

Feedback Control of Flow Separation Using DBD Plasma Actuator

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● Responsible Representative

Kengo Asada, Assistant Professor, Department of Information and Computer Technology, Faculty of Engineering, Tokyo University of Science

● Contact Information

Kengo Asada(asada@rs.tus.ac.jp)

● Members

Kengo Asada, Takuto Ogawa

● Abstract

The project develops flow control technic by using dielectric barrier discharge (DBD) plasma actuator to establish high efficient and robust vehicle systems such as rockets, aircrafts, and motor vehicles. We propose and demonstrate feedback control methods to adapt unsteady flows over the vehicles through a series of high-fidelity unsteady simulations.

● Reasons and benefits of using JAXA Supercomputer System

To perform large-scale three-dimensional unsteady flow simulations using the compressible fluid solver LANS3D, which has a wealth of computational achievements with a JAXA supercomputer system.

● Achievements of the Year

This project proposes a feedback control method (Fig. 1) for flow separation control around a NACA0015 airfoil (Reynolds number: 63,000) using a DBD plasma actuator (PA) and verifies its performance. The proposed feedback model regards the decrease in pressure value measured by a pressure sensor placed on the airfoil surface as a vortex passage and switches the driving state of the actuator placed near the leading edge of the airfoil according to the vortex passage.

In the fourth fiscal year of Reiwa, continuing from last year, we conducted a parametric study for the drive frequency of standard burst drive to improve the control authority at low angles of attack. Unlike feedback control, the standard burst drive is a drive method that switches a PA driving state ON and OFF according to a predetermined nondimensional burst frequency F^+ . The PA was positioned 5% of the chord length from the leading edge, and the angle of attack was set to 2 degrees. In this fiscal year, in addition to the nondimensional frequencies 1 and 6, which have been considered effective for the angle of attack after stall, higher frequencies 12 and 30 were investigated.

Figure 2 shows the lift-to-drag ratio and aerodynamic coefficients at each burst frequency. BR is the burst ratio, which represents the ratio of the ON and OFF duration of PA. BR is chosen so that the input energy is the same as much as possible at each burst frequency. "Continuous" denotes the continuous drive. The lift-to-drag ratio is the highest at $F^+=12$, and the lift is the highest at $F^+=30$. The drag force is the smallest at $F^+=6$. Figure 3 shows the distributions of the pressure coefficient (C_p) and skin friction coefficient (C_f). In the case where PA is not used (PA-OFF), a plateau C_p distribution is seen in the area from 60% to 80% of the cord length, and C_f is negative in this area, indicating flow separation. In the $F^+=30$ and Continuous cases, the plateau C_p area shifted toward the trailing edge. In the $F^+=1$ and 6 cases, the plateau C_p area is not seen. The case of $F^+=12$ has a C_p distribution close to PA-OFF, but the pressure is slightly higher in the area from 70% to 80% of the chord length. Therefore, the drag is lower than PA-OFF, resulting in the highest L/D. Figure 4 shows the instantaneous flow fields for each case. In the PA-OFF case, the laminar flow separates around the middle of the airfoil and reattaches after the turbulent transition. Although the transition reattachment position of the $F^+=12$ case, whose C_p distribution was similar to that of the PA-OFF case, was almost the same as that of the PA-OFF case, the two-dimensional vortices generated by PA are seen on the airfoil surface. Due to the advection of these vortices, the time-averaged pressure in the separation region becomes higher than that of PA-OFF. In addition, in the case of $F^+=6$, the two-dimensional vortices are maintained up to the trailing edge without collapsing, whereas in the high-frequency $F^+=30$ and Continuous cases, the position of the turbulent transition and the reattachment is downstream compared to PA-OFF.

As described above, the flow in the separation region changes depending on the burst frequency, and the aerodynamic coefficient also changes greatly. $F^+=12$ is good from the viewpoint of lift-to-drag ratio improvement, but $F^+=30$ is appropriate from the viewpoint of lift improvement. It is expected that more robust control can be achieved if a control mechanism that can automatically switch the drive frequency reflecting on these findings is incorporated into the feedback control method.

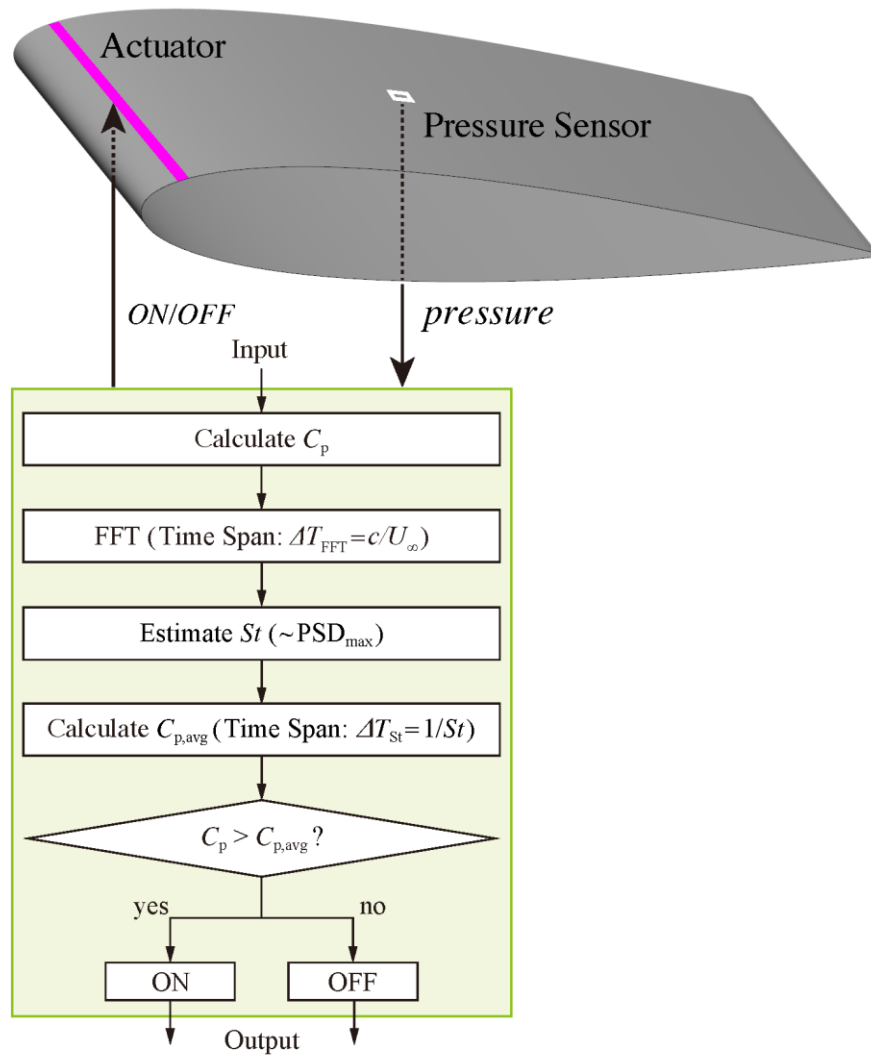


Fig. 1: Proposed feedback control model for airfoil flow separation

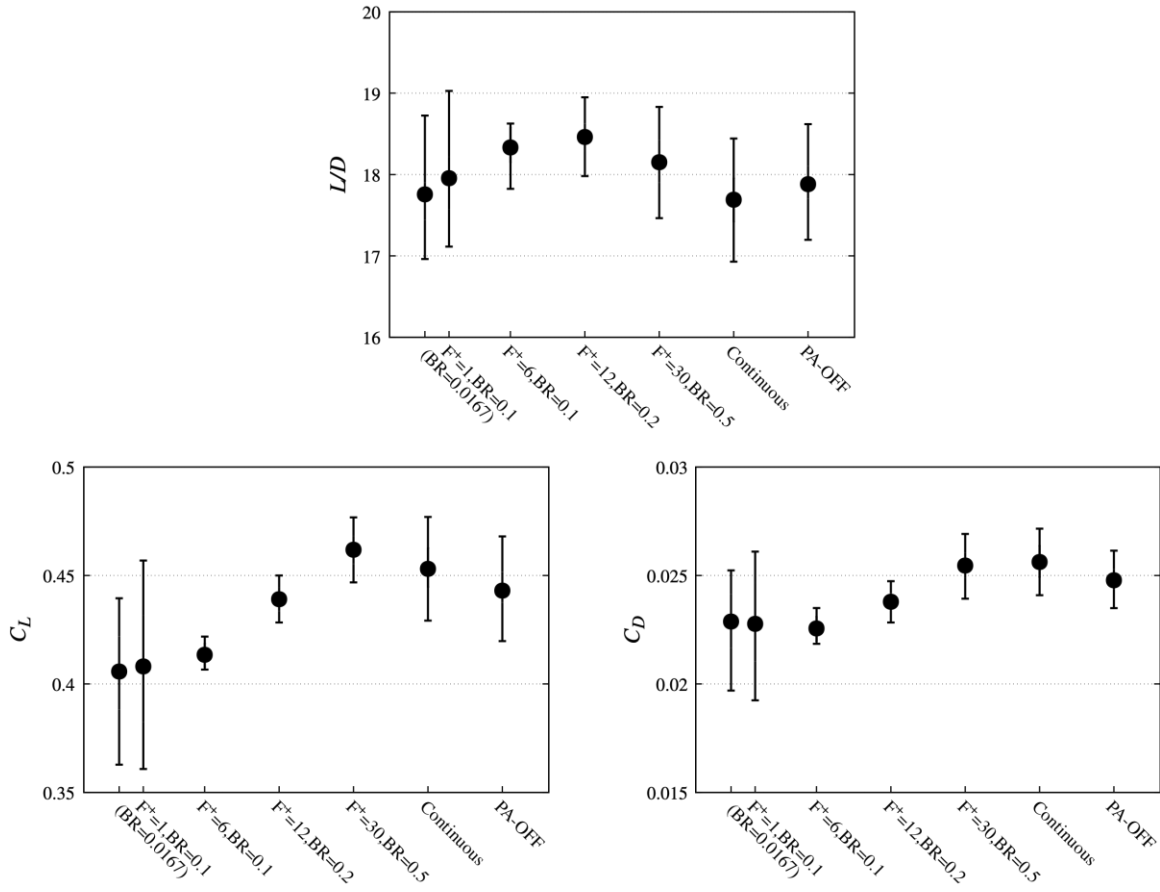


Fig. 2: Lift and drag ratio (L/D), lift coefficient (C_L), and drag coefficient (C_D)

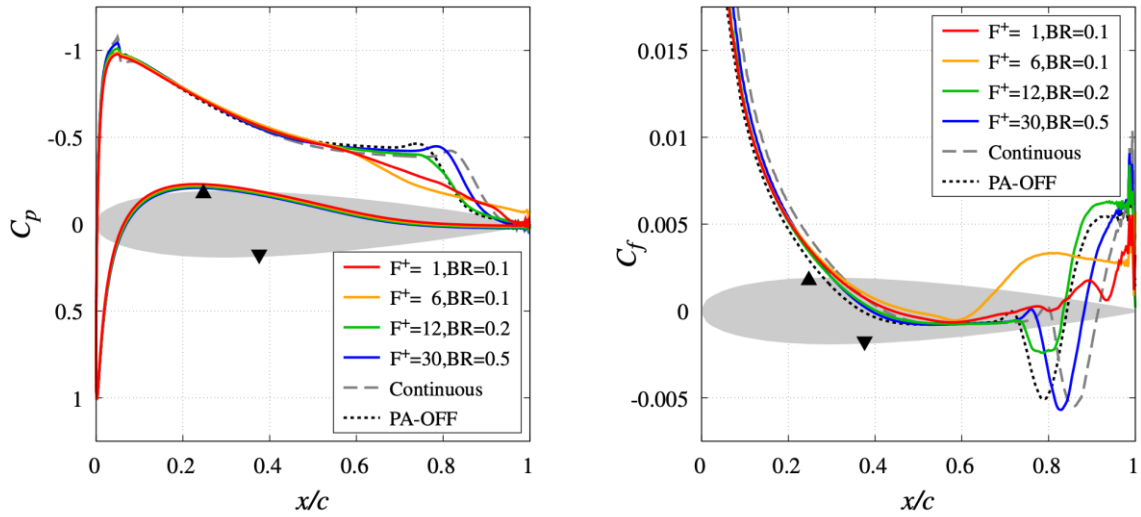


Fig. 3: Distribution of pressure coefficient (C_p) and skin friction coefficient (C_f)

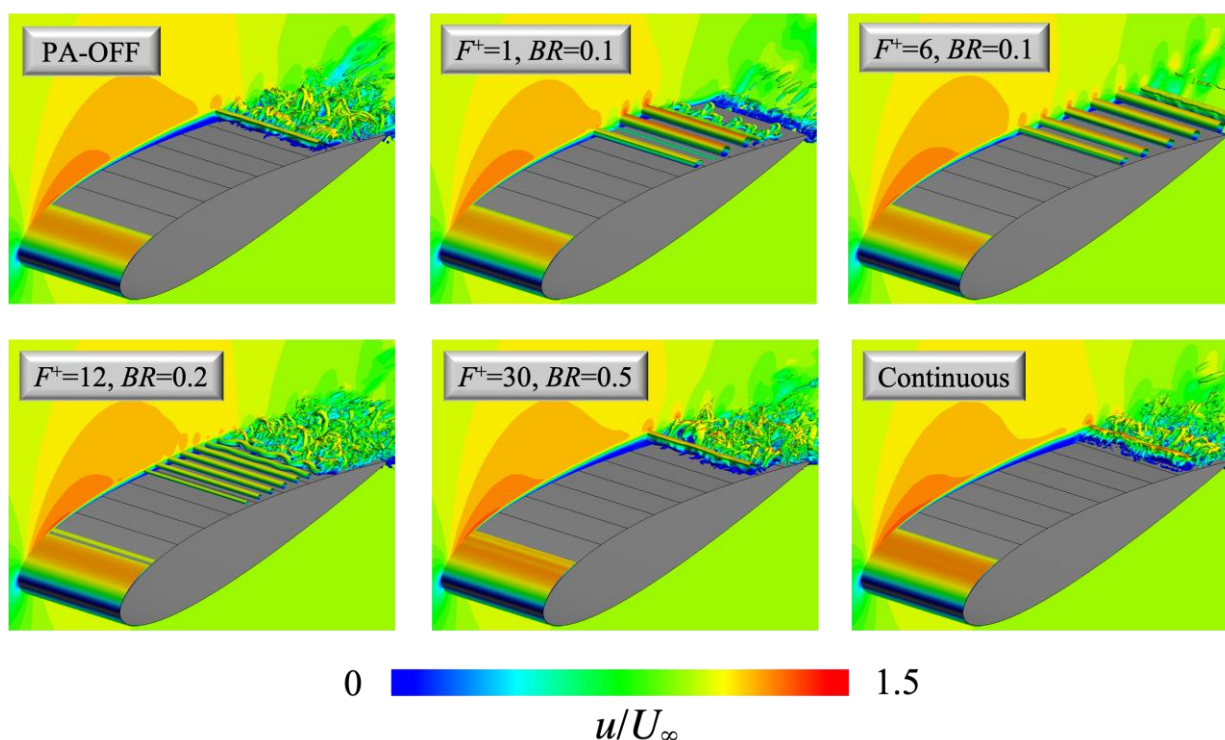


Fig. 4: Instantaneous flow fields

● Publications

- Peer-reviewed papers

Takuto Ogawa, Kengo Asada, Makoto Sato, Tomoaki Tatsukawa, Kozo Fujii, "Computational Study of the Plasma Actuator Flow Control for an Airfoil at Pre-Stall Angles of Attack," Applied Sciences MDPI, Vol. 12, No. 18, Sept. 2022.

● Usage of JSS

● Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	Automatic Parallelization
Number of Processes	79
Elapsed Time per Case	40 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources*1(%): 0.30

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage*2(%)
TOKI-SORA	8,075,364.21	0.35
TOKI-ST	0.00	0.00
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	0.00	0.00
TOKI-TST	0.00	0.00
TOKI-TGP	0.00	0.00
TOKI-TLM	0.00	0.00

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage*2 (%)
/home	60.00	0.05
/data and /data2	16,758.09	0.13
/ssd	200.00	0.03

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage*2 (%)
J-SPACE	11.12	0.05

*1: Fraction of Usage in Total Resources: Weighted average of three resource types (Computing, File System, and Archiver).

*2: Fraction of Usage : Percentage of usage relative to each resource used in one year.

- **ISV Software Licenses Used**

ISV Software Licenses Resources		
	ISV Software Licenses Used (Hours)	Fraction of Usage ^{*2} (%)
ISV Software Licenses (Total)	0.00	0.00

^{*2}: Fraction of Usage : Percentage of usage relative to each resource used in one year.