamical Investigation of the Inanition Roll with Particle Image Velocimetry*, Proceedings of the International Syposium on Musical Acoustics (ISMA 2001), Prugia, Italy, September 2001, pp 399-402

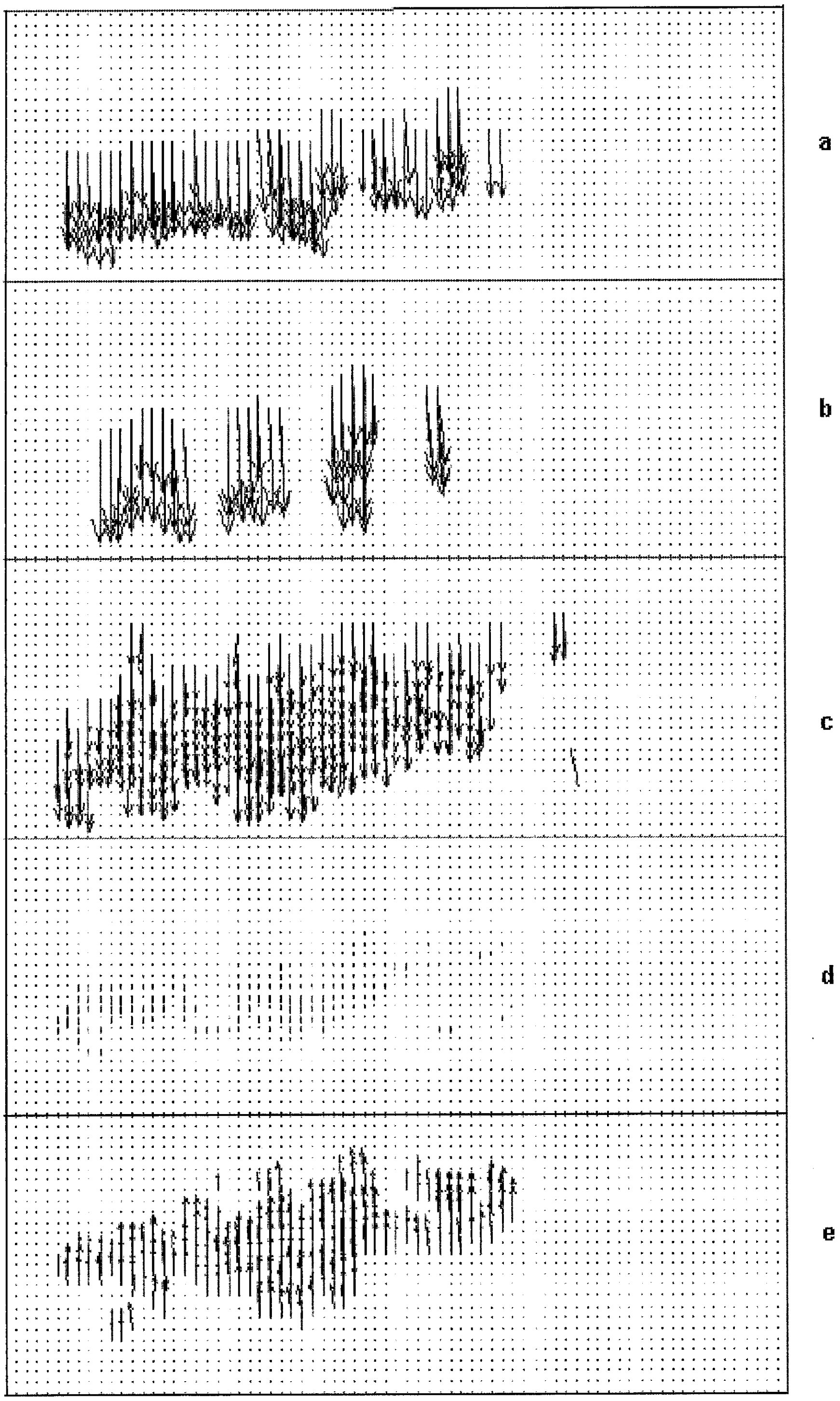


Figure 3 (a-e). Velocity vector maps during one cycle of particle motion.

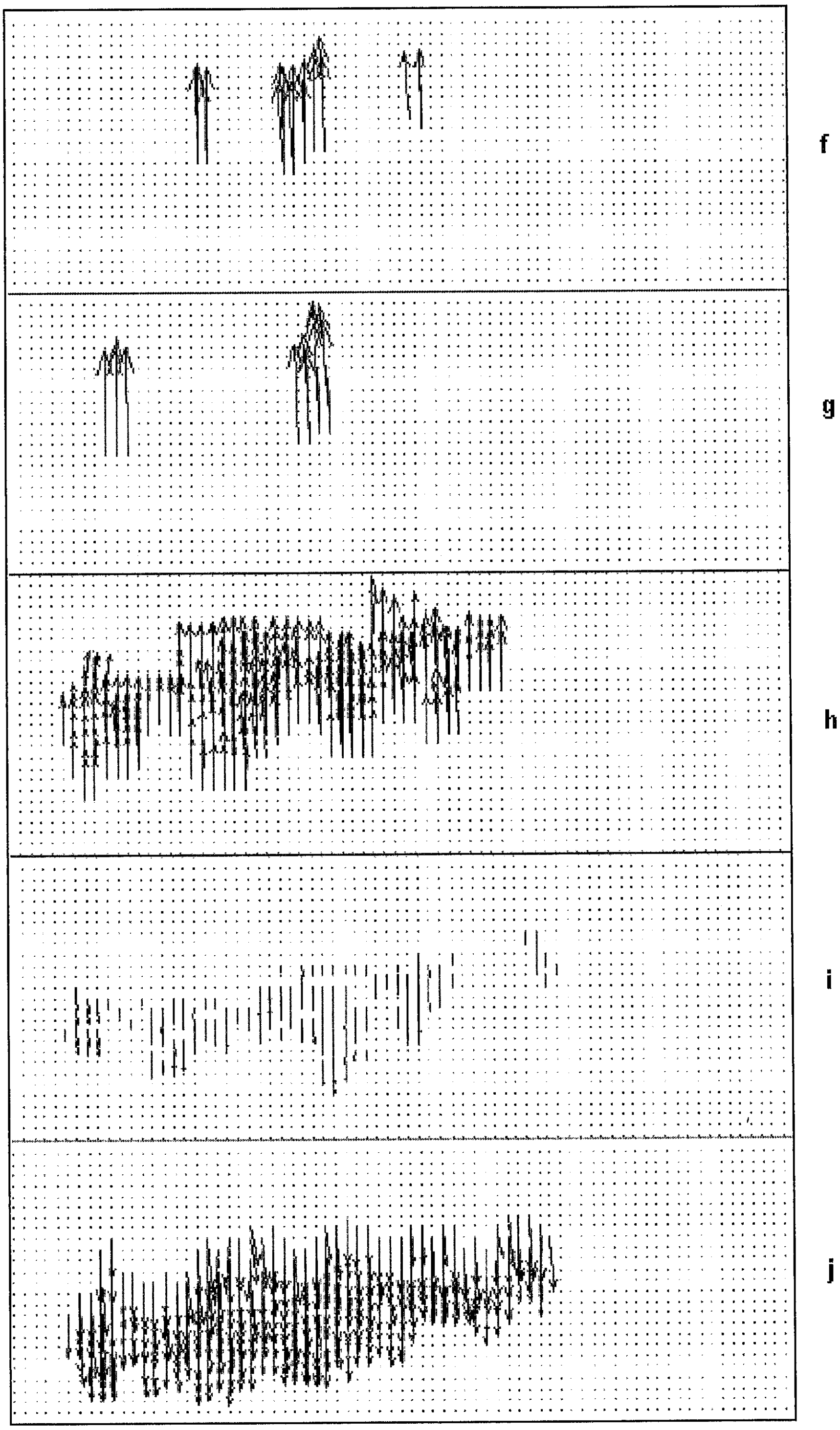


Figure 3 (f-j). Velocity vector maps during one cycle of particle motion.