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Multi-Exposed recordings for 3D Lagrangian particle tracking in turbulent boundary layer flows by means of Multi-Pulse Shake-The-Box

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Keywords: Lagrangian, 3D particle tracking, multi-pulse, Shake-The-Box, boundary layers

HIGHLIGHTS

- The Multi-Pulse Shake-The-Box (MP-STB) 3D Lagrangian Particle Tracking (LPT) algorithm is applied to experimental data from turbulent boundary layer (TBL) flows; four-pulse sequences of recordings are acquired by means of three different strategies.
- Two pulse-separation strategies (*polarization*- and *timing*-based) are presented, which make use of a dual 3D imaging systems to deliver single-exposed frames.
- A novel approach based on the use of a single imaging system and multi-exposed frames is proposed, which reduces the complexity and cost of the experimental setup.
- The multi-exposed-recordings strategy outperforms the other two approaches in terms of percentage of retrieved tracks by MP-STB at the expense of a twofold increase in the perceived seeding density.
- Results suggest the suitability of the multi-exposed strategy for 3D LPT with MP-STB in high-speed flows.

ABSTRACT

The MP-STB technique is applied to data from the investigation of turbulent boundary layers at several flow speeds. Two techniques (*polarization*- and *timing*-based) are presented which use two camera systems to record single-exposed images. Results from a TBL at 10 m/s investigation show good agreement with DNS (Fig. 1-left); nevertheless, only up to 70% of the actual particle tracks can be successfully retrieved by MP-STB. When a recording strategy based on multi-exposed recordings from a single-imaging system is adopted, the percentage of reconstructed tracks increases to approximately 95%. The multi-exposed MP-STB is applied here to the investigation of a TBL at 15 m/s (Fig. 1-right) and of a TBL with adverse pressure gradient at 21 ÷ 35 m/s.

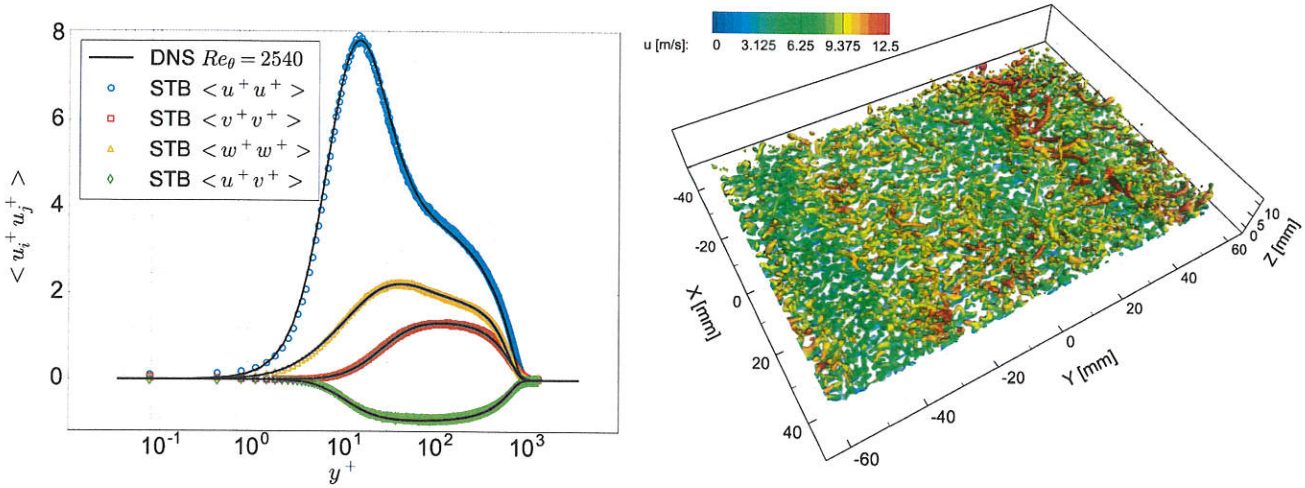

Fig. 1 *Left*: TBL profiles (**10 m/s**) obtained with MP-STB and *polarization*-based pulse separation technique. *Right*: instantaneous result (iso-surface of Q-criterion) from MP-STB applied to multi-exposed recordings from the investigation of a TBL at **15 m/s**.

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ABSTRACT

The Shake-The-Box (STB) is a processing algorithm for particle images recorded by means of 3D imaging systems, which enables volumetric Lagrangian particle tracking (LPT) at relatively high seeding densities. The method delivers the accurate measurement of position, velocity and acceleration of individual tracers and, coupled with regularization techniques, provides access to the full velocity gradient tensor. The STB technique, initially proposed for the reconstruction of time-resolved sequences of recordings, has been extended to the case of short recording sequences acquired by multi-pulse systems for the investigation of high-speed flows. The Multi-Pulse Shake-The-Box technique (MP-STB) exploits an iterative strategy to make up for the lack of time-resolved recordings and progressively simplify the reconstruction and tracking problem, therefore increasing the number of successfully identified particle tracks. Several strategies can be adopted to acquire multi-pulse recordings suitable for MP-STB; typically, a dual imaging system is used with the aim of separating the particle images from subsequent laser pulses onto individual camera frames. In the present study the use of multi-exposed recordings is proposed which employs a single imaging system, largely reducing the complexity of the experimental setup at the cost of an increase in the perceived seeding density. The MP-STB technique is applied here to experimental results from the investigation of boundary layer flows in air at speeds ranging from 15 to 35 m/s; results, presented in terms of instantaneous tracks and flow structures, suggest the suitability of the proposed multi-exposed strategy for carrying out 3D Lagrangian particle tracking with MP-STB in high-speed flows.

1. Introduction

Lagrangian particle tracking allows for the accurate measurement of single particle tracers position, velocity and acceleration. The Shake-The-Box technique (STB, Schanz et al 2016) extends the capabilities of 3D particle tracking methods (e.g. 3D-PTV, Maas et al 1993) to higher seeding densities, exceeding 0.1 ppp (particles per pixel). The scattered information obtained from particle tracking can be accurately interpolated onto a regular grid by means of cubic b-splines (FlowFit, Gesemann et al 2016) allowing for the evaluation of spatial gradients and, given