Experimental Thermal and Fluid Science 94 (2018) 99–108

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Flow over a flat surface behind delta winglets of varying aspect ratios

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A R T I C L E I N F O

Keywords:
Longitudinal vortex
Turbulence
Wind tunnel
Hotwire
Vortex generator

A B S T R A C T

The effect of winglet aspect ratio on the generated vortical flow over a flat surface was experimentally scrutinized in a wind tunnel using a triple sensor hot-wire. Aspect ratios of 1, 2 and 4 were considered at a Reynolds number based on winglet height of 6000 and an angle of attack of 30 degrees. A large longitudinal vortex structure was observed in the cross-stream plane. The streamwise velocity deficit at the main vortex core lessened, while that at the Upwash Region remained unaltered, with increasing aspect ratio. Moreover, the vortex moved downward and inward and its intensity decreased. The turbulence level decreased with a corresponding increase in Taylor microscale. The integral length was found to be independent of the aspect ratio but scaled with the winglet height.

1. Introduction

There are many applications where the effectiveness of convective heat transfer by air is important, convective cooling of solar photovoltaic (PV) panels is an example. On the hot surface, the convective heat transfer is mostly restricted by the boundary layer. Due to the function of the PV panel, its surface condition cannot be easily altered by means of curving [1] or dimpling [2] to disturb the boundary layer. Moreover, it cannot be covered with fins [3] for that would block the solar radiation. Therefore, turbulence generators (TGs) mounted on the frame is the most feasible measure to disturb the boundary layer and enhance the heat transfer. For this purpose, the flow mechanism behind desirable TGs must be scrutinized for better understanding and designing. One of the potential TGs that can fit into the PV narrow frame is rib [4,5]. Ribs can perturb the boundary layer by causing flow separation, recirculation and reattachment. The separated and reattached flow would lead to some strong unsteady behaviors, such as flapping separation bubbles, rolled-up vortices and shedding of large scale vortices. Grooves [6–8] are another promising turbulence generating technology. Turbulence intensity can be augmented in the near-wall region immediately downstream of the groove.

Another potential type of TGs, longitudinal vortex generators (LVGs) [9–11], can disturb the boundary layer in a different way, i.e., swirling the flow by rotating with an axis parallel to the main flow direction. The boundary is thus highly three-dimensional and the associated turbulence is long-lasting. There are two typical LVGs: wings and winglets, as shown in Fig. 1. A concise literature review on this is given in Wu et al. [12]. An isolated winglet can spawn one vortex and the rotating direction is controlled by the orientation of the winglet. One wing, on the other hand, can produce two counter rotating vortices with the inboard flow downward into the horizontal plane. The performance of these LVGs weighs heavily on geometries such as aspect ratio and angle of attack. This study specifically examines the impact of the aspect ratio on the vortex structures and underlying turbulence parameters of the flow behind a delta winglet. As such, it is an extension of our previous work [12].

2. Experimentation

Fig. 2 shows the experimental setup, including the tested winglets and the associated parameters; note the winglet Vertex and Rear Corner. The experiments were conducted inside a closed loop wind tunnel. The test section of the wind tunnel has a 76 cm by 76 cm cross section. The delta winglets were made from a 0.1 mm thick aluminum sheet. The height, h, was kept at 10 mm, and the chord length, c, varies from 40 to 10 mm, giving an aspect ratio (AR), $4\,h/c$, of 1 to 4. The winglets were attached on the base surface of the wind tunnel by one of the folds, 1000 mm away from the inlet of the test section. The incoming boundary layer (measured at the location of the winglet leading vertex) was turbulent with a boundary layer shape factor of 1.2, a boundary layer thickness of approximately 2.5 h, and no distinct frequencies were detected, as shown in Figs. 3 and 4. The angle of attack, α, was maintained at 30 degrees in the present study. The stream velocity was fixed at 10 m/s, resulting in a Reynolds number based on the winglet height of 6000. The background turbulence intensity was around 0.4%. A triple sensor hotwire probe (type 55P91) with a

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https://doi.org/10.1016/j.expthermflusci.2018.01.030
Received 1 September 2017; Received in revised form 19 December 2017; Accepted 23 January 2018
Available online 22 February 2018
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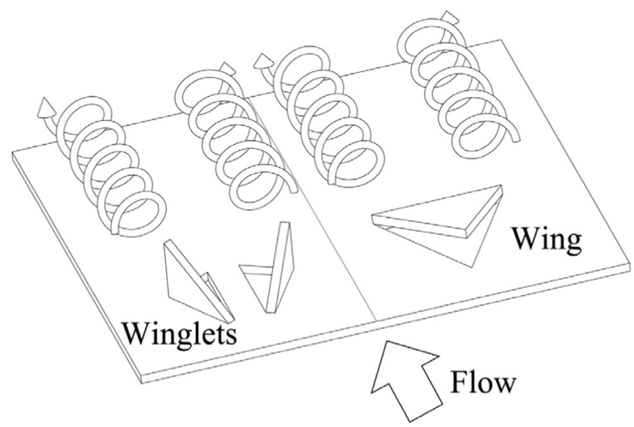

Fig. 1. Typical vortex generators.

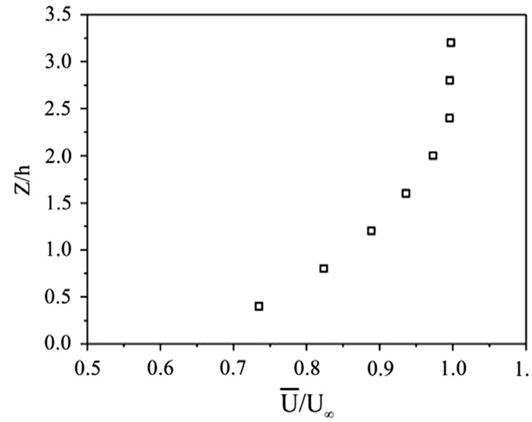

Fig. 3. Velocity profile for incoming flow.

constant-temperature anemometer was employed to obtain the velocity at 100 mm (10 h) downstream of the winglet. The measured planes were 50 mm × 30 mm for aspect ratio of 1 and 40 mm × 30 mm for aspect ratio of 2 and 4, with a spatial resolution of 2 mm. The velocity signals were sampled at 80 kHz for 12.5 s, resulting in a sampling number of 10^6. The signal was low passed at 30 kHz. All three velocity components, U, V, W, were measured simultaneously.

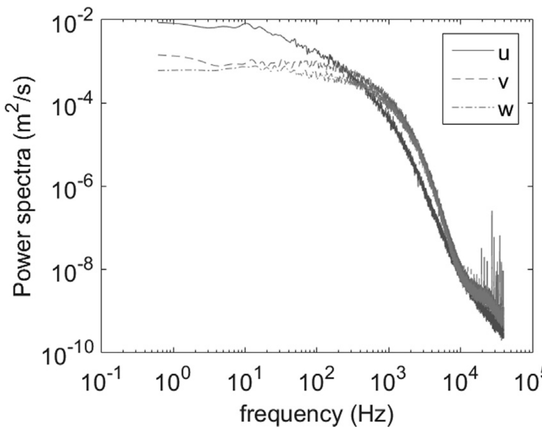

Fig. 4. Power spectra for incoming flow.

3. Data processes

The instantaneous velocities (U, V, and W) are obtained from hot-wire output voltage signals via calibration coefficient and ambient temperature. The time-averaged velocity ($\overline{U}$) is deduced from:

$$\overline{U} = \frac{1}{N}\sum_{i=1}^{N} U_i \quad (1)$$

where N is the sample size. The instantaneous fluctuating velocity (u) is calculated from:

$$u_i = U_i - \overline{U} \quad (2)$$

The root mean square velocity (u_{rms}) is computed from:

$$u_{rms} = \sqrt{\sum_{i=1}^{N} \frac{u_i^2}{N-1}} \quad (3)$$

Vorticity is calculated from:

$$\omega = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} \quad (4)$$

Dimensionless time-averaged velocity and turbulence intensity are deduced via dividing them by the free stream velocity, and dimensionless vorticity is obtained from:

$$\Omega = \frac{\omega \times h}{U_\infty} \quad (5)$$

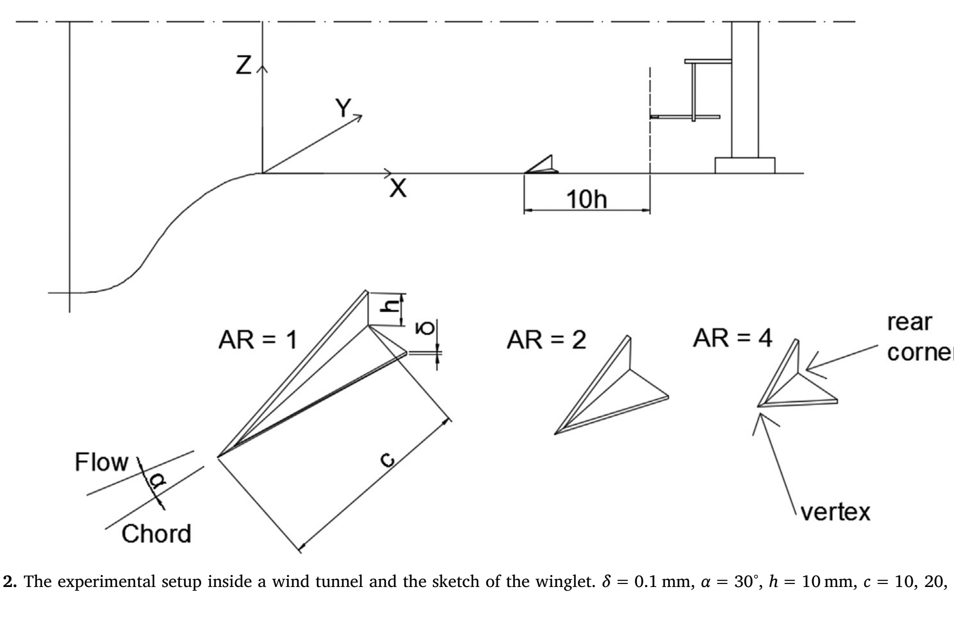

Fig. 2. The experimental setup inside a wind tunnel and the sketch of the winglet. δ = 0.1 mm, α = 30°, h = 10 mm, c = 10, 20, 40 mm.