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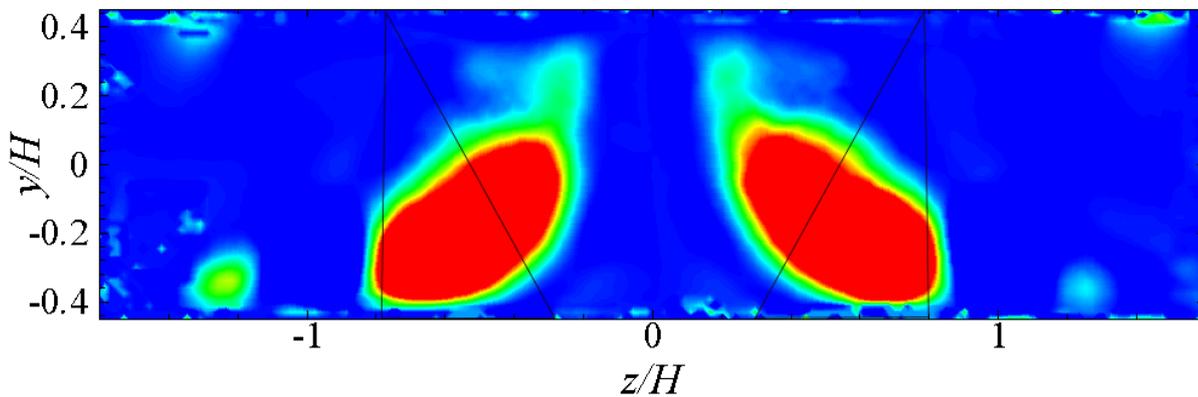
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Flow Investigation behind Delta Winglet Vortex Generators by Stereo PIV



Contour plots of the normalized Q -criterion downstream the DWP at $x/H=3$ and $Re_{DH} = 12000$.
The contours of the DWP are shown as black lines.

Introduction

Enhanced turbulent mixing is essential to intensify convective heat transfer in various industrial devices to improve performance and energy efficiency. Vortex generators (VGs) are passive flow control devices designed to generate swirling flows and provide a high level of heat transfer enhancement with moderate mechanical losses. With the high efficiency of this passive technique for flow control the use of VGs has attracted attention in several fields interested in the enhancement of rates of mass, momentum flux and heat transfer in many man-made devices (e.g. heat exchangers).

Scope of the work

The Delta Winglet Pair (DWP) vortex generator is a type of VG that generates longitudinal vortices. These delta shaped VGs (Figure 1) are arranged with an inclined angle of attack β to the main flow direction, producing counterrotating vortices. In this work, extensive Stereoscopic Particle Image Velocimetry (S-PIV) measurements have been conducted in a wind tunnel at different spanwise planes to investigate the flow characteristics downstream a single Delta Winglet Pair.

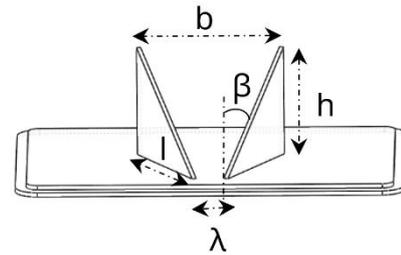
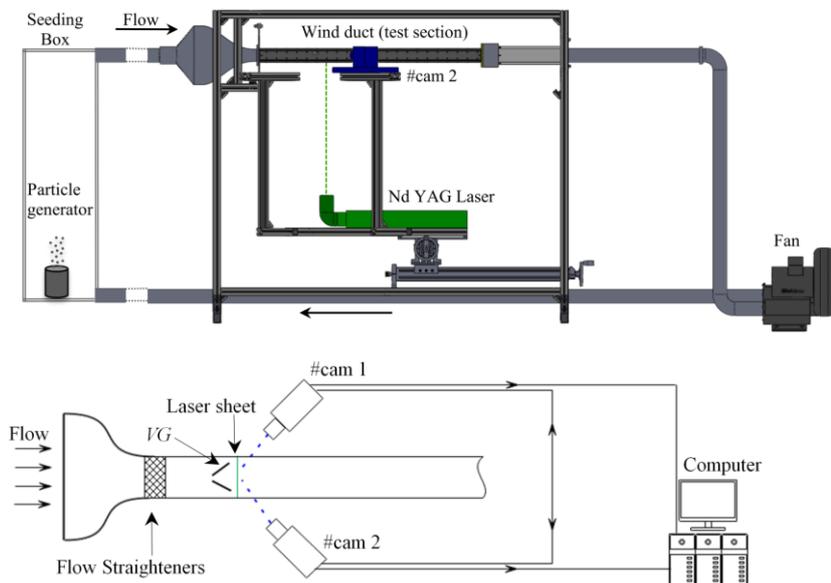


Figure 1 Sketch of the Delta Winglet Pair

The experimental setup

A closed loop flow system was designed for the purpose of performing experimental investigations of the flow features in a rectangular wind tunnel. The experimental setup, outlined in Figure 2 a), consisted of : 1) a seeding box containing the incense seeding particles; 2) a test section: a wind tunnel of 175x50 mm² cross-section and 1240 mm length. 3) an air path system: the airflow is provided by the fan connected to into the wind tunnel; 4) a vortex generator mounted in the test section and 5) a Stereo Particle Image Velocimetry (S-PIV) system.



a) Lateral view

b) top view

Figure 2 a) Sketch of the experimental wind channel loop and b) Schematic drawing of the experimental wind duct with Stereo-PIV optical configuration

Stereo PIV Measurements

Two Flow Sense CCD sensors were equipped with 60 mm lenses and arranged to enable an angular stereoscopic viewing (FIG. 2 b) of the region of interest. In order to avoid defocus of the images, a Scheimpflug angle between the camera plane and the optical axis of the lens was applied. The images were cropped to limit the image

recording to only the zone of interest (the transverse plane). The final resolution of the active sensor was approximately $2300 \times 1050 \text{ pixel}^2$ for cam #1 and $2400 \times 1050 \text{ pixel}^2$ for cam #2.

Parameters

Laser wavelength	532 nm
Time between laser pulses (δ_t)	55 to 750 μs
Sensor full size	4872 x 3248 pixels
Magnification	0.17
Aperture number $f\#$	
Cam #1	4
Cam #2	5.6
Depth of field (δ_x)	
Cam #1	1.51 mm
Cam #2	2.97 mm
Interrogation area	(16 x 16) to (128 x 128) pixels^2
Trigger rate	5 Hz

Dynamic Studio software ([DantecDynamics, 2019](#)) was used for system synchronization, data acquisition, image post-processing and flow field evaluation. A multilevel calibration target with a level distance of 1.2 mm was used to provide the relation between the particle image displacement in the image plane and the incense seeding particle displacement in the airflow. A Direct Linear Transformation was applied to find a space mapping relating image to object space, resulting in a calibration with average reprojection errors of 0.44 and 0.45 pixels for #cam 1 and #cam 2, respectively.

An Adaptive *PIV* method was applied on successive raw images from the two cameras to compute the respective *2D* velocity components. This method makes it possible to optimize the interrogation area's size and shape as a function of the local seeding density and flow regime. The interrogation area size is ranging from 128×128 to 16×16 pixels. As mentioned above, the image plane is rotated with respect to the object plane to obtain a better focus of each point of the images. This angular offset results in a perspective distortion. To correct for this, a dewarping is applied to all the recorded images before the *2D PIV* calculation. Finally, the calibration and *2D* vector fields are

used to reconstruct the three component vectors in the cross-section plane under investigation.

An important step concerns the identification of erroneous displacement vectors. This is done for all 2D vectors by using the Universal Outlier Detection Algorithm. However, to assure high quality data great care must be taken during the calibration procedure and the data acquisition. However, corrections applied on recorded data cannot fully correct for errors caused eg. by poor signal-to-noise ratio in the acquired raw images. In order to establish a large survey database including different flow regimes, the investigation of flow structures upstream and downstream the vortex generator is conducted for different Reynolds number ($Re_{DH} = 400; 800; 1500; 3000; 6000$ and 12000) at four streamwise positions: $x/H = 1.5; 3; 6$ and 15 .

Results

The coherent structures generated downstream the *DWP* at different transverse planes are analyzed for laminar to turbulent flow regime and are identified using the second invariant of mean velocity gradient tensor

$$(Q - criterion : Q = \frac{1}{2} (\|\boldsymbol{\Omega}\|^2 - \|\boldsymbol{S}\|^2) = -\frac{1}{2} \left[\frac{\partial w}{\partial y} \frac{\partial v}{\partial z} \right]).$$

Colour contours of the normalized *Q-criterion* ($Q^* = Q/U_0^2$) for all Reynolds number at different *y-z* cross-sections are presented in Figure 3. The results confirm the presence of one pair of two main vortices directed to the bottom-wall (noted 1 in Figure 3). The vortices lead to an exchange of fluid between the bottom wall and the core flow region. Moreover, for high Reynolds number ($Re_{DH} > 1500$), a secondary vortex pair is clearly identified by the *Q* values and is induced closer to the wall (noted 2 in Figure 3). At $x/H = 1.5$ the flow is largely dominated by streaming zones with is irrotational straining motion. The vortices strength is at its maximum at $x/H = 3$, where maximum values of *Q* are observed at the core vortices, $0.042, 0.11, 0.21, 0.73$ and 4.15 s^{-2} , for $Re_{DH} = 800, 1500, 3000, 6000$ and 12000 , respectively. Further downstream, it is observed that the peak of *Q-criterion* decreased rapidly in the streamwise direction. For instance, $Re_{DH} = 12000$ at $x/H = 15$, the *Q-criterion* peak decreases in downstream direction by factor of ten (at $x/H = 15$, $Q_{core} = 0.04 \text{ s}^{-2}$). At this stage (at $x/H=15$), the vortical structures exhibit circular pattern and are advected gradually to both side of the channel. Thus, the space increasing between the vortices leads to boundary-layer expansion and create a zone of low energy between the two main vortices. The vortices lose a large portion of their intensity due to wall friction and also by exchange with the induced vortices.

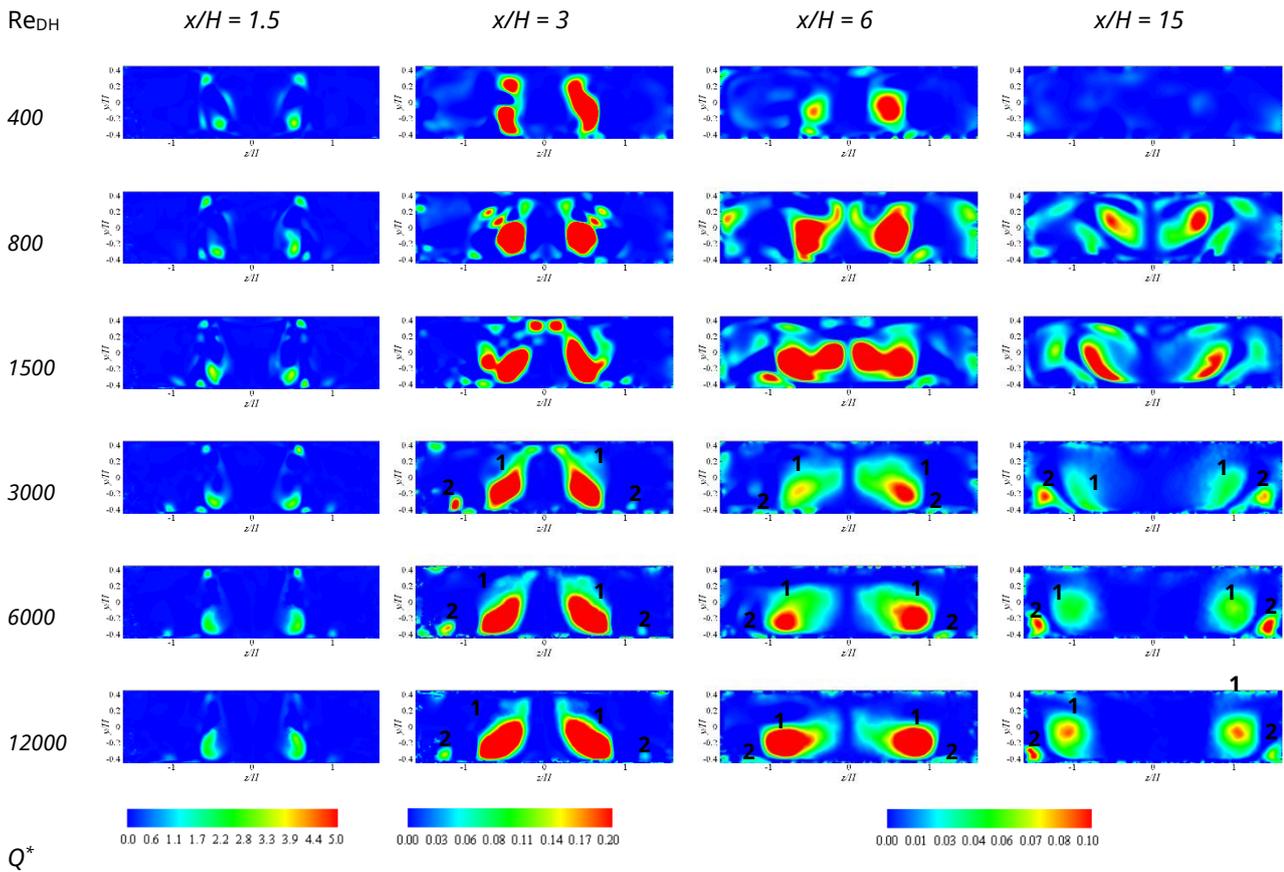


Figure 3 Contour plots of the normalized Q -criterion downstream the DWP at different Reynolds numbers and different cross sections

Aknowledgements

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