12TH INTERNATIONAL SYMPOSIUM ON FLOW VISUALIZATION
September 10-14, 2006, German Aerospace Center (DLR), Göttingen, Germany

VISUALISATION OF LARGE-SCALE FLOW STRUCTURES IN AIR USING A NOVEL 3D PARTICLE TRACKING VELOCIMETRY TECHNIQUE

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Keywords: *Particle Tracking Velocimetry, Thermal Convection*

ABSTRACT

The paper reports about the development of a novel flow measurement technique for convective flows in air. 3D particle tracking velocimetry (3D PTV) is used to investigate large-scale flow pattern and particle trajectories. As tracer particles modified helium filled soap bubbles are applied. Instead of the not applicable conventional laser light sheet technique the measurement volume with characteristic length scale of 7 m is been illuminated by halogen bulb or flash lamps.

1 INTRODUCTION

Large-scale flow fields occur under a wide variety of circumstances ranging from flows in office rooms, atriums, compartments of vehicles and airplanes to the motion of air in the earth atmosphere. These velocity fields are characterized by a strongly three dimensional turbulent behavior. Up to now there is no measurement technique to analyze a large-scale three dimensional turbulent flow fields in a volume with a characteristic length-scale of about 7 m.

3D PTV is a flexible technique for determination of velocity fields in liquid or gas flows. It is based on a digital photogrammetry method using more than two cameras, recording stereoscopic images of small reflecting and neutrally buoyant tracer particles in a large model cell. Central points of the method are the exact modeling of the geometry of the cell and the recording system, algorithmic aspects of image processing and determination of stereoscopic correspondences and finally the calibration of the system [1].

2 PREVIOUS WORKS AT THE "BARREL OF ILMENAU"

The "Barrel of Ilmenau" (BOI) is a unique experimental facility to investigate the properties of the Rayleigh-Bénard convection [2]. This large facility consists of a cylindrical tank with a variable height up to 6.3 m and a constant diameter of 7.15 m. Within the barrel, air is set into motion by thermal convection from a hot plate at the bottom to a free-hanging cool plate at the top.

In earlier works the visualization of the convection flow in the BOI was performed with conventional laser light sheet technique. Compared to the 3D PTV this technique has some disadvantages. First - because the flow is illuminated with a thin light sheet, only the velocity components within this plane can be evaluated. Also an upgrade to a stereo-PIV shows the third velocity component only in the laser sheet with a reduced resolution. These facts engender the necessity of a fully 3D technique with high spatial resolution based on the illumination of a flow volume rather than a flow sheet to give the information needed to construct the instantaneous 3D velocity fields. Second – because of the limited resolution of the used PIV cameras (Sensicam QE (PCO), 1376 x 1040 pixel) only a visualization of the half cross section at half height (3.5 m x 3.5 m) of the BOF was possible. And last but not least – due to the short lifetime and the low concentration of the tracer particles a visualization of the whole convection cell was impossible, because less than 10 % of the injected bubbles lived longer than one minute.

3 EXPERIMENTAL SETUP

3.1 Experimental test facility

Fig. 3.1 – The experimental test facility with 4.2 m length, 3.0 m width and 3.6 m height seen from outside (left) and the schematic sketch of the BOI (right).

In order to test all components of the 3D PTV system a rectangular box with 4.2 m length, 3.0 m width and 3.6 m height was constructed (Fig. 3.1). To increase the contrast of the tracer particles against the background the inside walls were painted black (Fig. 3.2). For capturing tracer particle images on one wall four cameras were mounted and the whole volume of test facility was illuminated by white light sources.

3.2 Cameras

The cameras were chosen on the requirement of a high resolution. The selected CANON EOS 20D is a digital CMOS still camera. It was combined with a 10-20 mm zoom objective. The basic properties are:

- Frame rate 5 f/s
- Resolution 3504 x 2336 pixel

- Pixel size 6.42 x 6.42 µm
- Chip diagonal 27.0 mm

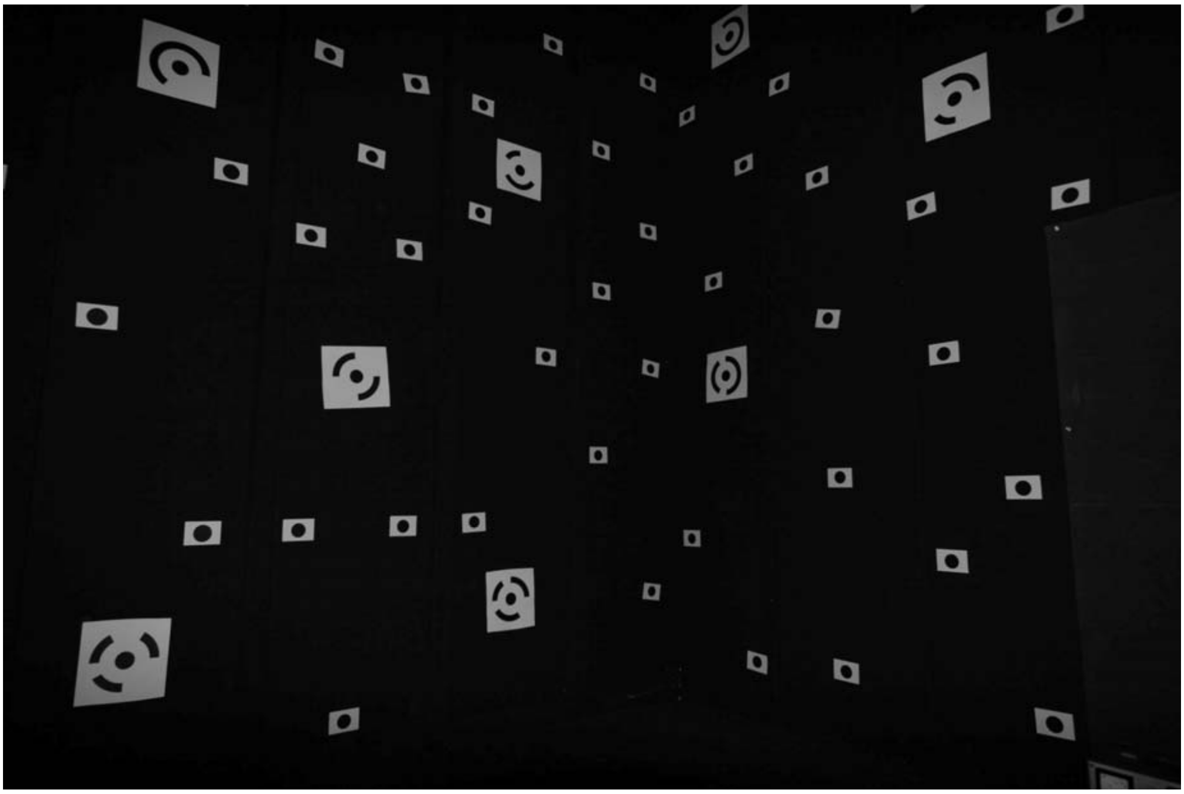

Fig. 3.2 – View inside the test facility with calibration targets on the walls.

3.3 Illumination

The illumination is one of the challenges of the experiment. To get an adequate image from small, moving particles in large volume, a light source with very high intensity is necessary. Because of the prevailing conditions of the experiment the illumination has to be placed inside the observation volume. Hence only light sources are suitable, which do not produce much heat. Otherwise they will influence the flow.

Special care has to be taken in the positioning of the light sources. Ideally, they would illuminate only the tracer particles but not the walls and they would not dazzle the cameras.

At current stage of our experiment conventional halogen lamps are used. For the future they are going to be replaced with flash lamps or strobe lights.

3.4 Tracers

To visualize the flow for PTV it has to be seeded with tracer particles. The basic condition is that the particles show a perfectly passive behavior so that they do not influence the flow in any way. The physical density of the particles should be equal to the ambient fluid and their size should be as small

as possible to fallow the flow accurately, but large enough to be detected by the measuring sensor. Their surface should be highly reflecting to maximize the amount of scattered light.
As neutrally buoyant tracer particles, helium filled soap bubbles are used. Because there is no possibility to store the bubbles, they have to be produced continuously during each visualization experiment by a bubble generator. The used special developed generator is characterized by a high generation rate, a high lifetime of more than 250 s (Fig. 3.3) and a stable operation under field conditions.

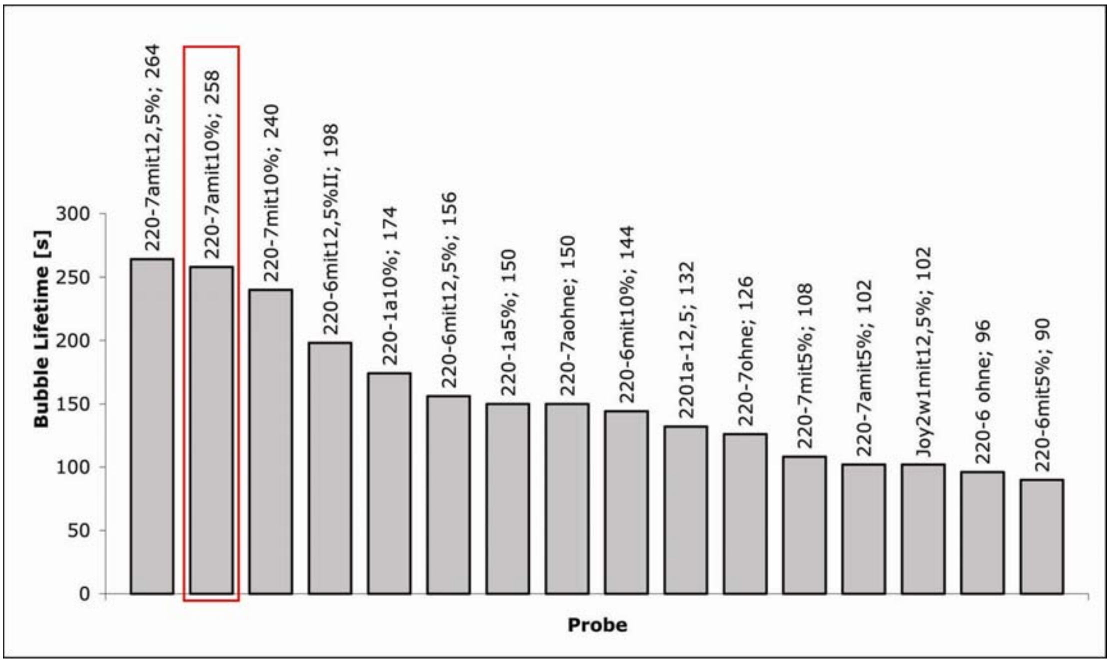

Fig. 3.3 – Lifetime measurements of helium filled soap bubbles in a test chamber. The lifetime was determined by counting the absolute number of bubble tracks in a certain time interval by means of CCD-camera images. The red framed probe with a life time of 258 s is used because of its maximum bubble generation rate.

4 RESULTS AND DISCUSSION

The first investigations with the 3D PTV system were done in the rectangular box described above. A fan generates a forced convection flow in air inside this simple test facility. All four still cameras are mounted on one wall. A personal computer is used to control the cameras and the light sources. The 3 mm sized soap bubbles are introduced by four nozzles for homogenous seeding inside the test facility (Fig. 4.1).
At first an accurate calibration of the cameras is very important for certain correspondence point finding and reliable three-dimensional reconstruction. For this purpose a large number of calibration targets, distributed on the wall is necessary (Fig. 3.2).
The particle tracking analysis is done successfully in a simple forced convection flow driven by a fan. The path lines of selected helium filled soap bubbles moving through our test facility were

detected by up to 20 contemporaneous images of all four cameras with a rate of three frames per seconds (Fig. 4.2).
After the testing period of the 3D PTV system, this measurement method will be applied to investigate the large-scale flow pattern in the BOI.

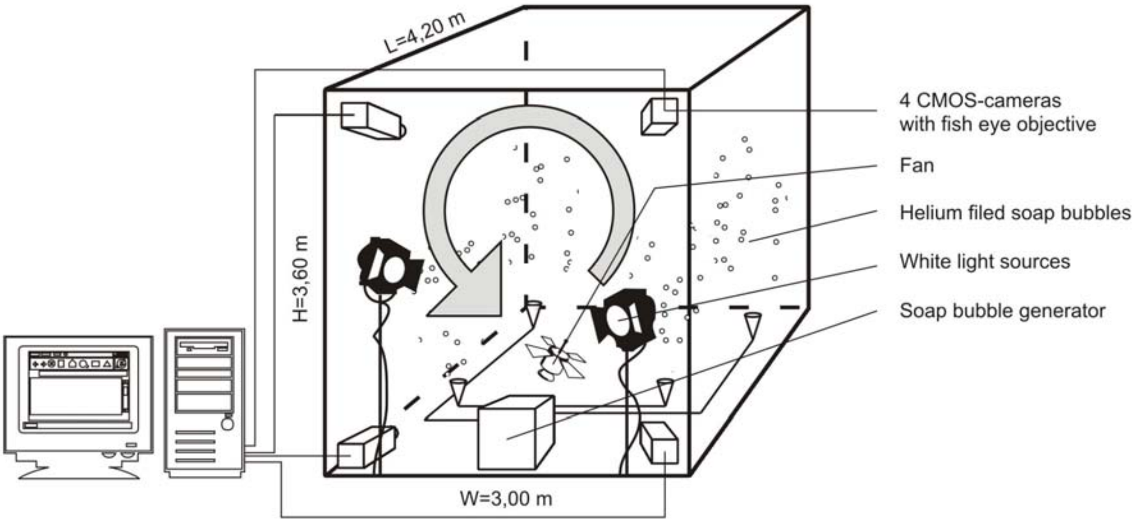

Fig. 4.1 – A schematic of the main components of the experimental setup

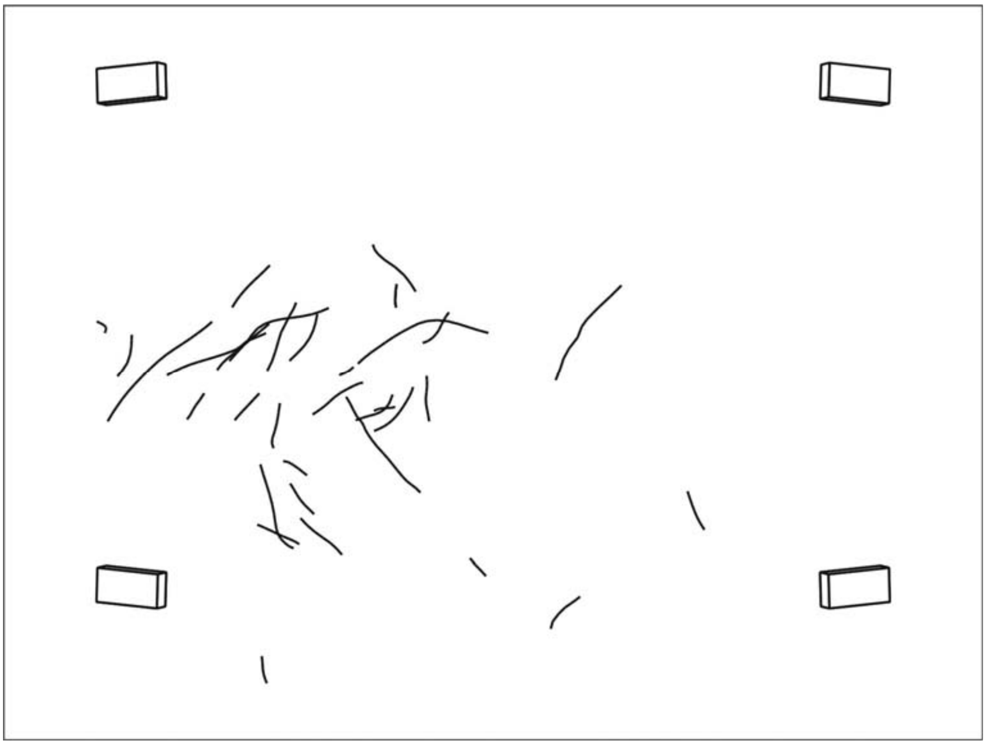

Fig. 4.2 – Example of the reconstruction of selected particle tracks inside the test cell in a forced convection flow. The boxes in the corners show the positions of the cameras.

5 REFERENCES

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