ON THE APPLICATION OF BACKGROUND ORIENTED SCHLIEREN (BOS) TO A TRANSONIC LOW-REYNOLDS TURBINE CASCADE

Alexandre Halby
Lorenzo Da Valle
Mizuki Okada
Bora O. Cakir
Gustavo Lopes
Sergio Lavagnoli

von Karman institute for Fluid Dynamics, Chaussée de Waterloo 72, Rhode Saint Genèse, BE-1640 Belgium

ABSTRACT

Background Oriented Schlieren (BOS) is an optical measurement technique that allows to investigate the density gradient in a gas flow field. In the present investigation, shock wave tracking, boundary layer development and shock wave unsteadiness arising in a low-Reynolds transonic low-pressure turbine cascade have been examined by means of BOS exploiting the simple required setup. An extensive experimental campaign on the SPLEEN (Secondary and Leakage Flow Effects in High-Speed Low-PrEssurE TurbiNes) C1 cascade has been performed at the VKI - S1/C wind tunnel at different flow conditions, specifically Re = [70k – 120k – 140k] and M = [0.90 – 0.95 – 1.0]. Components of the image acquisition setups are varied based on the motivation of performing time-averaged and time-resolved measurements. The results have been calculated by means of two different methodologies. The comparison between the two methods shows a rather good agreement.

INTRODUCTION

High-speed low-pressure turbines are a key-technology for the future generation of aircraft engines, characterized by ultra-high bypass ratio, and typically operating at transonic exit Mach numbers and low Reynolds numbers. These engine-relevant flow conditions are quite challenging to reproduce in conventional facilities, hence in literature there is a significant lack of experimental data [4]. This shortage of data is even more pronounced for the visualization techniques and for the quantitative measurements of the density gradient within a turbine cascade. In this regard, Schlieren based flow visualization approaches enable to characterize density varying flow features that commonly exist in compressible flow scenarios ($M>0.3$) [2]. The application of standard Schlieren techniques with collimated light beam setup requires either a double side optical access and considerably large lenses, or mirrors organized in complex single optical window setups. Differently, BOS offers the unique opportunity to investigate density gradients from a qualitative and a quantitative standpoint, featuring a non-intrusive setup that is relatively simple and affordable [3].

RESULTS AND DISCUSSION

The application of BOS to the low-Reynolds transonic cascade presents many challenges due to the overall low density flow conditions, resulting in registered displacement in the order of 1 pixel. Therefore, a pre-processing aimed at the correction of the disturbances arising during the acquisition has been performed. The data has been processed by means of the cross-correlation algorithm, that had been extensively used for PIV measurements, and by means of an optical flow algorithm, which is more tailored for BOS, and it provides an opportunity to enhance the resolution and the sensitivity of the pixel motion [1]. The results obtained from the two different techniques have been analyzed and compared. The boundary layer thickness and shock location are found to be in good agreement between both data reduction techniques. The time-resolved measurements have been processed by means of Proper Orthogonal Decomposition (POD) to understand the different modes that characterize the shock wave and the specific values of the frequency associated to each mode. The paraxial approximation has been introduced for this specific case to associate the detected pixel displacement with the correspondent density gradient, characterizing the shock intensity in the blade passage. The results obtained by means of the BOS technique have been compared with numerical simulation performed on the SPLEEN test case. The full paper discusses the setup used for the BOS in the VKI S1/C wind tunnel, the processing techniques used for the data analysis and the comparison between the results obtained among cross-correlation and optical flow as well as the comparison among numerical and experimental results.

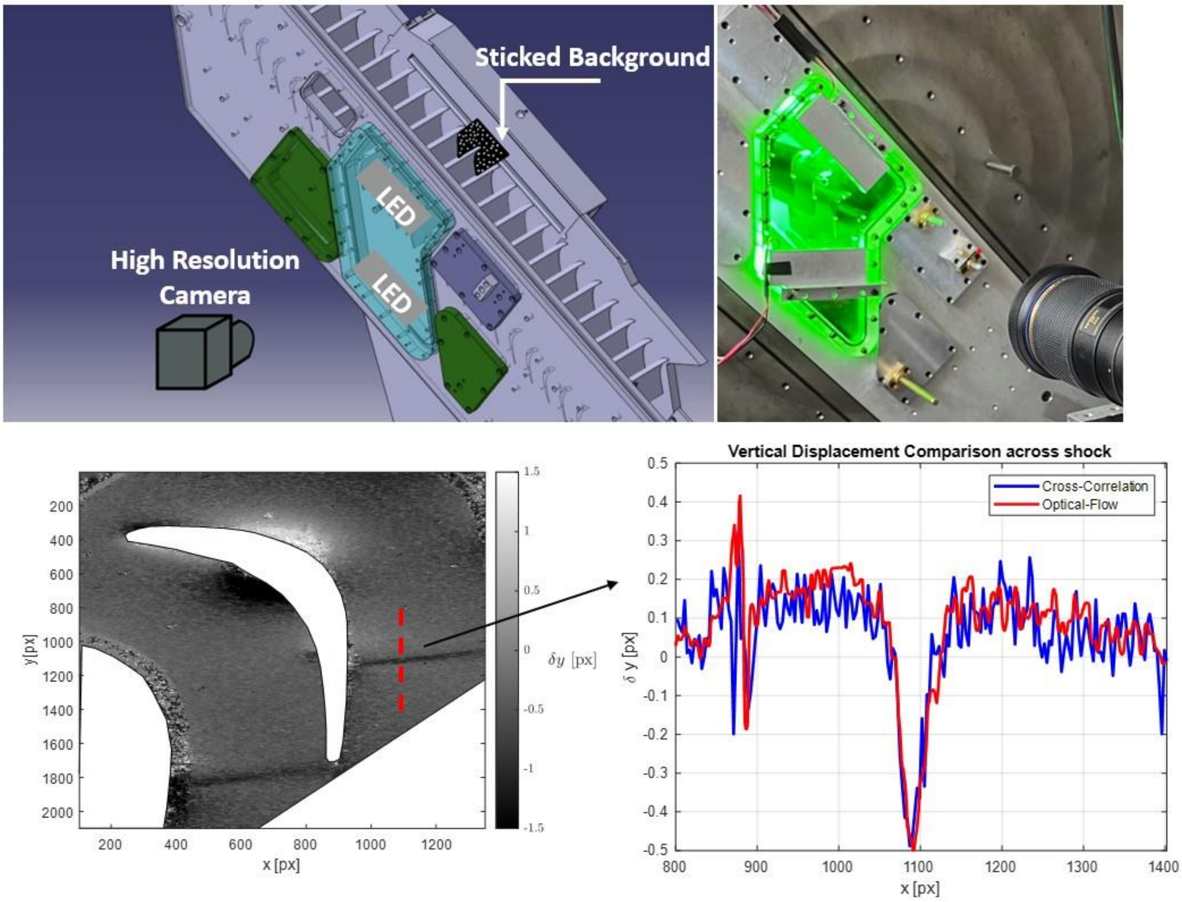

Figure 1. Scheme of the experimental configuration, image of the used setup, measured vertical displacement, and comparison between the displacement obtained from Cross-correlation and Optical-Flow algorithms

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