PIV Illumination Intensity: An Unexpected Source of Error in Particle Displacement and Calibration

C. Atkinson¹*, K. Oberleithner¹, J. Soria¹,²

1: Laboratory for Turbulence Research in Aerospace and Combustion, Monash University, Melbourne, Australia
2: Department of Aeronautical Engineering, King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia

* corresponding author: callum.atkinson@monash.edu

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Introduction

Over the years, significant effort has been made to quantify and improve the accuracy of Particle Image Velocimetry (PIV) measurements. Besides the filtering that stems from the temporal and spatial discretization of the fluid motion, numerous studies have focused on the influence of image noise, particle size, seeding density and velocity gradients on the accuracy of various PIV algorithms (Raffel et al. 2007 and references therein). Typically, these benchmarks involve the use of synthetic digital particle images. Unlike the real particle images recorded in experiments, the generation of synthetic images normally assumes that the response of each pixel or each region of the imaging sensor is uniform. In reality the transfer function of each pixel varies across the sensor, as demonstrated by Stanislas et al. (2013), yet is still assumed to be constant for a given camera and independent of the illumination used in a given experiment.

Recent jet experiments undertaken at the Laboratory for Turbulence Research in Aerospace and Combustion showed an unexpected offset between the location of the jet orifice in calibration images (recorded with ambient light and long exposure time) and in the PIV images (Nd:YAG illumination with 9 ns illumination pulse). After eliminating the possibility of laser sheet misalignment or camera movement and repeating the measurements it was determined that the only variations between the images were the illumination intensity and the exposure time.

In this study we investigate the effect of exposure time and illumination intensity on a number of commonly used PIV cameras by recording images of a back illuminated static particle field and performing a standard cross-correlation analysis between images of various illumination ratios. An assessment of bias and RMS displacement error is performed for each camera as a function of both the illumination intensity of an image and the difference in illumination intensity between one exposure and the next. Results for one particular PCO. 4000 camera indicated that intensity differences on the order of 50% can result in bias and RMS errors of 0.4 and 0.2 pixels, respectively.

Experimental Testing of the Influence of Varying Illumination on PIV Cameras

In order to test the imaging response of various PIV cameras, each camera was equipped with the same f=105 mm lens and focused on a synthetic particle image printout. The printout was back-illuminated by a light box in order to provide constant intensity illumination. The exposure time was modified in order to obtain a series of images of varying illumination. Five different camera models were assessed, including CMOS and CCD type sensors with resolutions ranging from four to twelve megapixels, with recording rates of two to 1000 Hz. Images of the synthetic particles were taken for different internal camera settings (number of analogue digital converters ADC and internal pixel clock speeds, where possible) with varying ratios of exposure time and effective variations in illumination intensity.

Fig. 1 (a) Correlation function from the cross-correlation of the same particle image taken at (b) t = 100 ms and (c) t = 2 ms exposure times.

Results

Fig. 1 illustrates the difference in recorded particle images for exposure times of 100 ms and 2 ms, respectively. A clear horizontal elongation of the particles is observed for the lower exposure time, which results in an elongation of the correlation peak. The effect of illumination intensity variations on the bias particle displacement errors for the PCO. 4000 camera are presented in Fig. 2. Each curve represents a particle image with a given exposure time, as indicated by the greyscale level for the errors in the horizontal component and red curves for the vertical. Similar results were observed for other PCO. 4000s tested, however the bias was not necessarily in the same direction.

Results from additional cameras will be presented and the implication of illumination sensitive particle displacement errors will be discussed.

Fig. 2 Bias particle displacement errors for synthetic particle images recorded on a PCO. 4000 camera

References
