Measurement of Lagrangian acceleration using the laser Doppler technique

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This paper deals with an extension of the laser Doppler technique for measuring Lagrangian acceleration .

1. Introduction

Knowledge of the Lagrangian or material acceleration is very valuable in fluid mechanics as the fundamental conservation equations are cast in terms of this acceleration, in particular the Navier-Stokes equations. This is especially true for turbulent flows where physical effects must often be modelled for simulation or predictive purposes. Little experimental data exists on the material acceleration in turbulent flows, primarily due to the difficulty of measurement. The only existing measurements are from particle tracking. Here we show that Laser Doppler measurements provide a much needed complimentary technique.

Due to the small size of the laser Doppler measurement volume the expected changes of velocity within the measurement volume are also small and the demands on the precision of the optical alignment and the accuracy of the signal processing are very high.

2. Optical Design

One aim of this project was to show that a commercial laser Doppler system can be used for reliable acceleration measurements. Our experiments demonstrate immediately the potential for upgrading existing laser Doppler systems for such measurements. The optical setup used is a standard three-velocity component laser Doppler system from TSI.

To validate the alignment precision of the optical system a method for scanning the measurement volume was developed. This measurement has shown that the fringe divergence in the system meets the needed requirements.

3. Signal Analysis

The signal analysis can be divided into two stages. In the first stage the information required to estimate the velocity and the acceleration are extracted from the signal. In the second stage a model signal is fitted to the burst signal. This model function is bias free and consistent, almost achieving the Cramer-Rao lower bound. The estimated parameters of the model signal provide the velocity and the acceleration.

4. Acceleration Measurements

In order to validate the measurement chain and the data processing several different experiments were performed. The aim of these experiments was to compare the measured acceleration to data that was obtained by calculations or with different measurement techniques.

In one experiment a von Karman swirling turbulent water flow was investigated at a Taylor microscale Reynolds-number of approx. 500 to determine whether the resolution of the laser Doppler system is sufficient to reliably measure Lagrangian acceleration . The measured data is compared with independently measured data from particle tracking with silicon strip detectors. In Figure 1 the normalized probability density functions (PDF) from silicon strip detectors (solid line) is compared with the Laser results (symbols). Good quantitative agreement is observed.

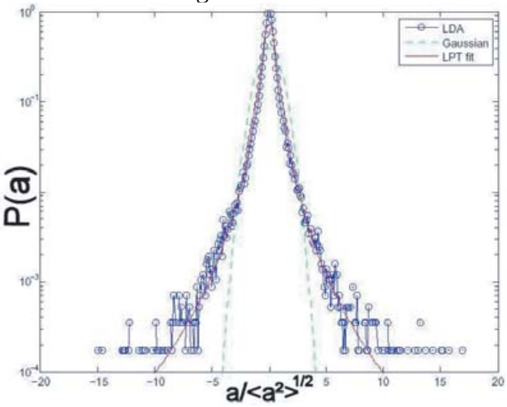

Fig. 1 Acceleration PDF

5. Conclusions

In this project a laser Doppler system that can measure not only the flow velocity but also its Lagrangian acceleration was successfully built and tested.

To obtain the velocity and the acceleration a model signal is fitted to the measured burst signal. The required values for the velocity and the acceleration result out of a parameter estimation procedure.

With careful alignment and an improved signal processing, an RMS value of approximately $20 m/s^2$ could be achieved in the turbulent flow studied. This is a very low value considering the corresponding small change of the velocity within the measurement volume and the high accelerations in turbulent flows.

The first validation measurements have shown that it is possible to measure Lagrangian acceleration with the laser Doppler system. The agreement between the laser Doppler measurement results and the results gained using particle tracking with silicon strip detectors is especially convincing.

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