

# Laser Scanning of Three-Dimensional Time-Varying Fluid Phenomena

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## 1 Introduction

Time-varying three-dimensional CFD simulations have been at the center of many of the modern computational, physical, and movie special-effect challenges. Results are presented on the first full-field, three-dimensional, time-varying scanning of fluid phenomena. The discussion includes a description of the acquisition hardware, the data-acquisition methodology, the geometrical (space and time) and image corrections applied, and the visualization results and analysis. The results of the three-dimensional field capability on computational and physical models, new challenges it brings to the visualization field, and new possible applications are also discussed.

## 2 Experiment

The experimental and infrastructure development is based on laser scanning and the acquisition of three-dimensional data, high-volume data storage, a repository of basic phenomena, and visualization and analysis of the results. The developed infrastructure is already proving useful. In reference to turbulence, the primary research focus, it is yielding large data sets for visualization and subsequent analysis. Visualization and analysis of the first data sets has dictated the design and implementation of a new class of experiments that is in progress, targeting the exploration of flow structure and new phenomena over a wide range of Reynolds numbers, the assessment of turbulence theories, and the validation of direct and large-eddy numerical simulations (DNS and LES).

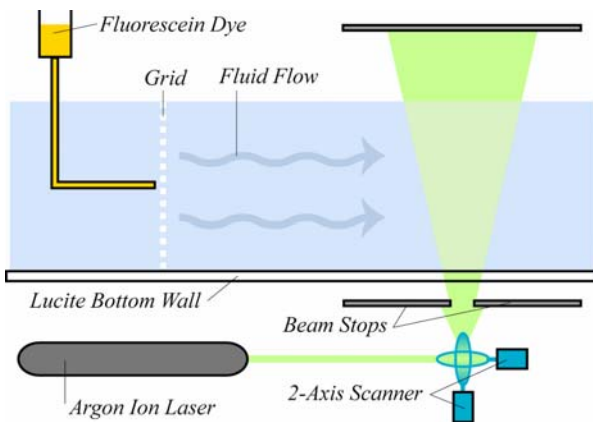


Figure 1. Side view of the Free Surface Water Tunnel. Three-Dimensional Laser Scanner Experimental Setup

The KFS camera system was designed and fabricated in-house. The KFS camera head contains a low-noise CCD (KFS CCD) designed at JPL by Mark Wadsworth and has  $1024 \times 1024$  pixel resolution based on  $12 \mu\text{m}^2$  pixels and 32 output channels. The 32 CCD output channels are buffered and fed to an 8-channel A/D converter board. Each converter board has four 12-bit 40 MHz converters that cover the 32 output channels of the KFS CCD. Real-time lossless image compression reduces image storage requirement by a factor of 1.5 to 3, depending on the data SNR. The integrated KFS camera system has a measured noise of  $25.8 \epsilon'$  at room temperature at 200 fps (frames/s).

Each A/D converter board transfers the real-time data to the data-storage clusters via S-Link fiber-optic links, at rates up to 160 MB/s per channel, for an aggregate rate of 1.28 GB/s for 8 channels. This permits the acquisition of terabytes of data, limited only by the speed of the disk arrays. By way of example, at the 100 fps rate in this experiment, this corresponds to a data rate of  $10^8$  12-bit measurements per second.

The first experiments address the dispersion of a scalar marker from a continuous (steady) point release. A fluorescent dye is released into turbulent flow in water, generated by a grid with  $\frac{1}{4}$ " grid wires spaced by 1". The laser-scanning system sweeps a laser beam across the measurement volume, causing the dye to fluoresce. See Fig. 1.

The KFS camera system image acquisition is synchronized with the volume sweeps. During the readout time, the beam is moved in the 3<sup>rd</sup> direction to prepare for the next sweep. In the first implementation described here, less than 1/3 of a second was required to perform 32 sweeps, image readouts, and data transfer to high-speed disk storage.

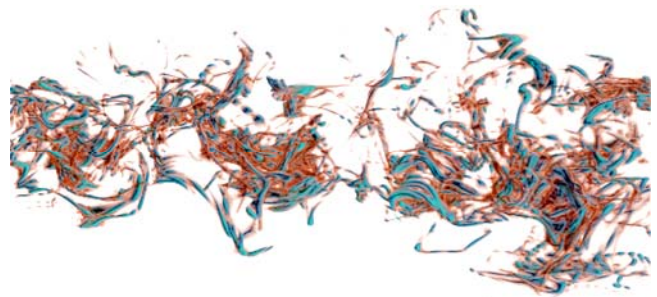


Figure 2. Volume rendering of a sample volume frame after intensity and geometric corrections

## 3 Discussion and Conclusions

Previous three-dimensional scalar data have been limited to scanning of relatively small volumes in the flow. The present experiments and data-acquisition, -storage, and -visualization infrastructure captures the full scalar-dispersion field and permits its topology to be recorded. A single volume frame that visualizes the resulting data, with intensity and geometric corrections applied, color-coded in terms of the concentration of the passive-contaminant scalar marker, is depicted in Fig. 2. Classically, one expects a Gaussian dispersion (mean) profile some distance downstream of the injection point. The experiments indicate a rather sparse (intermittent) worm-like concentration field whose topology is much like the enstrophy (vorticity squared,  $|\omega|^2$ ) field observed in direct numerical simulations, as opposed to previous smaller-scale volume-scanning experiments that concluded that the field is more sheet-like.

The experimental setup and data-acquisition and -processing infrastructure can also be extended to the special-effects industry and allows an internal digital volumetric model representation of the fluid that can be used to interact with digital characters.