Flow Control by DBD Plasma Actuator

Satoshi Kikuchi

Fluid Engineering Lab. (Imao Lab.)

Department of Mechanical Engineering,

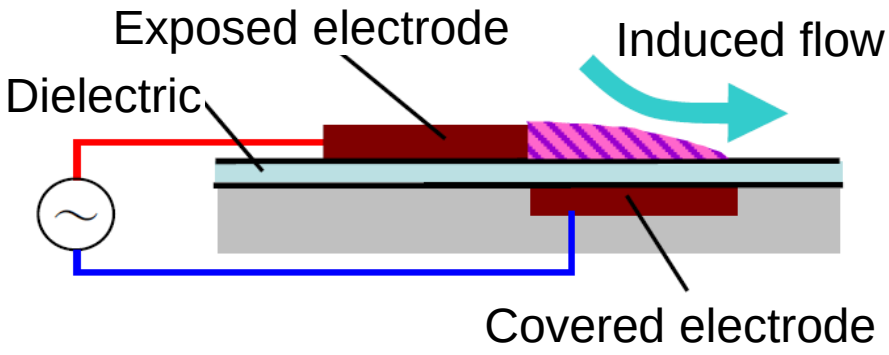
Faculty of Engineering, Gifu University

kikuchi@gifu-u.ac.jp

岐阜大学
GIFU UNIVERSITY

Dielectric-Barrier-Discharge (DBD) plasma actuator

The popular device for flow control



High AC voltage

Dielectric barrier discharge

⇒ Plasma

⇒ Induced flow

Advantage

- High response
- Simple structure
- Low power consumption

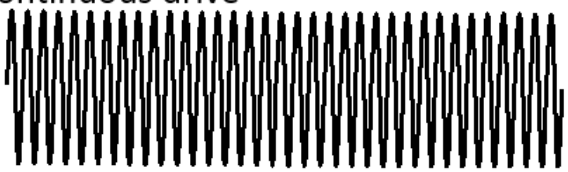
etc.

Disadvantage

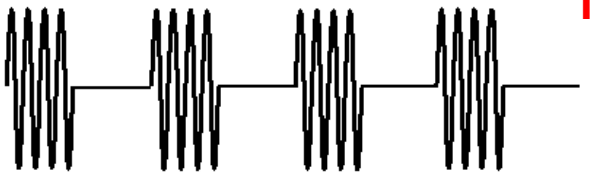
- Low momentum of the induced flow

Waveforms of applied voltage (Pulse modulation drive)

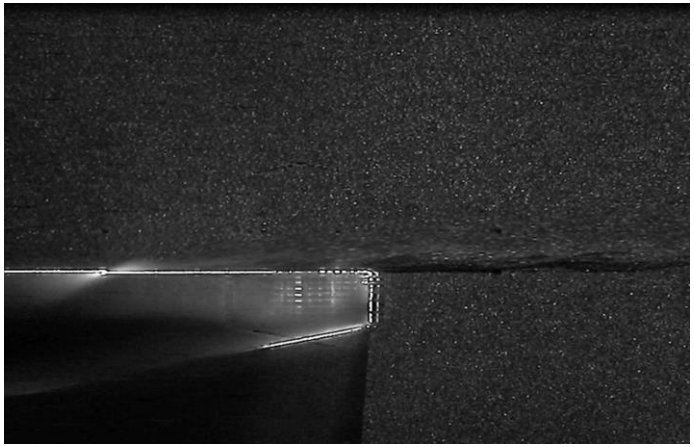
Continuous drive

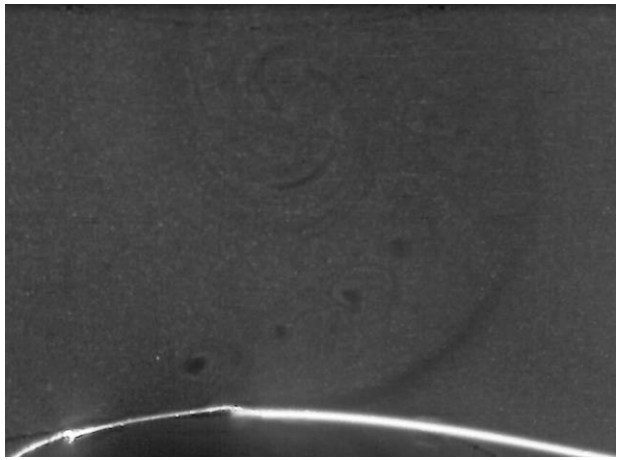


Pulse modulation drive



in stationary air





Continuous flow

Momentum is introduced to the flow.

Not effective

(Low momentum of the induced flow)

Intermittent flow

Pulse modulation drive

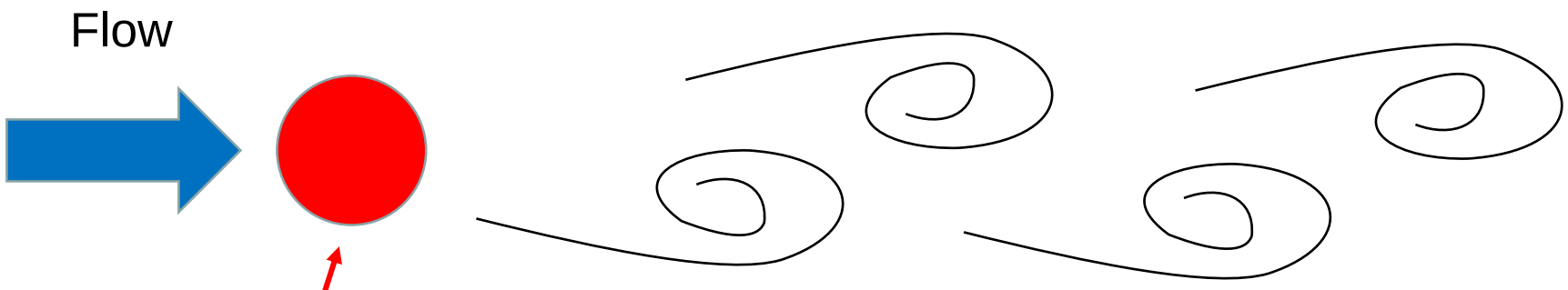
Perturbation is introduced to the flow.

Timing control of flow phenomena is possible.

Effective for separation flow.

⇒ We use this control.

1St control example
Wake of a cylinder



The wake of a cylinder :

the staggered arrangement of vortices

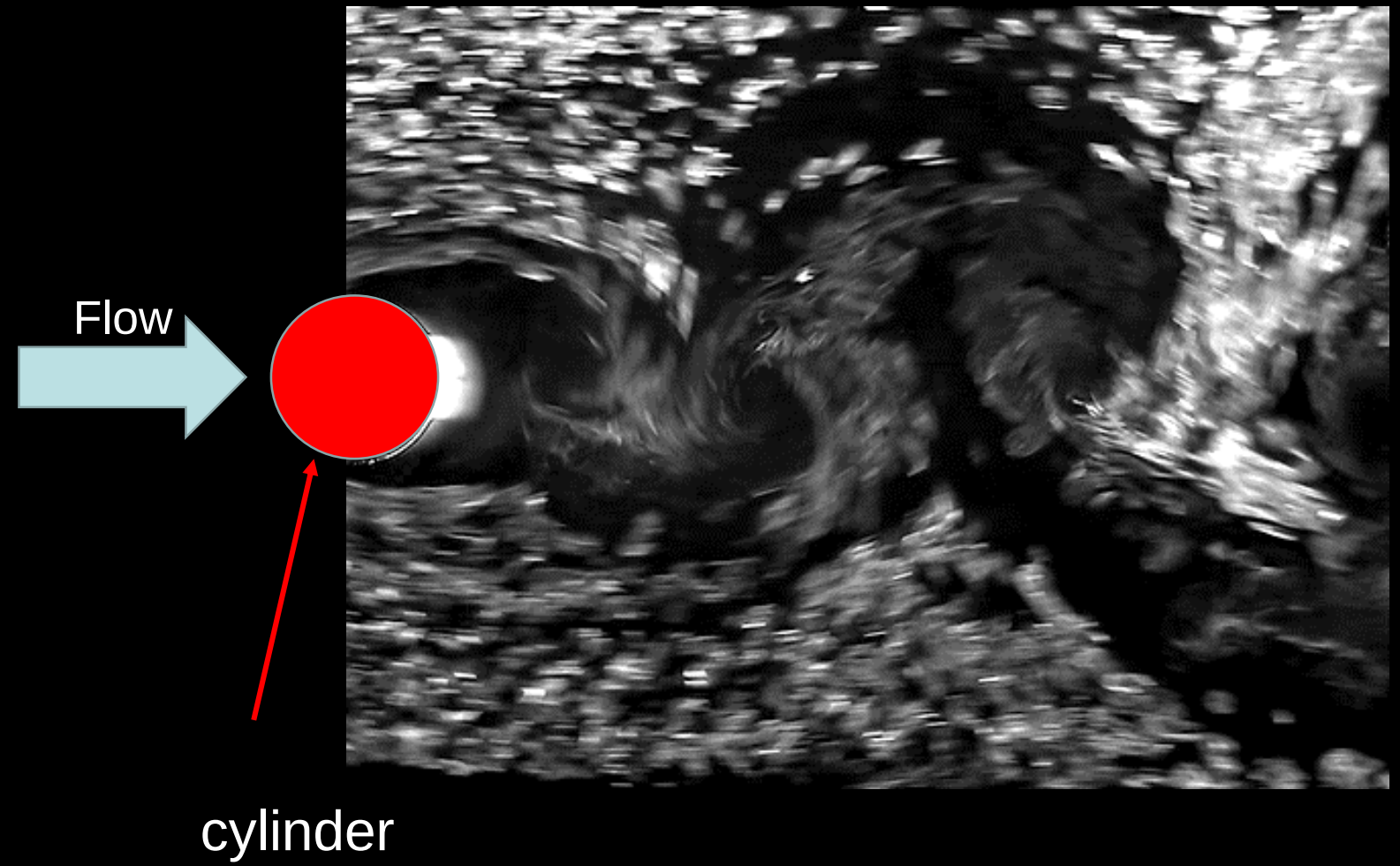
Karman vortex street

Karman vortex street

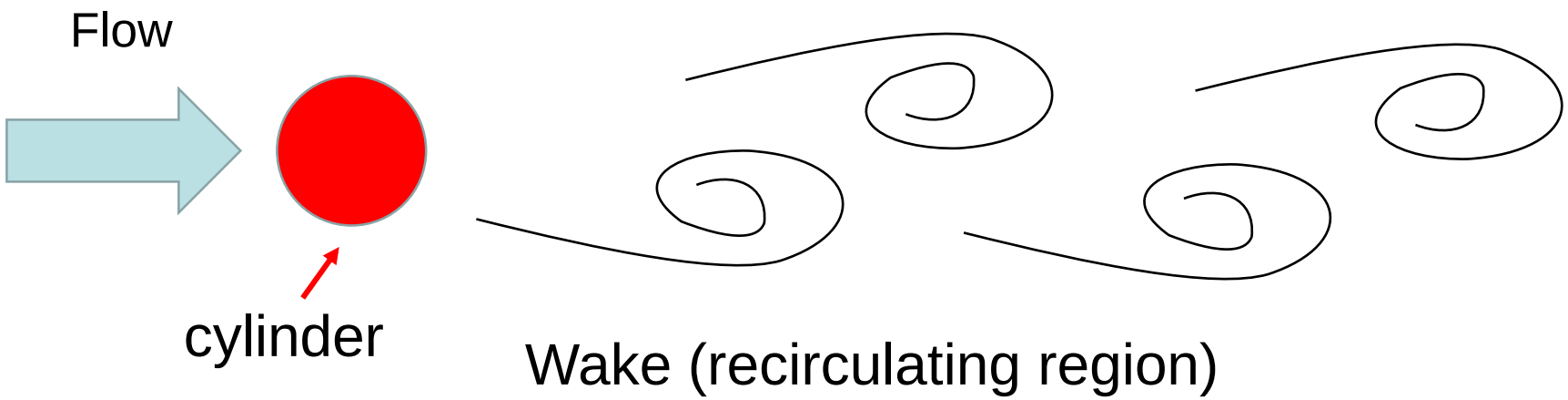
Flow Visualization by smoke wire method

(play speed 1/67)

without control



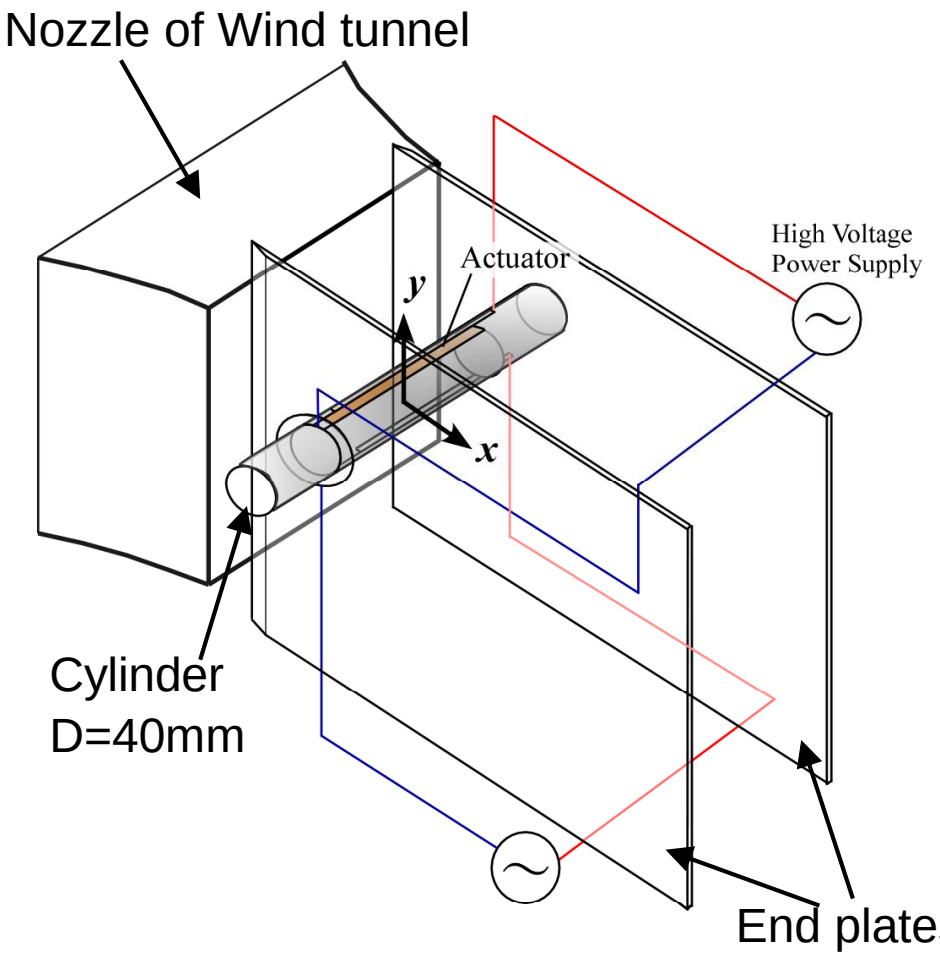
1St control example
Wake of a cylinder

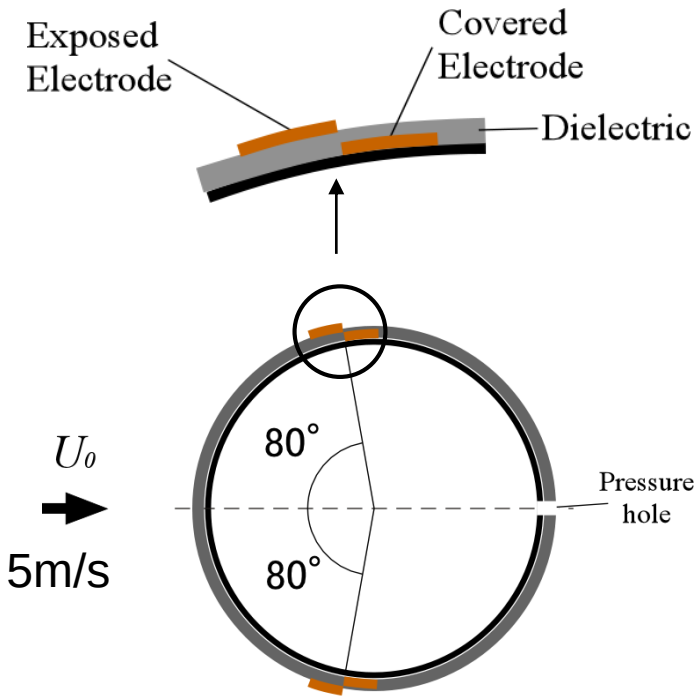


In Karman vortex street,
the arrangement of vortices changes with time.
⇒ Cause vibration and noise

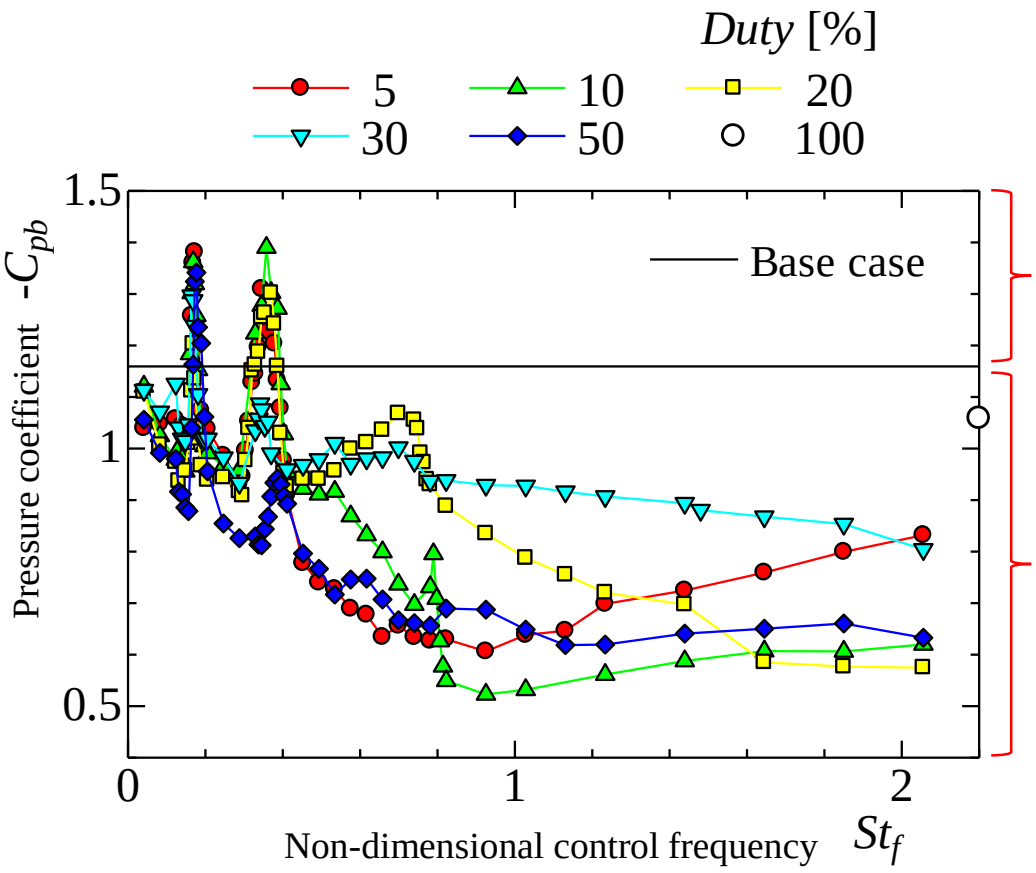
Control the Karman vortex street

Experimental setup





Result
Backpressure of cylinder

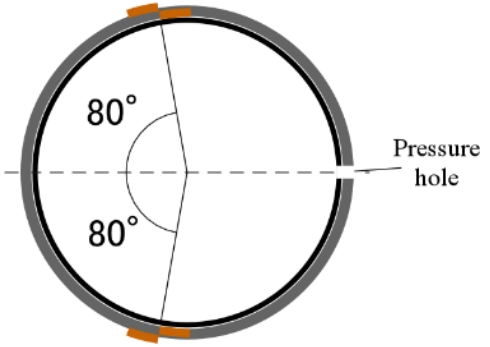


Drag

Increase

Decrease

U_0



Measurement position

This pressure give an indication of drag.

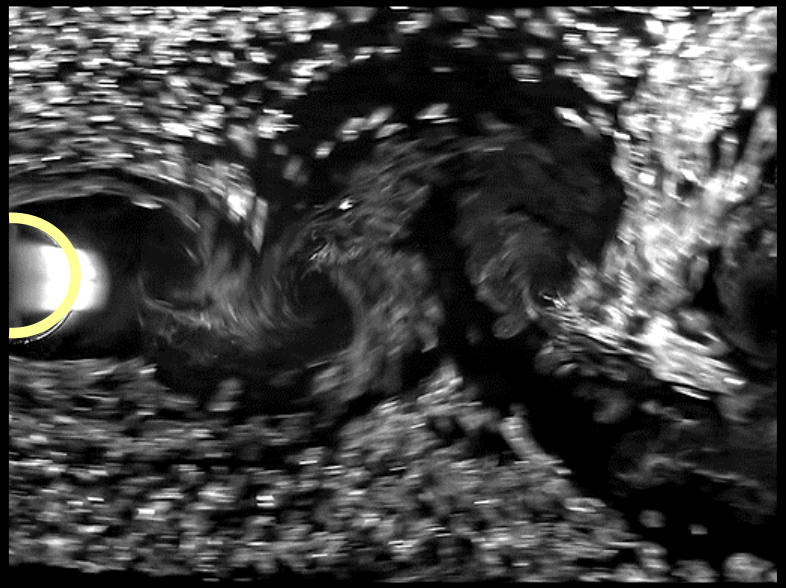
We can control the drag of cylinder.

$$C_{p_b} = \frac{2p_b}{\rho U_0^2} \qquad St_f = \frac{f_M D}{U_0}$$

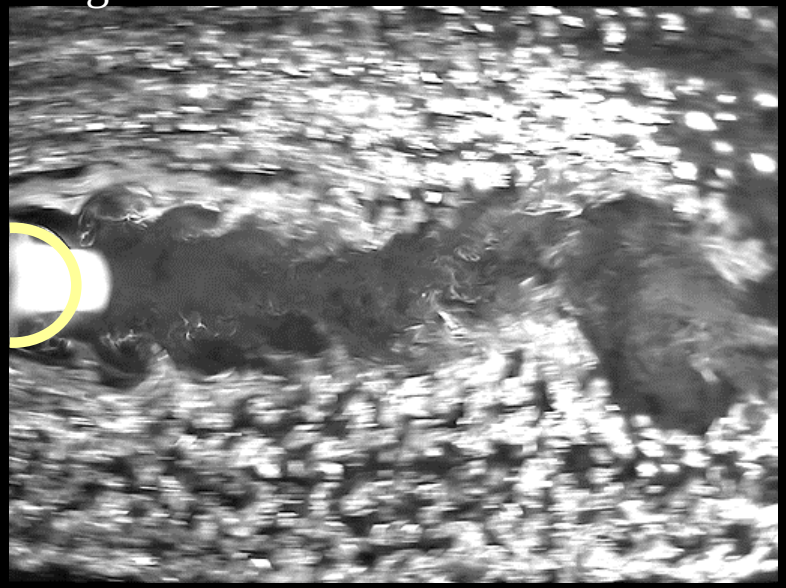
Flow Visualization

（play speed1/67）

Base case

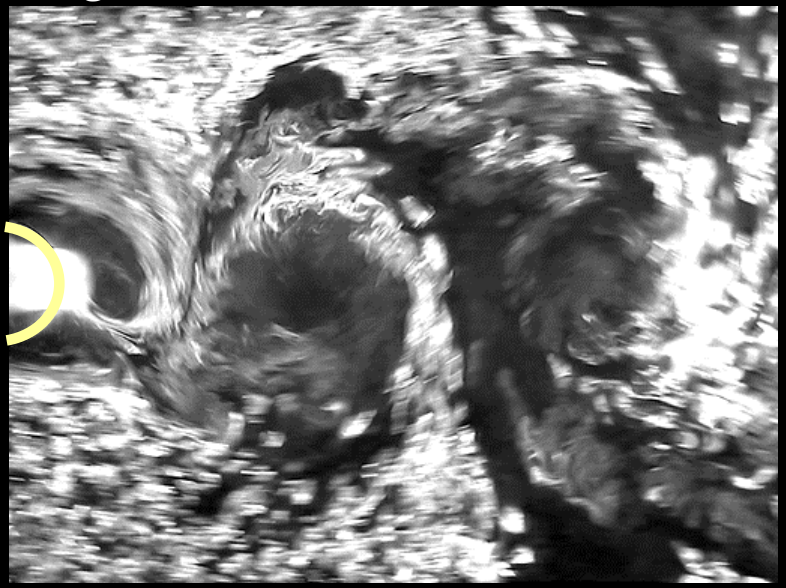


Drag decrease case



Karman vortex street disappeares.

Drag increase case



Karman vortex street is remaining.

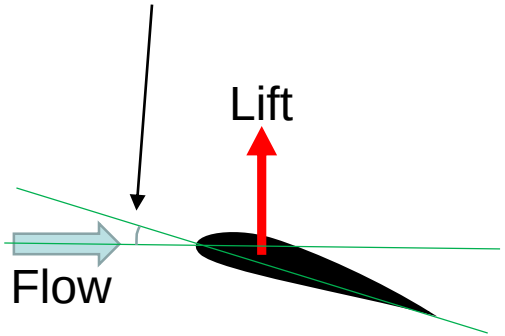
Karman vortex street can be controlled by the DBD plasma actuator.

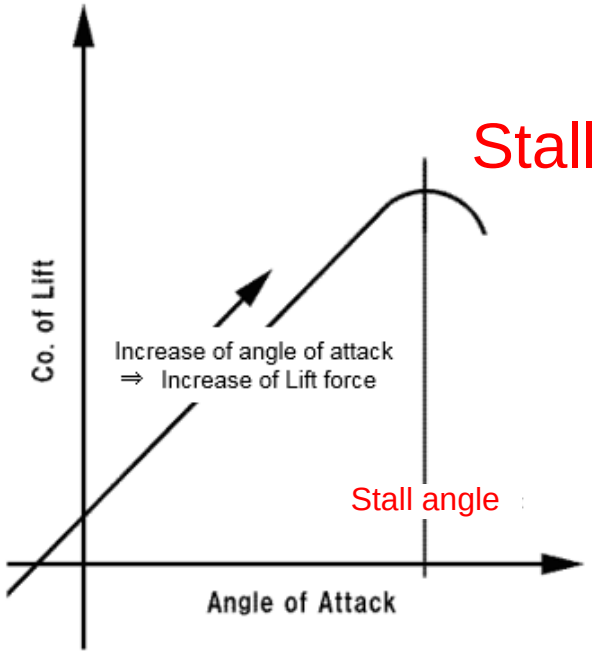
2nd control example
Flow separation over a wing

Wing

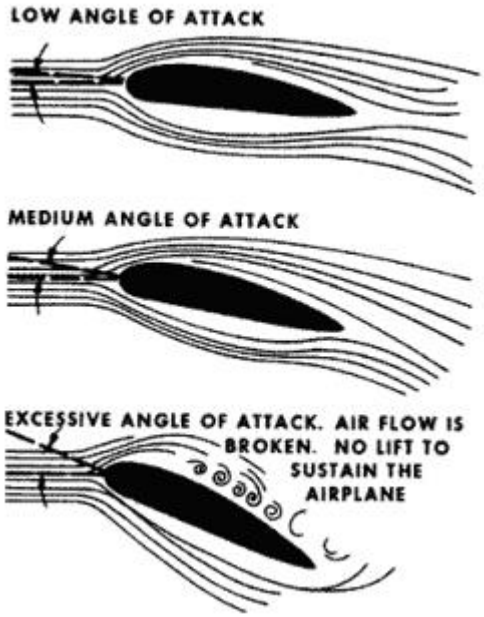
Important parameter

Angle of attack





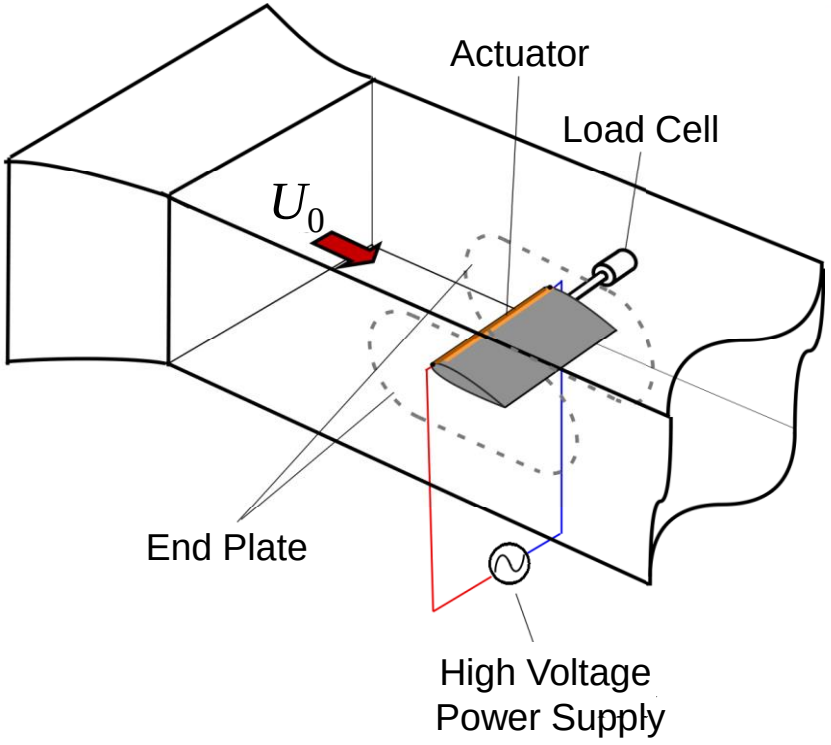
Change of lift by the angle of attack

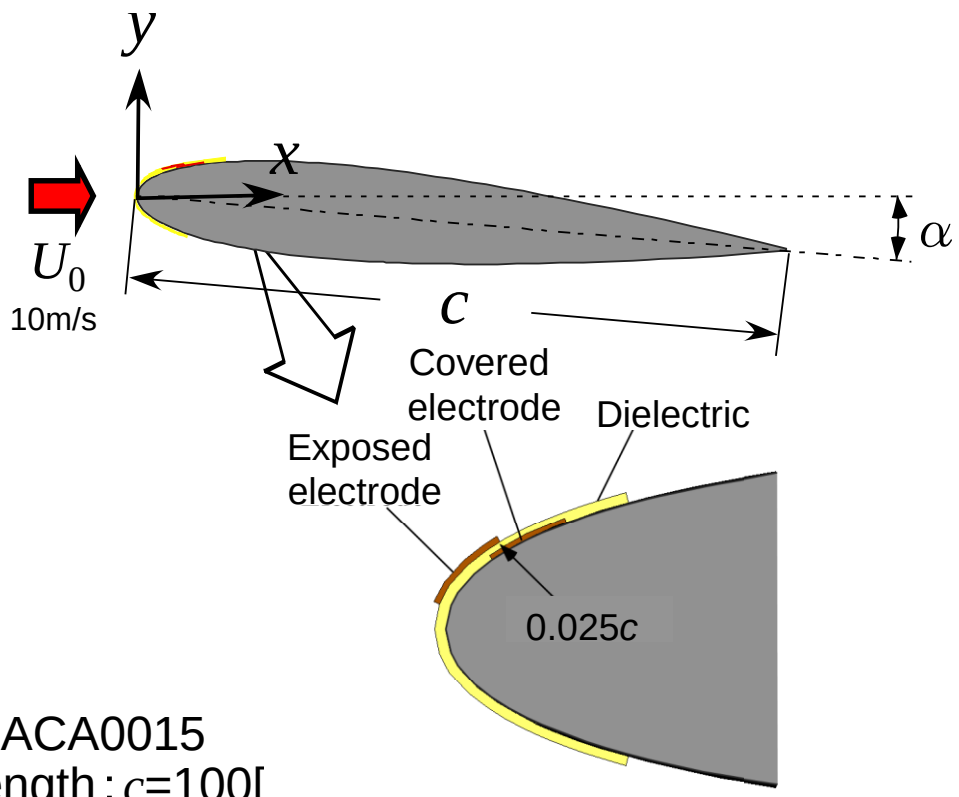


The aim of this control is the prevention of separation.

⇒ Increase of lift force at high angle of attack.

Experimental setup





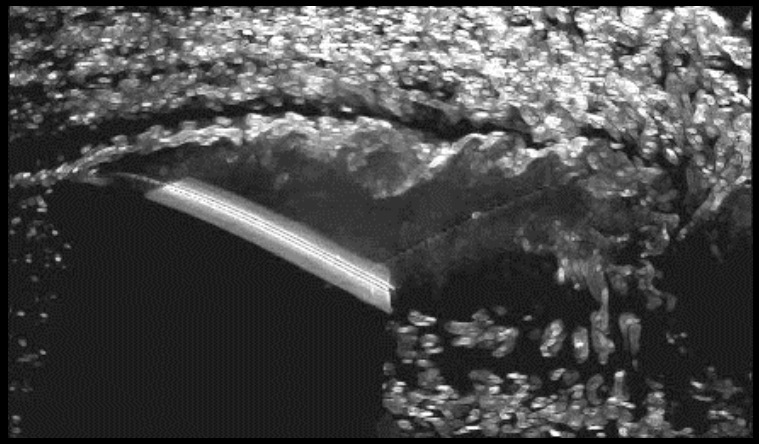
Airfoil : NACA0015
Chord length : c=100[
Span length : s=150[mm]
Aspect ratio : AR=1.5

岐阜大学
GIFU UNIVERSITY

Flow visualization

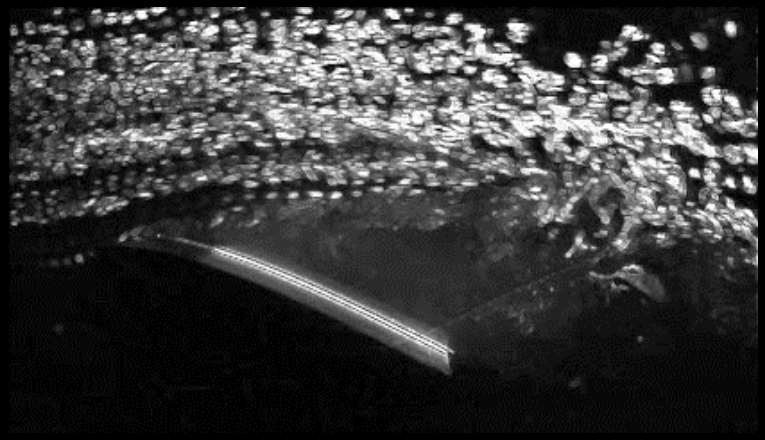
(high angle of attack)

No actuation

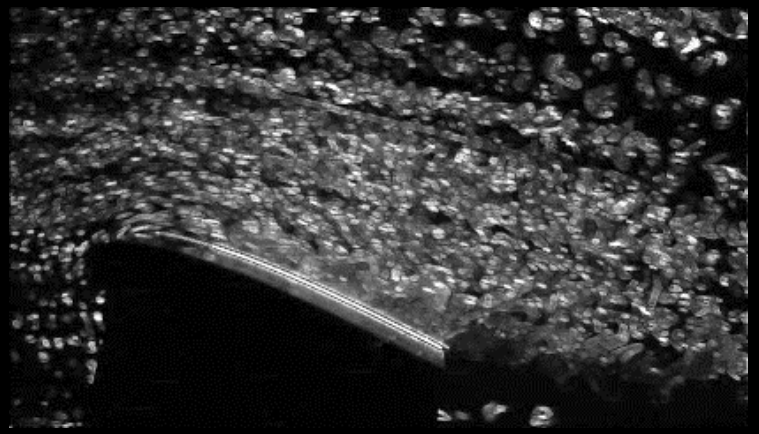


Flow separated near the leading edge

Continuous drive



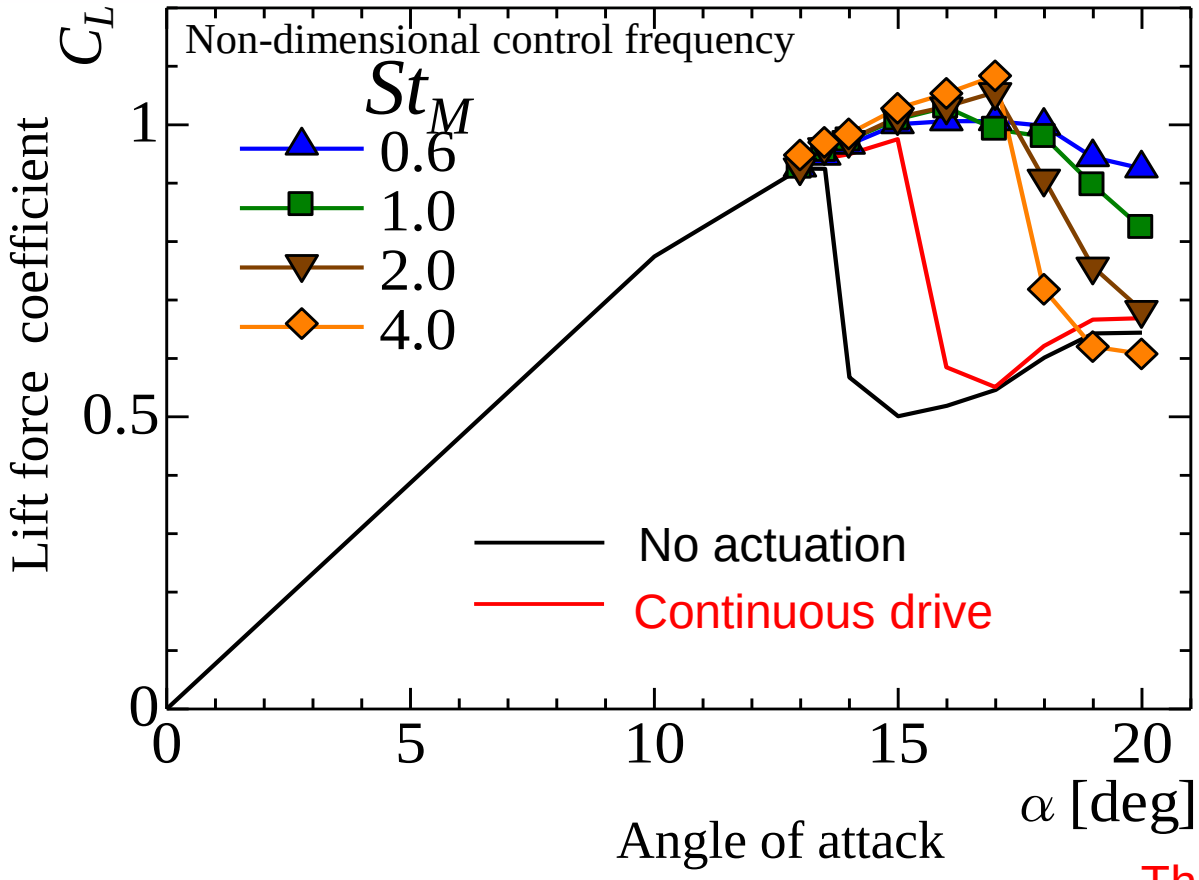
Pulse modulation drive



Leading edge separation is disappeared.

Result

Lift coefficient in varying angle of attack



- No control
  α_{stall} = 13 deg
- Continuous drive
  α_{stall} = 15 deg
- Pulse modulation drive
  α_{stall} = 17 deg

The control can delay the stall, and increase maximum lift.

岐阜大学 GIFU UNIVERSITY

3rd control example
Rectangular jet

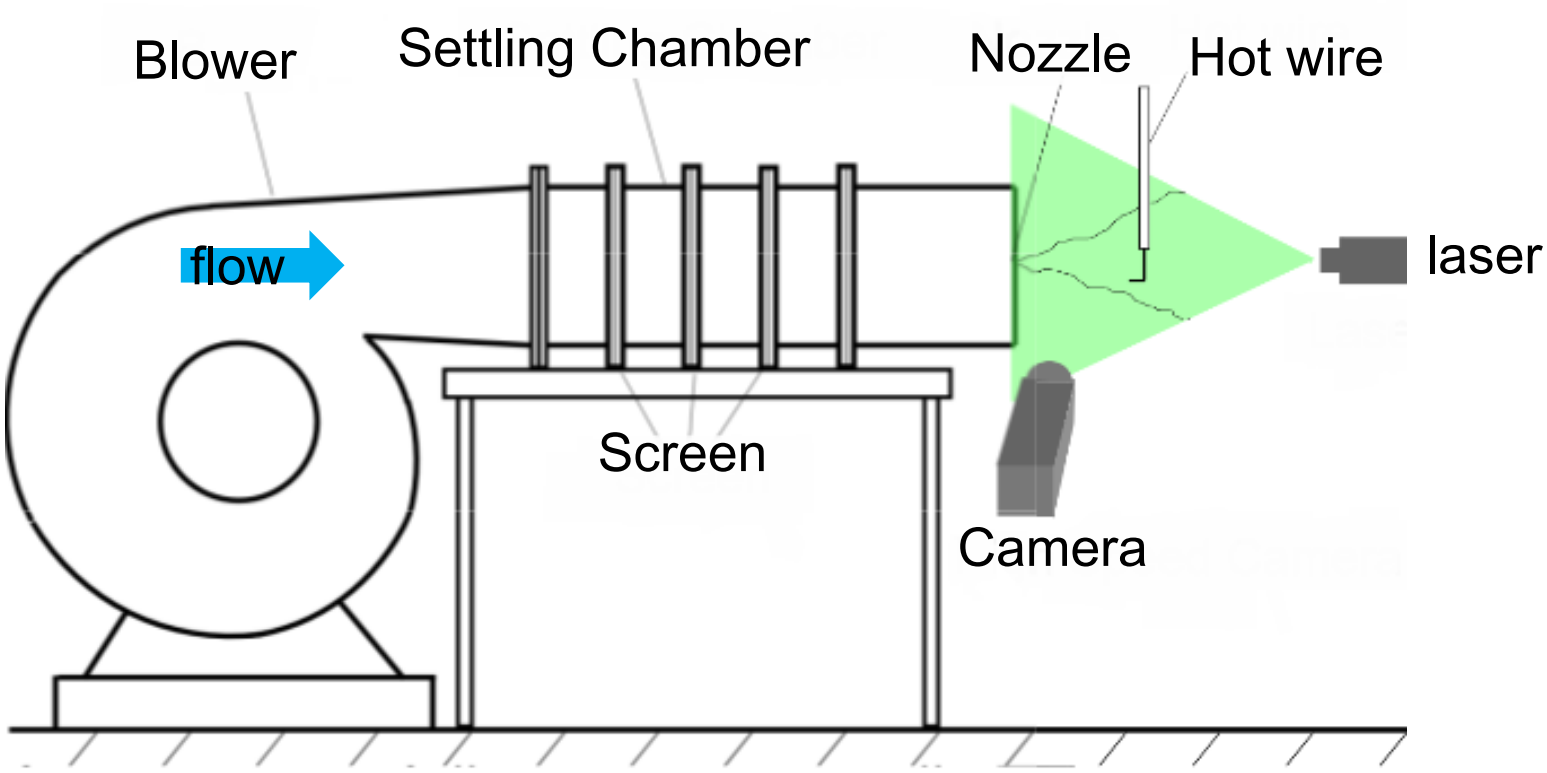
Turbulent jets are used in a variety of industrial applications such as mixing and cooling/heating.

Control of the width of the jet

↓

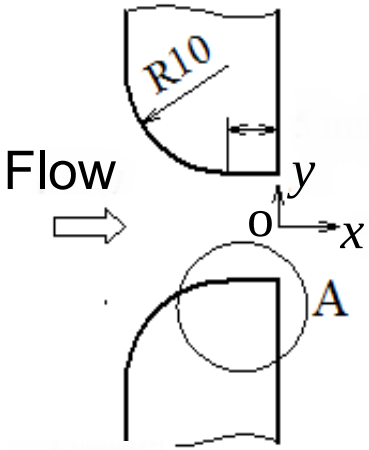
Control of the mixing and cooling/heating

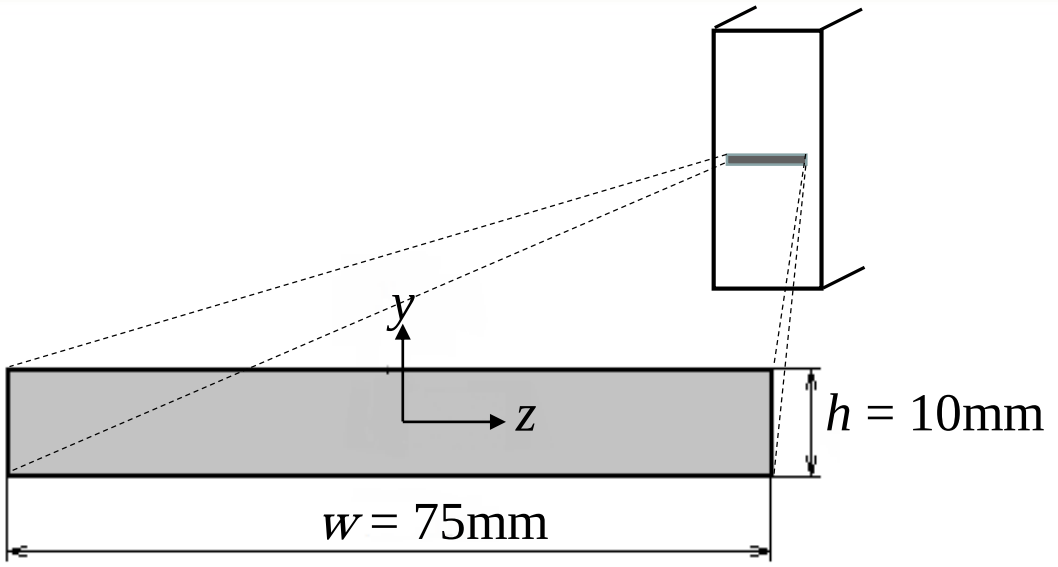
Experimental Apparatus



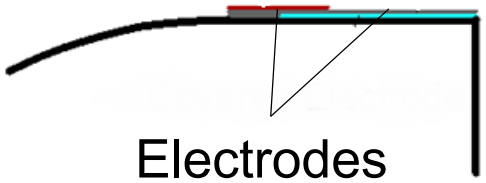
Experimental setup

Detail of the nozzle





Detail A



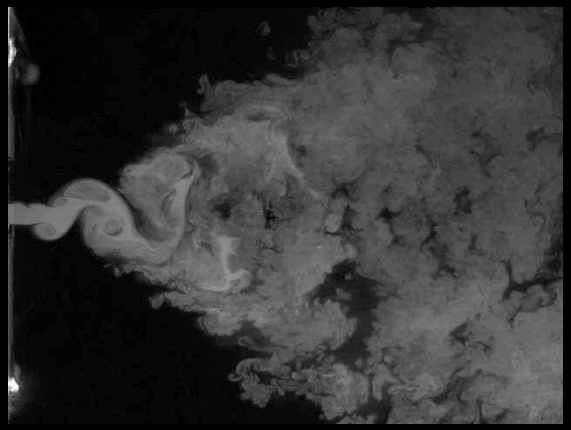
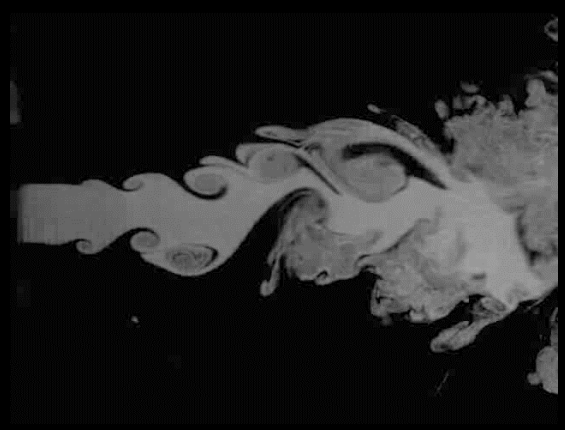
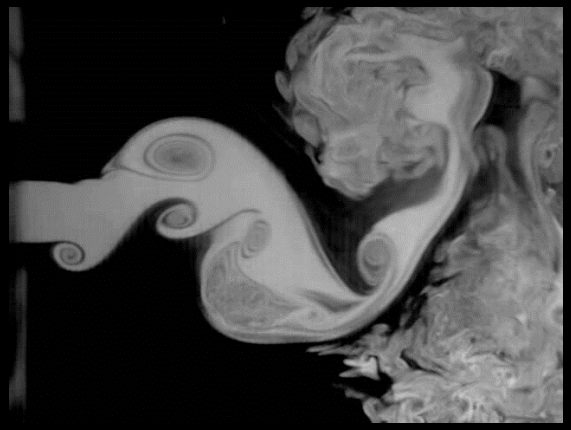
Nozzle exit velocity

U_0 = 5m/s

$Re = U_0 h/\nu$=3,300

Result of control

(play speed 1/267)

	Base case	Spread case (f_M=55Hz, *Duty*=10%, $\theta=\pi$)	Reduced case (f_M=700Hz, *Duty*=30%, $\theta=\pi$)
Wide view			
Close-up view			
		Large vortex is generated in the up and down, alternately.	Vortex does not become large near the nozzle It broke down in a little while.

We can control jet width by DBD plasma actuator.

Conclusion

Pulse modulated drive of the DBD plasma actuator is effective for the separation flow control.