Organisation of flow controlled with continuous jet vortex generators

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Outline

I. General Introduction

II. Experimental set-ups

III. Baseline flow without control

IV. Flow organisation of active control configurations

V. Conclusions and perspectives
I. General Introduction

⇒ Flow control to prevent flow separation

- Taylor 1947 (passive VGs)
- ...  
- Wallis 1952 (continuous jets VGs)
- ...  
- Godard 2006 (optimisation of active and passive VGs)
II. Experimental set-ups

1. Wind tunnel

Characteristics:

- \( U_\infty \) ranging from 3 to 10 m/s (±0.5 %)
- Temperature regulated (±0.2 °C)
- Thick boundary layer (\( \delta \approx 30 \) cm)
- \( \text{Re}_\theta \) ranging from 7 500 to 19 000
II. Experimental set-ups

2. Ramp model

\[ U_\infty \approx 10 \text{ m/s} \]

\[ \delta \approx 30 \text{ cm} \]

3 parameters: \( U_\infty, \alpha \), and \( \beta \)

- \( U_\infty \) for the Reynolds number
- \( \alpha \) to tune the adverse pressure gradient on the flat plate
- \( \beta \) to tune the adverse pressure gradient and the separation on the flap.
II. Experimental set-ups

3. Selected ramp configuration

- $\alpha = -2^\circ$: mild adverse pressure gradient on the flat plate
- $\beta = -22^\circ$: flow separation on the flap (strong enough)

$\Rightarrow H_{\text{step}} = 17.5 \text{ cm}$

Configuration similar to Lin 1999 (AIAA paper) and Selby et al 1992 (Exp in Fluids)

($Re_\theta$ about 11 500 and $\delta$ about 20 cm)
II. Experimental set-ups

4. Description of the PIV experiment

Laser reflection: Rhodamine Paint + filters (532 nm)
Energy: 400 mJ per pulse
II. Experimental set-ups

4. Description of the PIV experiment

Continuous field:
- about 94 cm along the wall
- 28.7 cm in wall-normal direction
- mesh lines normal to the wall
- 5000 fields

**IW size**: 4.9 mm x 4.9 mm
- First point: 2.4 mm from the wall
- ≈ 121,000 vectors
III. Baseline flow without control

1. PIV accuracy

- Comparisons with hot-wire profiles

Accuracy $\approx 1\%$ of $U_\infty$ (max 4%)
III. Baseline flow without control

1. PIV accuracy

- Comparisons with hot-wire profiles

Accuracy $\approx 0.8\%$ of $U_\infty$ (max $3\%$)
III. Baseline flow without control

2. Mean flow over the flap
III. Baseline flow without control

2. Mean flow over the flap

- Mean streamwise velocity distribution and separation border

\[
\frac{L_{sep}}{H_{step}} = 3.49 \quad (L_{sep} = 61 \text{ cm})
\]

\[
\frac{H_{sep}}{H_{step}} = 0.17 \quad (H_{sep} = 3 \text{ cm})
\]

III. Baseline flow without control

3. Turbulence organisation over the flap

- Streamwise turbulence intensity distribution
III. Baseline flow without control

3. Turbulence organisation over the flap

Streamwise fluctuating velocity distribution

⇒ Structures: \( L > 3H_{\text{step}} \) and \( H > 0.5H_{\text{step}} \) \((\delta_0 \approx H_{\text{step}})\)

(Chehroudi and Simpson 1985)
III. Baseline flow without control

3. Turbulence organisation over the flap

- Streamwise Reynolds stress production distribution

\[ -u'' \frac{\partial U}{\partial x} \cdot \frac{H_{\text{step}}}{U_\infty^3} \]

\[ -u'v' \frac{\partial U}{\partial y} \cdot \frac{H_{\text{step}}}{U_\infty^3} \]
III. Baseline flow without control

3. Turbulence organisation over the flap

- Wall-normal turbulence intensity distribution
III. Baseline flow without control

3. Turbulence organisation over the flap

- Wall-normal Reynolds stress production distribution

\[-\overline{v'^2} \frac{\partial V}{\partial y} \cdot \frac{H_{\text{step}}}{U^3}\]

Redistribution from \(<u'^2>\) to \(<v'^2>\)
III. Baseline flow without control

3. Turbulence organisation over the flap

- Reynolds shear stress distribution

High similarity with $v'^2$
III. Baseline flow without control

3. Turbulence organisation over the flap

- Reynolds shear stress production distribution

\[ \frac{\overline{v^2 \partial U}}{\partial y} \cdot \frac{H_{\text{step}}}{U_\infty^3} \]
IV. Flow organisation of active control configurations

1. Configurations selected

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Optimum:

(Godard and Stanislas 2006b, Aerospace science and technology)
IV. Flow organisation of active control configurations

1. Configurations selected
IV. Flow organisation of active control configurations

2. Profiles at hot-wire station 5

Upwash for the co-up configuration and downwash for the counter ones

*(McManus 1994, Godard and Stanislas 2006b, Kostas et al 2007, …)*
IV. Flow organisation of active control configurations

2. Profiles at hot-wire station 5

Upwash for the co-up configuration and downwash for the counter ones
IV. Flow organisation of active control configurations

3. Mean velocity over the flap

i. Mean streamwise velocity distribution

Without

Co-up

Counter-up

Counter-down
IV. Flow organisation of active control configurations

3. Mean velocity over the flap

ii. Backflow coefficient distribution
IV. Flow organisation of active control configurations

4. Turbulence organisation over the flap

i. Streamwise turbulence intensity distribution
IV. Flow organisation of active control configurations

4. Turbulence organisation over the flap

ii. Streamwise Reynolds stress production

\[-u'^2 \frac{\partial U}{\partial x} \cdot \frac{H_{\text{step}}}{U_\infty^3}\]

\[-u'^2 \frac{\partial U}{\partial y} \cdot \frac{H_{\text{step}}}{U_\infty^3}\]
IV. Flow organisation of active control configurations

4. Turbulence organisation over the flap

iii. Wall-normal turbulence intensity

\[ \frac{\partial^2 V}{\partial y^2} \frac{H_{step}}{U_{\infty}^3} \]

\[ \frac{\partial^2 V}{\partial y^2} \frac{H_{step}}{U_{\infty}^3} \]
IV. Flow organisation of active control configurations

4. Turbulence organisation over the flap

iv. Reynolds shear stress
IV. Flow organisation of active control configurations

4. Turbulence organisation over the flap

v. Wall-normal turbulence intensity (Co-up)
IV. Flow organisation of active control configurations

4. Turbulence organisation over the flap
   vi. Reynolds shear stress (Counter-down)
V. Conclusions and perspectives

=> Turbulence organisation not fundamentally changed by the control

- Intense turbulence region above the bubble border
- Large scale structures ($u'$)
- Production term $-\overline{u'^2} \frac{\partial \overline{U}}{\partial x}$ of $\overline{u'^2}$ dominant in the first part of the flap
- Redistribution from $\overline{u'^2}$ to $\overline{v'^2}$
- Strong similarity between $\overline{u'v'}$ and $\overline{v'^2}$

Perspectives:

=> Pulsed-jets and closed loop tests (Cédric Raibaudo)
Thank You for your attention

Questions ?