Forcing the shear layer of a backward-facing step flow using DBD plasma actuator


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Backward-facing step flow

\[ U_0 \]

\[ h \]

\[ \delta \]

\[ L_r \]

\[ X_r \]
Backward-facing step flow

A very simple geometry but a complex flow
Backward-facing step flow

The transitions of the shear layer is one of the key phenomena

Onset of the Kelvin-Helmholtz instability

Re$_h$ = 250
Re$_h$ = 450
Re = 500
Re = 630
Re = 850
Re = 1050
Re = 1200
Re = 3330
Backward-facing step flow

The transitions of the shear layer is one of the key phenomena

Onset of the 3D destabilization of KH vortices

\[ \lambda \approx 5h \]
Objective of the experimental study

One can use many different strategies to control the flow separation:

- Upstream of the separation
- At the separation
- Downstream the separation
- Constant or time dependant

Control using pulsed excitation just upstream the step edge
Experimental setup

Characteristics of the wind tunnel and BFS geometry

- Square cross-section
- $U_0 = 3$ to $15\ \text{m.s}^{-1}$ i.e. $Re_H = \frac{U_0 H}{\nu} = 2 \times 10^3$ to $12 \times 10^3$
- Expansion ratio $E = 0.17$
Actuation using a ionic wind induced by a DBD actuator

- Constant $HV = 6kV$
- Induced velocity $u_j \approx 4 \text{ m.s}^{-1}$
- High frequency AC
- Duty cycle 27%
PIV and visualization set-up

Seeding with oil microdrop lets

For each Reynolds numbers and excitation frequencies:
- 700 pairs of images
- Synchronisation with the excitation frequency for phase reconstruction

18mJ double cavity YaG LASER

4Hz double frame CCD Camera

PIV window

18mJ double cavity YaG LASER

30
800

U₀

Plasma discharge

δ

H₁=100

H=20

Seeding with oil microdrop lets

For each Reynolds numbers and excitation frequencies:
- 700 pairs of images
- Synchronisation with the excitation frequency for phase reconstruction
PIV and visualization set-up

For a single Reynolds number and different excitation frequencies and duty cycles:

- 500Hz sampling rate
- 3 000 images are recorded
Characteristics of the BFS flow

Evolution of the $U_x$ velocity field as a function of the Reynolds number
Characteristics of the BFS flow

Visualization of the vortex shedding in the shear layer for $Re_H = 8000$
Characteristics of the BFS flow

Evolution of the recirculation length $L_r$ as a function of the Reynolds number

![Graph showing the evolution of recirculation length $L_r$ with Reynolds number $Re$. The graph includes various symbols and lines representing different experimental conditions.](image)
Visualisations of forced shear layer.
Modification of the mean-flow characteristics

Evolution of the recirculation length $L_r$ with the forcing frequency for $Re_H$

![Graph showing the evolution of $L_r$ with $St$ for $f/f_0 = 1$.]
Phase-Averaging
Spatio temporal diagrams
Streamwise wavelength of the perturbation

Spatiotemporal diagram in \( y=0 \) for \( U_y, \text{Re} = 3050, f = 30 \text{ Hz} \)
Streamwise wavelength of the perturbation

Spatiotemporal diagram in y=0 for \( U_y \), Re = 3050, f = 50 Hz
Streamwise wavelength of the perturbation

Spatiotemporal diagram in $y=0$ for $U_y$, $Re = 3050$, $f = 100$ Hz
Streamwise wavelength of the perturbation

Spatiotemporal diagram in $y=0$ for $U_y$, $Re = 3050$, $f = 120$ Hz
Role of the phase velocity

Retour aux visus
Spatial transient growth of the perturbation
Conclusions

1. Large gains on $x_r$ over a large range of frequencies
2. Optimal frequencies around $f_0$ with critical behaviour
3. Two different behaviours with respect to the frequency ratio.
4. For $f<f_0$ control of the shear layer based on vortex pairing where phase velocity seems to be the key element. Importance of the nature of the perturbation.
5. For $f>f_0$ frequency locking on the forcing frequency