Performance Report of Tohoku University Students' Projects
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Development of Data-Driven Science-Based Flow Field State Estimation Model and Flow Control Method

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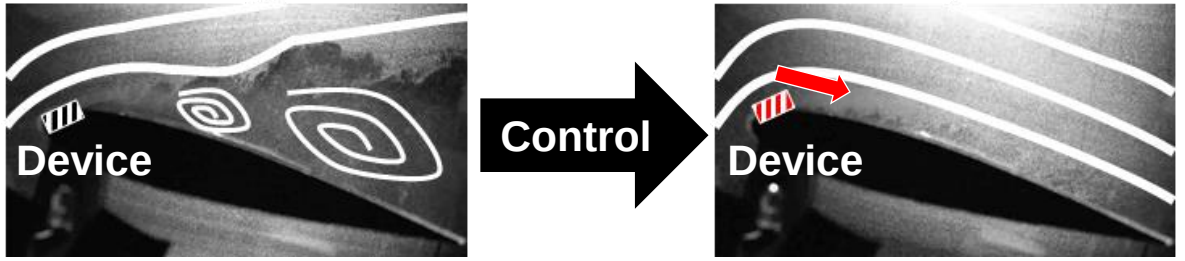
Backgrounds

☐Separated Flow

- ➢Vibration and noise sources



Separated Flow **Attached Flow**

☐Feedback Control

- ➢Active control based on flow field

<Previous Research>

- Feedback control of the flow around an airfoil based on pressure sensors by Plasma Actuator (Shimomuea et al., 2020)

➡ Flow field-based feedback control can be effective

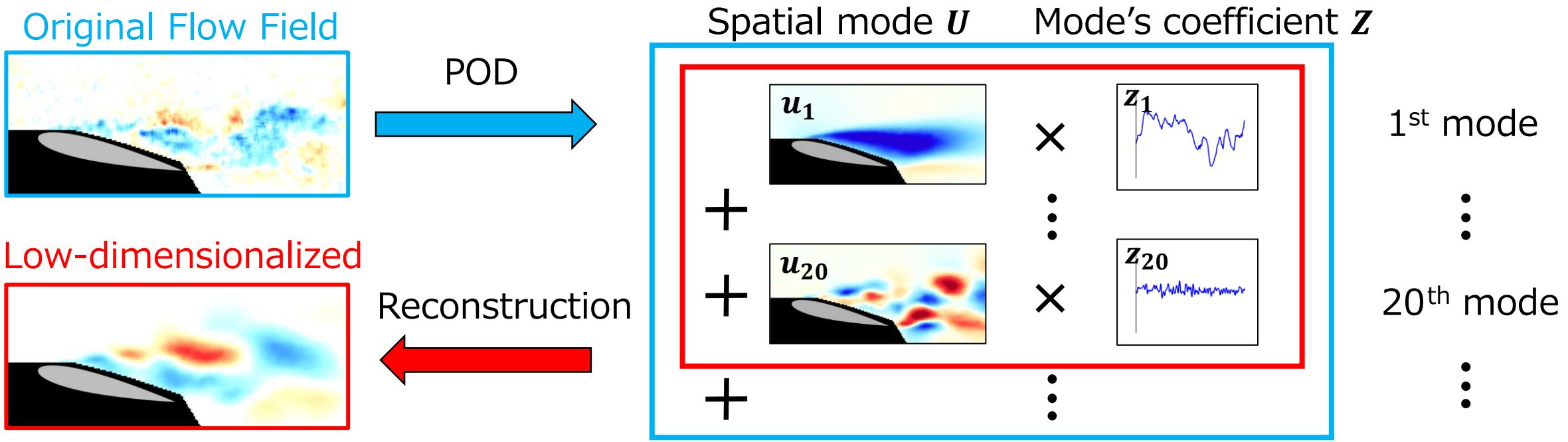
☐Problems

- ➢The flow field data is huge
- ➢It is difficult to measure the flow field in a real aircraft

Previous research

☐ Proper Orthogonal Decomposition; POD

➢Methods that can extract the main flow structures (Taira *et al.*, 2017)



If low-dimensionalized spatial mode U_r is known, the flow field can be estimated by estimating Z

Previous research

☐ Flow field estimation method based on unsteady pressure

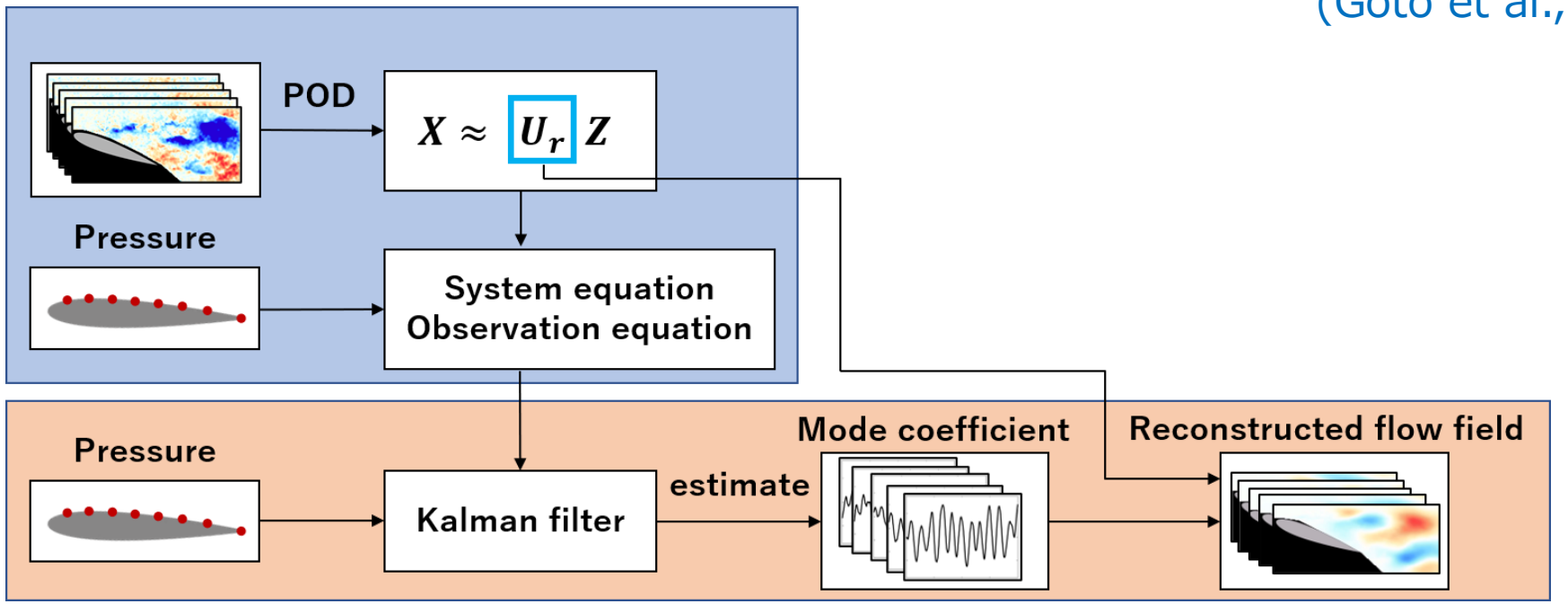
(Goto et al., 2022)

Step1

Create models

Step2

Estimation



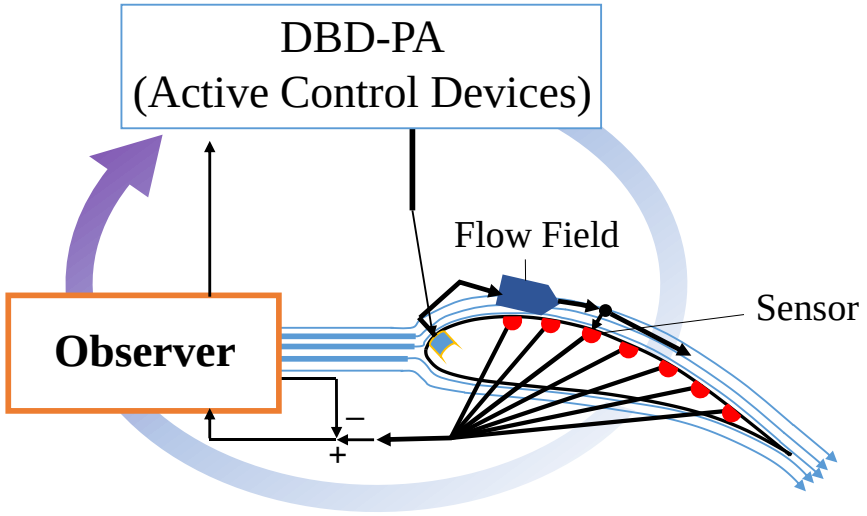
➢Pressure sensors can be attached on actual fluid machinery

Real-time estimation and driving actuator are necessary for feedback control

Objective

Perform feedback control based on estimated flow field
in real time, and investigate the effect of the feedback control

- Develop a system to estimate flow field and feedback control in real-time
- Feedback control based on estimated flow field
  - Investigate the effect



Wind tunnel testing

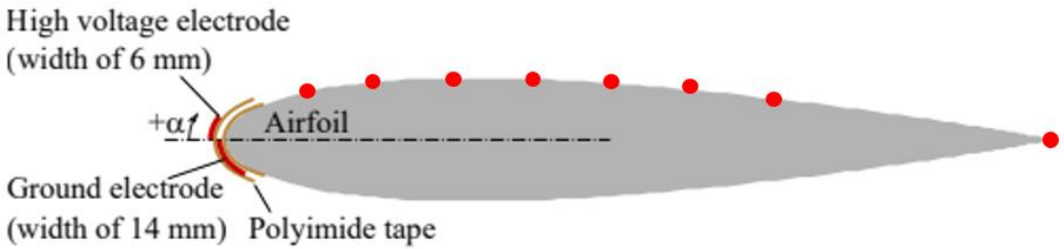
☐Experimental apparatus

- ➢ Wind Tunnel : T-BART
- ➢ NACA0015 Airfoil model
  - ✓ Code length : 100 mm
  - ✓ Unsteady pressure sensors : 8
  - ✓ Static pressure sensors : 18
- ➢ Plasma actuator
- ➢ Compact RIO (cRIO-9047)

T-BART

☐Experimental apparatus

- ➢ Angle of Attack : 16 deg
- ➢ Flow Velocity : 10m/s
- ➢ $Re \approx 6.7 \times 10^4$



● unsteady pressure sensor

☐Synchronous measurement

- ➢ Sampling rate (PIV, Pressure) : 5kHz
- ➢ measurement time : 1s

Feedback control condition

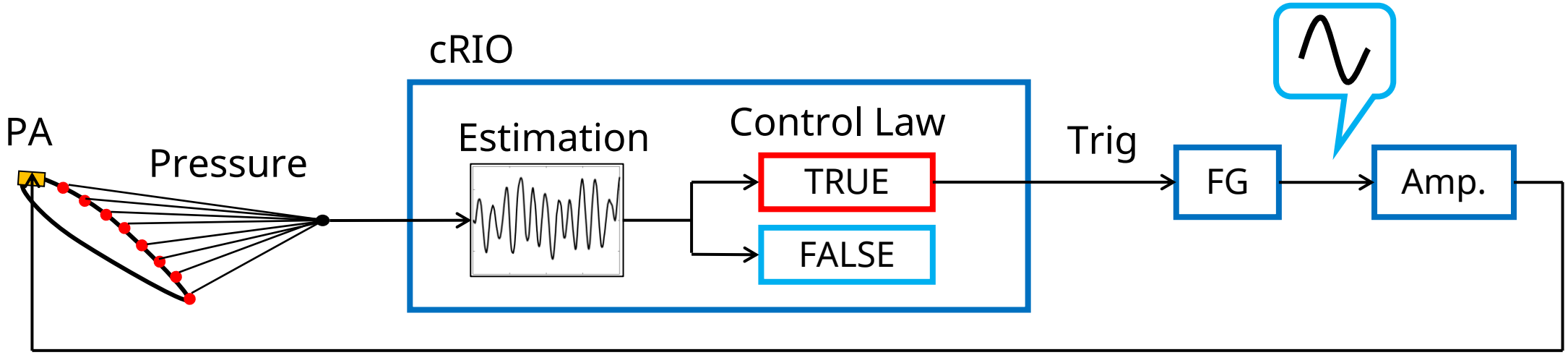
☐Flow Field Estimation, Control

- ➢Real-time estimation : 5 kHz
- ➢Feedback control : 1 kHz

Control Law	PA driving condition
1	1st mode's coefficient > 0
2	1st mode's coefficient < 0
3	2nd mode's coefficient > 0
4	2nd mode's coefficient < 0

☐PA driving voltage

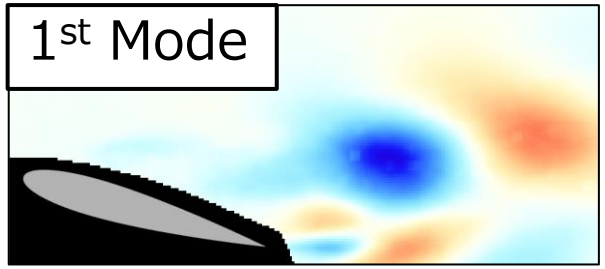
- ➢Sine wave (Amplitude 8 kV, Frequency 10 kHz)

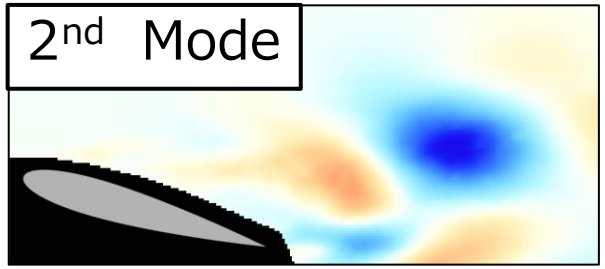


Result: Training data

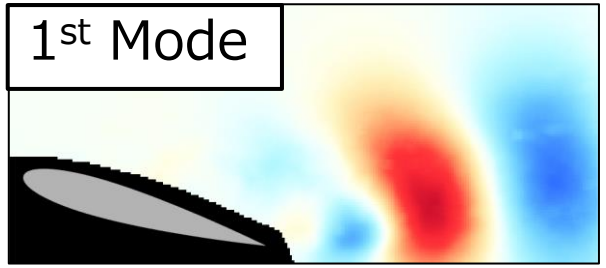
☐Spatial mode

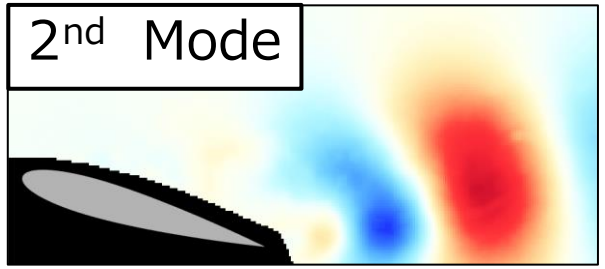
Main stream direction





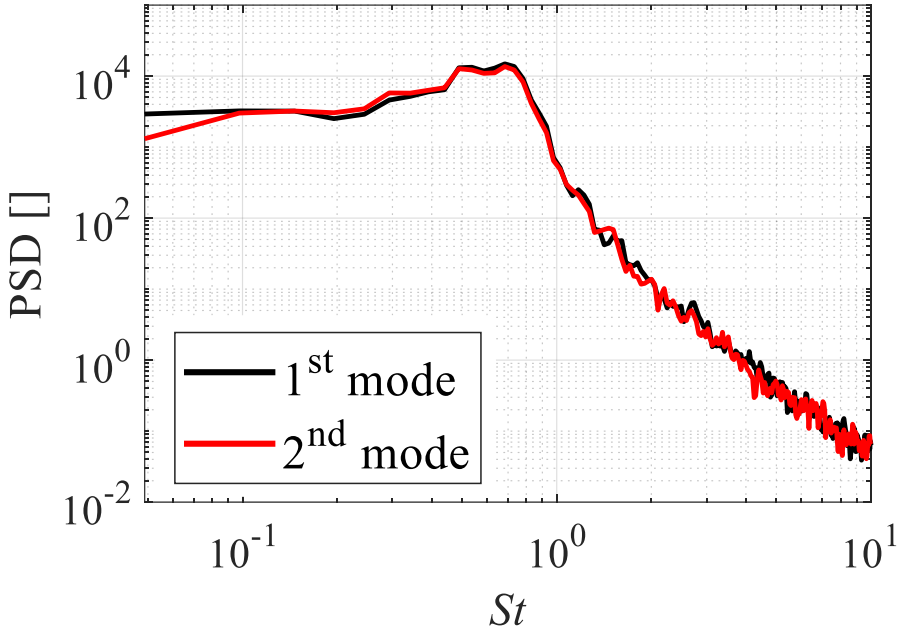
Vertical direction





➢The qualitative structures of the 1st mode and 2nd mode are similar

☐Frequency

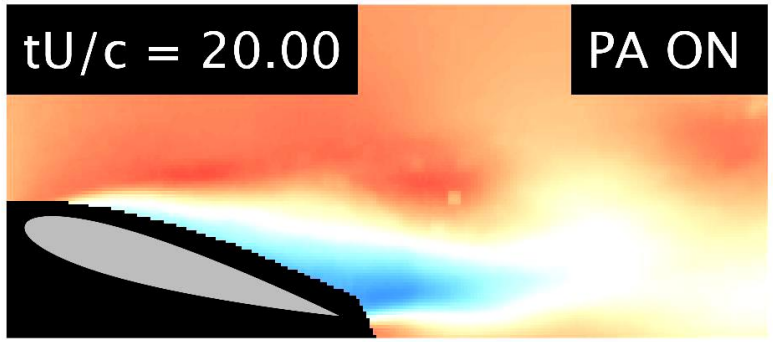


➢Frequency components are similar

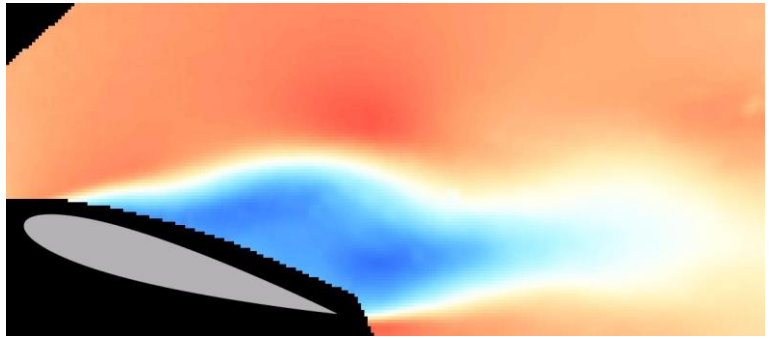
The 1st mode and 2nd mode stand for the paired vortex structure

Result: Real-time estimation

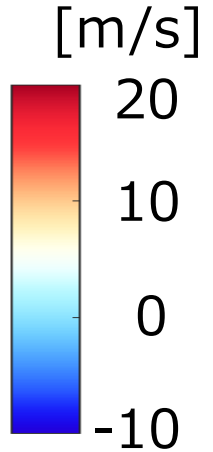
☐Control Law 1 （PA driving when 1st Mode > 0 ）

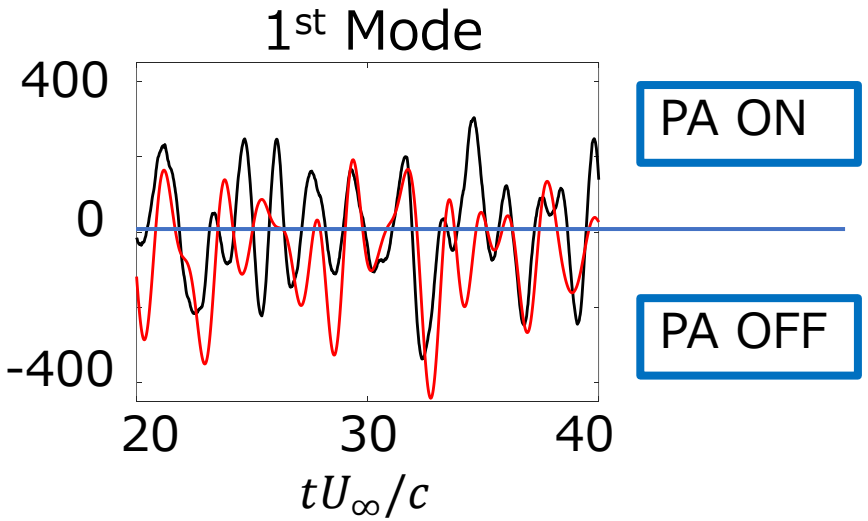


Real-time estimation(20 modes)



PIV(20 modes)





PA ON

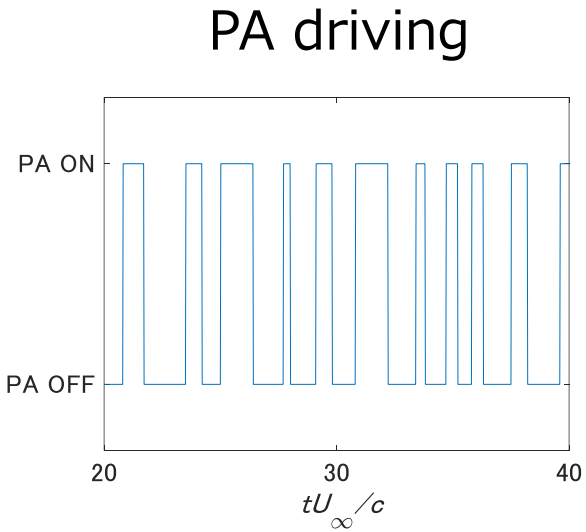
PA OFF

Estimated value

True value

Feedback timing accuracy

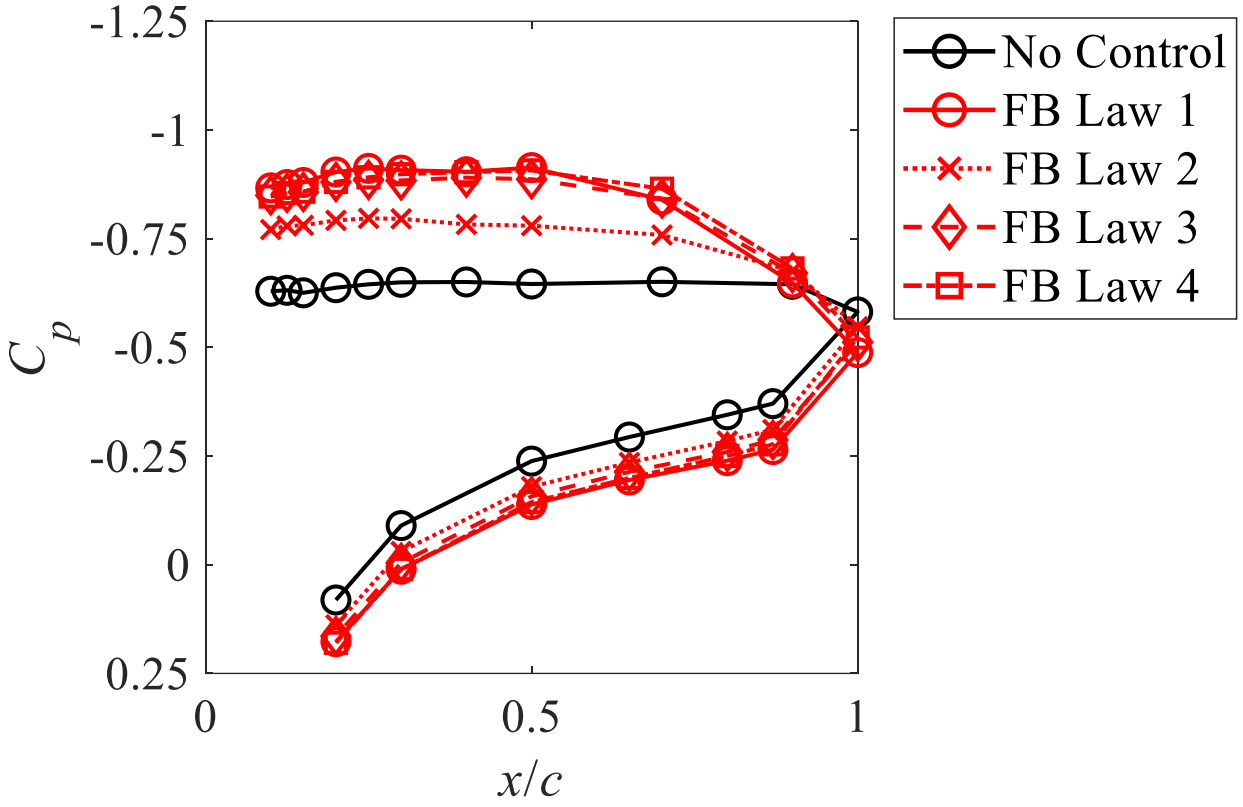
$S = 72.7\ \%$



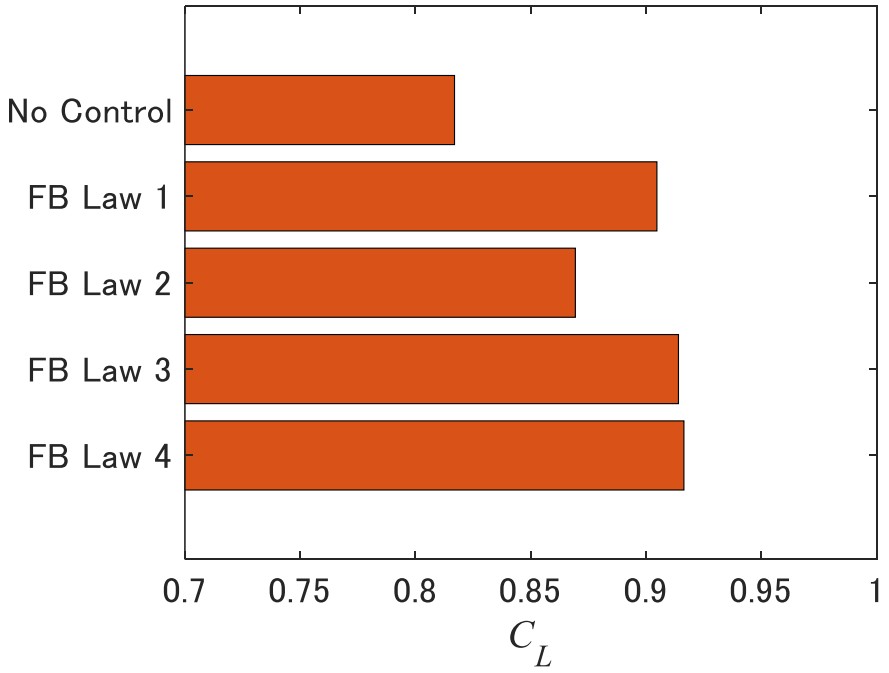
➢The flow structure is roughly estimated in real time

Result: The effect of feedback control

☐The pressure coefficient



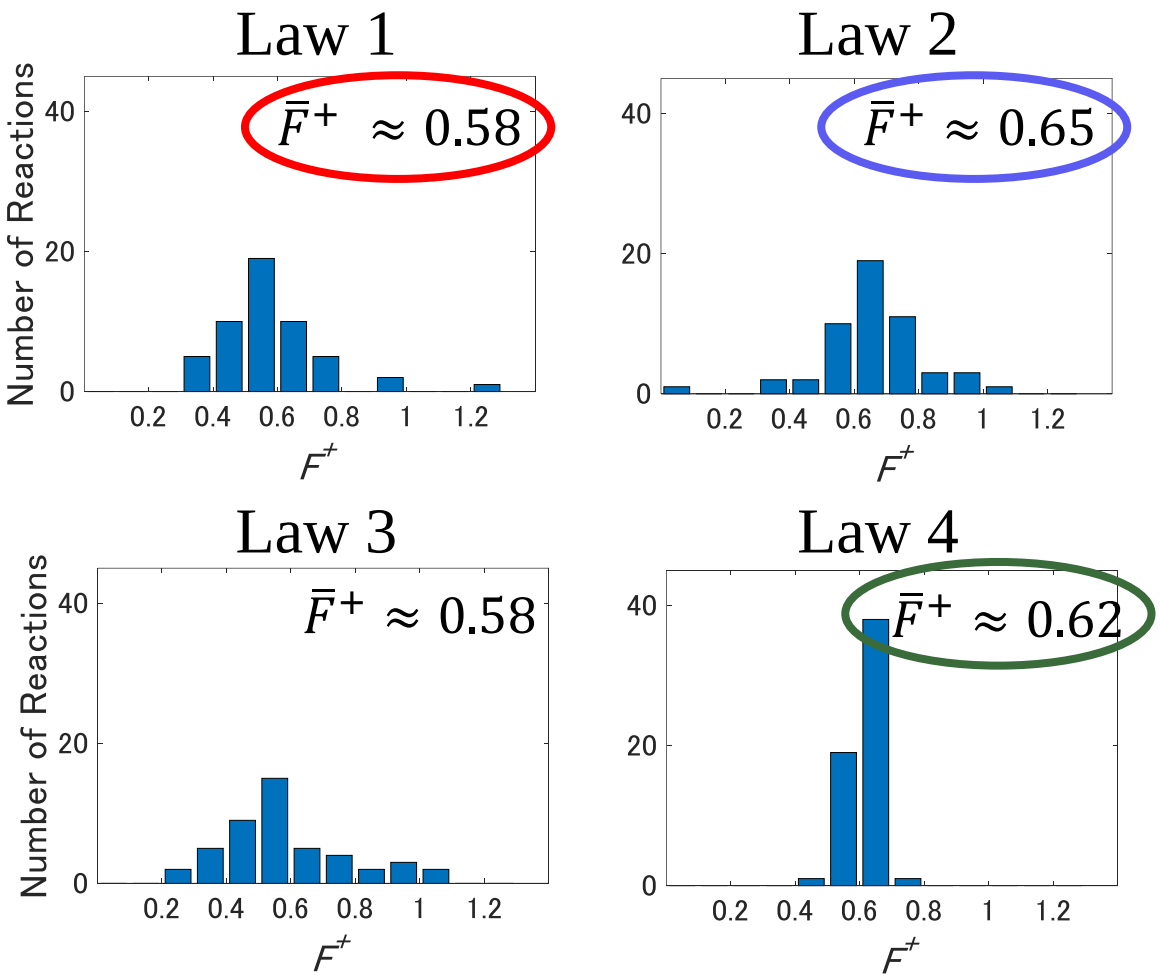
☐The lift coefficient

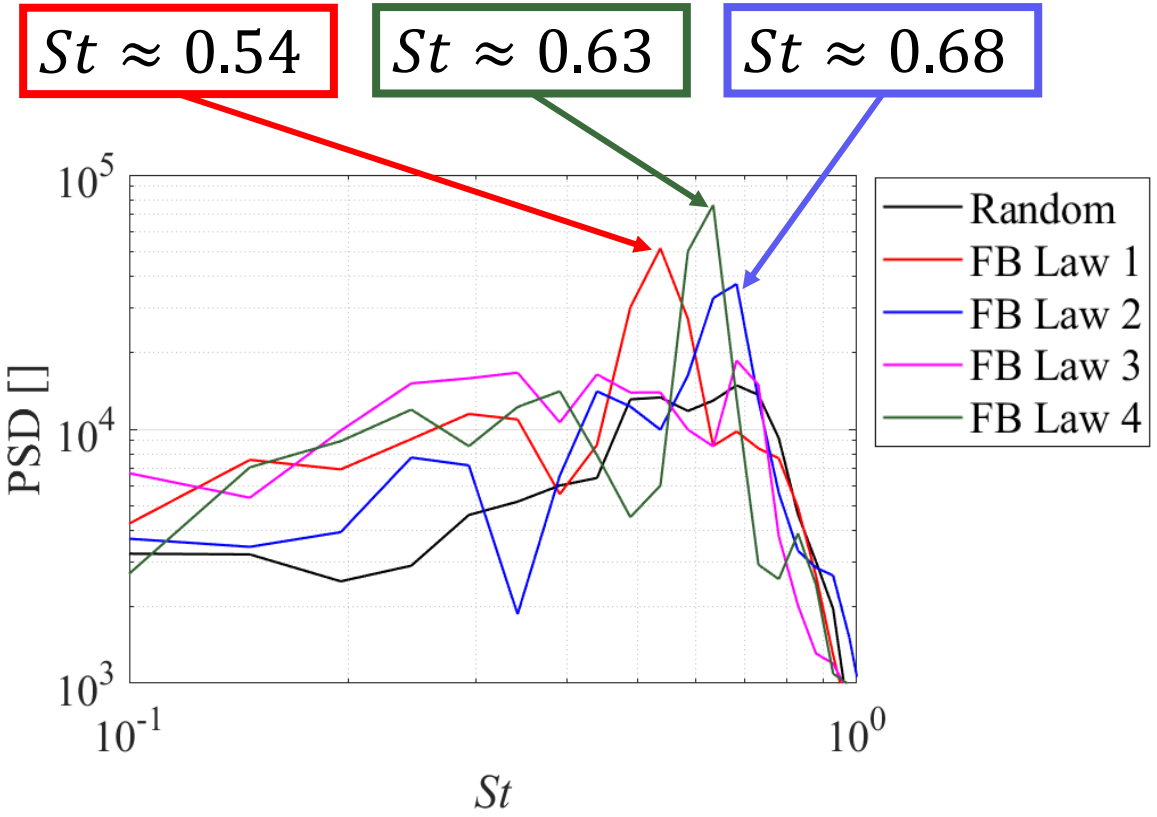


➢Law 1,3,4 : The aerodynamic performance was improved

Result: The effect of feedback control

☐The frequency of PA driving





Frequency components of the 1st mode

➢Law 1,2,4 : The frequency of PA on/off ≈ The Vortex frequency

Conclusion

- Real-time flow field estimation of 5 kHz and flow field-based feedback control of 1 kHz was achieved.
- Feedback on the vortex structure changed the vortex frequency and improved aerodynamic performance.