【海報論文】
☐一般組 ☑研究生組
☐大學組

2023 11th 台灣TAIWAN 工業與應用數學會年會
TWSIAM Annual Meeting

Large eddy simulation of NACA 0012 flapping wing using a nanosecond pulsed-DBD plasma actuator

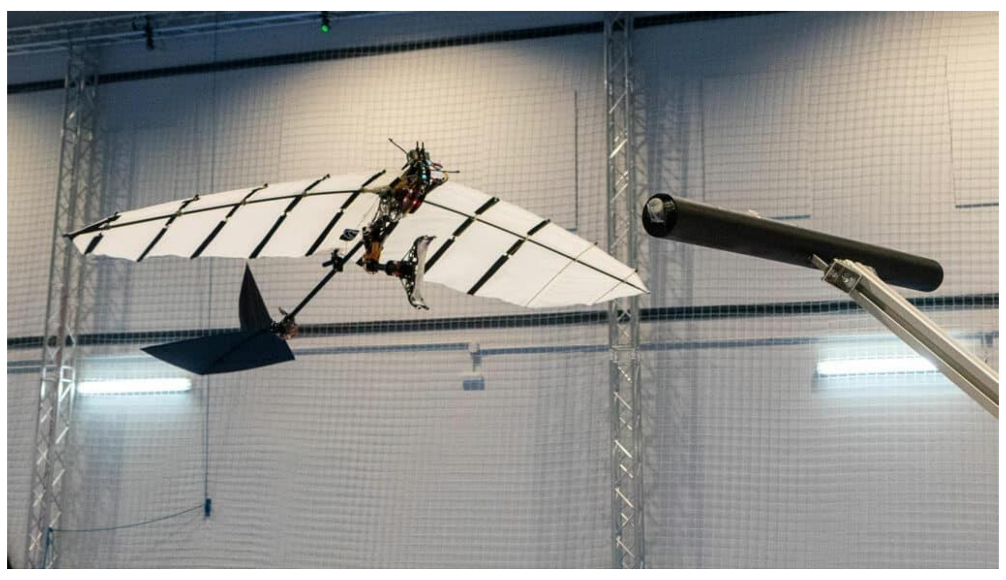
You-Chen Wang (王佑宸), ***Department of Vehicle Engineering, National Taipei University of Technology, Taiwan***
(t110448039@ntut.edu.tw)
Advisor: Prof. Chin-Cheng Wang (王謹誠)

Abstract

This study investigated the control of dynamic stall on a three-dimensional NACA0012 flapping wing at Reynolds number of 1.35×10^5 using linear alternating current (AC) and nanosecond (NS) dielectric barrier discharge (DBD) plasma actuators. We used the Large Eddy Simulation (LES) Smagorinsky turbulence model to simulate three cases: NACA 0012 flapping wing without a plasma actuator, with a linear AC-DBD plasma actuator, and with a NS-DBD plasma actuator. Compare the effects of the three cases on the flow field.

Motivation

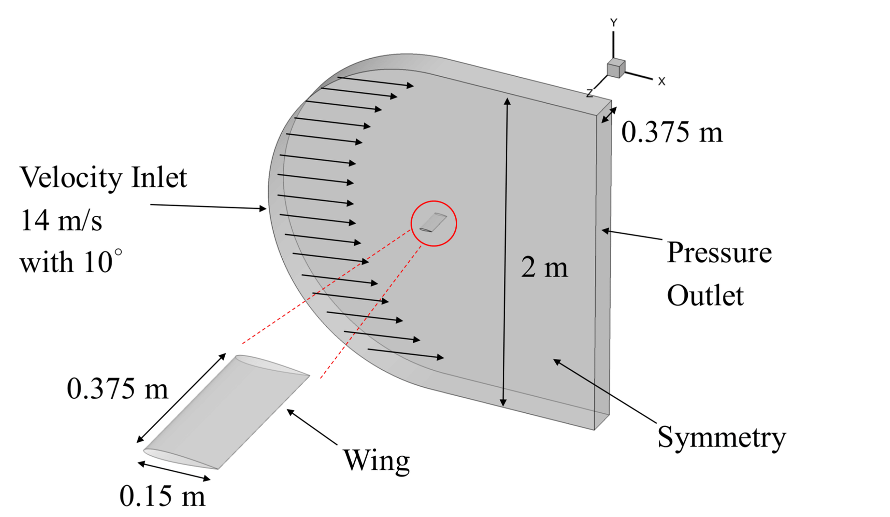
The flapping wing was designed and developed by simulating the wing shape and flight characteristics of birds and insects, exhibiting dynamic stall under periodic changes in the angle of attack. There are many ways to control dynamic stall, and in recent years, dielectric barrier discharge (DBD) plasma actuators have been recognized as a very promising flow control device. Among them, NS-DBD plasma actuators generate high-speed pulsed discharges that can produce greater energy in a short time, allowing for better control of dynamic stall.



https://www.inceptivemind.com/epfl-flapping-wing-robot-land-autonomously-like-bird/28841/

Problem descriptions

A. The computational domain



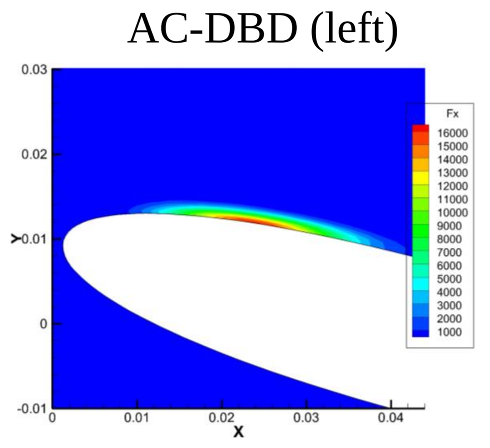
B. Flapping wing motion

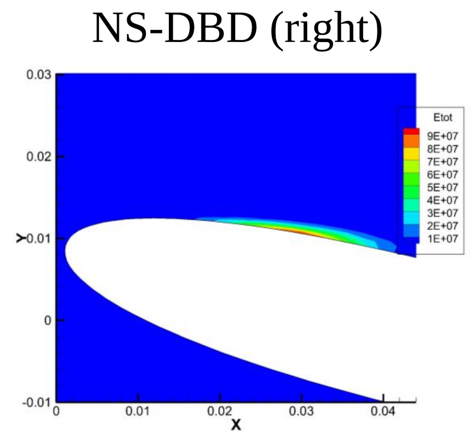
$$\alpha(t) = \alpha_{mean} + \Delta\alpha \sin(\omega t),\ \alpha_{mean} = 10^\circ,\ \Delta\alpha = 15^\circ$$

$$\omega = 2\pi f,\ f = 2.97\ \text{Hz},\ -5^\circ \le \alpha \le 25^\circ$$

C. Plasma induced force and energy contours

AC-DBD (left) NS-DBD (right)





Governing equations and plasma sources

Continuity equation in LES

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0$$

Filtered Navier-Stokes equations

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + 2\nu\frac{\partial S_{ij}}{\partial x_j} - \frac{\partial \tau_{ij}}{\partial x_j} + F$$

Energy equations

$$\frac{\partial}{\partial t}(\rho E) + \nabla\cdot[\vec{v}(\rho E + p)] = \nabla\cdot\left(K_{eff}\nabla T - \Sigma h_j \vec{J_j} + \tau\cdot\vec{v}\right) + E_{tot}$$

LES filter

$$\overline{u}(x) = \int_\Delta G(x - x')u'(x)dx'$$

Smagorinsky model

$$\tau_{ij}^a = \tau - \frac{1}{3}\delta_{ij}\tau_{kk} = -2\nu_t \bar{S}_{ij}$$

Plasma induced forces

$$F = (f_x)\hat{i} + (f_y)\hat{j}$$

$$f_x = F_{x0}\phi_0^4 \exp\left[-\left(\frac{(-x-x_0)-(y-y_0)}{y}\right)^2 - \beta_x(y-y_0)^2\right]$$

$$f_y = F_{y0}\phi_0^4 \exp\left[-\left(\frac{(-x-x_0)}{y}\right)^2 - \beta_x(y-y_0)^2\right]$$

$$y = \frac{0.12}{0.2}\times 0.15\times\left[0.2969\sqrt{\frac{x}{0.15}} - 0.1260\left(\frac{x}{0.15}\right) - 0.3315\left(\frac{x}{0.15}\right)^2 + 0.2843\left(\frac{x}{0.15}\right)^3 - 0.1015\left(\frac{x}{0.15}\right)^4\right]$$

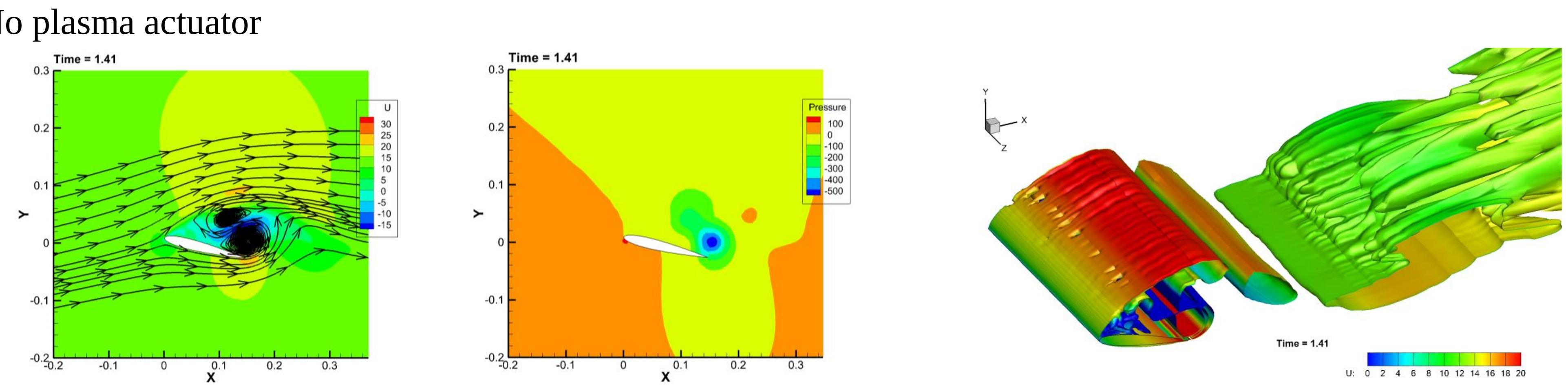
Nanosecond-pulsed energy

$$E_{tot} = E_0 * \sin^2(2\pi f t)$$

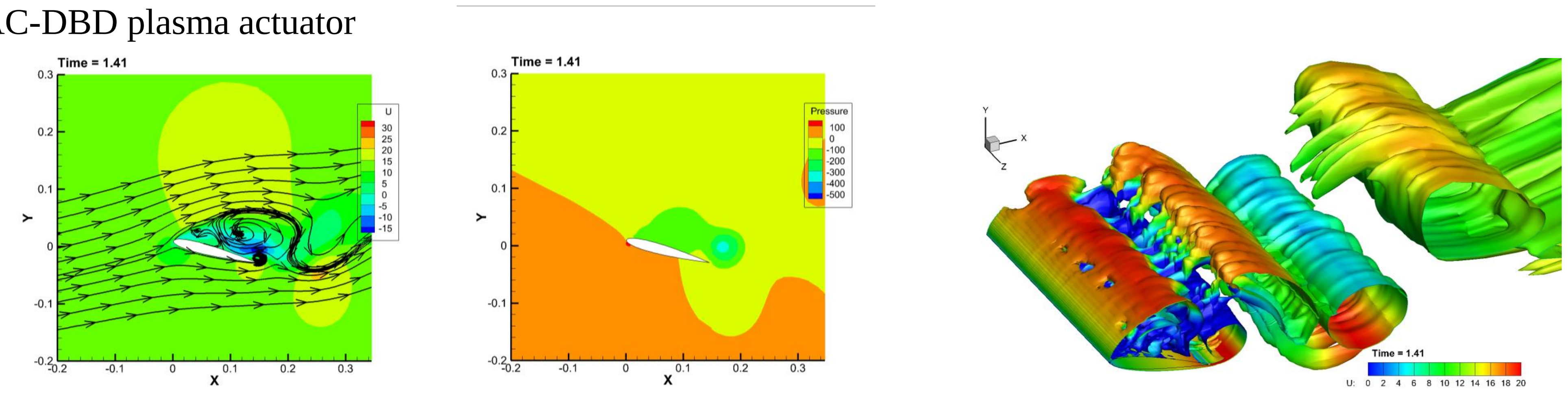
Comparison of different plasma actuation

U-velocity contour, pressure contour, and Q-criterion of each case at 1.41s (24° of 5th cycle)

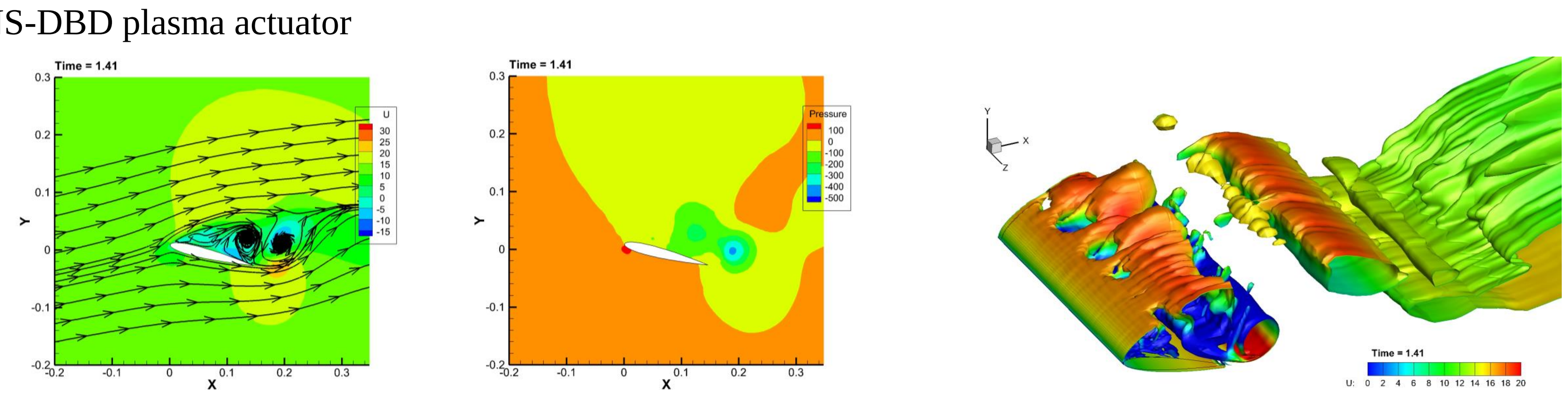
A. No plasma actuator



B. AC-DBD plasma actuator

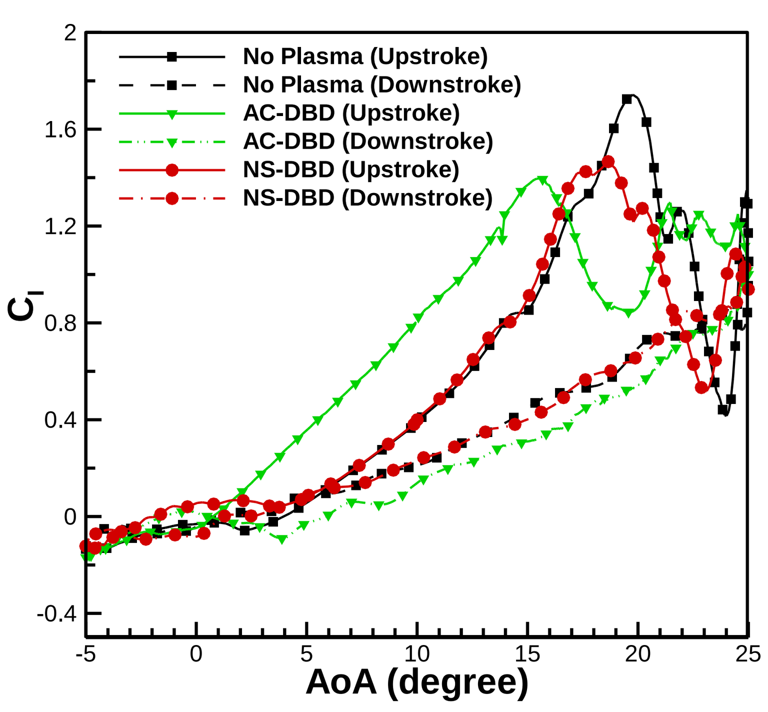


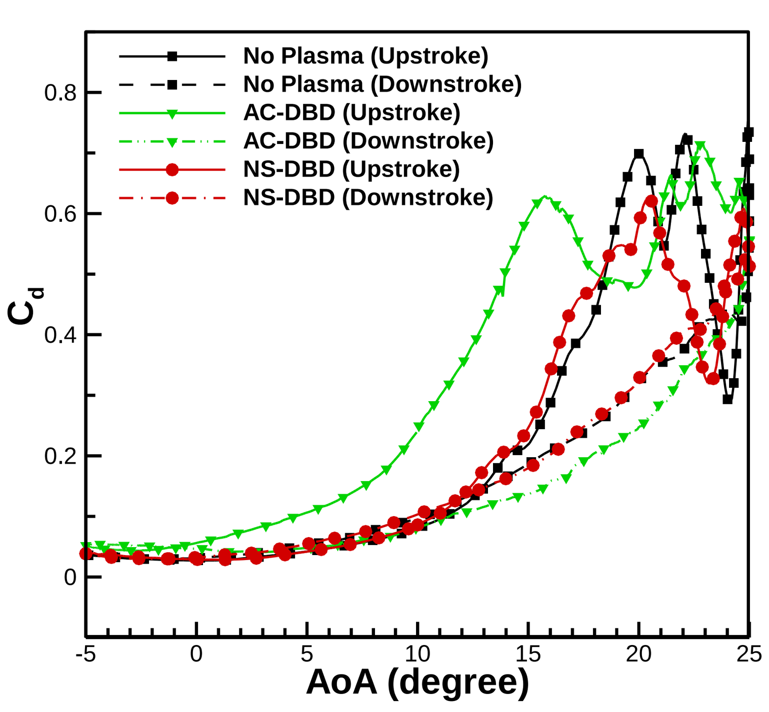
C. NS-DBD plasma actuator



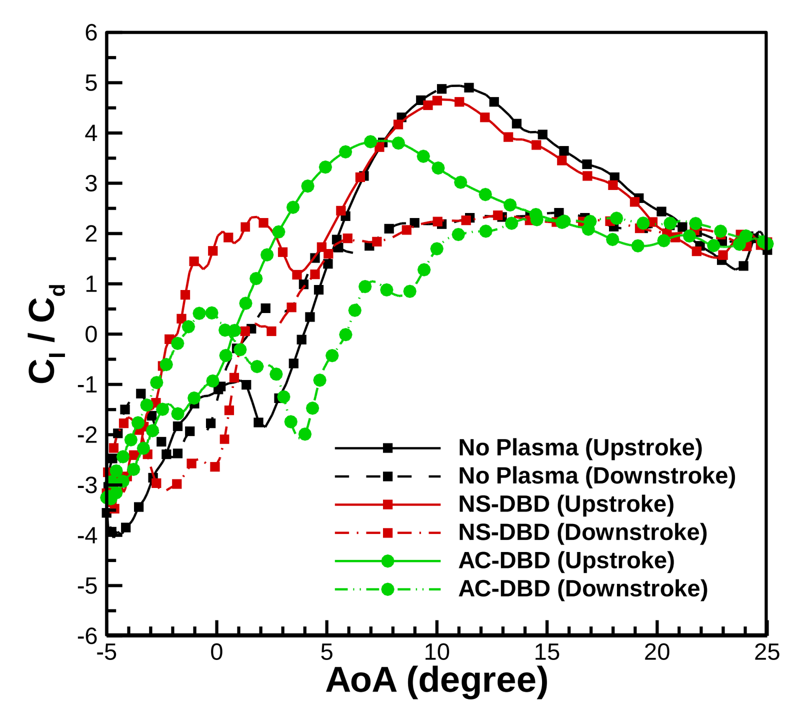
Aerodynamic characteristics

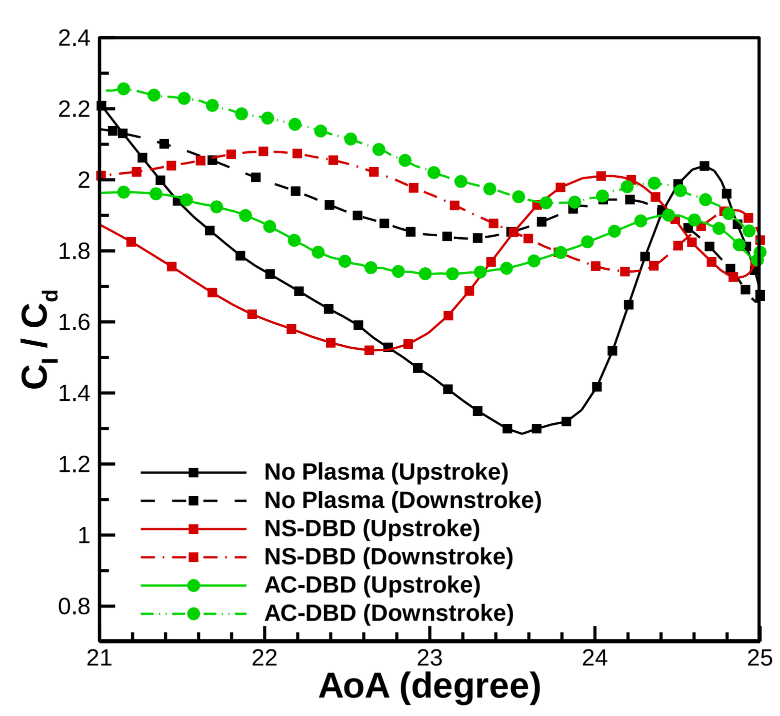
● Lift and drag coefficients vs. angle of attack (AoA)





● Lift-to-drag ratio vs. angle of attack (AoA) and AoA details from 21° to 25°





Conclusions

1.The airflow over the wing is attracted by the plasma actuation.
2.The AC-DBD plasma actuator can further increase the lift coefficient.
3.The NS-DBD plasma actuator has a better lift-to-drag ratio.
4.The vortex induced by the NS-DBD plasma actuator can move rapidly from the upper surface of the wing.