Computational Simulations of a pair of Rectangular Vortex Generators on a flat plate.


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UNIVERSITY LOCATION

THE BASQUE COUNTRY
Area: 7,089 Km²

VITORIA-GASTEIZ
Population: 236,525 inhab.
OUTLINE

1. INTRODUCTION
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3. RESULTS
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Introduction

Applied aerodynamics on aircraft wings

Source: Vortex generators on the wing of an airplane at the Air Force Museum of the German Federal Armed Forces in Berlin. Image credit: Wikimedia Commons
http://phys.org/news/2012-09-scientists-purpose-vortex.html#JCP
What is a VG? How does it work?

These passive devices are used for flow control:

- Modifying the boundary layer motion.
- Generation of longitudinal vortices.
- Overturn of the BL flow via large scale motions.
- Bringing high momentum fluid down into the near wall region of the boundary layer.
- In short: separation of the flow is delayed.
VGs on Airfoils

- GEOMETRY: triangular or rectangular vanes.
- Dimensioned: to the local boundary layer thickness.
- Lay-out: in cascades in groups of two.

Ref.: G. Godard, M. Stanislas 2005

Figure 3: Counter rotating passive device configuration.
VGs on Airfoils

- Main functionality:
  - to delay or prevent separation of the flow.

**Figure 4:** (a) Flow across an airfoil. (b) Separated flow over the top surface of an airfoil.

**Figure 5:** Effect of vortex generators on the performance of DU 97-W-300.

*Source:* J.D. Anderson Jr., *Brief History of the Early Development of Theoretical and Experimental Fluid Dynamics*. Wiley & Sons 2010

VGs on Wind Turbines

Increased wind turbine performance from implementing VGs on the blades has also been confirmed through various field tests.

**Figure 6 (a)**: Effects of VGs on a 2.5 MW wind turbine performance.

**Figure 6 (b)**: Effects of VGs on a 1 MW wind turbine performance.
VGs on Wind Turbines
VGs on Wind Turbines

SOURCE: pictures were taken by the author in EWEA Conference 2012, Copenhagen.
Computational Set Up

- The flow domain dimensions: 32h, 10h and 30h.

\[ \text{Re} = \frac{\rho U_{\infty} H}{\mu} = 20000 \]

**Figure 7:** Computational domain and plane location where the measurements were conducted.
Computational Set Up

- **Unsteady state** computations have been carried.

- CFD computations: EllipSys3D code. RANS equations.

- The convective terms are discretized utilising the third order Quadratic Upstream Interpolation for Convective Kinematics (QUICK).

- **$k$-$\omega$ SST** (Shear Stress Transport)

\[
Re = \frac{\rho U_\infty H}{\mu} = 20000
\]

$H = 0.01 \text{ m}$

$L = 2H$
Mesh

- Block structured mesh (2x10^6 cells)
- Around the VG geometry: 7x10^5 cells.
  Downstream the VG: 4x10^5 cells.

Figure 8: Mesh Sections on the VG. (a) Cross flow section and (b) top view.
Analytical model

• The axial, $u_z$, and rotational, $u_\theta$, velocities are linearly related:

$$u_z = u_0 - ru_\theta / l$$

Together with the Batchelor vortex model four parameters:

$$u_\theta(r, \theta, z) = \frac{\Gamma(z)}{2\pi r} \left[ 1 - \exp\left( -\frac{r^2}{\varepsilon^2(\theta, z)} \right) \right]$$

$$u_z(r, \theta, z) = u_0(z) - \frac{\Gamma(z)}{2\pi l(\theta, z)} \left[ 1 - \exp\left( -\frac{r^2}{\varepsilon^2(\theta, z)} \right) \right]$$

four parameters: $\varepsilon(\Theta,z)$, circulation $\Gamma(z)$, $u_0(z)$ and $l(\Theta,z)$,
Axial Velocity Fields

Figure 9: Axial velocity fields at five plane positions: $z/h = 5-15$. 

$x/h = 5$
Axial Velocity Fields

Figure 9: Axial velocity fields at five plane positions: $z/h = 5-15$. 

$z/h = 7.5$
Axial Velocity Fields

$\frac{x}{h} = 10$

**Figure 9:** Axial velocity fields at five plane positions: $z/h = 5-15$. 
Axial Velocity Fields

$x/h = 12.5$

**Figure 9**: Axial velocity fields at five plane positions: $z/h = 5-15$. 

**INTRODUCTION**

**COMPUTATIONAL SET UP**

**ANALYTICAL MODEL**

**RESULTS**

**CONCLUSIONS**
Axial Velocity Fields

Figure 9: Axial velocity fields at five plane positions: $z/h = 5-15$.

$x/h = 15$
**FORCES PLOT**

**Total Force** = \(0.0418(\beta) - 0.0287\)

\[R^2 = 0.9911\]

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Conclusions

- The main vortex generated by the VG possesses helical symmetry and self-similar behavior for both the axial and azimuthal velocity profiles. It has been proven based on five plane positions $z/h=5-15$ downstream of the trailing edge of the VG and with $\beta=20^\circ$ of the vane to the incoming flow.

- From the point of view of self-similarity, computational simulations are able to reproduce the physics of the vortex generated by a rectangular VG with considerable reliability.
Future Work

- Additional work:
  - Comparison with wind tunnel experimental data.
  - Computations with Different VG geometries.
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Thank you very much for your attention!

Eskerrik asko zuen arretagatik!

¡Muchas Gracias por vuestra atención!